

LECTURE 2: CARDIOVASCULAR SYSTEM: THE HEART

INTRODUCTION

Heart disease “heart attack” (myocardial infarction) continues to be our number one killer so the importance of understanding how the heart works is obvious. Atherosclerosis is the underlying cause of death from myocardial infarction. The anatomy of the heart is relatively simple with its 4 chambers, 4 valves, and several veins and arteries. However, the physiology of this muscular pump requires more consideration. The importance of the various controls over heart rhythm and contract force (i.e., cardiac output) is significant: the cardiac conduction system, nerves, hormones, and end-diastolic volume.

The heart is composed of cardiac muscle cells, a striated involuntary muscle (we discussed this in our Anatomy and Physiology I), innervated by two nerves of autonomic inputs (sympathetic and parasympathetic). Clinical evaluation of the heart begins with two basic assessments; heart rate and auscultation.

The cardiovascular system has two major divisions: a pulmonary circuit and a systemic circuit. Each circuit begins and ends in heart, and blood travels through these circuits in sequence. The heart is the size of a fist; it is located in the thoracic cavity in the mediastinum, between the lungs and deep to the sternum. The base of the heart is directed toward the right shoulder and the apex points toward the left hip. The heart wall consists of three layers: *epicardium*, *myocardium*, and *endocardium*. The myocardium is composed mainly of cardiac muscle and forms the bulk of the heart, and it is the myocardium that causes contraction. The heart has four chambers: two upper chamber (right and left atria) and two lower chambers (right and left ventricles). A valve lies between each atrium and its ventricle and at the exit of each ventricle into its great artery. The valves of the heart ensure a one-way blood flow. Blood flow is kept entirely separate on the right and left sides of the heart. The right side of the heart furnishes blood to the pulmonary circuit, which carries blood to the lungs and returns it back to the heart. The left side of heart supplies the systemic circuit, which carries blood to the body’s tissues and returns it back to the heart. The blood vessels of the heart wall constitute the coronary circulation.

The heart does receive both sympathetic and parasympathetic nerves that modify heart rate and contraction strength, but the heartbeat is *myogenic* i.e. the signal for contraction originates within the heart itself because cardiocytes (heart cells) are inherently autorhythmic. So heart cell would contract without nerve input, but nerve input is needed to regulate rhythmicity of the heartbeat. In terms of metabolism, cardiac muscle depends almost exclusively on aerobic respiration to make ATP. The heartbeat is coordinated by a cardiac conduction system composed of an internal pacemaker and nervalike conduction pathways through the myocardium. Contraction of the heart is called systole, and relaxation is diastole.

Every cell relies on surrounding interstitial fluid for oxygen, nutrients and waste disposal. And this fluid composition is kept stable through continues exchange between blood and peripheral tissue. The major function of the cardiovascular system is to circulate substances throughout the body. Its organs function to supply cells and tissues with oxygen and nutrients and also to remove wastes (CO₂ & urea) from cells and tissues. If cells do not receive O₂ and nutrients and wastes accumulate, cells will die.

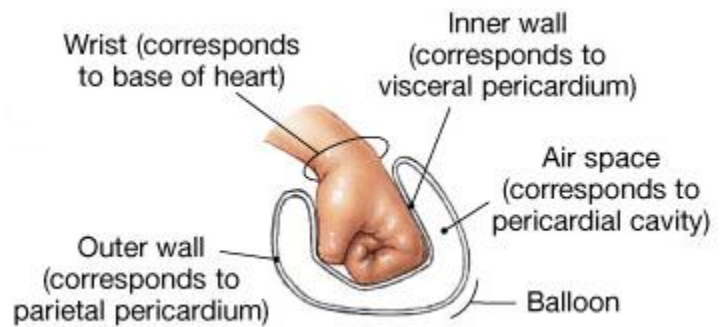
STRUCTURE OF THE HEART

The heart is enclosed in a doubled-walled sac called the pericardium. Deep to the pericardium is the serous pericardium

1. **Size and Location of the Heart:** The heart is the size of a fist and weighs 250–300 grams. The heart surrounded by the pericardium sac is found in the mediastinum and two-thirds lies left of the midsternal line. The base is directed toward the right shoulder and the apex points toward the left hip.
 - a. Location = within mediastinum
 - b. Size = closed fist 300g (adult)
 - c. Base = wide superior border
 - d. Apex = inferior point.
2. **Coverings of Heart:** The heart is enclosed in a doubled-walled sac called the pericardium. The parietal pericardium lines the inside of the pericardium. The visceral pericardium, or epicardium, covers the surface of the heart. To visualize the relationship between the heart and pericardial cavity, imagine pushing your fist toward the center of a large, partially inflated balloon. The balloon represents the pericardium, and your fist the heart. Your fist, where the balloon folds back in itself, corresponds to the base of the heart. The air space

inside the balloon correspond to the pericardial cavity.

- a. Visceral pericardium = innermost delicate (simple squamous) epithelial tissue over (loose areolar) connective tissue covering surrounding the heart muscle.
- b. Parietal pericardium = inner (simple squamous) epithelial tissue over (loose areolar) connective tissue lining of fibrous pericardium.



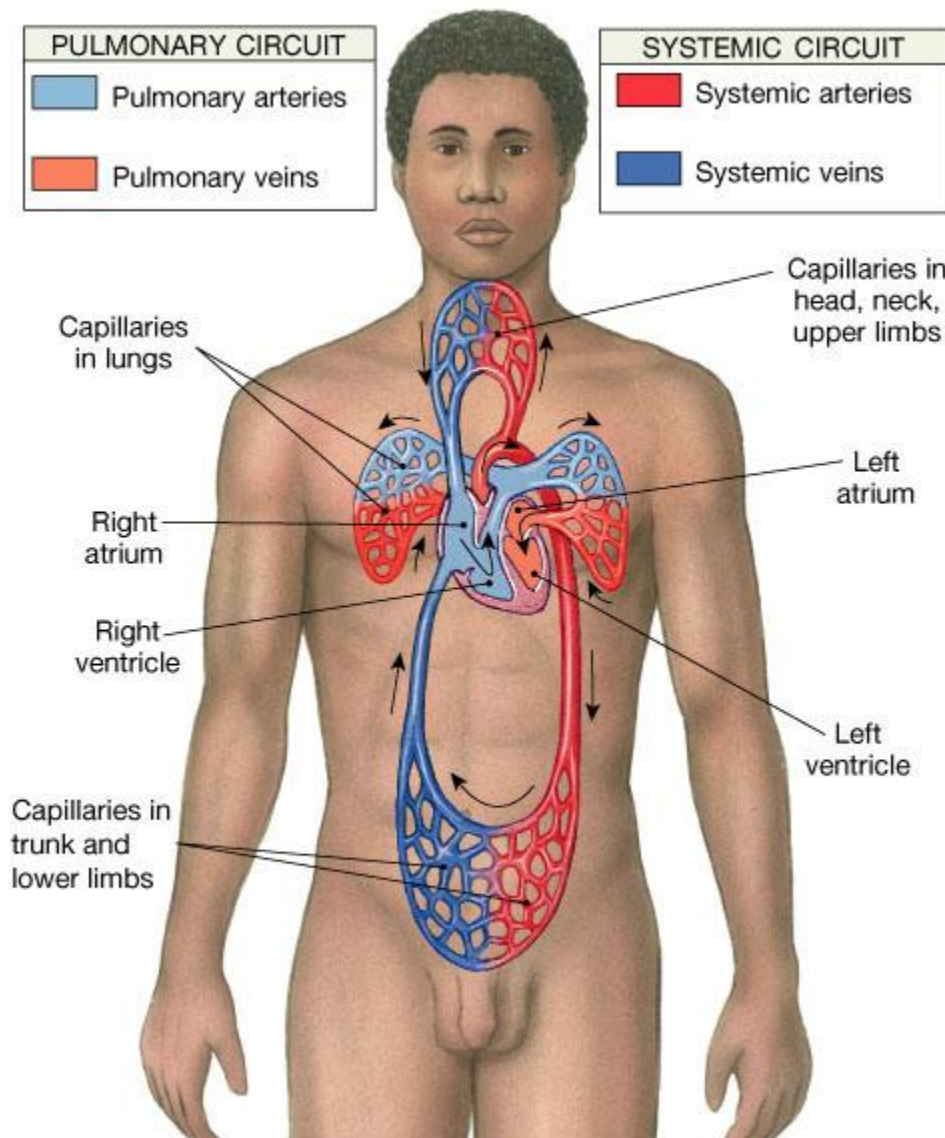
3. **Wall of the Heart:** composed of 3 layers:

- a. Epicardium = the epicardium or visceral pericardium, covers the outer surface of the heart.
- b. Myocardium = the myocardium or muscular wall of the heart is the middle layer of heart wall. This layer contains cardiac muscle tissue, blood vessels and nerves. This layer forms the bulk of the heart. Because it is a muscle tissue, this is the layer that contracts i.e. myocardium is responsible for contraction of heart.
- c. Endocardium = the inner surface of the heart, including those of the heart valve are covered by the endocardium. This layer is a simple squamous epithelium that smoothens and covers the inner lining of heart chambers and valves i.e. the endocardium lines the chambers of the heart and the valves.

4. **Heart Chambers and Valves**

- a. The heart has four chambers:
 - i. Two chambers at the superior pole (base) are the right and left atria (two upper chambers called atria receive blood); and
 - ii. Two inferior chambers, the right and left ventricles, are pumps that eject blood into the arteries (two lower chambers called ventricles pump blood).
 1. Right ventricle pumps the blood to the lungs via pulmonary circuit
 2. Left ventricle pumps the blood to the peripheral tissue (cells throughout the body) via system circuit.
 - iii. Atrioventricular vales (Tricuspid and Bicuspid valves)- consist of folds of fibrous tissue, and permit blood in one direction: from Atria to Ventricles
 - iv. Semilunar valve (Aortic and Pulmonary) –permit unidirectional blood flow from the ventricles to the pulmonary artery and aorta.

Right Atrium	Left Atrium
Receives blood low in oxygen from body	Receives oxygenated blood from lungs
Sends blood to R. Ventricle	Sends blood to L. Ventricle
Tricuspid Valve	Bicuspid Valve (Mitral Valve)
Prevent backflow of blood from ventricles to the atriums Gives blood unidirectional flow Blood from the atrium to the ventricles pass through these valves	
Right Ventricle	Left Ventricle
Receives blood from R. Atrium	Receives blood from L. Atrium
Sends blood to lungs	Sends blood to body
Pulmonary Semilunar Valve	Aortic Semilunar valve
Prevent backflow of blood from the arteries back to the ventricles Gives blood unidirectional flow Blood from the ventricles to the Aorta and Pulmonary Artery passes through these valves	



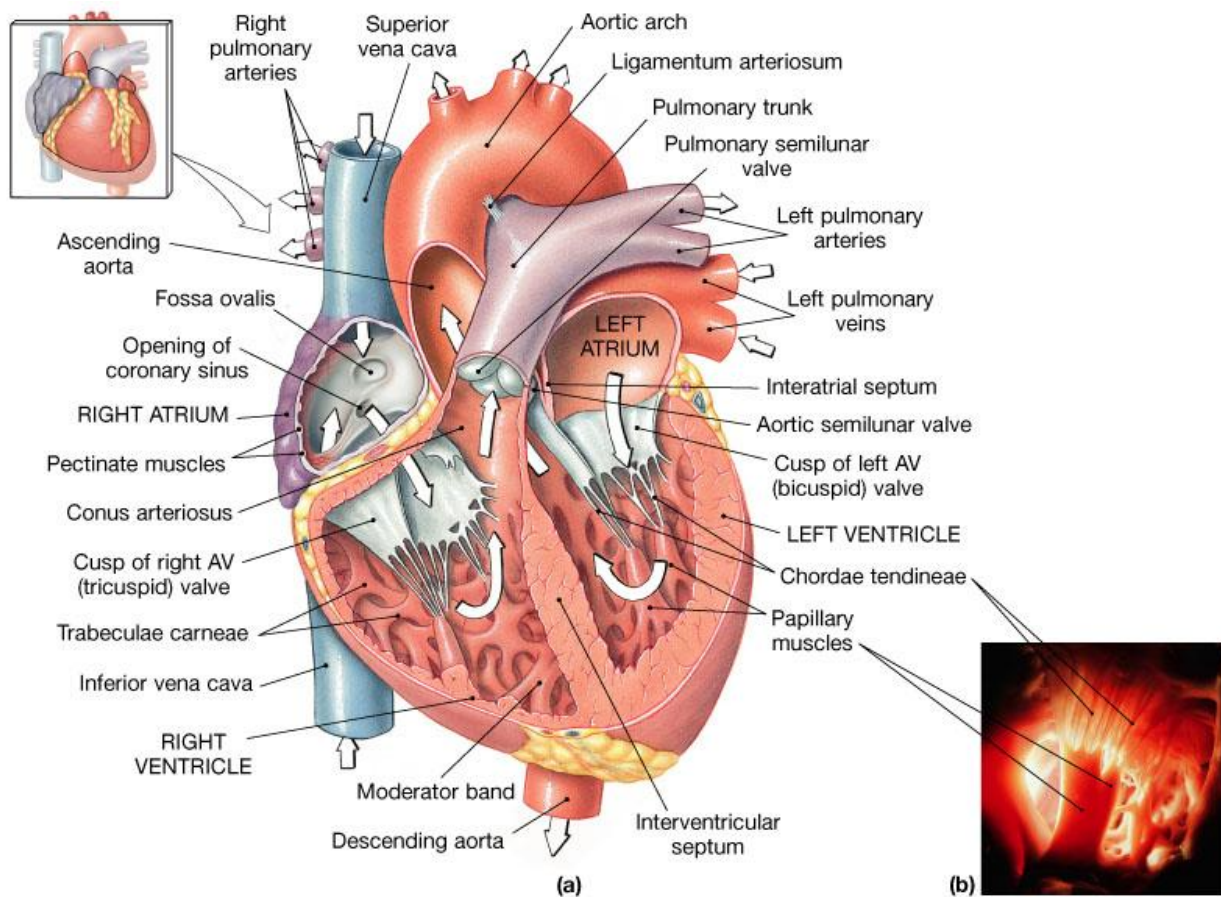
ATRIA THE UPPER CHAMBERS ARE CALLED

1. Right and left atrium are separated by the interatrial septum.
2. They are thin walled and receive blood returning to the heart by way of the great veins.
3. **Right atrium (RA)**
 - a. Receives blood from systemic circuit through 2 great veins:
 - i. Superior vena cava (From head and upper body) ,
 - ii. Inferior vena cava (From lower body)
 - b. It also receives blood from cardiac veins through the coronary sinus. The coronary veins of the heart return blood to coronary sinus (a large thin walled vein) that opens into right atrium.
 - c. RA has a valve (called tricuspid valve) that guards the entrance of right ventricles, and permits blood flow from RA into right ventricle.
 - d. In embryo there is oval opening that permit blood flow from right atrium to left atrium while the lungs are developing before birth i.e. the blood from the right atrium does not go to the right ventricle, but instead flows to the left atrium. This opening is sealed permanently 48 hours after birth
4. **Left atrium (LA)**
 - a. Receives blood from the pulmonary vein.
 - b. From respiratory capillaries (capillaries found in the lungs) blood collects into vein that ultimately unites to form the 4 pulmonary veins (2 left and 2 right pulmonary veins).

- c. LA has a valve (called bicuspid valve) that guards the entrance of left ventricles, and permits blood flow from LA into left ventricle.

VENTRICLES THE LOWER CHAMBERS ARE CALLED

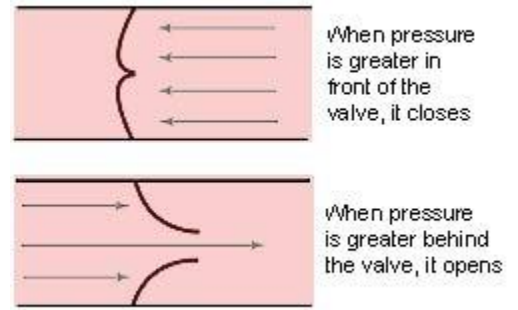
1. Ventricles are thick walled chambers that pump the blood via two circuits (pulmonary circuit and systemic circuit). Right and left ventricles are separated by the interventricular septum.
2. **Right Ventricle**
 - a. Blood travels from the right atrium into the right ventricle through an opening (think of this opening a door that opens when atrium contracts and closes when ventricle contracts) called tricuspid valve.
 - b. The free edge of each valve consist of three flaps (tricuspid) attached to dendinous connective tissue fibers called chordae tendineae. Chordae tendineae attaches the flaps of the valve to the muscular projections (papillary muscle) found in the ventricles.
 - c. Trabeculae carneae, are series of muscular ridges on the inner surface of the ventricles.
3. **Left Ventricle**
 - a. The left ventricle is much larger compared to right ventricle. It has thicker and muscular wall which enables the left ventricles to develop high pressure to push blood throughout the body (large distance between heart and the furthest cell e.g. the cell at the tip of the toe and fingers) via the system circuit. Whereas the right ventricle needs to pump blood, at lower pressure to the lungs (less distance between heart and lungs) via the pulmonary circuit.
 - b. Blood from the left atrium passes through an opening called Bicuspid Valve to the left ventricle i.e. bicuspid valve permits the flow of blood from the left atrium into the left ventricle
 - c. Like right ventricle, the cusps of the bicuspid valve is attached to the papillary muscle by chordae tindeneae



VALVES

Heart valves function to ensure a one-way flow of blood through the heart. The valves are not made of muscle, but rather are composed of sheets of tough connective tissue (leaflets) that act like flaps. The heart valves open and

close passively because of pressure differences on either side of the valve. When pressure is greater behind the valve, the leaflets are blown open and the blood flows through the valve. However, when pressure is greater in front of the valve, the leaflets snap shut and blood flow is stopped. The motion of a heart valve is analogous to the motion of the front door of your house. The door, which only opens in one direction, opens and closes due to pressure on the door.



1. Atrioventricular valves (AV valves)

- a. The tricuspid valve lies between the right atrium and right ventricle.
 - i. Tricuspid valve closes when the right ventricle contracts, preventing the backflow of blood from the right ventricle to the right atrium
- b. The bicuspid valve (also called mitral valve) lies between the left atrium and left ventricle
 - i. Bicuspid valve closes when the left ventricle contracts, preventing the backflow of blood from the left ventricle to the left atrium
- c. The free edge of each cusps of both bicuspid and tricuspid valves are attached to Chordae tendineae, and chordae tendineae is attached to the papillary muscle on the surface of ventricles i.e. chordae tendineae connects the cusps of atrioventricular valves to the papillary muscle. This connection is important in preventing the valve from swinging backward when the ventricles contract and the pressure in the ventricles increase i.e. to ensure that the AV valves do not invert (turn inside-out), they are attached to small papillary muscles by tough tendons called the chordae tendineae. Papillary muscle contract in synchrony with the ventricles, thus maintaining constant tension on the valve leaflets to prevent them from swinging backward as ventricles contract.
 - i. Chordae Tendineae = tendon-like, fibrous cords that connect the cusps of AV valves to the papillary muscle (inner surface) of ventricles; prevent cusps from swinging back into atria.
 - ii. Papillary Muscle = the muscular columns that are located on the inner surface of the ventricles.

2. Semilunar valves

- a. The pulmonary semilunar valve lies within the pulmonary trunk.
 - i. Pulmonary semilunar valve guards the entrance to the pulmonary artery i.e. it regulate the flow of blood from the right ventricle to the pulmonary artery.
 - ii. When right ventricle contracts (systole) pressure inside the ventricle increases, and forces the semilunar valve to open, and then blood is ejected from the right ventricles to the pulmonary artery.
- b. The aortic semilunar valve lies within the aorta.
 - i. Aortic semilunar valve guards the entrance to the Aorta i.e. it regulate the flow of blood from the left ventricle to the Aorta.

MAJOR BLOOD VESSELS ASSOCIATED WITH THE HEART

1. Arteries carry blood away from the heart.

- a. Carry blood that is high in O_2 & low in CO_2 , except pulmonary arteries that are low in O_2 & high in CO_2
- b. Aorta carries blood from the left ventricle to the body.
- c. Pulmonary arteries carry blood from the right ventricle to the lungs (via the pulmonary trunk).
- d. Coronary arteries carry blood to the myocardium.

2. Veins carry blood toward the heart.

- a. Carry blood that is high in CO_2 & low in O_2 , except the pulmonary veins that are high O_2 & low CO_2 .
- b. Superior vena cava brings blood from the head and upper limbs.
- c. Inferior vena cava brings blood from the trunk and lower limbs.
- d. Coronary sinus (posterior surface) brings blood from the myocardium.
 - i. All of the above veins (superior and inferior vena cava and coronary sinus) deposit their

blood into the right atrium

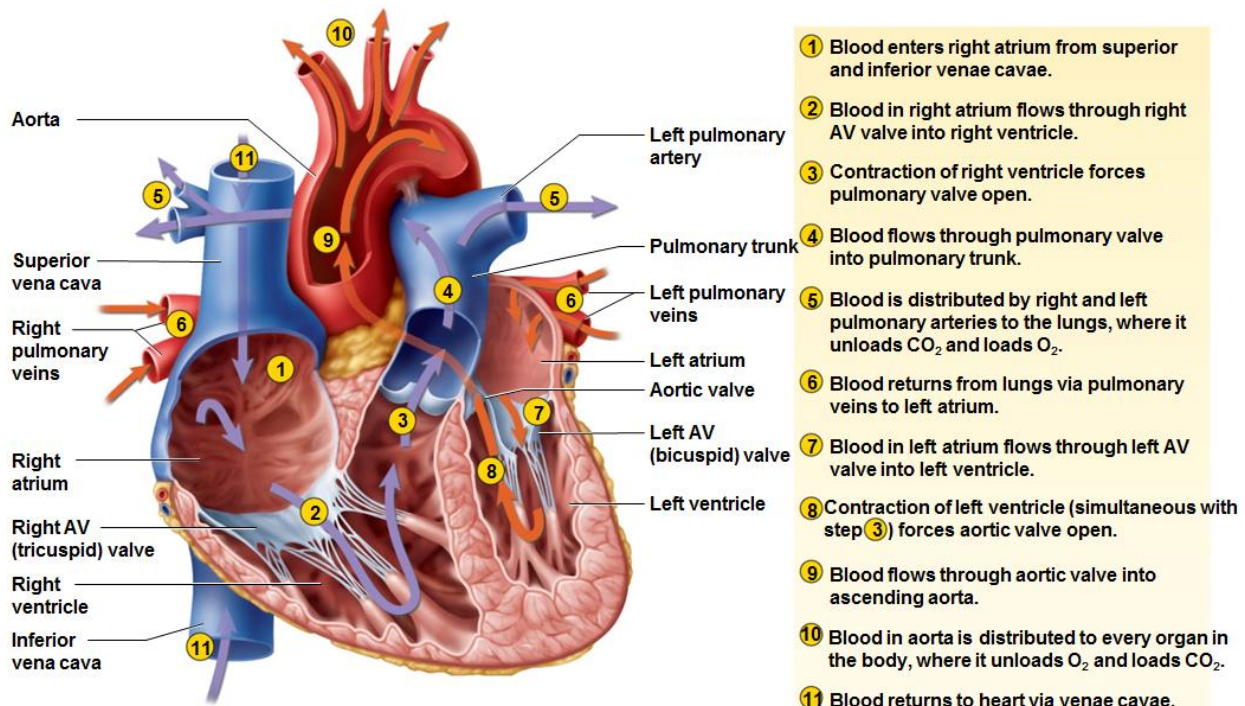
- e. Pulmonary veins bring blood from the lungs to the left atrium:
 - i. 2 from right lung
 - ii. 2 from left lung

PATHS OF BLOOD THROUGH THE HEART

1. **Right atria** – receives blood from superior and inferior vena cava when atria are relaxed (diastole). This blood is deoxygenated blood (poor in oxygen), as it returns to the heart from the cells. From the right atrium blood flows to the right ventricle through the tricuspid valve when atrium contracts (systole).
2. **Right ventricle** – receives blood from right atrium and pumps it to the pulmonary artery through the pulmonary semilunar valve
3. **Pulmonary artery** – pulmonary arteries deliver the blood to the lungs and at the lungs they branch into capillaries
 - a. At the lungs gas exchange occurs
 - i. Oxygen diffuses from the alveoli (lungs) to the capillary and carbon dioxide diffuses from the capillary to the alveoli. After the exchange the blood becomes oxygenated (rich in oxygen)
4. **Pulmonary Vein** - after the gas exchange at the lungs pulmonary veins collect the blood and deliver them to the left atrium.
5. **Left atria** – receives blood from pulmonary veins and then the blood from the left atrium flows to the left ventricle through the bicuspid valve when atrium contracts (systole)
6. **Left ventricle**- receives blood from the left atria and pumps it to the aorta through the aortic semilunar valve
7. **Aorta** branches into smaller arteries and delivers the blood to the cells throughout the body.
 - a. Gas exchange occurs between the cell and the capillaries
 - i. Oxygen diffuses from the capillaries to the cell and carbon dioxide diffuses from the cell to the capillaries.
8. After the gas exchange the blood is delivered back to the heart by superior and inferior vena cava.

SUMMARY OF THE PATHS OF BLOOD THROUGH THE HEART

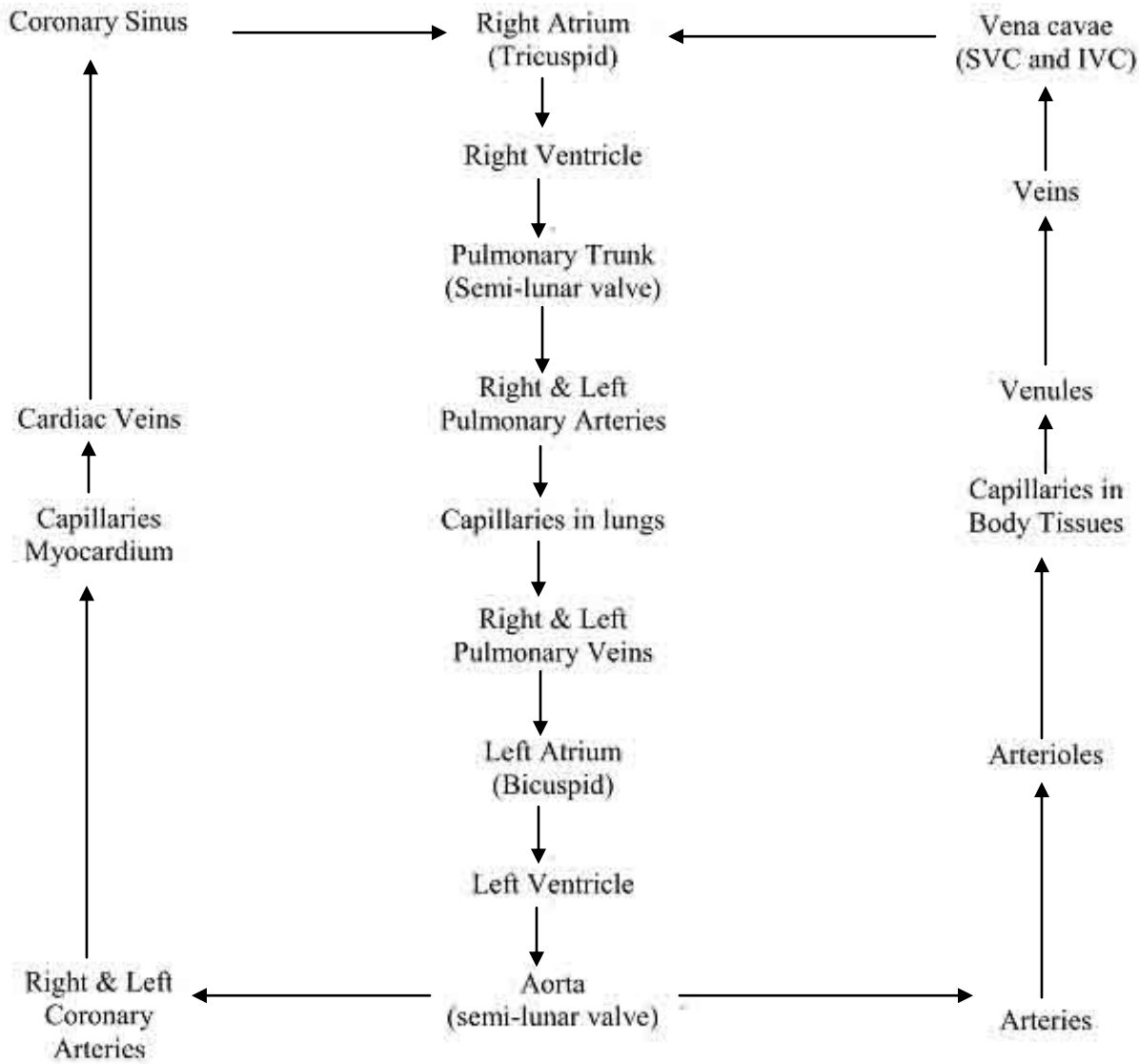
1. right atrium (deoxygenated blood) NOTE: blue = deoxygenated blood
2. (tricuspid valve)
3. right ventricle
4. (pulmonary semi-lunar valve)
5. pulmonary trunk
6. pulmonary arteries
7. capillaries (alveoli) in lungs (gas exchange will occur between alveoli and capillaries and blood becomes oxygenated)
8. pulmonary veins (oxygenated blood) NOTE: red = oxygenated blood
9. left atrium
10. (bicuspid or Mitral valve)
11. left ventricle
12. (aortic semi-lunar valve)
13. ascending aorta
14. Capillaries (gas exchange will occur between the cells and capillaries and blood will become deoxygenated)
15. Veins
16. Superior vena cava and Inferior vena cava
17. Right atrium (the circle will repeat itself)



BLOOD SUPPLY TO THE HEART:

1. Coronary Circulation (i.e. Pathway through Myocardium or how the heart muscle itself is supplied with blood).
2. Cardiac Muscles require reliable supplies of Oxygen and nutrients.
3. Coronary circulation supplies blood to heart muscles
4. Blood pressure here is the highest in the systemic circuit to ensure continuous blood flow
5. The right coronary artery supplies blood to right atrium, portion of both ventricles and portions of the conducting system of heart including atrioventricular nodes
6. The left coronary artery supplies blood to the left ventricle, left atrium and interventricular septum
7. Cardiac vein drain blood from left Ventricle and Atrium, and Interventricular septum and empties in Great Cardiac Vein
8. Middle Cardiac vein drain blood from RA, portion of both Ventricle and AN nodes and empties in Great Cardiac Vein
9. The pain of angina comes from a blockage in an artery that supplies blood to the heart. The blockage can be either complete or partial, main coronary artery or smaller coronary artery

SUMMARY OF PULMONARY, CORONARY AND GENERAL SYSTEMIC CIRCULATIONS



CIRCUITS OF HEART

Blood flows through 2 distinct circuits; the pulmonary circuit and the systemic circuit.

1. Pulmonary circuit

In the Pulmonary Circuit, blood that is high in carbon dioxide and low in oxygen flows from the right heart to the lungs. In the capillaries of the lungs, blood takes on oxygen and offloads carbon dioxide. Oxygenated blood then flows from the lungs to the left heart.

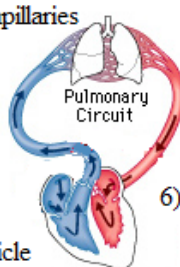
- a. Delivers blood from the right ventricle of the heart to the lungs and from the lungs to the left atrium of the heart

4) Gas exchange between the alveoli of the lung and pulmonary capillaries

3) Pulmonary capillaries of the lungs

2) Pulmonary Arteries

1) Right Ventricle



5) Pulmonary Veins

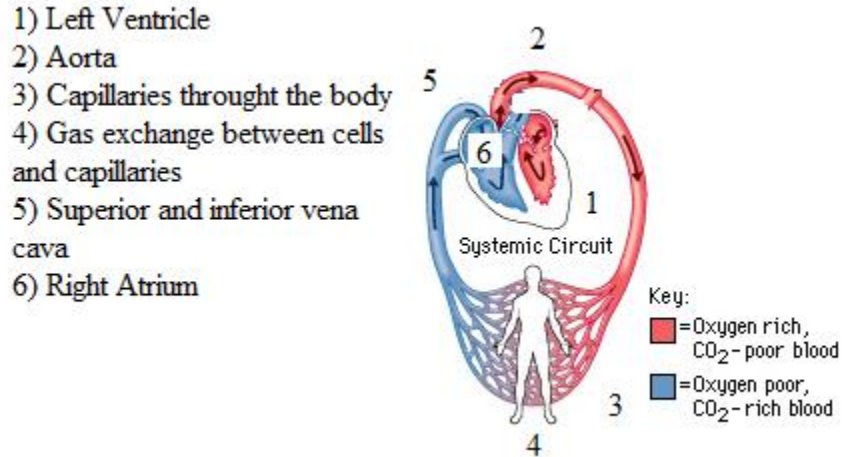
6) Right Atrium

Key:
■ = Oxygen rich, CO₂-poor blood
■ = Oxygen poor, CO₂-rich blood

2. System circuit

In the Systemic Circuit, oxygenated blood flows from the left heart to the systemic tissues (meaning all cells of the body). Systemic capillaries are the site of exchange of nutrients and wastes. The blood offloads oxygen to the tissues and picks up carbon dioxide wastes. Deoxygenated blood then flows from the systemic tissues to the right heart, completing the circuit.

- a. Delivers blood from the left ventricle of the heart to the rest of the body and collects blood from the rest of the body and delivers it to the right atrium of the heart.

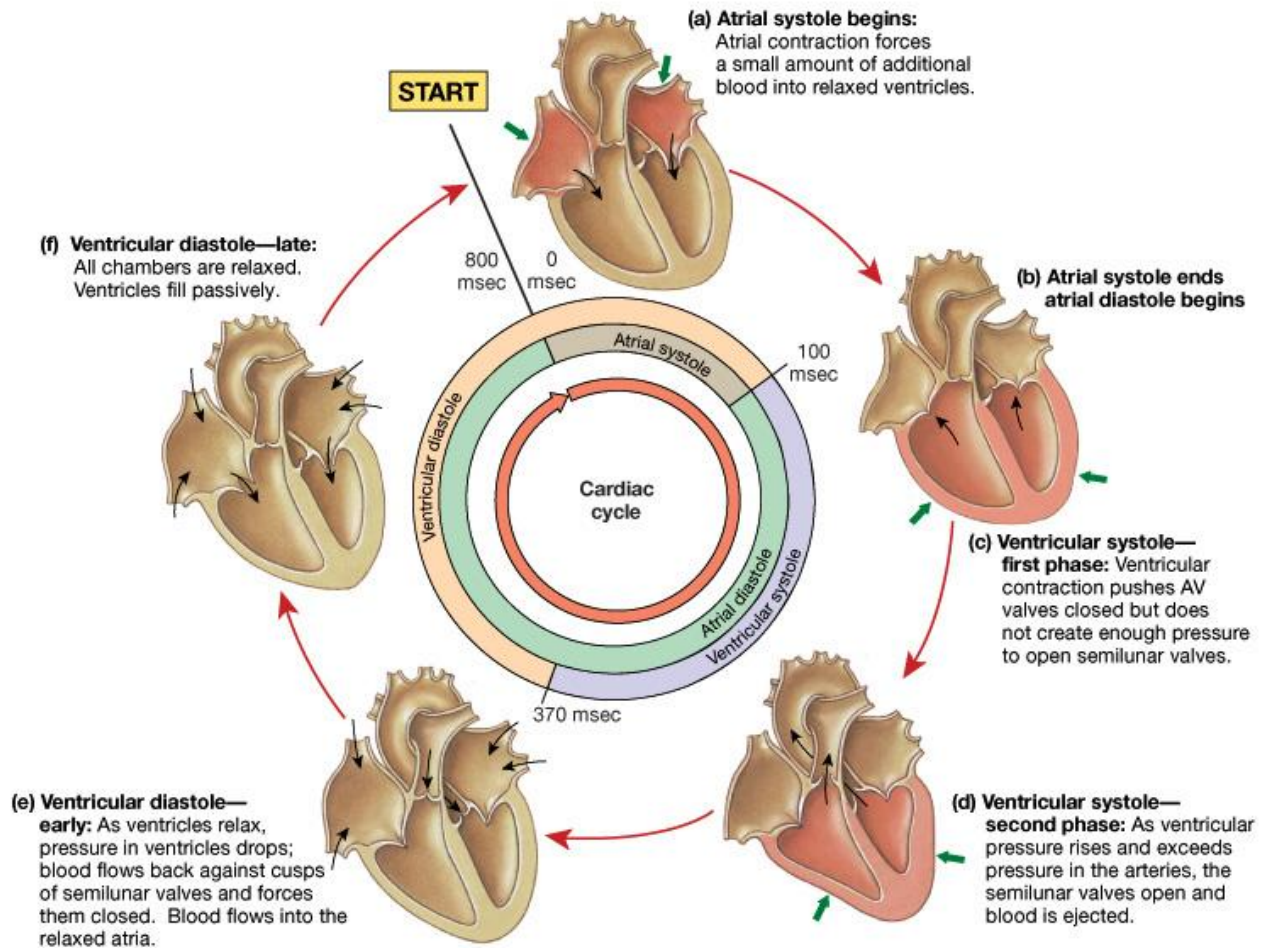


THE CARDIAC CYCLE

1. Each heartbeat is followed by a brief resting phase, which allows time for the chambers to relax and prepare for the next heartbeat. The period between the start of one heartbeat and the beginning of the next is a single cardiac cycle. Therefore the cardiac cycle includes alternating periods of contraction and relaxation.
2. Although we think of a heart as a pump, but in fact it is four pumps that work in pair. Therefore the heart works in a coordinated fashion as a dual pump, where the atria and ventricles alternately contract (systole) and relax (diastole).
3. The cardiac cycle includes all of the events associated with one heartbeat.
 - a. When the two atria are in systole pumping blood into the ventricles, the two ventricles are in diastole, filling with blood.
 - b. When the two ventricles are in systole pumping blood into the arteries, the two atria are in diastole, filling with blood.
4. Blood flows from areas of high pressure to areas of low pressure.
 - a. When the two atria are in contract, the ventricles are relaxed and the chordae tendineae are loose and the Atrioventricular valves are open. During atria contraction, the pressure in the atria is high and the pressure in the ventricles are low, thus blood moves from area of high pressure (atria) to area of low pressure (ventricles) through the open atrioventricular valves. As blood flows to the ventricle and the ventricles are filling, ventricular pressure increases.
 - b. When the two ventricles contract, blood moving back toward the atria pushes the cusps of the atrioventricular valves together, closing them and preventing backflow of blood to the atria. At the same time the contraction of papillary muscles tenses the chordae tendineae, stopping the cusps from swinging backward. Ventricles continue to contract and the pressure keeps increasing in the ventricles. When the pressure in the right ventricle become higher than the pressure in pulmonary artery, the pulmonary semilunar valve opens and blood flow to the pulmonary artery. When the pressure in the left ventricle become higher than the pressure in aorta, the aortic semilunar valve opens and blood flow to the aorta.
5. The AV valves and SL valves open and close alternately, as well.
 - a. When the two atria are in systole, the pressure is high, which opens the AV valves allowing blood to pass into the ventricles. The SL valves are closed at this time.
 - b. When the two ventricles are in systole, their high pressure pushes the cusps of the AV valves closed.

Only when the pressure in the ventricles becomes greater than the pressure in the arteries, do the SL valves open which allows the blood to pass into the arteries.

- c. NOTE: Isovolumetric contraction, is the moment when AV valves closes and the pressure in the ventricles continue to increase but the semilunar valves are not open yet i.e. the moment that all 4 valves are close



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EART SOUNDS

- There are four heart sounds designated as S1, S2, S3 and S4. The first (S1) and second (S2) sounds are heard clearly with the stethoscope.
- These sounds that can be heard through a stethoscope, represent the closing of heart valves, and therefore help in diagnosing any problems occurring in the valves.
 - lubb (the first sound): closing of AV valves (ventricular systole) loud and long
 - dupp (the second sound): closing of SL valves (ventricular diastole) short and sharp
 - The S3 and S4 sounds are very faint. These sounds are produced by the flow of blood into ventricles (S3) and atrium (S4).
- Significance: If the closing of the valve cusps is incomplete, some blood may leak backward = heart murmur.

CARDIAC CONDUCTION SYSTEM (CCS)

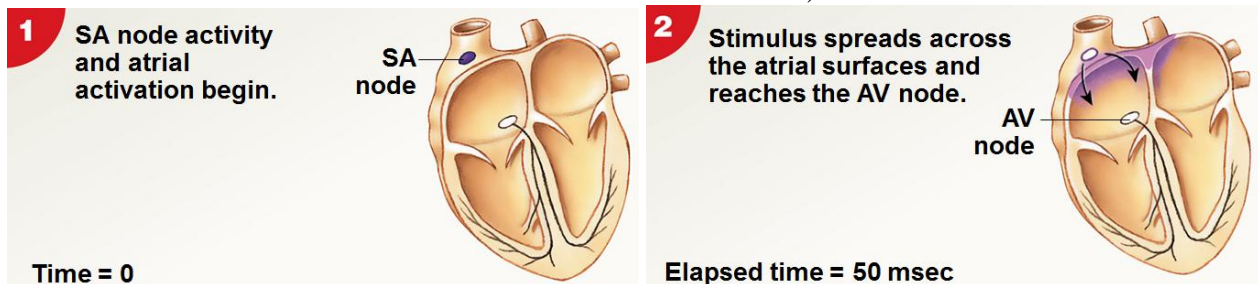
The goal of cardiovascular regulation is the maintenance of adequate blood flow to vital tissues. The best overall indicator of the blood flow is the cardiac output (the amount of blood pumped by the ventricle in one minute) i.e. the amount of blood ejected or pushed by the heart in one minute. The cardiac output depends on two factors: the heart rate (how many time the heart beats in one minute) and the stroke volume (the amount of blood pumped or ejected out of the heart ventricle with each contraction (heartbeat). For example if the stroke volume is 80ml (80 milliliter

of blood is ejected or pumped out of the heart with each contraction of ventricle) and heart rate is 75 (heart beats 75 times in one minute) then cardiac output is = 80 times 75. The body adjusts cardiac output to ensure that peripheral tissues receive adequate supply of oxygen. Under different conditions, and when necessary heart rate could increase to increase cardiac output e.g. during exercise. The heart rate is a key factor in cardiac output. Heart rate is established by the sinoatrial node and distributed by the conducting system.

Cardiac muscle tissue contracts without an input from the nervous system. This property is called automaticity. The conduction system is a network of specialized cardiac muscle cells responsible for initiating and distributing the stimulus to contract. There are specialized areas of cardiac muscle tissue (1%) in the heart that are autorhythmic (self-exciting). These cells compose the CCS and are responsible for initiating and distributing cardiac (electrical) impulses throughout the heart muscle (i.e. cause the heart to beat). These specialized areas together coordinate the events of the cardiac cycle, which makes the heart an effective pump.

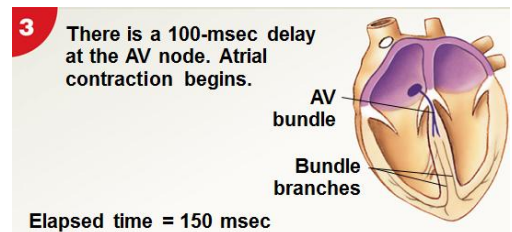
1. Sinoatrial Node (SA Node):

- Each heart beat begins when action potential is generated at the SA node.
- SA node located in right uppermost atrial wall
- The electrical impulse generated by this cardiac pacemaker is then distributed by other cells of the conducting system
- PACEMAKER = self-exciting tissue (rhythmically and repeatedly [60-100 per minute] initiates cardiac impulses)
- When the SA node fires, the impulse travels (depolarizes) the conducting cells of the atria distribute the contractile stimulus to the atrial muscle, as the impulse travels toward the ventricles i.e. an action potential is generated at the SA node, and then the stimulus is spread across the atrial surface (atria contracts and blood flows for the atria to the ventricles) as the stimulus toward the AV node.



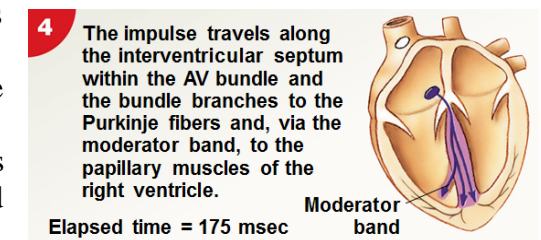
2. Atrioventricular Node (AV Node):

- The AV node is located in interatrial septum (junction between the atria and ventricles).
- Serves as a delay signal that allows for ventricular filling i.e. the signal or stimulus is delayed at the AV node to allow atria to eject all the blood to the ventricles. Toward the end of this delay ventricle contraction begins.



3. Atrioventricular (AV) Bundle (Bundle of His):

- The AV node delivers the stimulus to the AV bundles located within the interventricular septum.
- The AV bundle is only electrical connection between the atria and ventricles
- The AV bundle splits into left and right bundle branches (left branch delivers stimulus to the left ventricle and right branch to the right ventricle)
- As the impulse travels through the AV node, the atria are still contracting and the AV valves are still open.



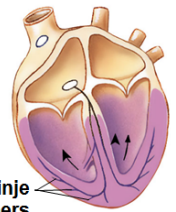
4. Right and left bundle branches

- Right and left branches branch to the Purkinje Fibers.

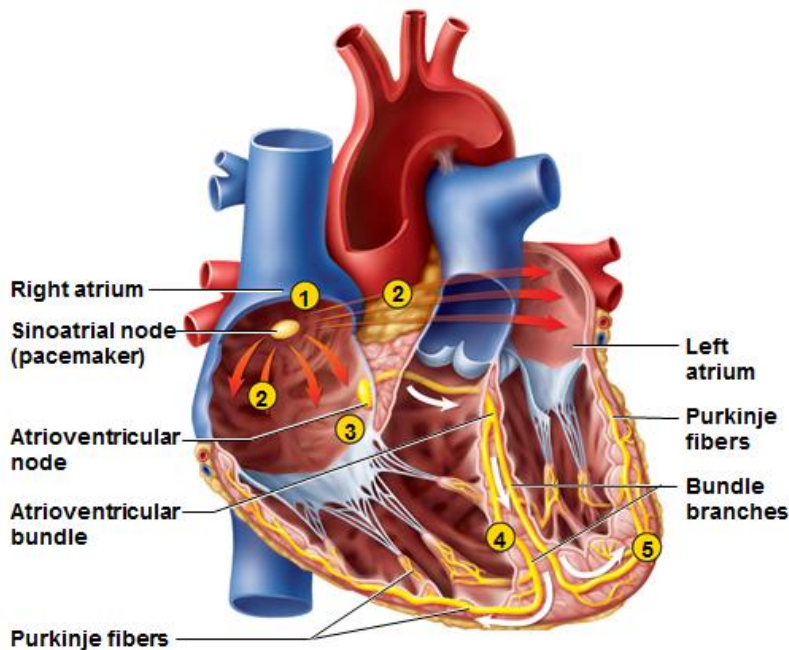
5. Purkinje Fibers (Conduction Myofibers)

- The impulse is distributed by the Purkinje fibers throughout the ventricles. At this point atrial contraction is completed, and AV valves close.
- Purkinje fibers are located within the papillary muscles of the ventricles
- The Purkinje fibers conduct the impulse into (depolarize) the mass of muscle tissue in the ventricular syncytium, which then cause the ventricles to contract forcing blood out.
- Contraction of the papillary muscles prevent the atrioventricular valves from reversing into the atria.

5 The impulse is distributed by Purkinje fibers and relayed throughout the ventricular myocardium. Atrial contraction is completed, and ventricular contraction begins.



Elapsed time = 225 msec



- SA node fires.
- Excitation spreads through atrial myocardium.
- AV node fires.
- Excitation spreads down AV bundle.
- Purkinje fibers distribute excitation through ventricular myocardium.

Figure above shows summary of conducting system

ABNORMAL PACEMAKER FUNCTION

- Bradycardia - abnormally slow heart rate
- Tachycardia - abnormally fast heart rate
- Ectopic pacemaker
 - Abnormal cells
 - Generate high rate of action potentials
 - Bypass conducting system
 - Disrupt ventricular contractions

CARDIAC MUSCLE CELL CONTRACTION VS SKELETAL MUSCLE FIBER

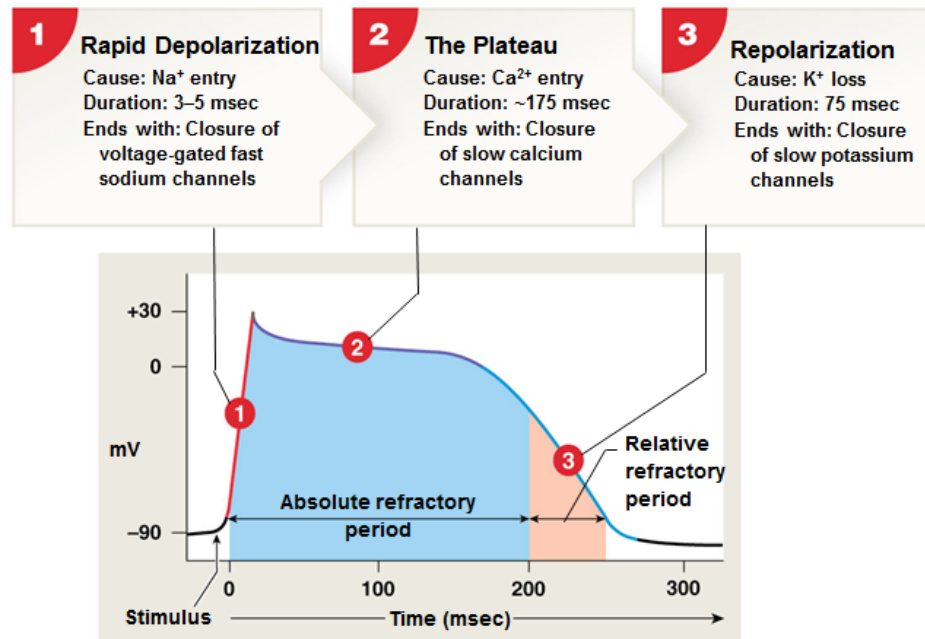
- Cardiac muscle cell contractions last longer than skeletal muscle fiber contractions primarily due to differences in membrane permeability
- In cardiac muscle action potential is long because calcium ions continue to enter the cell for an extended period.
- The action potential in a cardiac muscle can be divided into 3 phases:
 - Depolarization**
 - Sodium channels open (the membrane becomes permeable to sodium) and sodium rushes in to the cell (recall that concentration of sodium is high outside the cell and low inside the cell, also recall that at rest inside the cell is negative and outside the cell is positive). As sodium enters the cell, the charge inside the cell move from negative toward the positive (this increase in charge from negative to positive is called depolarization)

b. Plateau

- i. As the transmembrane potential approaches positive charge (+ 30 mV), sodium channels close and the cell begins to actively pump sodium out of the cell to restore resting potential (to return the cell back to relax mode). However as the sodium channels are closing, calcium channels are opening. As sodium is pumped out to restore membrane potential, at the same time calcium enters the cell thus the entry of calcium roughly balances the loss of sodium, and the transmembrane potential does not change until the slow calcium channels also close. For the period that calcium channels are open and transmembrane potential almost does not change is the plateau phase

c. Repolarization

- i. After slow calcium channels close, potassium channels begin to open, and potassium rushes out of the cell (recall that concentration of the potassium is high inside the cell and low outside the cell, so potassium moves from high concentration to low concentration). Rapid movement of potassium out of the cell restore resting potential (inside the cell returns to the original negative charge as positively charged potassium leave the cell)



ELECTROCARDIOGRAM (ECG)

The electrical events occurring in the heart are powerful enough to be detected by electrodes on the surface of the body. A recording of these electrical events over a period of time is an electrocardiogram (ECK or EKG). Physicians can use the ECG data to assess the performance of conducting components of the heart

1. Definition ECG = a recording of the electrical changes that occur in the myocardium during the cardiac cycle.
2. Instrument used to record an ECG = electrocardiograph
3. Used to determine if: the conduction pathway is normal; the heart is enlarged; certain regions are damaged
4. Rules to remember:
 - a. Depolarization precedes contraction
 - b. Repolarization precedes relaxation
5. Three waves per heartbeat:
 - a. **P wave** is a small upward wave.
 - i. represents atrial depolarization (spreads from SA node throughout both ath
 - ii. After P wave begins, atria contract.
 - b. **QRS Complex**
 - i. Begins as a downward deflection continues as large, upright, triangular wave ends as a downward wave

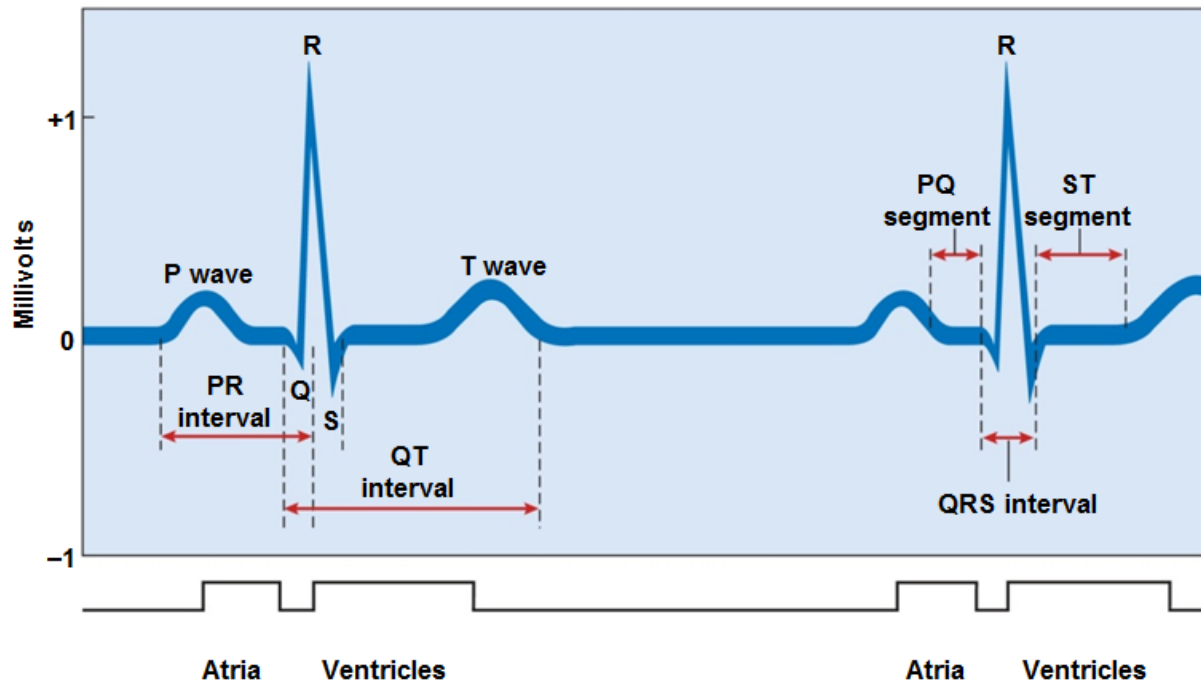
- ii. Represents onset of ventricular depolarization (spreads throughout ventricles)
- iii. Shortly after QRS begins, ventricles start to contract.

c. T wave

- i. Dome-shaped, upward deflection
- ii. Represents ventricular repolarization
- iii. Occurs just before ventricles start to relax

6. Abnormal ECG's:

- a. enlarged P = enlargement of an atrium possibly due to mitral stenosis
- b. enlarged Q wave = MI
- c. enlarged R wave = ventricular hypertrophy



REGULATION OF CARDIAC CYCLE

1. Recall that cardiovascular center is located in medulla of brainstem. The cardiac centers of medulla oblongata contain the autonomic headquarters for cardiac control. These centers innervate the heart by means of cardiac plexus.
 - a. Parasympathetic (normal) decreases cardioinhibitor reflex center i.e. Parasympathetic stimulation Releases ACh (acetylcholine is a neurotransmitter) and ACh decreases heart rate
 - b. Sympathetic (stress) increases cardioacceleratory reflex center i.e. Sympathetic stimulation Releases NE (norepinephrine), and NE increases heart rate

LIFE SPAN CHANGES

2. Aging takes a toll on the cardiovascular system.
 - a. Signs of CV disease may appear long before symptoms.
 - b. Cholesterol deposits in arteries as one ages.
 - c. Accumulation causes hypertension and cardiac disease (see below).
3. Autopsies performed on soldiers killed in the Korean and Vietnam wars revealed significant plaque buildup in arterial walls of otherwise healthy young men.
4. Heart and blood vessel disease increases exponentially with age.
5. About 60% of men over age 60 have at least one narrowed coronary artery.
6. The same is true for women over age 80.

7. Cardiac cells are replaced by fibrous connective tissue and fat as one ages.
8. Blood pressure increases with age, while resting heart rate decreases.
9. Moderate exercise correlates to lowered risk of heart disease in the elderly.

General Summary of Cardiac Cycle

Phase	Ventricular contraction (systole)	Atrial relaxation (diastole)	Ventricular relaxation (diastole)	Atrial contraction (systole)
Blood flow	Blood is forced from ventricles into arteries.	Atria fill with blood.	Ventricles fill with blood.	Blood is forced from atria into ventricles.
Valves	SL open AV closed	SL open AV closed	AV open SL closed	AV open SL closed
Pressure	V high	A low but rises as filling continues	V low but rises as filling continues	A high

Summary Table of CCS

CCS COMPONENT	LOCATION	SIGNIFICANCE	SENDS CARDIAC IMPULSE TO
Sinoatrial Node	right uppermost atrial wall	Pacemaker initiates cardiac impulse 60-100 times per minute	Atrioventricular Node
Atrioventricular Node	interatrial septum	delay signal to allow for ventricular filling	Atrioventricular Bundle
Atrioventricular Bundle	superior interventricular septum	only electrical junction between atria & ventricles	right and left bundle branches
Right and left bundle branches	lateral interventricular septum	passes signals down to apex	Purkinje fibers
Purkinje fibers	in papillary muscles of ventricles	conduct impulse to the mass of ventricular myocardium and forces blood out prevent the atrioventricular valves from reversing into the atria	N/A

Summary Table of Ventricles

Right Atrium	Right Ventricle	Left Atrium	Left ventricle
Collect blood or receive the blood from the superior and inferior vena cava. Blood returning from the systemic circuit (deoxygenated blood) first enters here.	Pump the deoxygenated blood to the pulmonary artery Left and right pulmonary arteries carry blood to the lungs. Start of the pulmonary circuit Sends deoxygenated blood to the lungs	Collect blood or receive the blood from left and right pulmonary veins. Blood returning from the pulmonary circuit (oxygenated blood) first enters here.	Pumps the oxygenated blood to the aorta Aorta delivers blood to the cells throughout the body Start of the systemic circuit Has thicker wall than the right ventricles because: should withstand more pressure and contract more forcefully

Summary of ECG

P waves	QRS complex	T waves
Depolarization of Atria	Depolarization of Ventricles	Repolarization of Ventricles

Summary of valve

Tricuspid	Bicuspid	Aortic Semilunar	Pulmonary Semilunar
Located on the right side between RA and RV. Opens when atria contracts It is close when Semilunar valves are open Closes when ventricular muscles (wall) contract permits one-way blood flow from the RA to the LV	Located on the left side between LA and LV Opens when atria contracts It is close when Semilunar valves are open Closes when ventricular muscles (wall) contract permits one-way blood flow from the LA to the LV	Located on the left side between LV and Aorta Opens when ventricles contract and AV valves close	Located on the right side between RV and pulmonary artery Opens when ventricles contract and AV valves close