Cardiovascular System

Functions of the Circulatory System

The heart (positioning, coverings, anatomy)

General structures of blood vessels

Arterial blood flow, venous return

Blood pressure

Autoregulation

Circulations in special regions

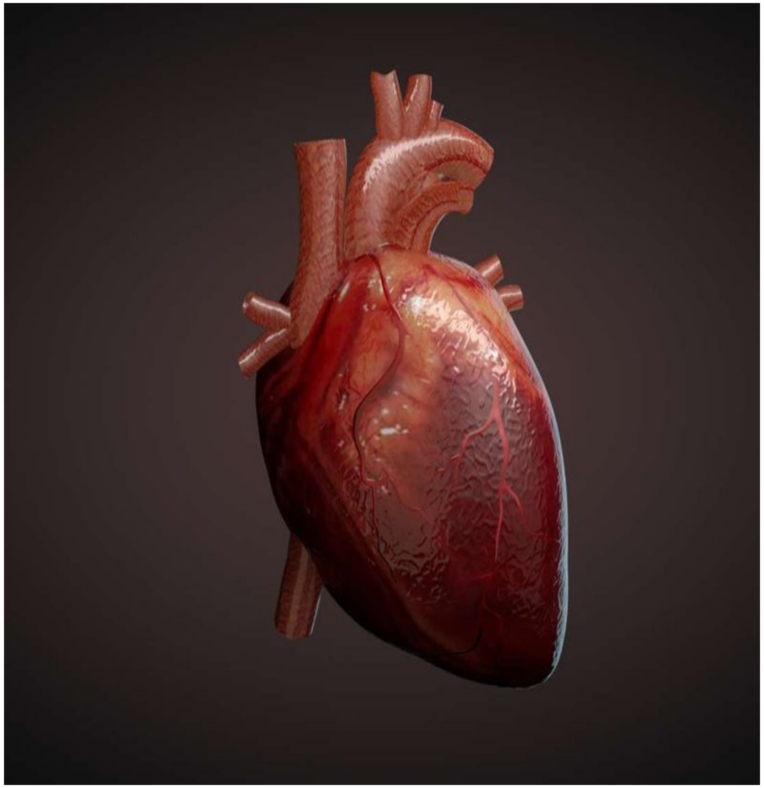
Cardiac Conduction System

Introduction

Consists of heart, blood vessels, ~ 5 liters of blood

The heart is the body's hardest-working organ

- about the size of a closed fist
- average heart easily pumps over 5 liters of blood throughout the body every minute.
- **Normal Heart Rate= 60 - 100 bpm**



Cardiovascular System

Main function is **transport**:

- Transports water, gases (O_2, N_2), nutrients throughout the body.
- Carries waste products and CO_2 from cellular metabolism to the kidneys and other excretory organs (skin, lungs).
- Circulates electrolytes and hormones.
- Transports various immune substances that contribute to the body's defense mechanisms (White blood cells clean up cellular debris and fight pathogens that have entered the body.)

Functions of the circulatory System

- Helps regulate temperature
  - Blood vessels help maintain a stable body temperature by controlling the blood flow to the surface of the skin. Blood vessels near the skin's surface open during times of overheating to allow hot blood to dump its heat into the body's surroundings. In the case of hypothermia, these blood vessels constrict to keep blood flowing only to vital organs in the body's core
- Balance the body's pH due to the presence of bicarbonate ions, which act as a buffer solution.

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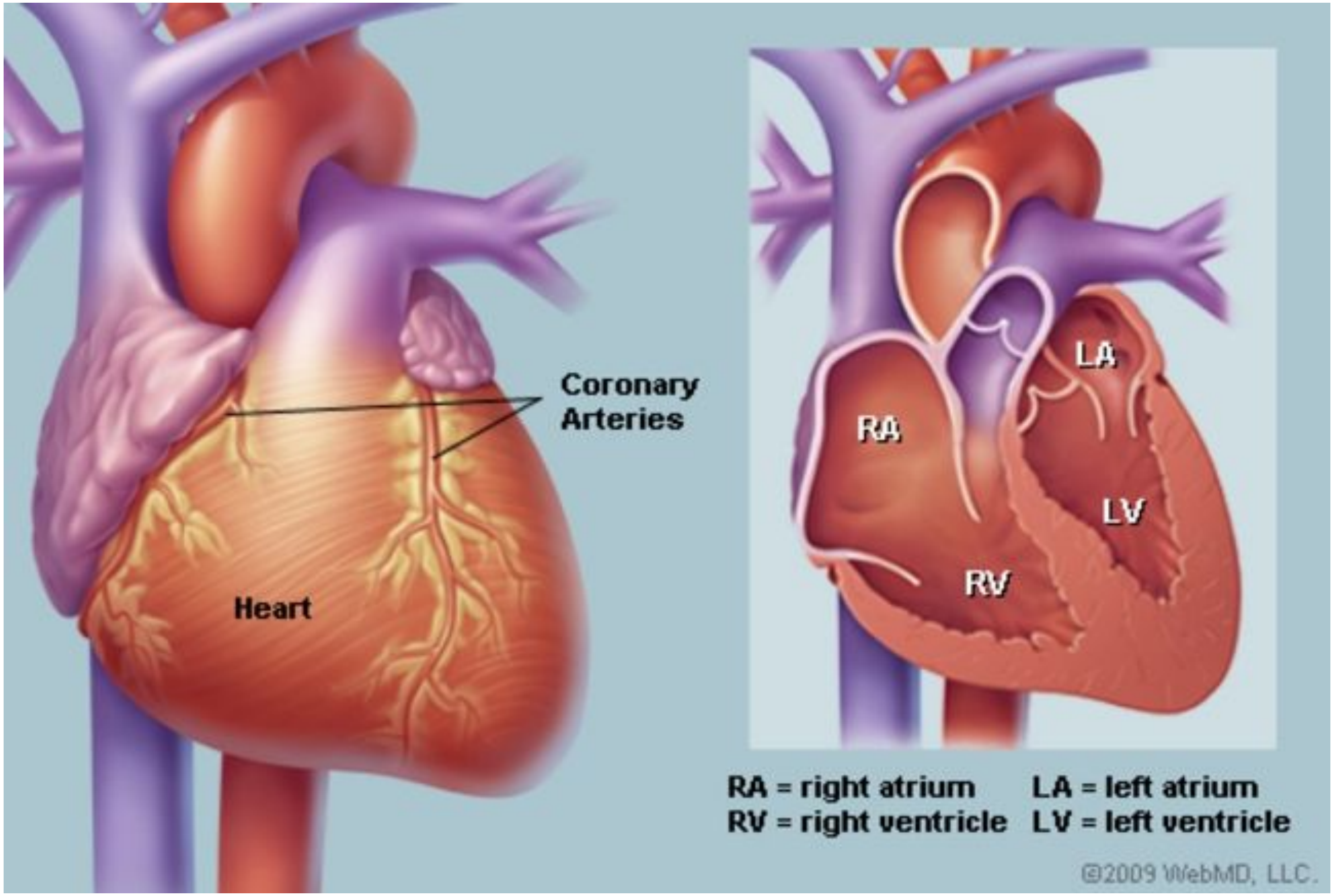
Coronary
Arteries
Heart
LA
RA
LV
RV
RA = right atrium
RV = right ventricle
LA = left atrium
LV = left ventricle
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The Heart

- weighs between 200 to 425 grams,
- heart may beat more than 3.5 billion times in a lifetime
  - Daily the average heart beats 100,000 times, pumping about 2,000 gallons (7,571 liters) of blood.
- Located in the middle mediastinum, and lies medially between the two lungs and the pleural membranes that cover them
- 2/3 of the heart’s mass is just barely to the left of the midline with the other 1/3 on right
- Base of the heart is tipped up medially and posteriorly, while the apex projects inferiorly and laterally.

Position & Size of Heart

- The heart sits within a fluid-filled cavity called the pericardial cavity
- The walls and lining of the pericardial cavity are a special membrane known as the pericardium
- Pericardium
  - is a type of serous membrane that produces serous fluid to lubricate the heart and prevent friction between the heart and its surrounding organs
  - serves to hold the heart in position and maintain a hollow space for the heart to expand into when it is full.
  - surrounds the heart and the proximal ends of the aorta, vena cava, and the pulmonary artery

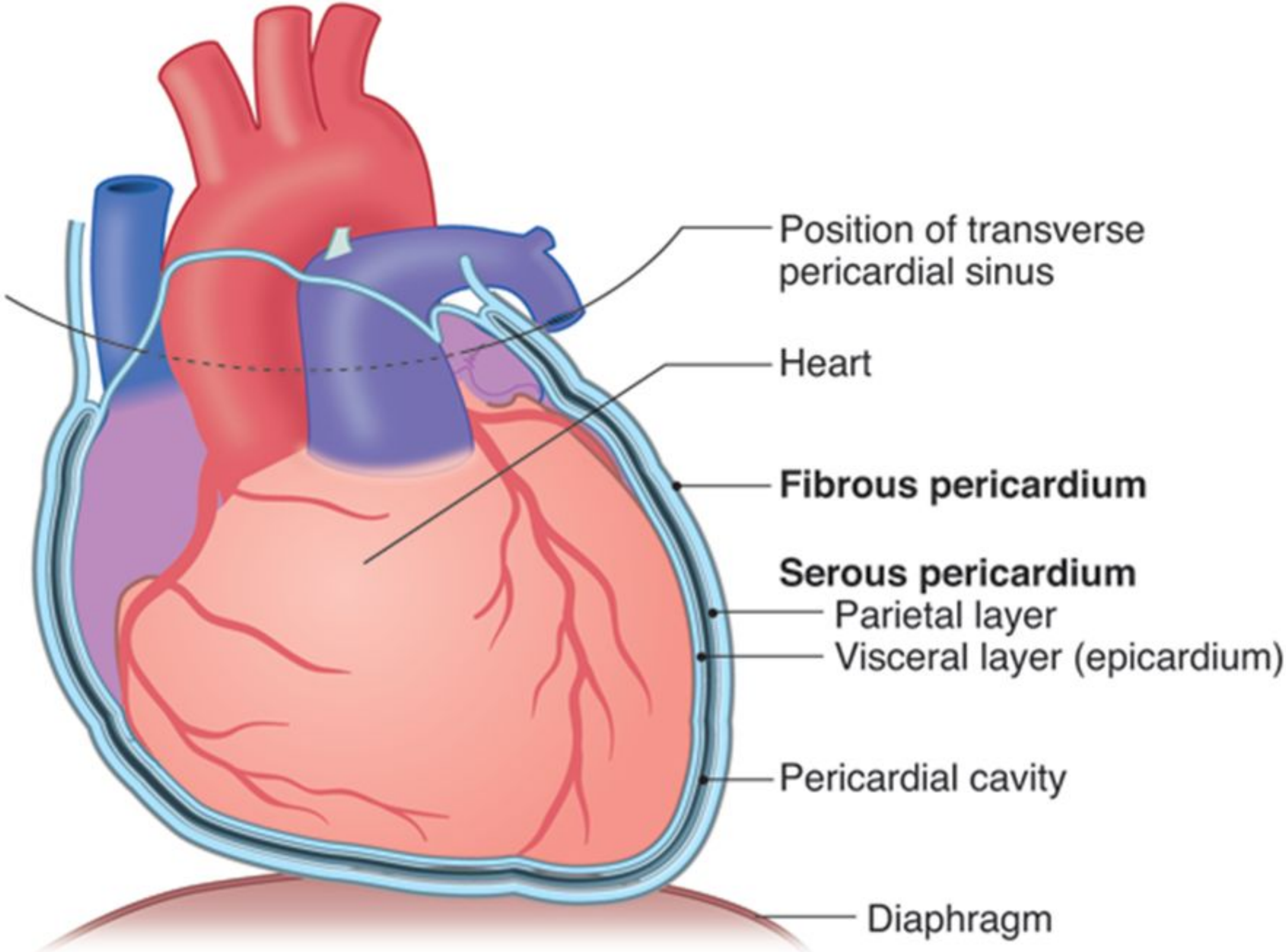
Coverings of the Heart

Composed of a tough outer fibrous layer lined by a delicate serous membrane.

The fibrous pericardium is a very dense and non-flexible connective tissue that helps protect and anchor the heart

The inner serous pericardium is subdivided into a parietal layer, which adheres to the outermost fibrous layer and a visceral layer that is also viewed as the outer surface of the heart wall. A thin pericardial fluid lubricates the space between the visceral and parietal pericardium

Anatomy of the Pericardium


Position of transverse pericardial sinus
Heart
Fibrous pericardium
Serous pericardium
Parietal layer
Visceral layer (epicardium)
Pericardial cavity
Diaphragm

The pericardium has several functions:

- Keeps the heart contained in the chest cavity.
- lubricate the heart and prevent friction between heart and its surrounding organs
- Prevents the heart from over expanding when blood volume increases.
- Limits heart motion.
- Barrier to infection

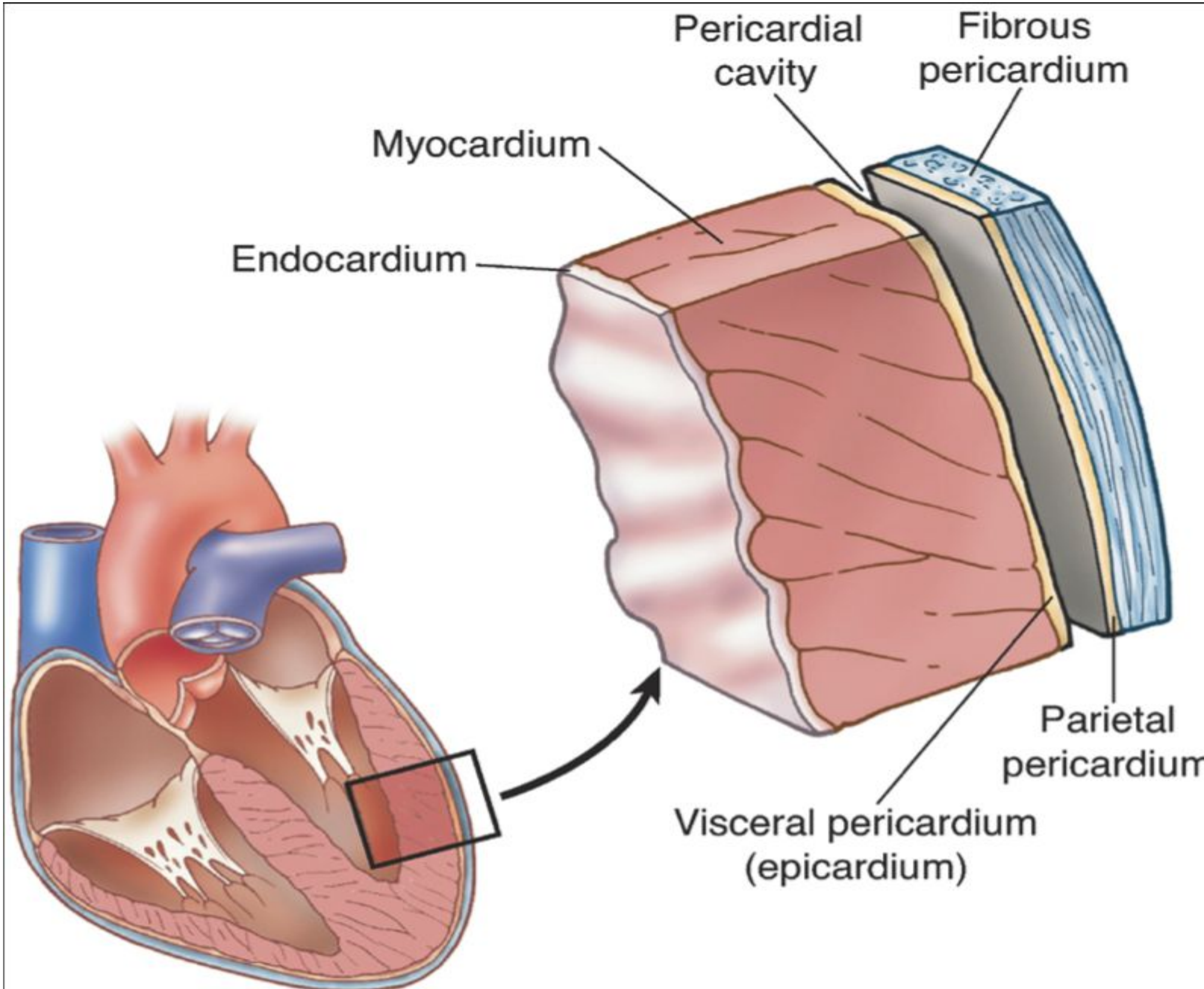
Functions of the Pericardium

The wall of the heart consists of three distinct layers—the epicardium (outer layer), the myocardium (middle layer), and the endocardium (inner layer).

Cardiac muscle, like skeletal muscle, is striated. Unlike skeletal muscle, its fibers are shorter, they branch, and they have only one (usually centrally located) nucleus.

Cardiac muscle cells connect to and communicate with neighboring cells through gap junctions in intercalated discs.

Anatomy of the Heart


Pericardial cavity
Fibrous pericardium
Myocardium
Endocardium
Parietal pericardium
Visceral pericardium (epicardium)

The epicardium, the thin, transparent outer layer of the heart wall, is also called the visceral layer of the serous pericardium.

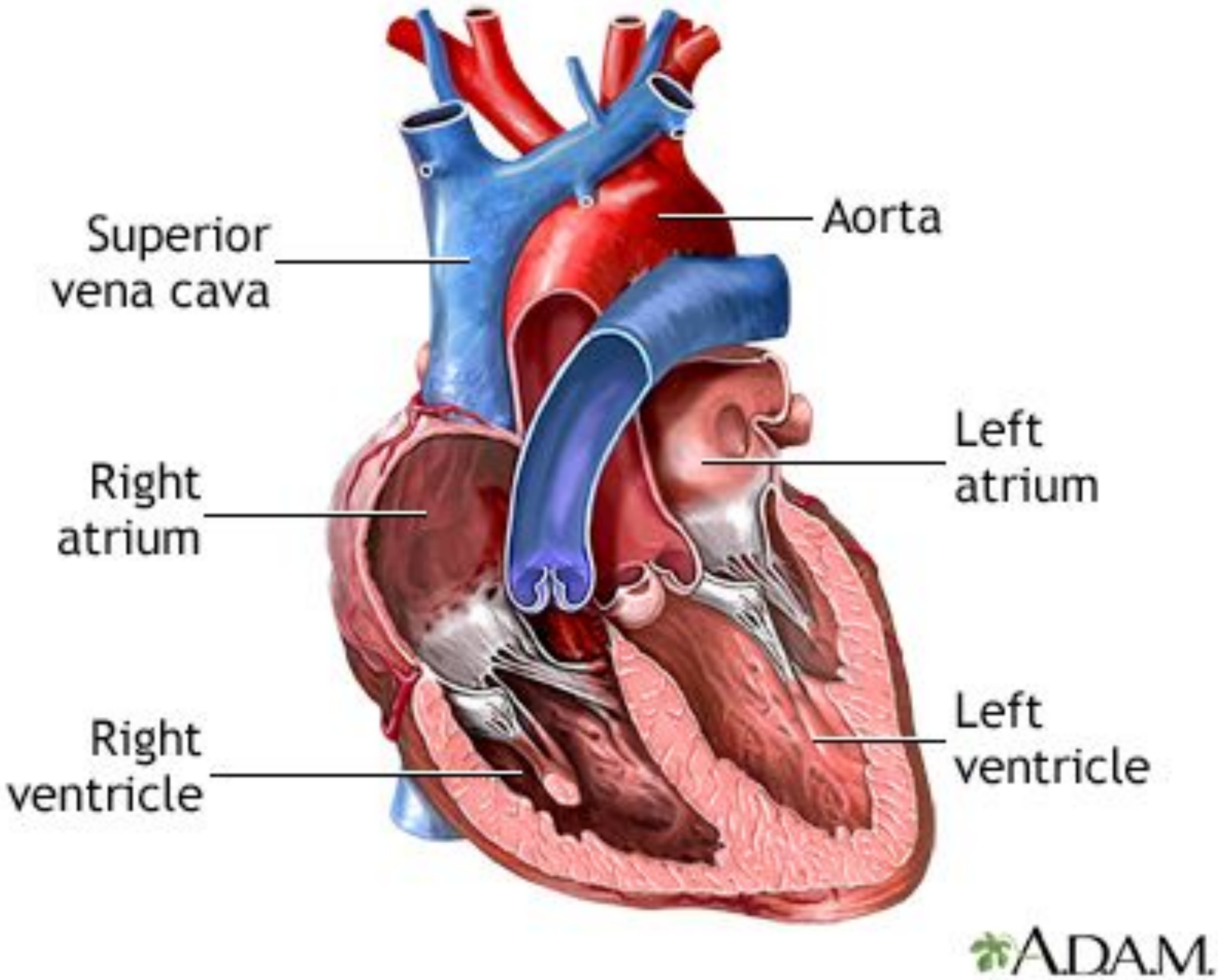
The myocardium, the thick middle layer, is composed of cardiac muscle, forms the wall of atria and ventricles.

The endocardium is a simple squamous epithelium, a thin, three-layered membrane lining the heart.

Anatomy of the <3 layers

- The heart has 4 chambers
  - The upper chambers are the left and right atria
  - The lower chambers are the left and right ventricles
- A wall of muscle called the septum separates the left and right atria and the left and right ventricles
- The left ventricle is the largest and strongest chamber in the heart. It’s walls are about a half-inch thick, they have enough force to push blood through the aortic valve and into the body

Anatomy of the heart Cont.


Superior
vena cava
Aorta
Left
atrium
Right
atrium
Right
ventricle
Left
ventricle
A.D.A.M.

Right atrium and right ventricle takes venous blood from the body and pumps it to the lungs for oxygenation.

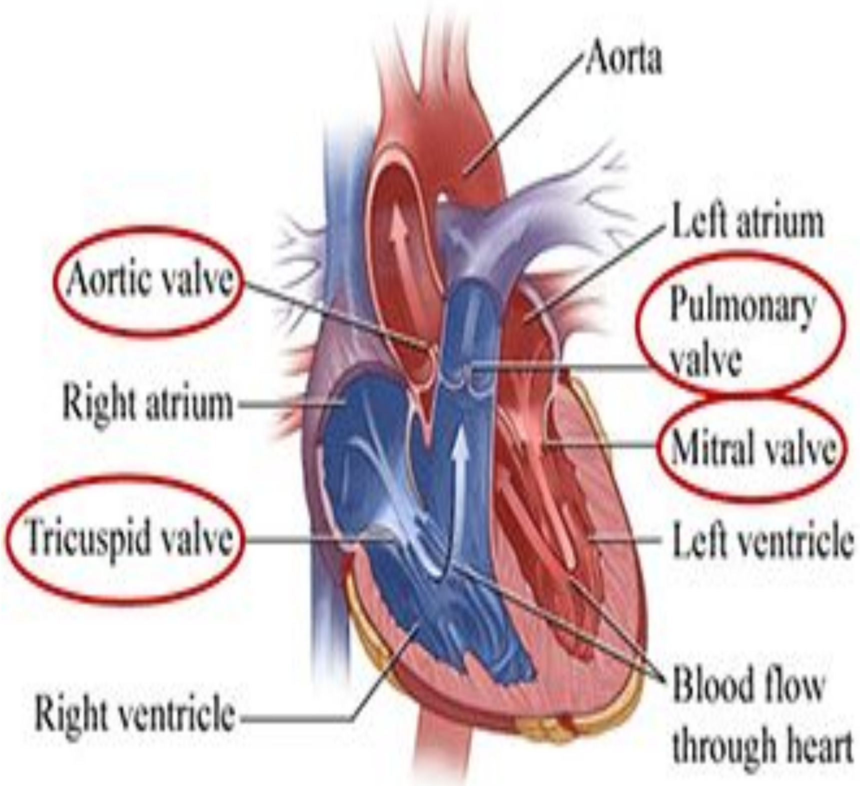
Left atrium and left ventricle, taking freshly oxygenated pulmonary blood and pump it to the body.

The right and left atria loads the ventricles.

The right and left ventricles are strong pumps responsible for the pulmonary and systemic circulation.

Overview of heart functions

Blood always flows from an area of high pressure to an area of low pressure. The flow of blood (dictated by differences in pressure, not muscles), operates the valves of the heart.



Valves and Blood Flow

Valves operate in pairs:

Atrioventricular valves open to allow blood to flow from the atria into the ventricles.

Semilunar valves open to allow blood to flow from the ventricles, into the outflow vessels.

AV valves

Positioned at the entrance to the ventricles:

The right AV valve (Tricuspid valve) opens into the right ventricle

The left AV valve (Bicuspid or mitral valve) opens into the left ventricle

Semilunar valves

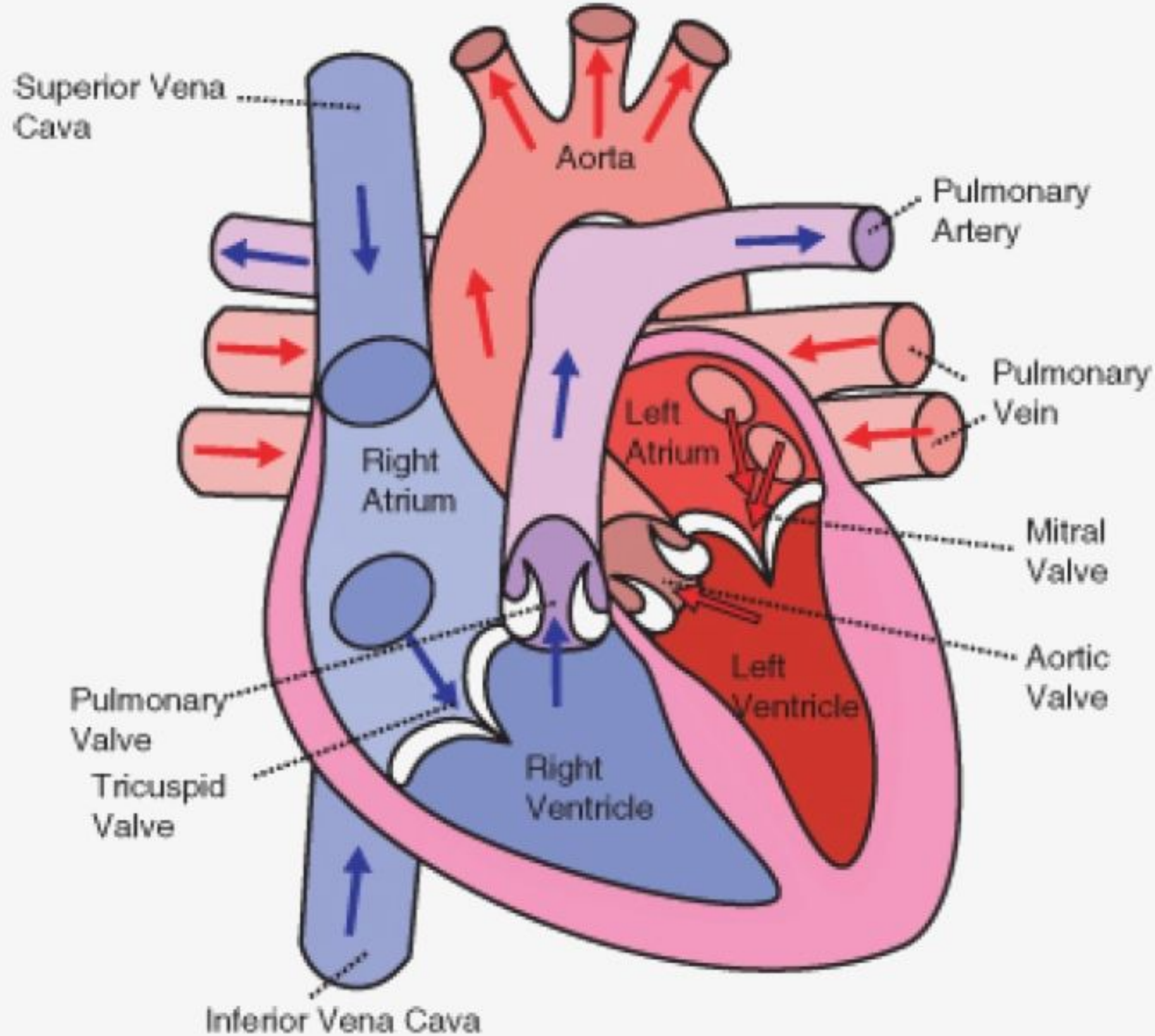
positioned at the entrance to the outflow vessels

The pulmonary valve (Right outflow) opens into the pulmonary trunk

The aortic valve (Left outflow) opens into the aortic arch

https://youtu.be/CWFyxn0qDEU

Valve operation


Superior Vena Cava
Aorta
Pulmonary Artery
Pulmonary Vein
Left Atrium
Right Atrium
Mitral Valve
Aortic Valve
Left Ventricle
Pulmonary Valve
Tricuspid Valve
Right Ventricle
Inferior Vena Cava

Arteries are vessels that always conduct blood away from the heart – with just a few exceptions, arteries contain oxygenated blood.Most arteries in the body are thick-walled and exposed to high pressures and friction forces.

Veins are vessels that always bring blood back to the heart - with just a few exceptions, veins contain deoxygenated blood.Most veins in the body are thin-walled and exposed to low pressures and minimal friction forces.

Vessels

The major arteries that attach to the heart are the arch of the aorta (with its ascending and descending portions), the pulmonary trunk (with its left and right pulmonary arteries), and the coronary arteries.

The major veins that attach to the heart are the superior and inferior venae cavae, the 4 pulmonary veins, and the coronary sinus (on the back of the heart).

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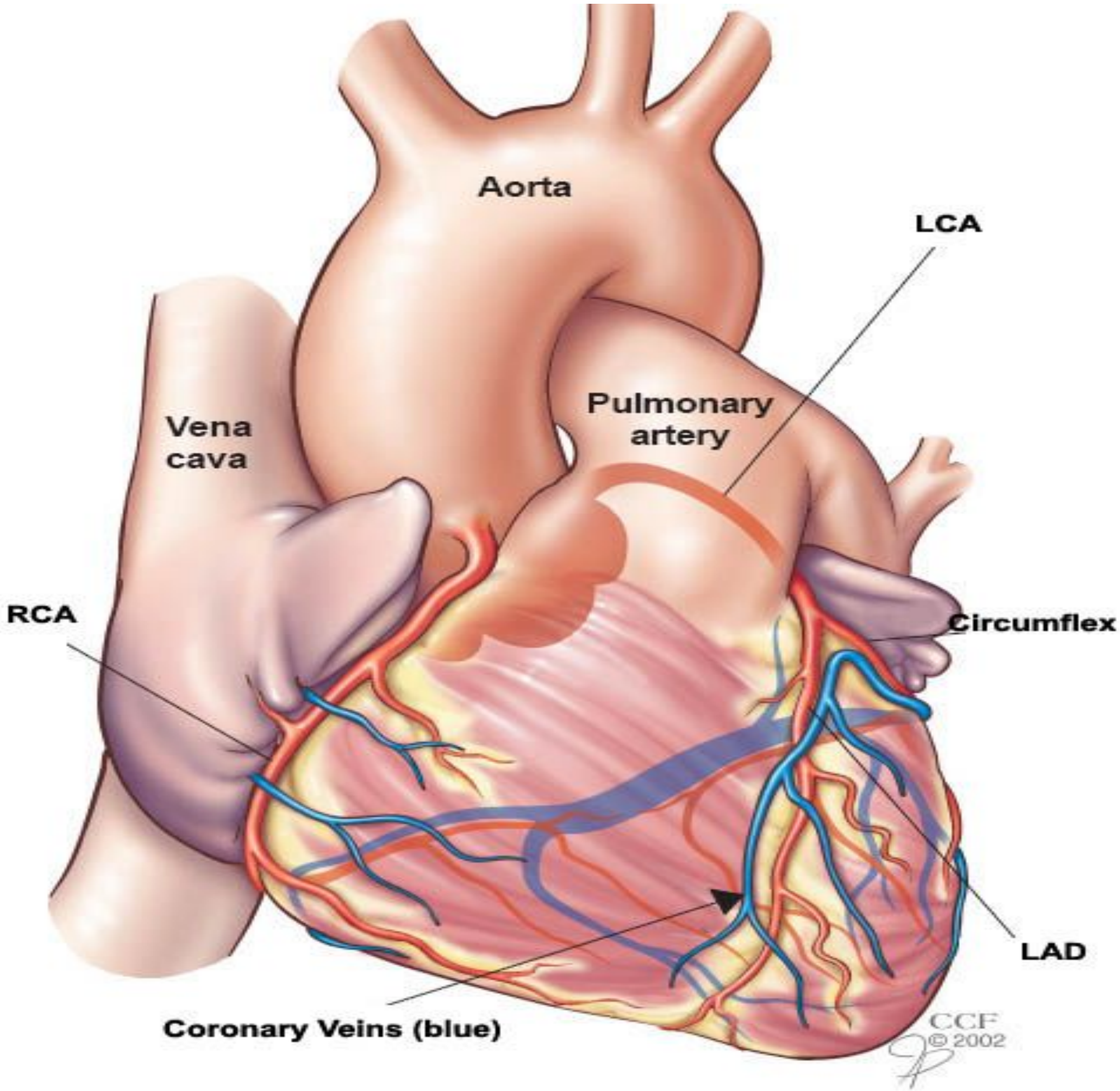


Aorta
LCA
Pulmonary artery
Vena cava
RCA
Circumflex
LAD
Coronary Veins (blue)
CCF
© 2002

	Arteries	Veins
Oxygen Concentration	Arteries carry oxygenated blood (with the exception of the pulmonary artery and umbilical artery).	Veins carry deoxygenated blood (with the exception of pulmonary veins and umbilical vein).
Types	Pulmonary and systemic arteries.	Superficial veins, deep veins, pulmonary veins and systemic veins
Direction of Blood Flow	From the heart to various parts of the body.	From various parts of the body to the heart.
Anatomy	Thick, elastic muscle layer that can handle high pressure of the blood flowing through the arteries.	Thin, elastic muscle layer with semilunar valves that prevent the blood from flowing in the opposite direction.
Location	Deeper in the body	Closer to the skin
Rigid walls	more rigid	Collapsible
Valves	Aren't present (except for semi-lunar valves)	Are present, especially in limbs

Arteries:

- carry blood away from the heart.

Large elastic arteries (>1 cm); medium muscular arteries (0.1 – 10 mm); arterioles (< 0.1 mm)

Capillaries: site of nutrient and gas exchange

Veins: carry blood towards the heart

Venules are small veins (< 0.1 mm)

All blood and lymph vessels in the body share components of 3 basic layers or "tunics"which comprise the vessel wall:

- Tunica interna (intima)
- Tunica media
- Tunica externa

- The tunica interna is the inner elastic lining in direct contact with blood.

Anatomy of Vessels

The tunica interna is the inner elastic lining in direct contact with blood.

The epithelium of the intima is the same endothelium that makes up the endocardial lining of the heart. It has an active role in vessel-related activities.

The tunica media (middle layer) is chiefly composed of smooth muscle that regulates the diameter of the vessel lumen.

The tunica externa composed of fibrous and connective tissues that support the vessel.

Elastic arteries perform the important function of storing mechanical energy during ventricular systole and then transmitting that energy to keep blood moving after the aortic and pulmonary valves close.

Medium sized muscular arteries have more smooth muscle in their tunica media. Muscular arteries help maintain the proper vascular tone to ensure efficient blood flow to the distal tissue beds. Examples include the brachial artery in the arm and radial artery in the forearm.

Tunics

An anastomosis is a union of vessels supplying blood to the same body tissue. Should a blood vessel become occluded, a vascular anastomosis provides collateral circulation (an alternative route) for blood to reach a tissue.

Arterioles deliver blood to capillaries and have the greatest collective influence on both local blood flow and on overall blood pressure.

Capillaries are the only sites in the entire vasculature where gases, water and other nutrients are exchanged.

Veins and venules have much thinner walls, less muscle and elastic tissue than corresponding arterioles and arteries of similar size. Veins are designed to operate at much lower pressures. Because intravenous pressure is so low; veins have valves to keep blood flowing in only one direction. When exposed to higher than normal pressures, veins can become incompetent (varicose veins).

Vessels Continued

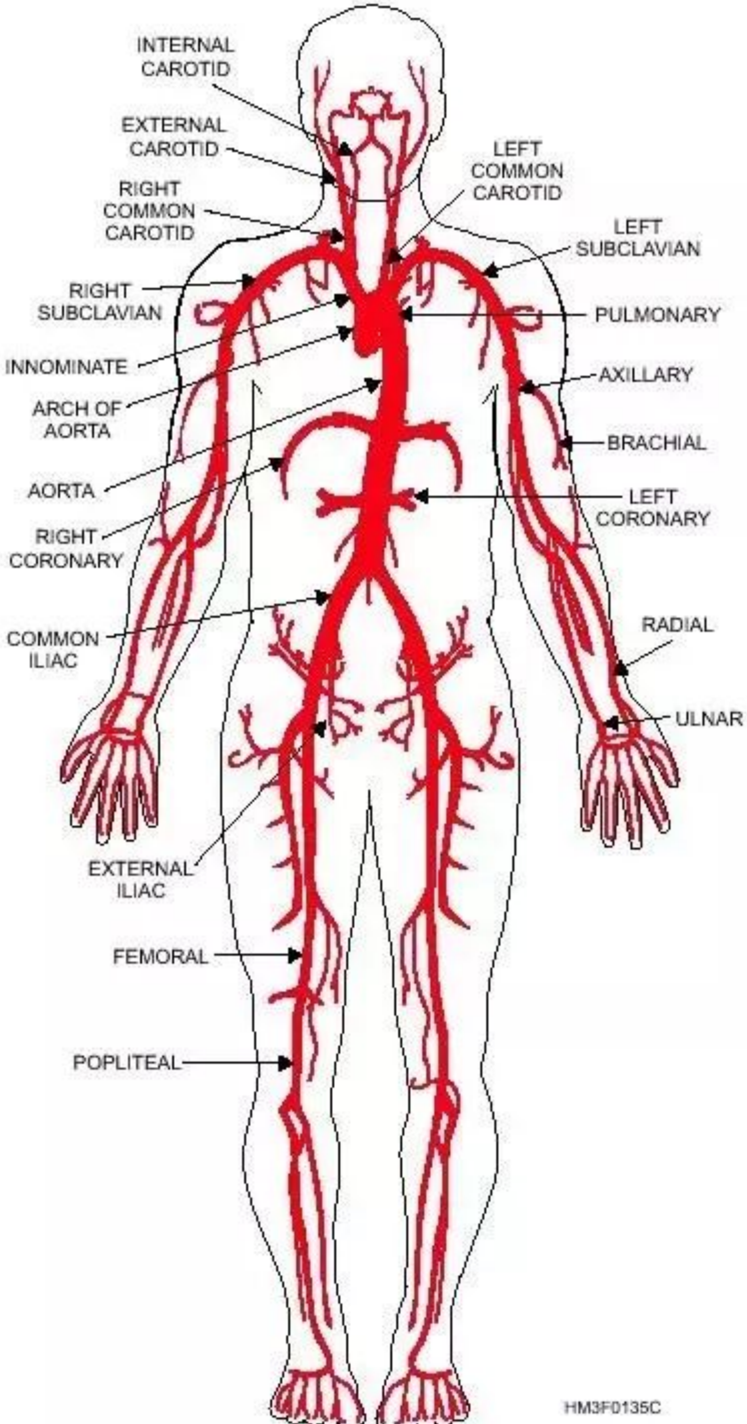
Arteries of systemic circulation

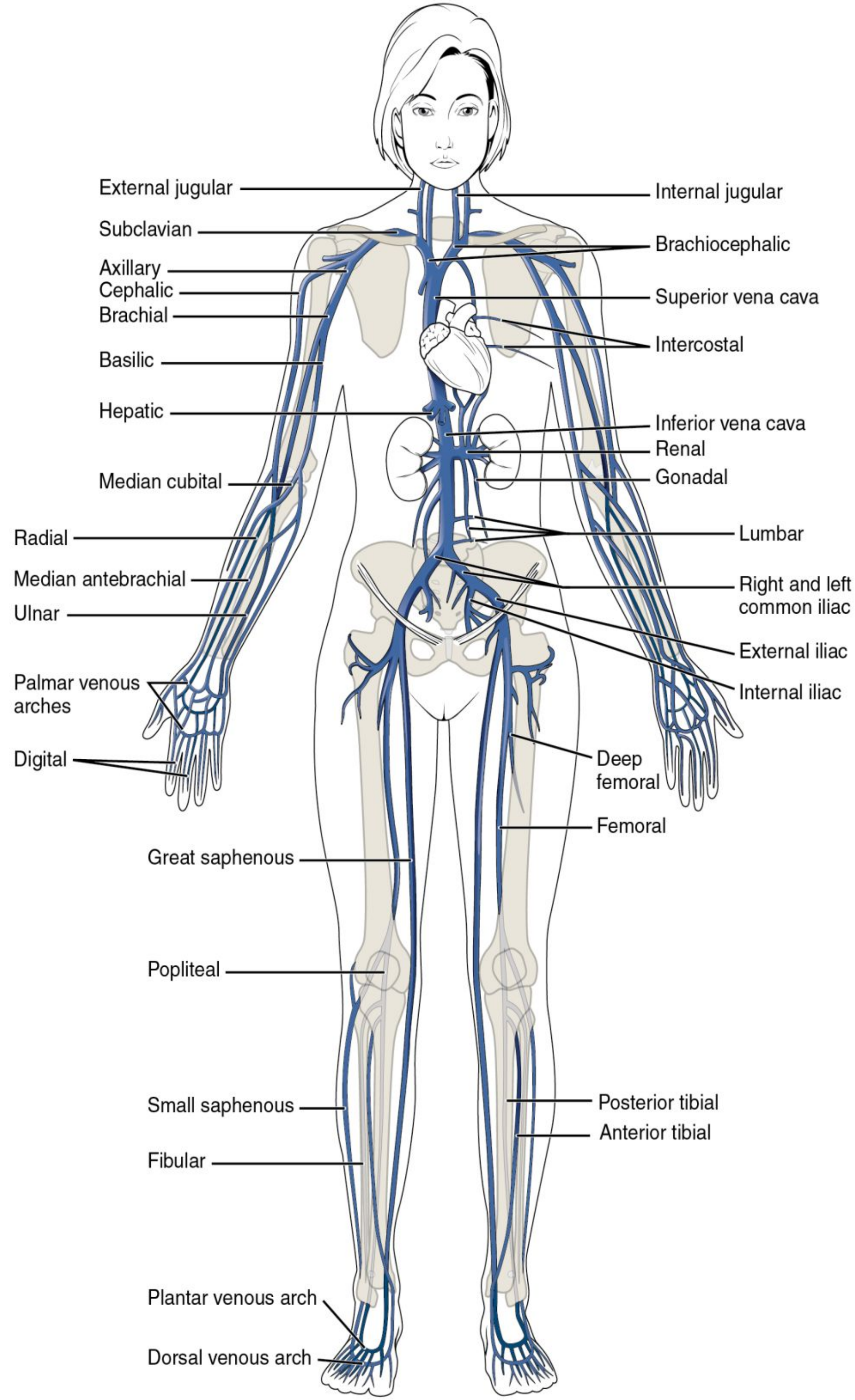
Aorta (one), Brachiocephalic (one), Common Carotid, External Carotid, Internal Carotid, Subclavian, Axillary, Brachial, Radial, Ulnar, Bronchial (3), Renal, Iliac (common, internal, external), Femoral, Popliteal.

Veins of systemic circulation

Vena Cava, Brachiocephalic (two), External Jugular, Internal Jugular, Subclavian, Axillary, Brachial, Median Cubital, Iliac (common, internal, external), Femoral, Popliteal, Saphenous, Hepatic portal

Major Arteries & Veins


INTERNAL CAROTID
EXTERNAL CAROTID
RIGHT COMMON CAROTID
LEFT COMMON CAROTID
LEFT SUBCLAVIAN
RIGHT SUBCLAVIAN
PULMONARY
INNOMINATE
ARCH OF AORTA
AXILLARY
BRACHIAL
AORTA
LEFT CORONARY
RIGHT CORONARY
RADIAL
COMMON ILIAC
ULNAR
EXTERNAL ILIAC
FEMORAL
POPLITEAL
HM3F0135C


External jugular
Internal jugular
Subclavian
Brachiocephalic
Axillary
Cephalic
Superior vena cava
Brachial
Intercostal
Basilic
Hepatic
Inferior vena cava
Renal
Gonadal
Median cubital
Radial
Lumbar
Median antebrachial
Right and left common iliac
Ulnar
External iliac
Palmar venous arches
Internal iliac
Digital
Deep femoral
Femoral
Great saphenous
Popliteal
Small saphenous
Posterior tibial
Anterior tibial
Fibular
Plantar venous arch
Dorsal venous arch

As blood flows to the tissues of the body, hydrostatic and osmotic forces at the capillaries determine how much fluid leaves the arterial end of the capillary and how much is then reabsorbed at the venous end. These are called Starling Forces.

Filtration is the movement of fluid through the walls of the capillary into the interstitial fluid.

Reabsorption is the movement of fluid from the interstitial fluid back into the capillary.

Fluid Exchange(Starling Forces)

Two pressures promote filtration: (1) Blood hydrostatic pressure (BHP) generated by the pumping action of the heart. (2) Interstitial fluid osmotic pressure (IFOP).

Two pressures promote reabsorption: (1) Blood colloid osmotic pressure (BCOP) is due to the presence of plasma proteins too large to cross the capillary - averages 36 mmHg on both ends. (2) Interstitial fluid hydrostatic pressure (IFHP)

Normally there is nearly as much fluid reabsorbed as there is filtered.

At the arterial end, net pressure is outward and fluid leaves the capillary (filtration).

At the venous end, net pressure is inward (reabsorption).

The exchange of gases and small particles (like certain nutrients and wastes) is a purely passive diffusion process. Gases and these other substances simply move into or out of the capillary down their concentration gradient.

https://youtu.be/6ecmOuCIoNc

Continued

Systemic circuit ejects blood into the aorta, systemic arteries, and arterioles and is powered by the left side of the heart.

Pulmonary circuit ejects blood into the pulmonary trunk and is powered by the right side of the heart.

Deoxygenated blood flows into the right atrium from 3 sources (the two vena cavae and the coronary sinus). Blood then follows a pathway through the right heart to the lungs to be oxygenated.

Oxygenated blood returns to the left heart to be pumped through the outflow tract of the systemic circulation.

Blood Flow

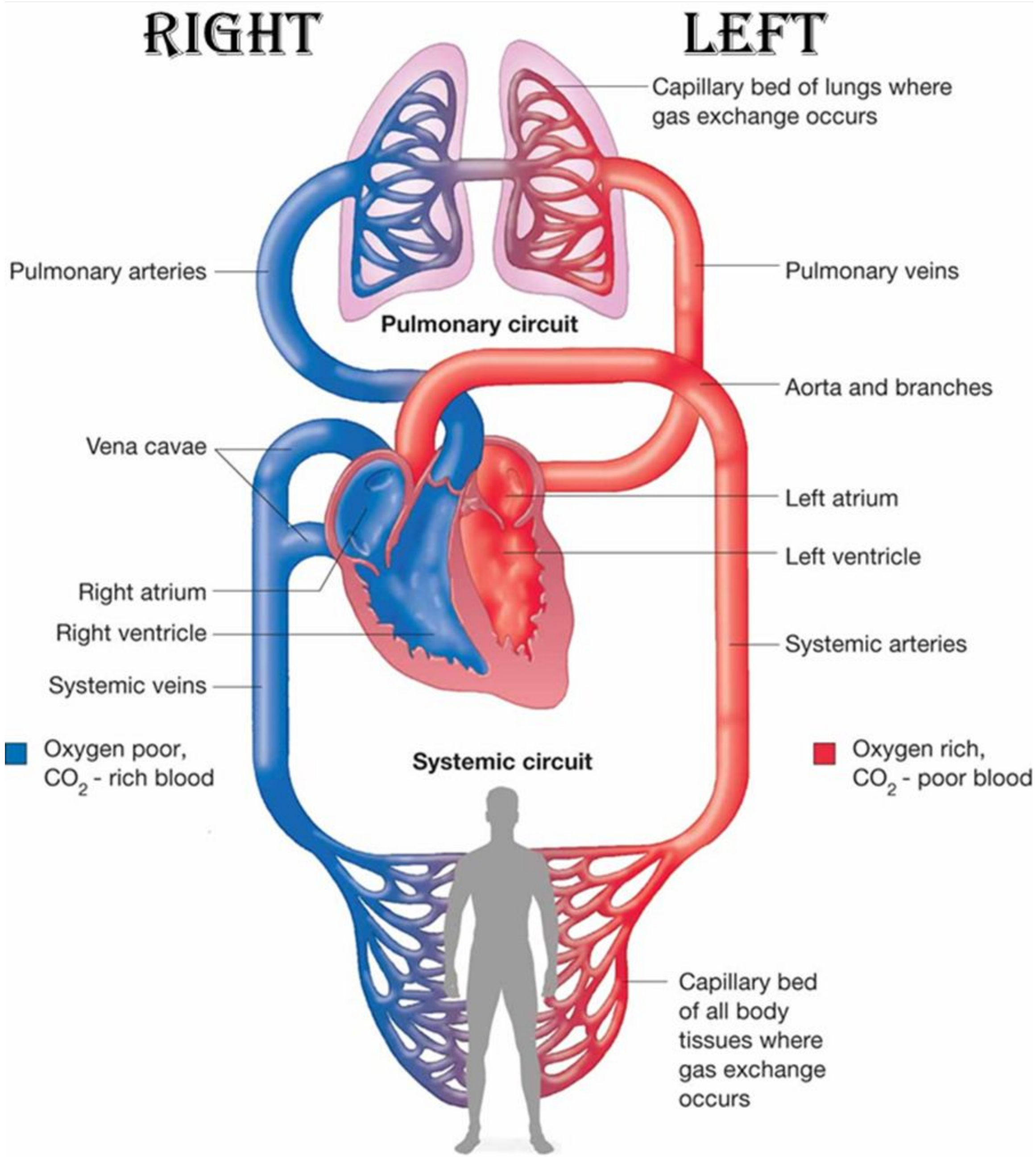
The volume of blood returning through the veins to the right atrium must be the same amount of blood pumped into the arteries from the left ventricle - this is called the venous return.

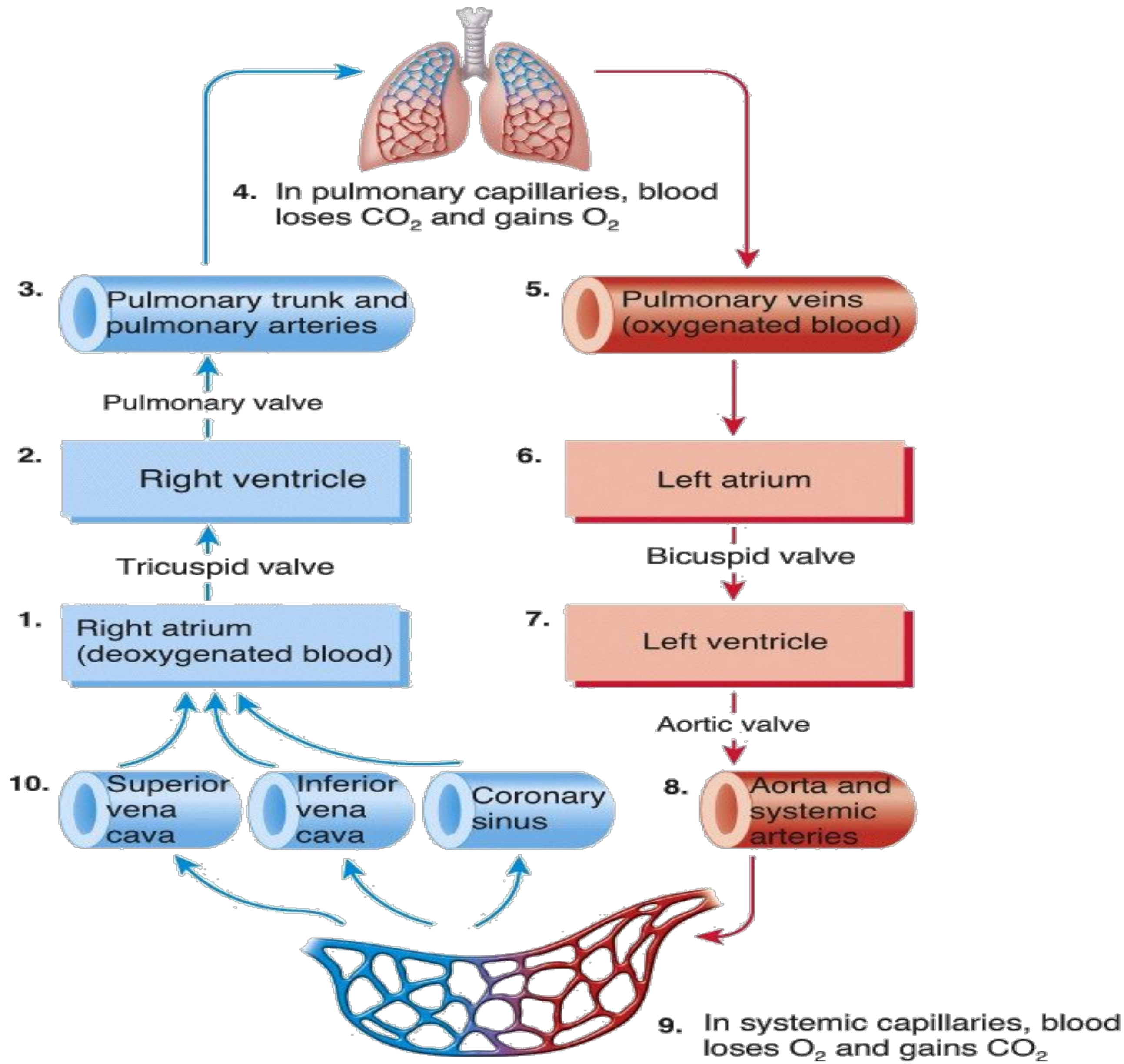
Besides pressure, venous return is aided by the presence o**f venous valves, a skeletal muscle pump, and the action of breathing.** The skeletal muscle pump uses the action of muscles to milk blood in 1 direction (due to valves).

The respiratory pump uses the negative pressures in the thoracic and abdominal cavities generated during inspiration to pull venous blood towards the heart.

https://youtu.be/X9ZZ6tcxArI

Blood Flow – Venous Return


RIGHT
LEFT
Capillary bed of lungs where gas exchange occurs
Pulmonary arteries
Pulmonary veins
Pulmonary circuit
Aorta and branches
Vena cavae
Left atrium
Left ventricle
Right atrium
Right ventricle
Systemic arteries
Systemic veins
Oxygen poor, CO_2 - rich blood
Systemic circuit
Oxygen rich, CO_2 - poor blood
Capillary bed of all body tissues where gas exchange occurs



(b) Diagram of blood flow

- Blood pressure is a measure of the force (measured in mmHg) exerted in the lumen of the blood vessels.Represents the pressure of the blood as it moves through the arterial system.
- Blood flow is the amount of blood that is actually reaching the end organs (tissues of the body).
- Resistance is the sum of many factors that oppose the flow of blood.

The relationship between blood flow, blood pressure, and peripheral resistance follows a simple formula called Ohms Law.

Blood Pressure (BP) = Flow x Resistance

Blood Pressure, flow & resistance

In an effort to meet physiological demands, we can increase blood flow by:

- Increasing BP
- Decreasing systemic vascular resistance in the blood vessels

Usually our body will do both.

Peripheral resistance is itself dependent on other factors like the viscosity of blood, the length of all the blood vessels in the body (body size), and the diameter of a vessel.

At any given time the rate of blood flow to any organ of the body (the brain, the kidneys, the muscles) is inversely proportional to the resistance in that organ's capillary bed.

Continued

Systolic pressure: pressure at the height of the pressure pulse

Diastolic pressure: the lowest pressure

Pulse pressure: the difference between systolic and diastolic pressure

Cardiac output: the amount of blood the heart pumps each minute=Heart Rate (HR) x Stroke Volume (SV)

Heart Rate: how often the heart beats each minute, Regulated by a balance between the activity of the sympathetic nervous system and the parasympathetic nervous system

Stroke Volume: how much blood the heart pumps with each beat.

Vascular resistance (VR)

Mean arterial pressure = Cardiac Output (CO) x VR

https://youtu.be/ZVklPwGALpI

Continued

Homeostasis in the body tissues requires the cardiovascular system to adjust pressure and resistance to maintain adequate blood flow to vital organs at all times – a process called autoregulation. Autoregulation is controlled through negative feedback loops.

Autoregulation of blood pressure and blood flow is a complex interplay between:

- The vascular system
- The nervous system
- The endocrine hormones and organs like the adrenal gland and the kidney
- The heart

Autoregulation

The vascular system senses alterations of BP and blood flow and signals the cardiovascular centers in the brain. The heart then appropriately modifies its rate and force of contraction. Arterioles and the precapillary sphincters adjust resistance at specific tissue beds.

- For example, during emergencies, the autonomic nervous system will vasodilate the precapillary sphincters in the skeletal muscles, lungs, and brain, while constricting the precapillary sphincters found in tissues such as the skin, GI tract, and kidneys.
- This sends the majority of the cardiac output (blood flow) to those organs important in a fight or flight response, while temporarily depriving (through vasoconstriction) the nonessential organs.

Continued

Coronary circulation: The myocardium (and other tissues of the thick cardiac walls) must get nutrients from blood flowing through the coronary circulation. Even then, only during the relaxation phase of ventricular diastole, will blood actually flow through the coronary circulation.

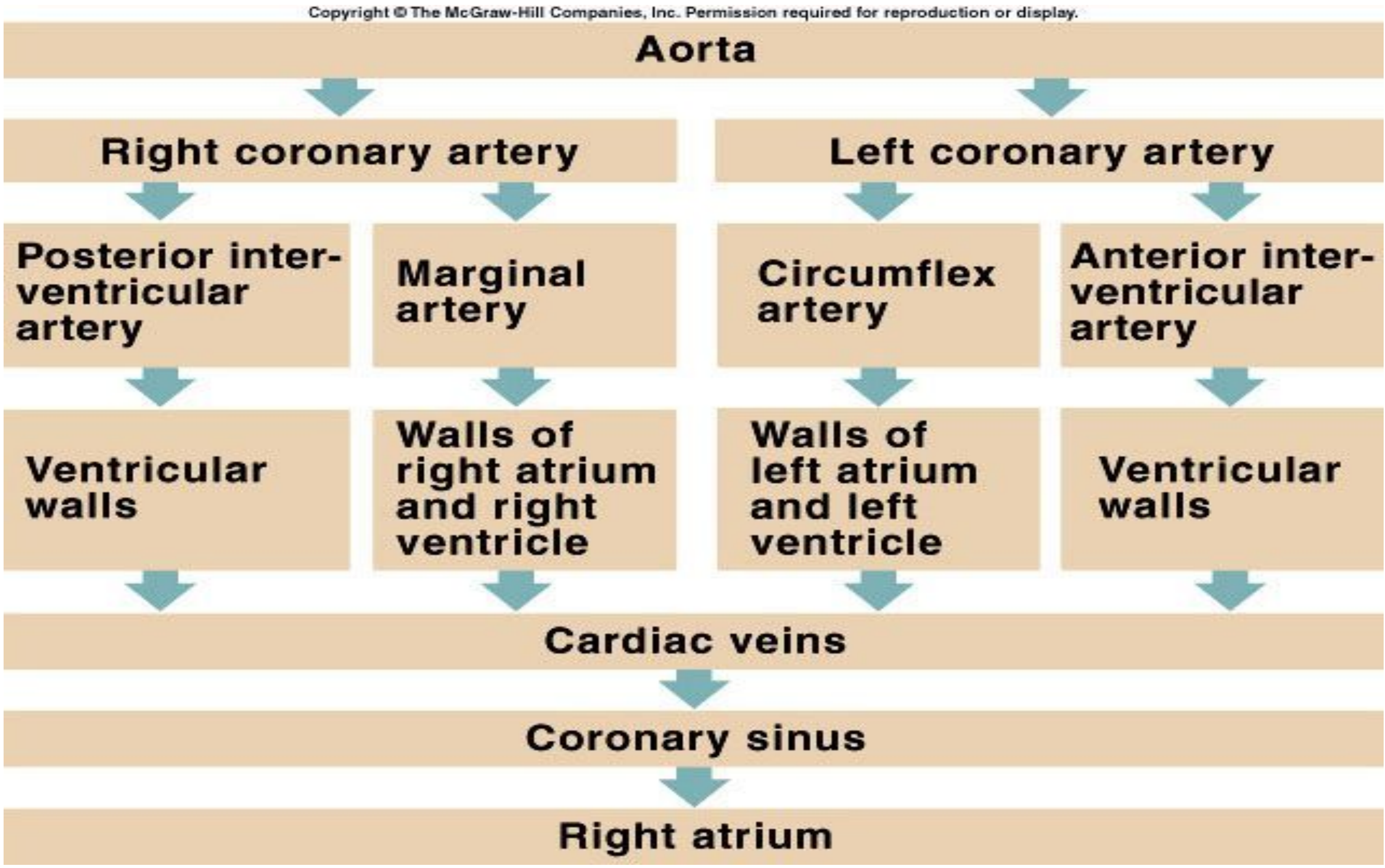
The direction of blood flow:

- **from the aorta to the left and right coronary arteries (LCA, RCA):**
- **LCA to Left anterior descending artery and circumflex branches**
- **RCA to marginal and posterior descending artery.**

Coronary veins all collect into the coronary sinus on the back part of the heart, The coronary sinus empties into the right atrium where the deoxygenated coronary blood joins with oxygen-depleted blood from the rest of the body.

https://youtu.be/3wpT-4bSmoU

Coronary Circulation



Coronary Circulation Flowchart

The pulmonary circulation leaves the right heart to allow blood to be re-oxygenated and to off-load CO_2. Consists of Right side of the heart, Pulmonary artery, capillaries and veins.

https://youtu.be/mkVLAkHExLU

Pulmonary Circulation

The systemic circulation leaves the left side of the heart to supply the coronary, cerebral, renal, digestive and hepatic circulations. It consists of the left side of the heart, Aorta and its branches, capillaries supplying the brain and peripheral tissues, systemic venous system and the vena cava.

https://youtu.be/9zuXfM49uhI

Systemic Circulation

The bronchial circulation provides oxygenated blood to the lungs through the **Bronchial arteries**, as opposed to the pulmonary circulation, which oxygenates blood through the **Pulmonary arteries.**

The **hepatic portal circulation** transports the nutrient- rich venous blood from the digestive tract capillaries, and transport it to the sinusoidal capillaries of the liver through the **hepatic portal vein.**

As it percolates through the liver sinusoids, the hepatocytes of the liver, acting as the chemical factories of the body, metabolize the nutrients and chemicals absorbed from the intestines to maintain homeostasis (extracting sugars, fats, proteins when appropriate and then dumping them back into the circulation when necessary). When talking about drugs, this hepatic circulation & metabolism before joining the systemic circulation is called the **first pass effect.**

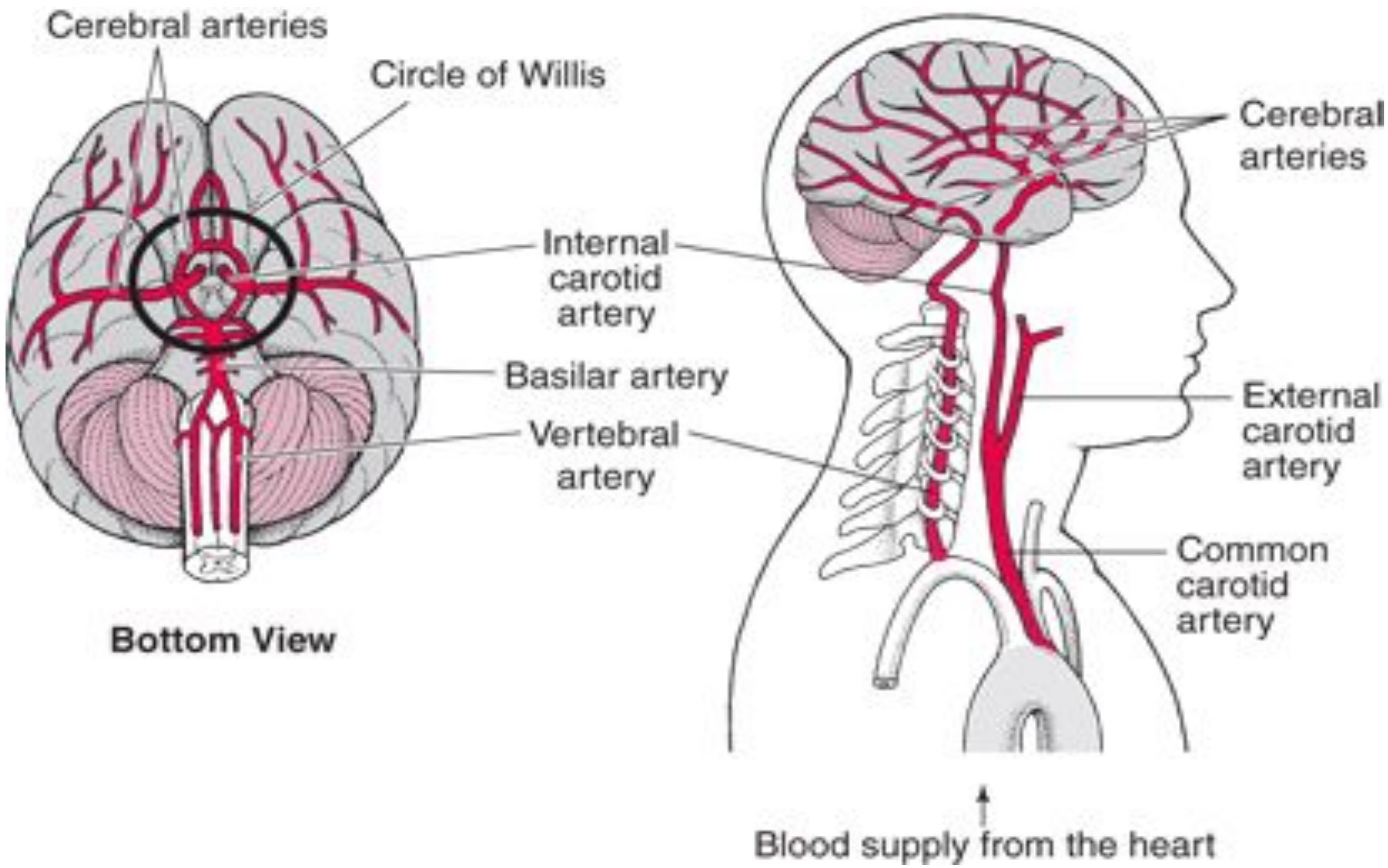
https://youtu.be/P5_BxsbmXcA

Bronchial & Hepatic Portal Circulation

The brain is one of the most highly perfused organs in the body. It is therefore not surprising that the arterial blood supply to the human brain consists of two pairs of large arteries, the **right and left internal carotid** (front) and the **right and left vertebral arteries**(back).
The internal carotid arteries principally supply the cerebrum, whereas the two vertebral arteries join distally to form the **basilar artery.** Branches of the vertebral and basilar arteries supply blood for the cerebellum and brainstem. Proximally, the basilar artery joins the two internal carotid arteries and other communicating arteries to form a complete anastomotic ring at the base of the brain known as the **circle of Willis**. The circle of Willis gives rise to three pairs of main arteries, the **anterior, middle, and posterior cerebral arteries**, which divide into progressively smaller arteries and arterioles that run along the surface until they penetrate the brain tissue to supply blood to the corresponding regions of the cerebral cortex.

https://youtu.be/uMMMqkVZAhk

Cerebral Circulation

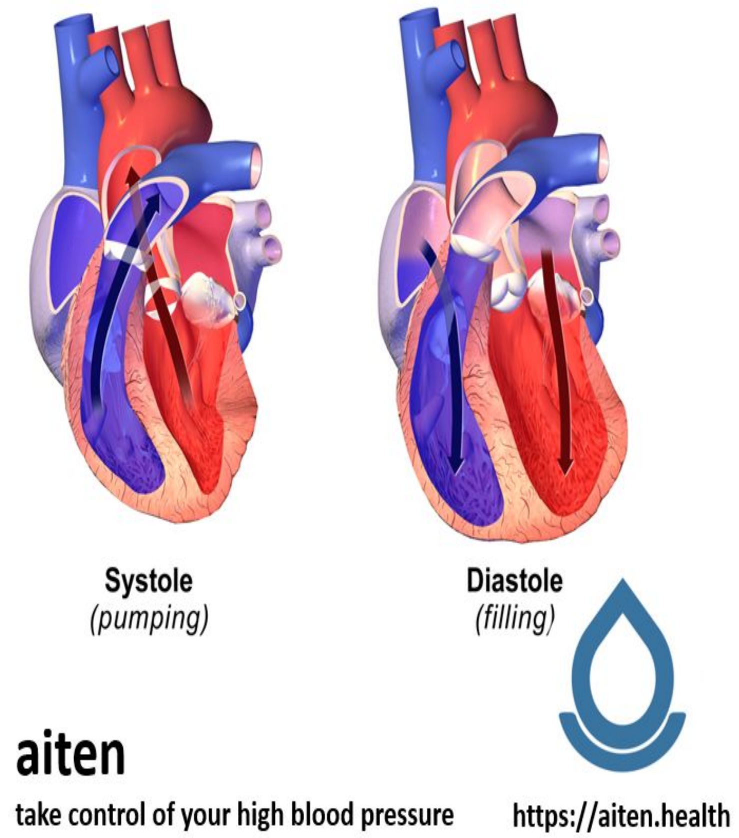


Cerebral Circulation

Used to describe the rhythmic pumping action of the heart

Divided into two parts:

- **Systole: the period during which the ventricles are contracting**
- **Diastole: the period during which the ventricles are relaxed and filling with blood**



Cardiac Cycle

- The cardiac cycle includes all of the events that take place during one heartbeat. There are 3 phases to the cardiac cycle: atrial systole, ventricular systole, and relaxation.

Atrial systole: During the atrial systole phase of the cardiac cycle, the *atria contract* and push blood into the ventricles. To facilitate this filling, the *AV valves stay open* and the *semilunar valves stay closed* to keep arterial blood from re-entering the heart. The atria are much smaller than the ventricles, so they only fill about 25% of the ventricles during this phase. The ventricles remain in diastole during this phase.

- **Ventricular systole**: During ventricular systole, the *ventricles contract* to push blood into the aorta and pulmonary trunk. The pressure of the ventricles forces the *semilunar valves to open and the AV valves to close*. This arrangement of valves allows for blood flow from the ventricles into the arteries. The cardiac muscles of the atria repolarize and enter the state of diastole during this phase.

Relaxation phase: During the relaxation phase, *all 4 chambers of the heart are in diastole* as blood pours into the heart from the veins. The ventricles fill to about 75% capacity during this phase and will be completely filled only after the atria enter systole.

The cardiac muscle cells of the ventricles repolarize during this phase to prepare for the next round of depolarization and contraction. During this phase, the *AV valves open* to allow blood to flow freely into the ventricles while the *semilunar valves close* to prevent the regurgitation of blood from the great arteries into the ventricles.

Cardiac Cycle

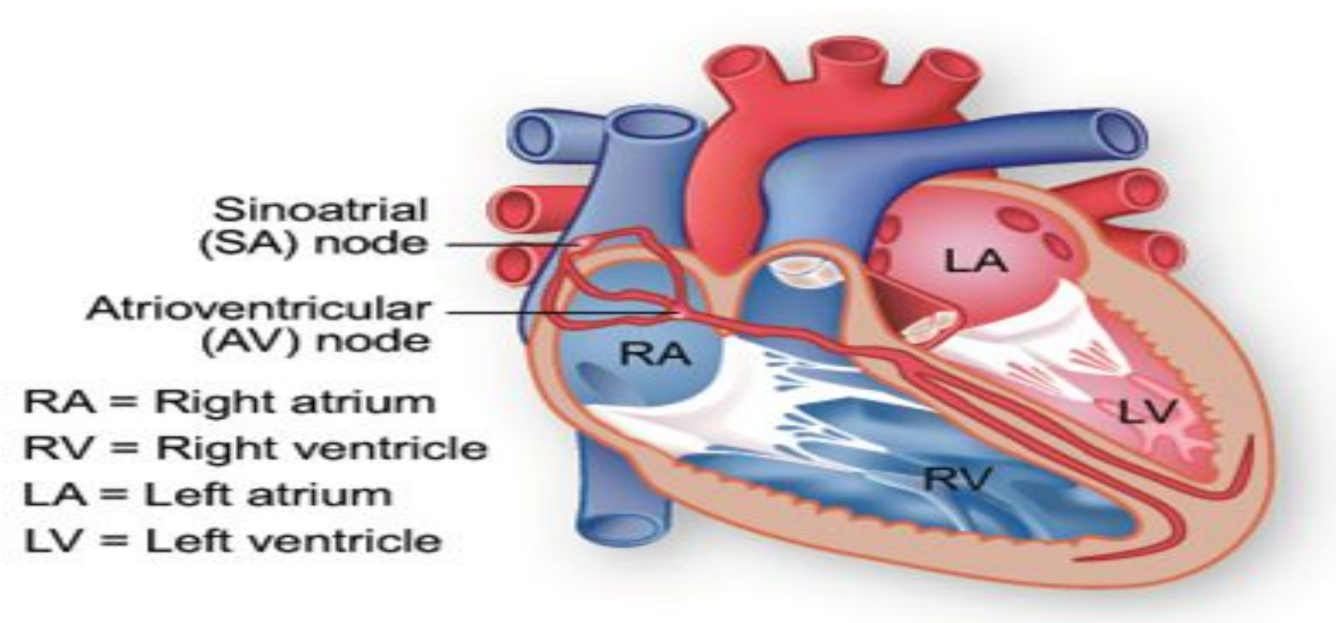
During embryonic development, about **1%** of all of the muscle cells of the heart form a network or pathway called the cardiac conduction system. This specialized group of myocytes is unusual in that they have the ability to spontaneously depolarize.

The rhythmical electrical activity they produce is called autorhythmicity. Because heart muscle is autorhythmic, it does not rely on the central nervous system to sustain a lifelong heartbeat.

Cardiac Conduction System

Cardiac Conduction System controls rate and direction of electrical impulse in the heart. Impulses are generated in the **SA node** that is located in the right atrial wall just below where the superior vena cava enters the chamber. SA has the fastest rate of firing.

The action potential generated from the SA node reaches the next pacemaker by propagating throughout the wall of the atria to the **atrioventricular node (AV node)** in the interatrial septum.



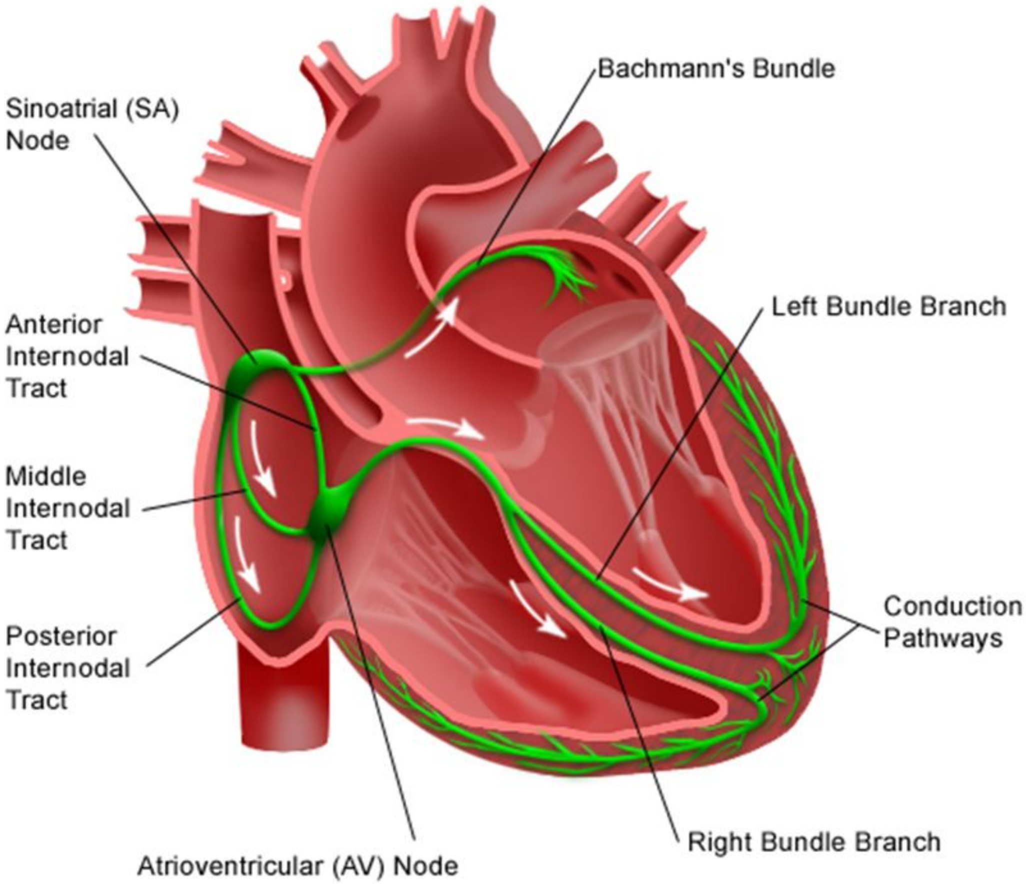
At the AV node, the signal is slowed, allowing the atrium a chance to mechanically move blood into the ventricles.

From the AV node, the signal passes through the **AV bundle (AKA The Bundle of His)** to the **left and right bundle branches** in the interventricular septum towards the apex of the heart. Finally, the **Purkinje fibers** rapidly conduct the action potential throughout the ventricles.

https://youtu.be/eOX_NmYLKOE

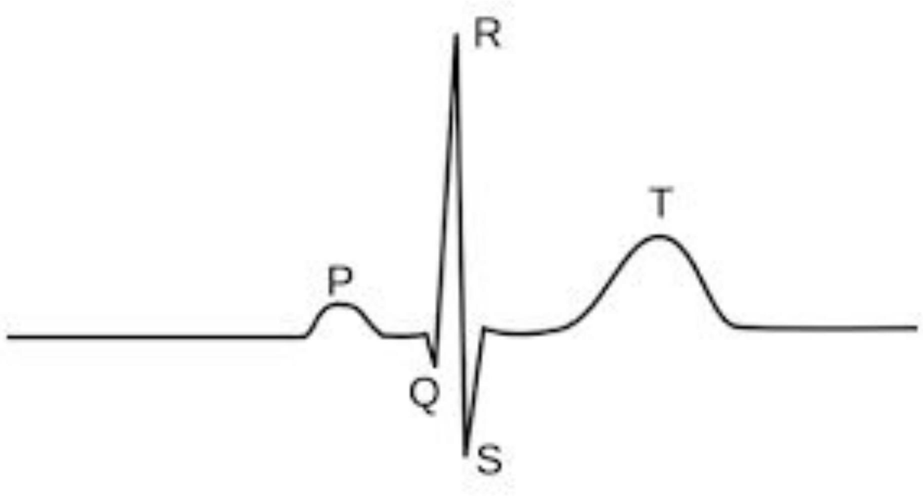
Continued

Electrical System of the Heart

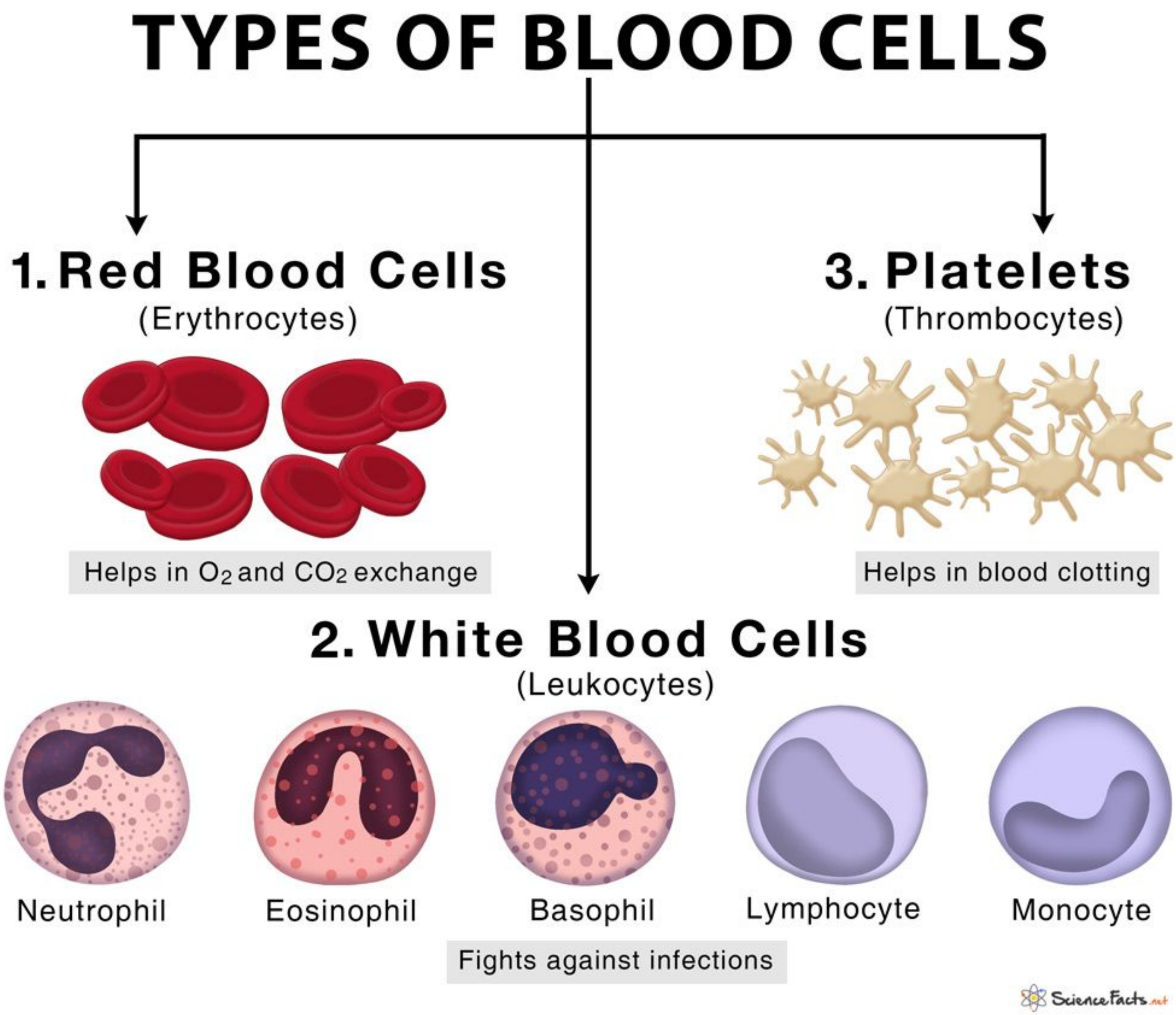


EKG/ECG Simplified

P wave = Atrial depolarization
QRS complex = Ventricular depolarization (& atrial repolarization)
T wave = Ventricular repolarization



Blood Cell Types



Blood Cell Types

Erythrocytes (Red Blood Cells) = Donut shaped cells that carry oxygen

Thrombocytes (Platelets) = Blood cell pieces involved in blood clotting

Leukocytes (White Blood Cells) = Part of your body's immune system

Neutrophils = first responders of immune system, phagocytosis
Monocytes = become macrophages in tissue, phagocytosis
Lymphocytes = B & T cells, produce Antibodies, directly fight foreign invaders
Eosinophils = Kills parasites, cancer cells, involved in allergies
Basophils = Produces Histamine, involved in allergies/asthma