CARDIOVASCULAR PHYSIOLOGY

Siwa O.B. (BCMS-CUEA,Uzima/DCMS-Egerton)

Introduction;

- Cardiovascular system include the heart and blood vessels.

- The heart acts as a pumping machine that pumps blood via the blood vessels to different tissues and organs in the body while at the same time receiving deoxygenated blood from body tissues and pumping it again to the lungs for oxygenation.

- The heart is composed of cardiac muscles and connective tissues.
- It normally weighs about 250-300g and is heavior in men than women.
- It weighs about 250-300g in females and 300-350g in males.
- The heart also has its own blood supply via the coronary arteries.

Tissues of the heart

1). The heart wall;

- Composed of three layers;

i. Pericardium-the outer layer.

ii. Myocardium-the middle layer.

iii. Endocardium-inner layer.

i). **Pericardium;**

- Also composed of three layers of tissues;

a) Outer fibrous pericardium.

b) Parietal pericardium.

c) Visceral pericardium.

- In between the visceral and parietal pericardium is a serous fluid(pericardial fluid) whose main function is to permit smooth movement of the heart during contraction and relaxation.
- The visceral and parietal pericardium together with the pericardial fluid are called serous pericardium.

Functions of the pericardium.

i. Protects the heart and all underlying tissues.
ii. Fibrous in nature and prevents over distension of the heart.
iii. Attaches the heart to adjacent structures e.g. the diaphragm below.

ii). **Myocardium.**

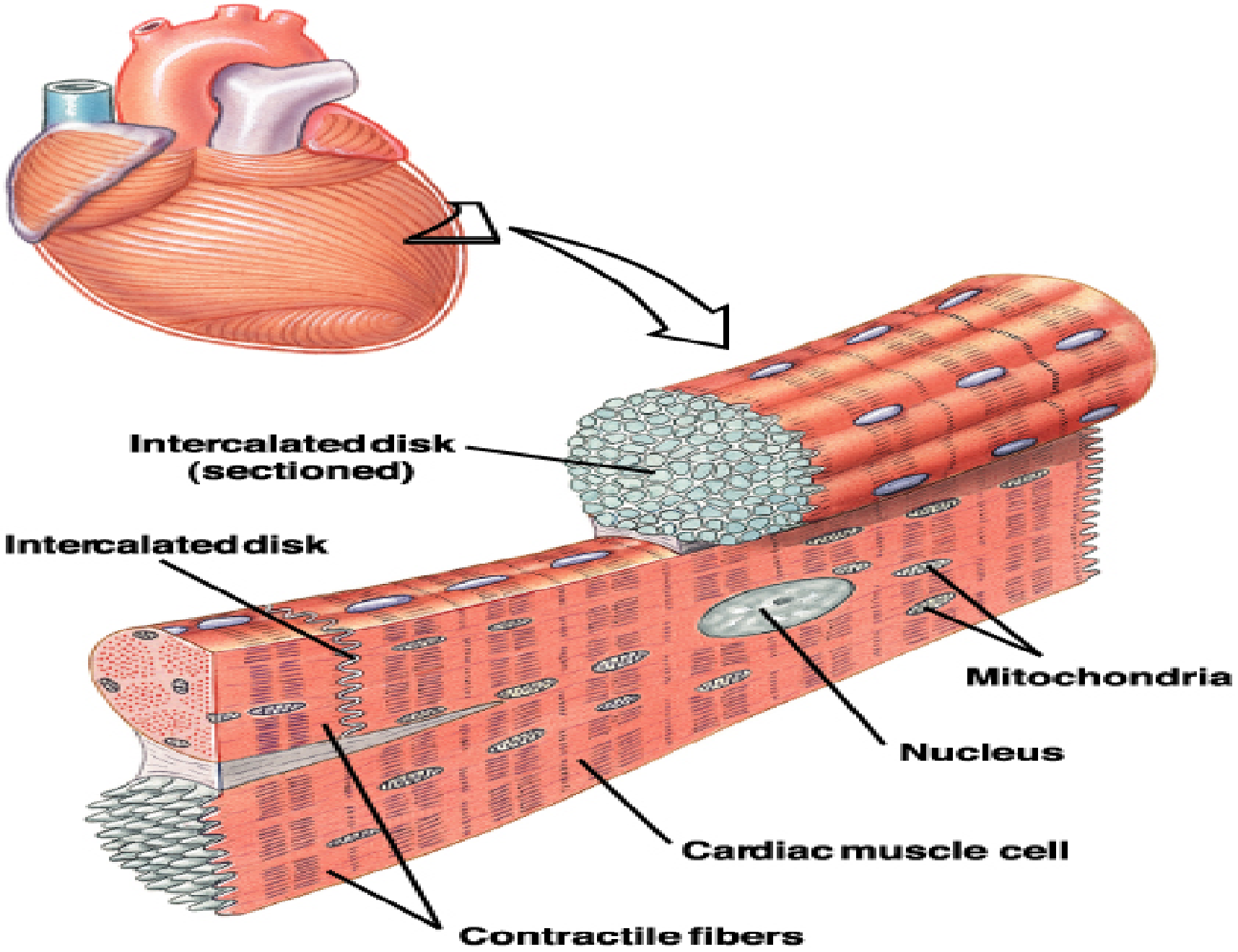
- Composed of specialised cardiac muscles.
- Cardiac muscle fibers are striated – sarcomere is the functional unit
- Fibers are branched; connect to one another at intercalated discs.
- The discs contain several gap junctions.

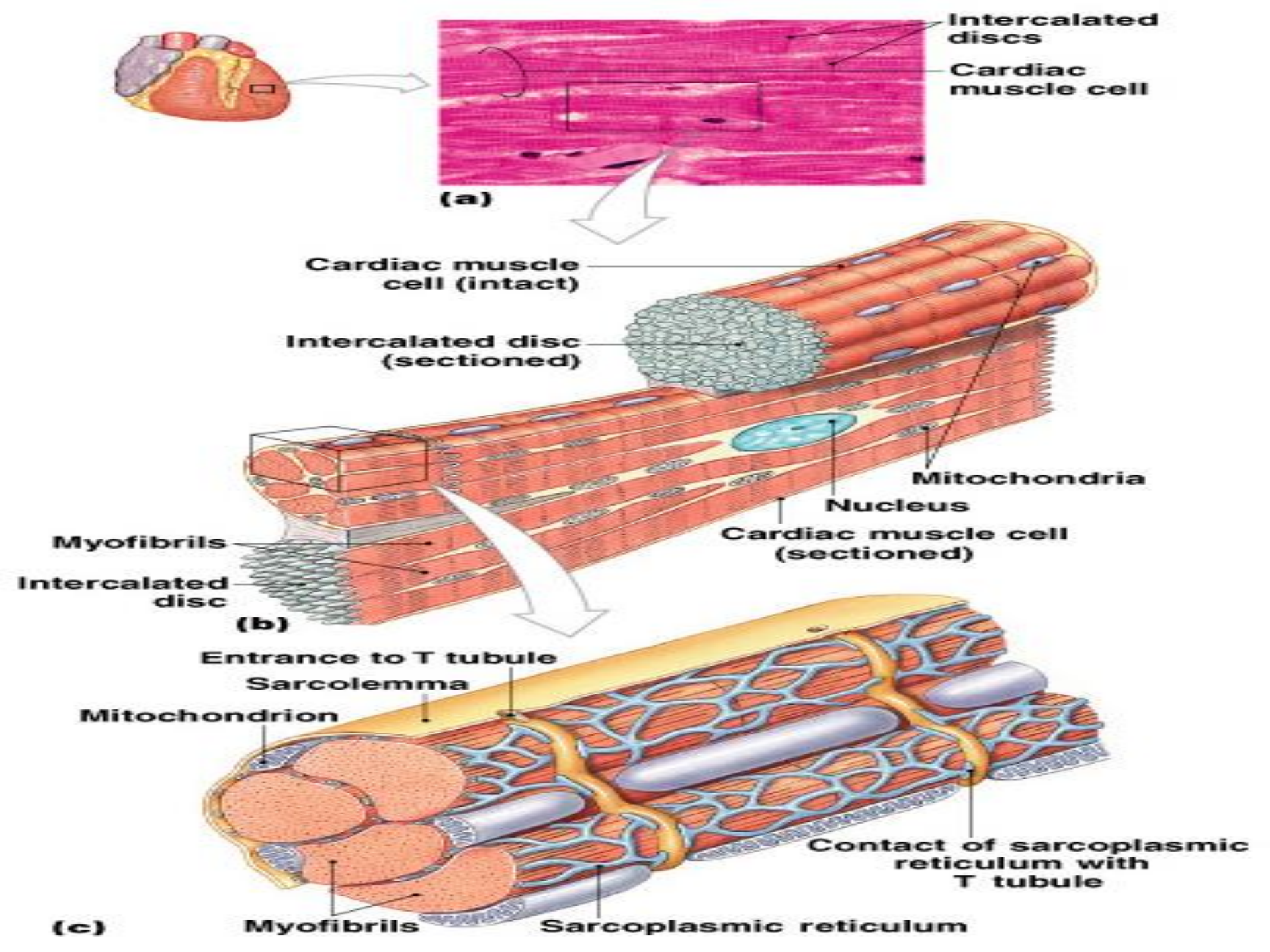
Intercalated Discs

- Are specialized contact points between cardiocytes.
- Join cell membranes of adjacent cardiocytes (gap junctions, desmosomes)
  - Maintain structure
  - Enhance molecular and electrical connections
  - Conduct action potentials

Because intercalated discs link heart cells mechanically, chemically, and electrically, the heart functions like a single, fused mass of cells

- Nuclei are centrally located and the myofibrils have abundant mitochondria.
- SR is less abundant than in skeletal muscle, but greater in density than smooth muscle.
- Sarcolemma has specialized ion channels that skeletal muscle does not – voltage-gated Ca2+ channels.
- Fibers are not anchored at ends; allows for greater sarcomere shortening and lengthening.
- Due to end to end connection of the the cardiocytes , an impulse from one cell will spread simultaneously to other cells.


Intercalated disk
(sectioned)
Intercalated disk
Mitochondria
Nucleus
Cardiac muscle cell
Contractile fibers


Intercalated discs
Cardiac muscle cell
(a)
Cardiac muscle cell (intact)
Intercalated disc (sectioned)
Mitochondria
Nucleus
Cardiac muscle cell (sectioned)
Myofibrils
Intercalated disc
(b)
Entrance to T tubule
Sarcolemma
Mitochondrion
Contact of sarcoplasmic reticulum with T tubule
(c)
Myofibrils
Sarcoplasmic reticulum

Functions of the myocardium.

i. Conduction of electrical impulse via specialised conducting fibers.
ii. Motor function-their contraction and relaxation aids in the pumping action of the heart.
iii. Maintains the anatomical structure of the heart.
iv. Has neuro transmiter receptors(dopamine receptors) that may alter heart rate.

iii). <u>Endocardium;</u>

- This is the innermost layer made of connective tissues that permit smooth flow of blood in the heart.
- Normally lines the heart chambers and valves that inhibits backflow of blood in the heart chambers during pumping.

<u>Functions of the endocardium;</u>

a) Lines the chambers and valves of the heart, protecting them from friction thus permit smooth flow of blood.

- The myocardium gives the heart its cone shape.
- In the anatomical position, the heart is an upside down structure with the apex below and base above.
- Its size is approximately equall to the owners fist.
- The autonomic portion of the peripheral nervous system influence the heart by altering the rate of contraction and relaxation.
- These nerves originate from the cardiac center in the medulla oblongata.

- Parasympathetic supply is via the vagus nerve that mainly supply the SA and AV nodes.
- The parasympathetic nerves reduce the rate at which impulses are produced.
- Sympathetic nerves also supply the SA and AV nodes, myocardium of atria and ventricles. Sympathetic nerves increase the force and rate of heart beat.

2). The heart valves.

- Are formed by double fold of endo cardium and strengthened by connective tissues.
- The heart has four valves; two on each side of the heart.
- The right side has;

a) Right atrio ventricular valve or tricuspid valve.

b) Pulmonary valve.

- The left side has;

a) Left atrio ventricular valve or mitral valve.

b) Aortic valve.

The valves of the right side of the heart.

Right atrioventricular valve/Tricuspid valve.

1. Separates right atrium from right ventricle.
2. Prevents backflow of blood from the right ventricle to RA.

Pulmonary valve.

1. Separates right ventricle from pulmonary artery.
2. Prevents backflow of blood from pulmonary artery to RV.

The valves of the left side of the heart

Left Atrioventricular valve/Mitral valve

1. Separates the LA from LV.
2. Prevents backflow of blood from Aorta to LV.

Aortic valve.

1. Separates LV from Aorta.
2. Prevents backflow of blood from Aorta to LV.

Chordae tendinae.

- These are tendinous cords which extend from the inferior surface of the valve cusps(flaps) to little projections of myocardium into the ventricles covered with endothelium called papillary muscles.

The cardiac cycle.

- This refers to series of events that occur at the beginning of one heart beat to the next.
- The normal heart beat in a healthy adult ranges between 50-100(72 average).
- During each heart beat, the heart contracts(systole) and relaxes(diastole).
- The contraction and relaxation of the heart results to opening and closing of the heart valves.

Specialised excitatory and conducting system of the heart

- The heart muscles are able to generate their own action potential.
- The action potential is generated by specialised tissues found in the myocardium.
- The action potential causes the myocardium to contract and relax thus generating heart beat.
- The heart sounds are recorded by an echocardiogram(phonocardiogram) while the action potentials are recorded by an elecro cardiogram.

- The specialised excitatatory and conducting fibers include;

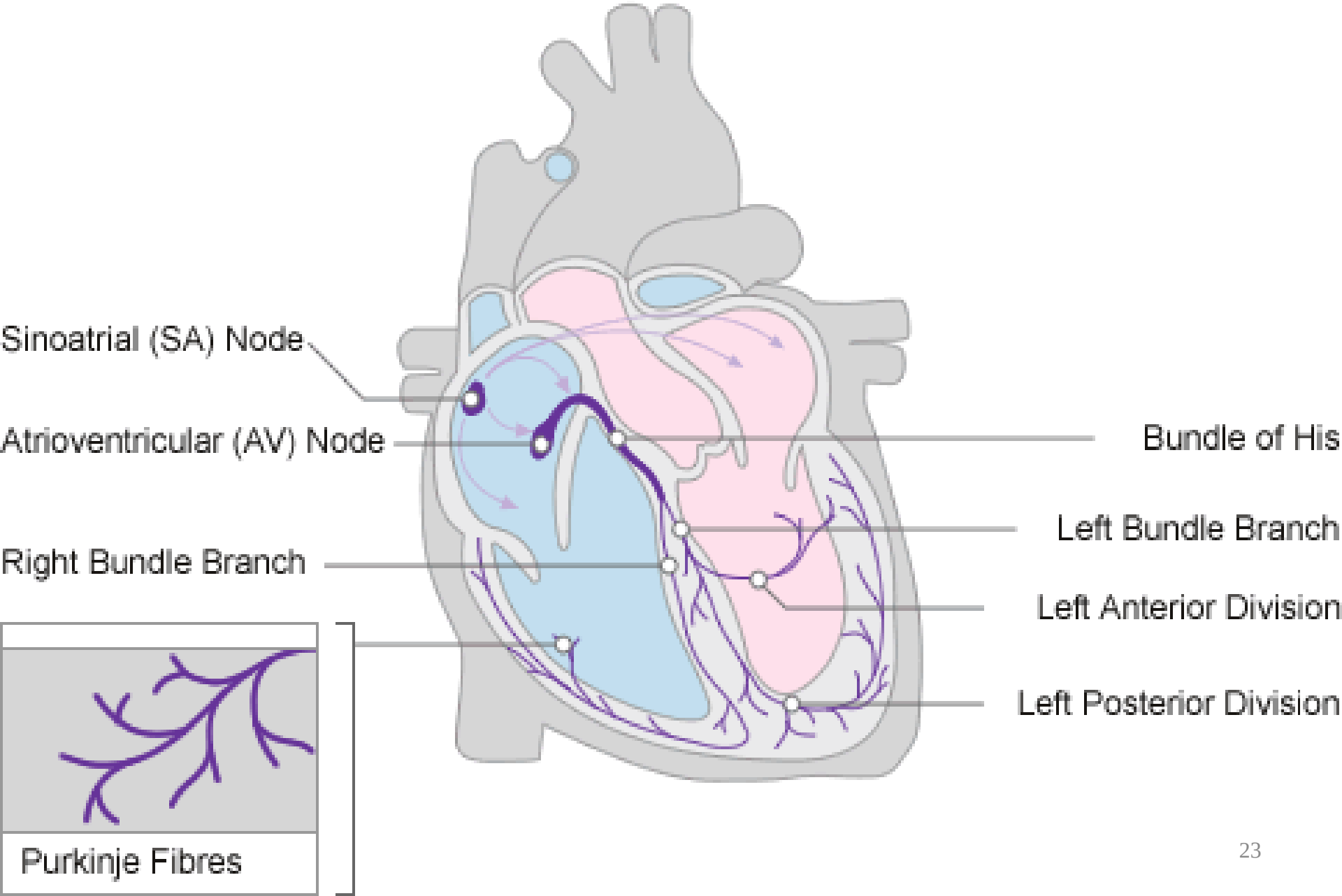
1. Sino Atrial Node(SA-NODE)-Sinus Node.

2. Atrioventricular Node(AV-NODE).

3. Atrioventricular bundle of His.

4. Purkinje fibers.

The cardiac conduction system



1.SA-Node(sinus node).

- Composed of small flattened ellipsoid strip of specialised cardiac muscles located in the superior posterolateral wall of RA immediately below and slightly lateral to the opening of the superior vena cava.
- These muscles are electrically unstable and depolarise(discharge) and repolarise(recharge) regularly about 60-80 times a minute.
- These muscles discharge faster than any other part of the heart and it is called the primary pace maker of the heart.

2.AV-Node.

- Located in the posterior wall of the RA immediately below the tricuspid valve.
- Transmit electrical signals from the atria into the ventricles.
- Normally has a secondary pace maker function and takes over this role incase of failure in the SA node or failure with transmission of impulses from the atria.
- However its intrinsic firing rate is much slower at 40-60 bpm.

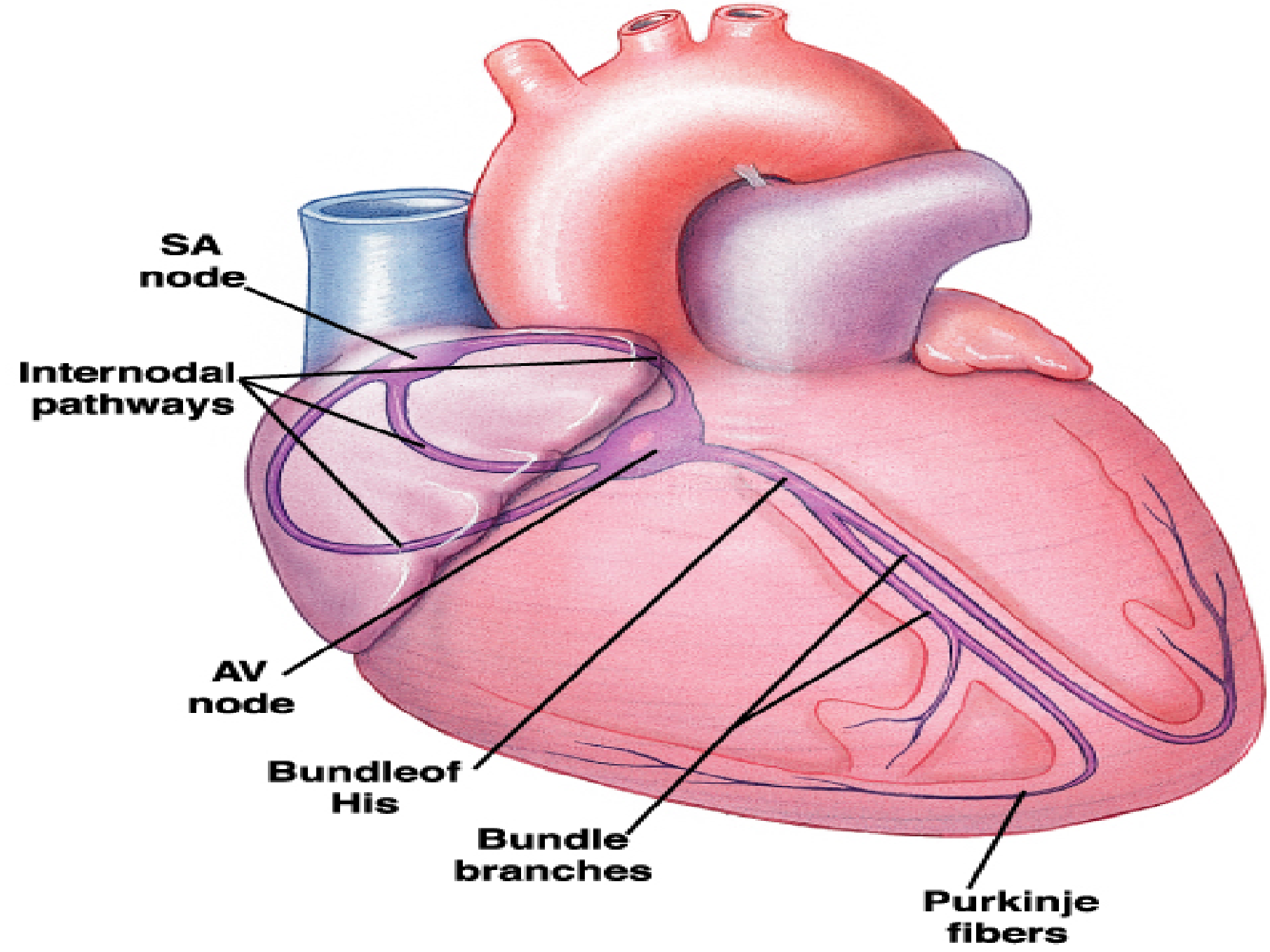
3. AV bundle/bundle of His.

- Are specialised fibers originating from the AV node.
- They cross the AV fibrous tissue that separates atria from ventricles and then separate into right and left bundle branches.
- Within the ventricular myocardium, they separate into a network of fibers called purkinje fibers.
- The AV bundle, bundle branches R and L, and purkinje fibers transmit electrical impulses from AV bundle to the apex of the myocardium where a wave of contraction begins.
- The AV bundle never allows impulses to travel backwards from the ventricles to the atria thus permits only forward impulse transmission to the ventricles.

4. Purkinje fibers.

- Are a group of specialised fibers that are longer than the AV bundles and the ventricular muscles.
- They transmit action potential at a higher velocity than the ventricular muscles and bundle of His.
- They have fewer myofibrils and contract less during neurotransmission.
- These fibers relay electrical impulses from the AV node via AV bundle to the apex of the myocardium resulting to rapid ventricular contraction pumping blood into the pulmonary artery and aorta.

- Specialized muscle cells “pace” the rest of the heart; cells contain less actin and myosin, are thin and pale microscopically.
- Sinoatrial (SA) node; pace of about 65 bpm.
- Internodal pathways connect SA node to atrioventricular (AV) node.
- AV node could act as a secondary pacemaker; autorhythmic at about 55 bpm.
- Bundle of His
- Left and right bundle branches
- Purkinje fibers; also autorhythmic at about 45 bpm


SA
node
Internodal
pathways
AV
node
Bundleof
His
Bundle
branches
Purkinje
fibers

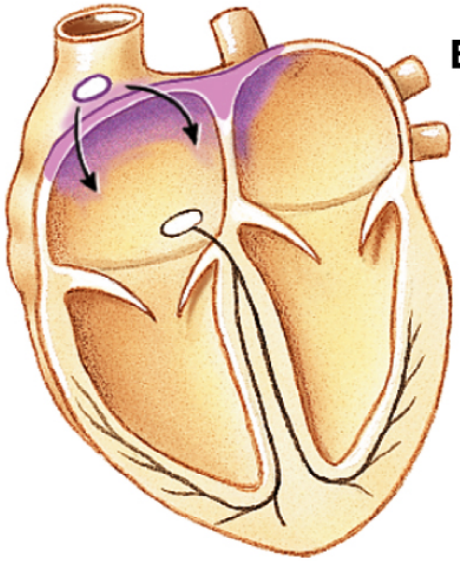
The process of cardiac cycle.

- The SA node initiate an action potential that spreads over the myocardium of both atrium causing them to contract thus emptying the atria and thus filling the ventricles(atrial systole-0.1s).
- From the SA node, the impulse is transmitted to the AV node via the internodal pathways; however this transmission lags for a fraction of a second to allow the atria to completely empty to the ventricles.
- The AV node then triggers an impulse which spreads over the ventricular muscle via AV bundle of His, its branches and purkinje fibers.

- A wave of contraction then sweeps upwards from the apex across the walls of both ventricles pumping the blood into pulmonary artery and aorta(ventricular systole-0.3s).

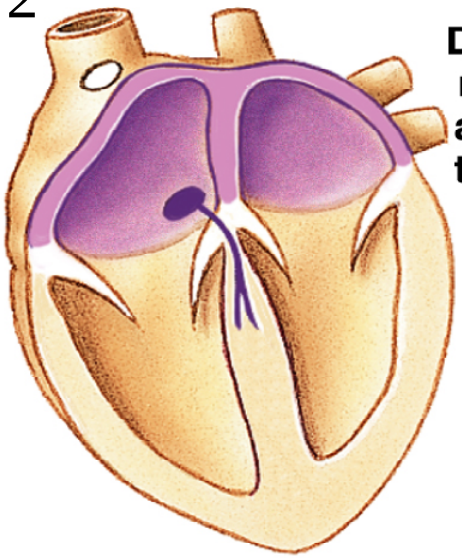
- The ventricles then relax after contraction and the cycle is complete in approximately 0.4s; the myocardium then recovers in preparation to the next cycle.

1



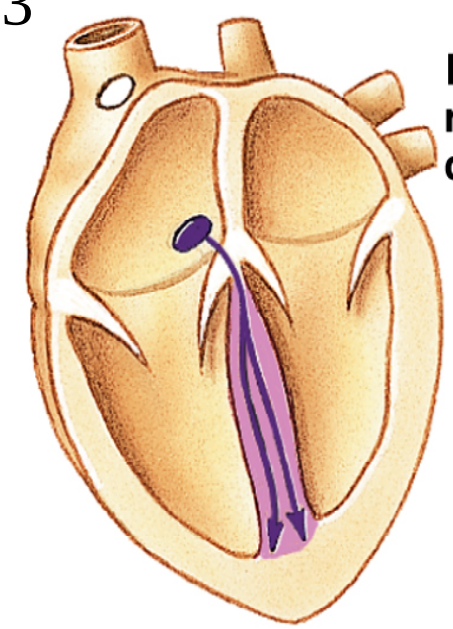
Electrical activity goes rapidly to AV node via internodal pathways.

2



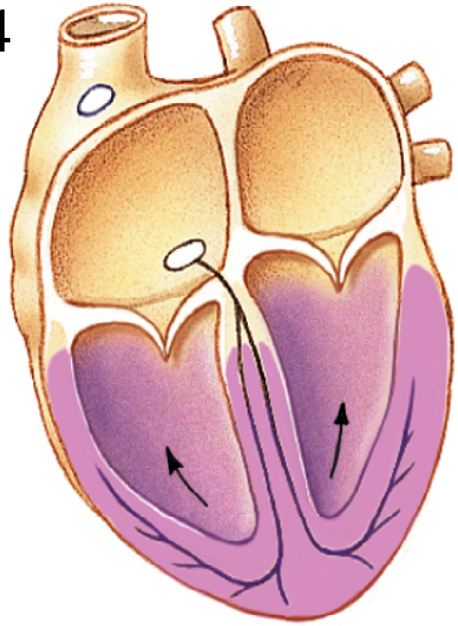
Depolarization spreads more slowly across atria. Conduction slows through AV node.

3



Depolarization moves rapidly though ventricular conducting system to the apex of the heart.

4



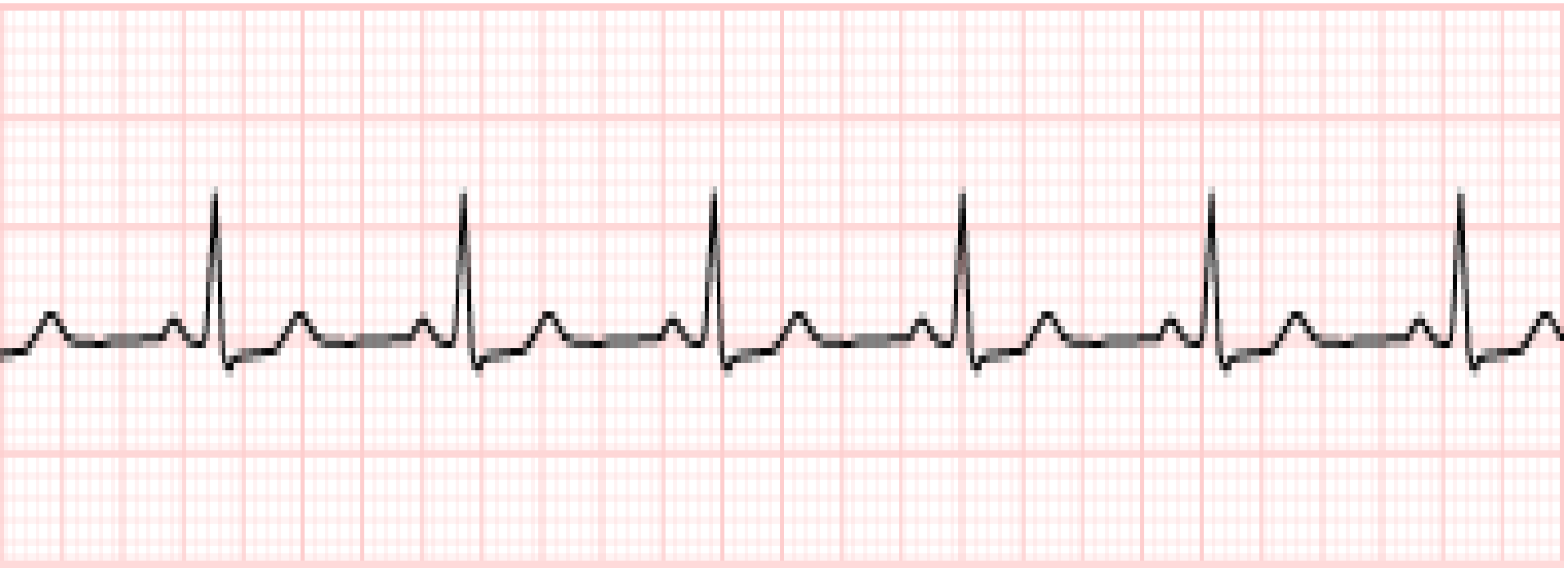
Depolarization wave spreads upward from the apex.

Normal cardiac electrocardiography

- When the heart generates an action potential, the adjacent body fluids and tissues which are good conductors of electricity become polarised and depolarised in the process.
- This pattern of eletrical impulse can be recorded in an electrocardiogram.
- A normal elctrocardiogram consist of;

1. P wave.
2. QRS Complex(wave).
3. T-Wave.

- The QRS complex is often(though not always) three separate waves.



1. **P-Wave;**

- Arises due to an impulse from the SA node during atrial depolarisation prior contraction of the atrium.

2. **QRS-Complex;**

- Arises due to impulse generated when ventricles depolarise prior contraction i.e when an action potential spreads from the AV node through AV bundle and purkinje fibers.

3. **T-Wave;**

- Arises during ventricular repolarisation i.e relaxation of ventricles thus it is a repolarisation wave.

- Normal atrial repolarisation occurs during ventricular contraction i.e depolarisation; and is not always seen due to the larger QRS complex.

CARDIAC SOUNDS;

- The heart has four sounds; S1, S2, S3, S4;- corresponding to the opening and closing of the heart valves.

- The opening of the heart valves cause no audible sound, however during closure; the valve leaflets will bulge backwards due to back surging of the blood and then bounce forward into each respective ventricle.

- The sudden forward surge of blood causes the ventricular walls together with the taut valves to vibrate and this vibration produces turbulence waves into the blood.

- These vibrations travel via adjacent tissues to the chest wall and can be heard via the stethoscope.

- Heart sounds from each valve can be auscultated on each specific regions of the anterior thoracic wall.

1. Aortic region- Between the 2^{nd} and 3^{rd} inter costal spaces at the right sternal border.
2. Pulmonic region- Between the 2^{nd} and 3^{rd} inter costal spaces at the left sternal border.
3. Tricuspid region- Between the 3^{rd} ,4^{th} ,5^{th} and 6^{th} inter costal spaces at the left sternal border.
4. Mitral region (apex of the heart)- Between the 5^{th} and 6^{th} intercostal spaces in the mid clavicular line.

1) S1 –This is due to ventricular contraction i.e contraction of the AV-Valves (lub).
2) S2 –This is due to the contraction of aortic and pulmonic valves (dub).
3) S3 –This is a weak rumbling sound caused by oscillation of blood back and forth between walls of the ventricles due to blood from the atria. This inrushing blood causes a reverberation back and forth between the walls of the ventricles. This sound cannot be easily auscultated via stethoscope but only via stethoscope.

4) S4 –This is an atrial sound that is recorded in an echocardiogram and can never be heard via stethoscope due to its very low frequencies. It occurs due to atrial contraction and is caused due to inrushing of blood into the ventricles.

- The S1, S2 is heard in all healthy people.
- S3 can only be heard in 1/3 to ½ of general population.
- S4 can be recorded in only ¼ of the general population.
- Other heart sounds are called murmurs and are due to abnormality of the heart valves.

HAEMODYNAMICS;

Cardiac Output (c.o);

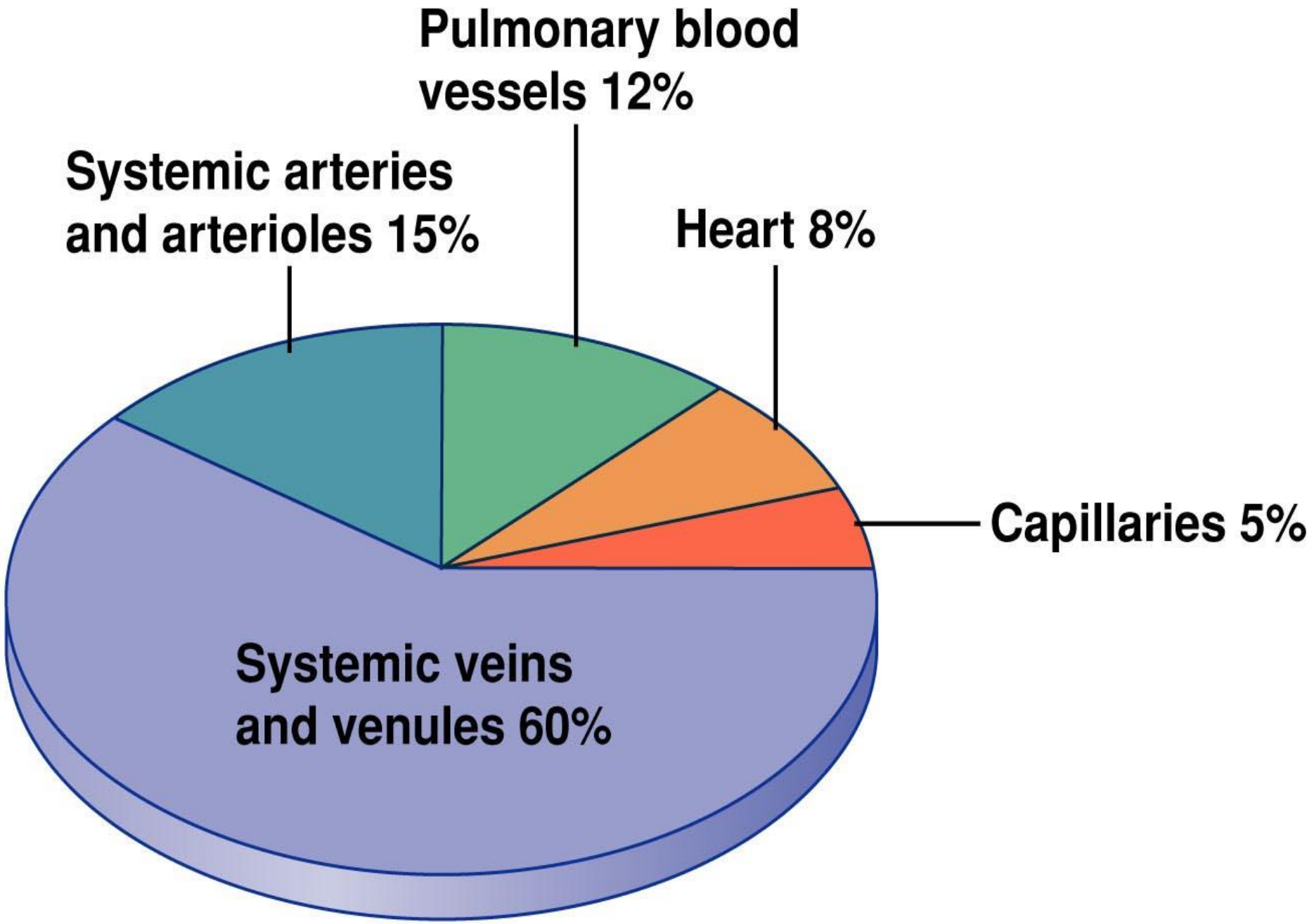
- This is the volume of blood ejected from the ventricles per minute.
- Cardiac output is influenced by;

i. Stroke volume.

ii. Heart rate.

iii. Venous return.

C.O =STROKE VOLUME X HEART RATE.



i. Stroke volume;

- This is the volume of blood in the ventricles before they contract i.e ventricular and diastolic volume called (preload).

- This is influenced by amount of blood returning to the heart via superior and inferior vena cava (the venous return).

Factors affecting stroke volume;

1. Arterial blood pressure.

- The ventricular end diastolic volume (preload); is the amount of blood returning to the heart (venous blood).
- The volume of blood the heart receives will affect the volume of blood that it will pump to the circulatory system.
- After load is the resistance of the blood vessels to the blood being pumped from the heart.

- The resistance due to arterial blood pressure is determined by the elasticity of the large arteries and peripheral resistance of the arterials.
- The higher the after load i.e resistance, the higher the workload on the ventricles and thus the stroke volume might be reduced if systemic blood pressure is significantly higher than normal

2. Blood volume;-

- If the normal volume of blood is reduced e.g in haemorrhage, the stroke volume, cardiac output and venous return will be reduced.

ii Venous return.

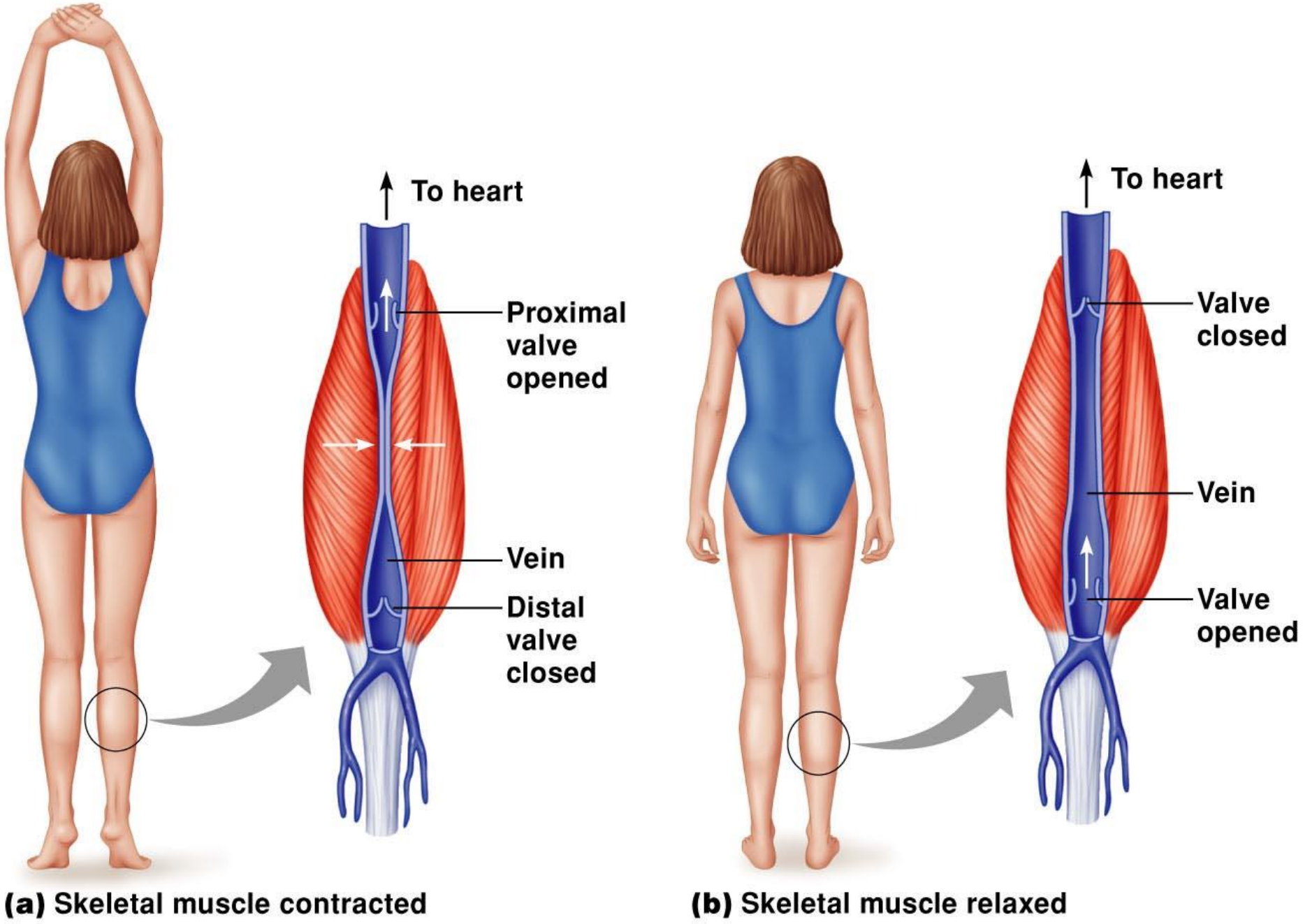
- The heart will normally pump all the blood returned to it.
- Many factors assist in help returning blood from the systemic circulation to the heart.
- One of the main factors is the pumping action of the heart though this alone is not sufficient to help achieve this.

- Other factors that help achieve effective venous return include;

a) Position of the body e.g venous return is reduced due to gravity when standing compared to the less resistance experienced when lying down flat.

b) Muscular contraction i.e skeletal muscle pump.

c) Respiratory pump; i.e when the diaphragm contracts and relaxes.



(a) Skeletal muscle contracted

(b) Skeletal muscle relaxed

iii. Heart rate;

- The higher the heart rate, the higher the C.O and vice versa.

Factors affecting heart rate;

1. Autonomic nervous system.

- Sympathetic nerves increases heart rate while parasympathetic nerves decreases.

2. Hormones.

- Catecholamines and thyroxine increases heart rate.

3. Hypoxia.—High CO2 levels increases heart rate.

4. Electrolyte imbalance- Hyper kalaemia decreases heart rate while hypercalcaemia increases it.
5. Drugs- Drugs like beta receptor antagonists e.g Atenolol reduces heart rate.
6. Position- Heart rate is higher in upright position than when lying down.
7. Emotional state of the body- Excitement and anxiety increases heart rate.
8. Gender- Heart rate is higher in women than men.
9. Age- Heart rate is higher in children than in adults.

10. Temperature- The higher the temperature, the faster the heart rate due to increased metabolism.

11. Exercise- The more active the body muscles due to increased metabolism and increased oxygen demand, the faster the heart rate.

12. Baro receptor reflex- Detect changes in blood pressure and accelerates or decelerates heart rate depending on the physiological condition of the body.

BLOOD PRESSURE;

- Blood pressure is the force exerted on the blood vessels by the circulating blood.

BP= CARDIAC OUTPUT X PERIPHERAL RESIST.

- Normally it is the arterial blood pressure.
- Blood pressure is expressed as Systolic/diastolic.
- Its S.I unit is mmHg.

- The difference between the systolic and diastolic blood pressure is the pulse pressure.

- Blood pressure is not constant and varies with age, gender, physiological state of the body e.t.c
- It is also affected by intake of drugs, other chemicals and hormones.
- According to the American Heart Association, the normal blood pressure is;

systolic 90-140mmHg

diastolic 60-90 mmHg

- High blood pressure/hypertension (HTN); is a non specific term which refers to elevated blood pressure. However, arbitrary levels have been set to help identify individuals who are at risk of developing complications thus put them in appropriate care.
- On average, normal blood pressure is considered to be 120/80 mmHg.
- However values above this level within the normal range is associated with high risk of developing HTN.

Arterial blood pressure

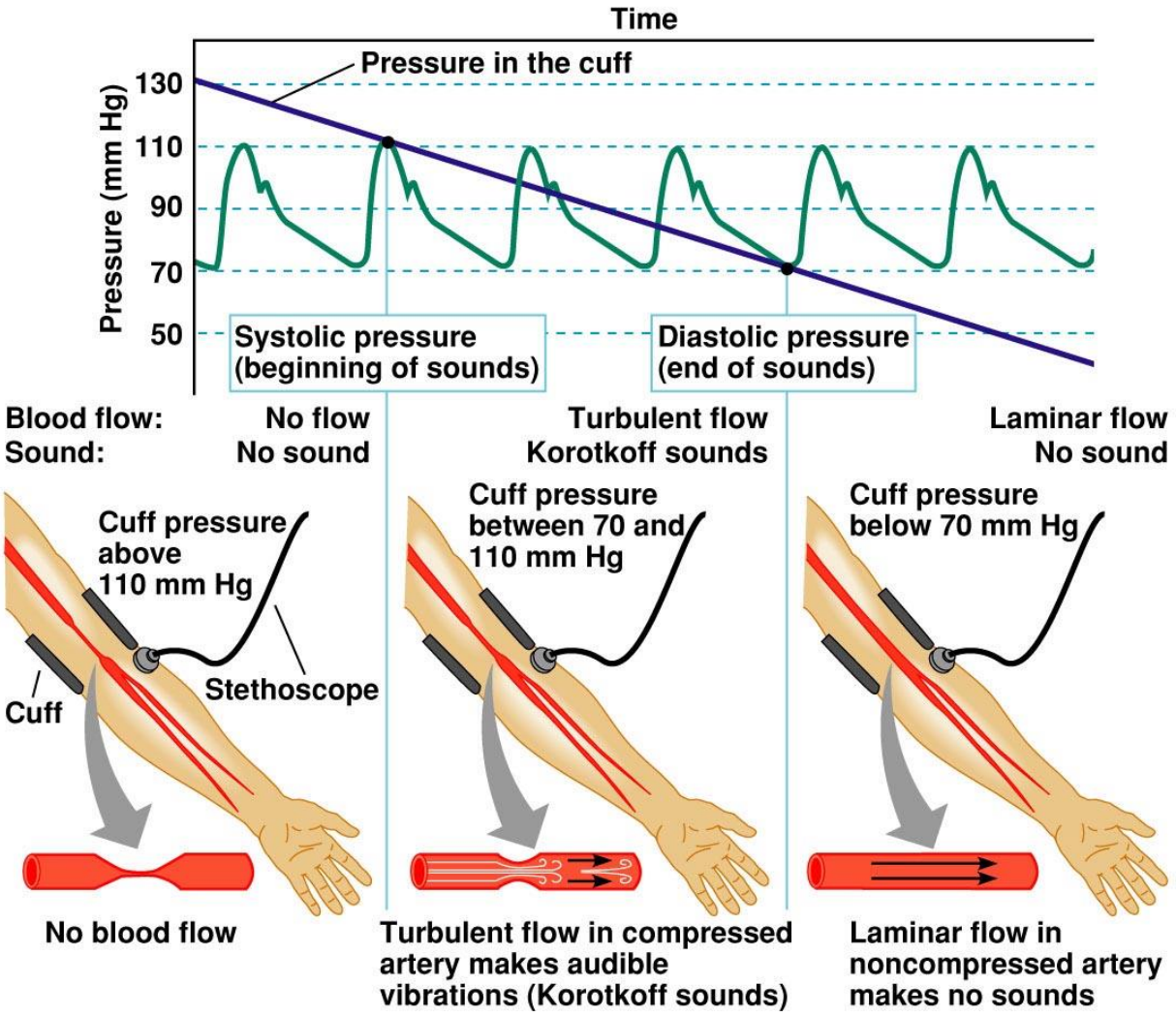


Figure 14.8

Factors affecting blood pressure;

1. Cardiac output- The higher the cardiac output, the higher the BP. High stroke volume increases systolic pressure more than diastolic.
2. Peripheral/arteriolar resistance- Vasoconstriction increases resistance thus high BP. Vasodilatation reduces BP.

- The lumen of blood vessels (arteries) may be reduced by deposition of artheromatous plaques e.g in hypercholesteronaemia or by fibrous tissues and Calcium deposits and this increases resistance thus high BP.

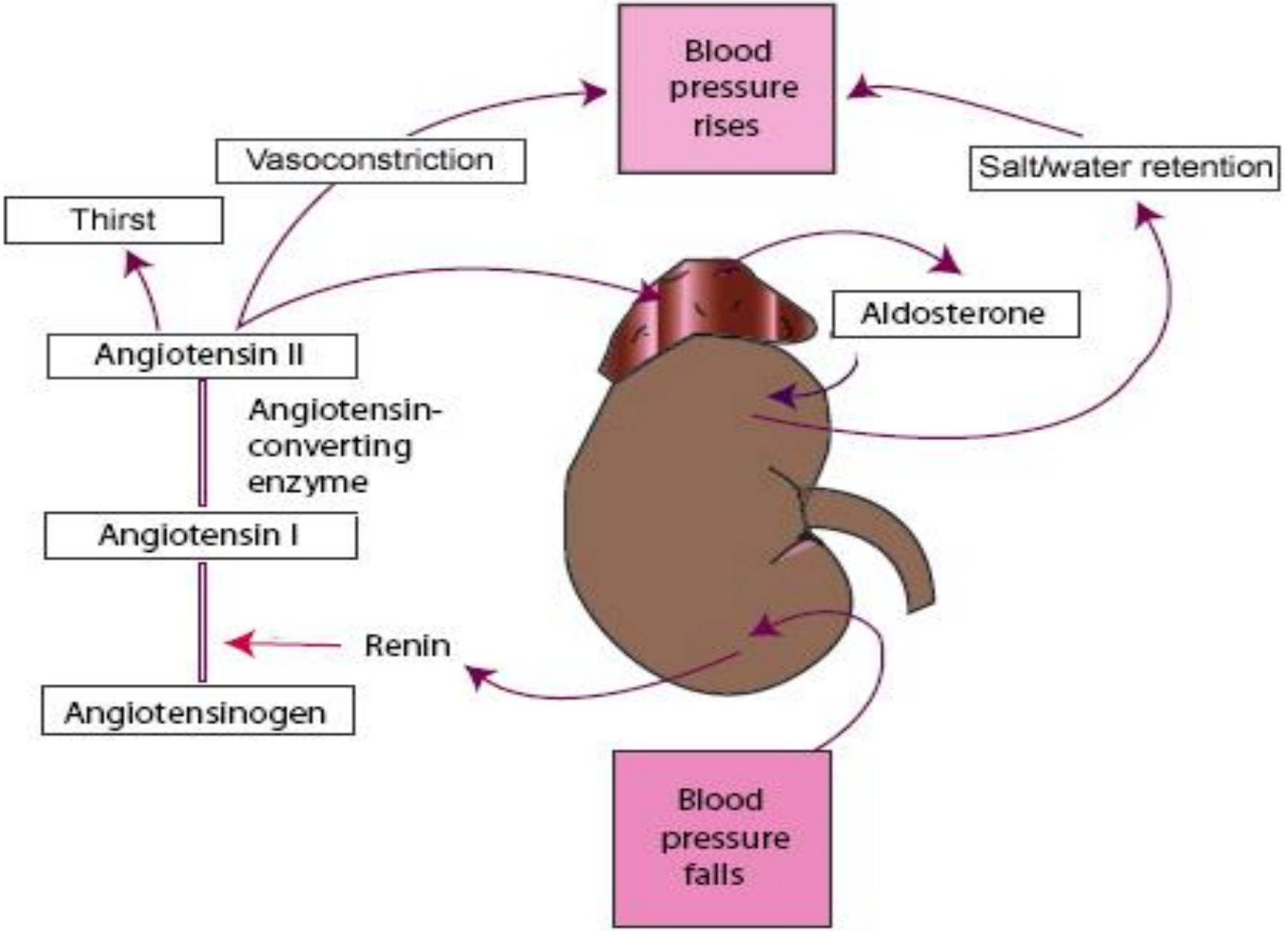
4. Auto regulation- The body organs automatically adjust blood flow and pressure in their own local vessels independently to protect them from sudden pressure change e.g kidney and brain.

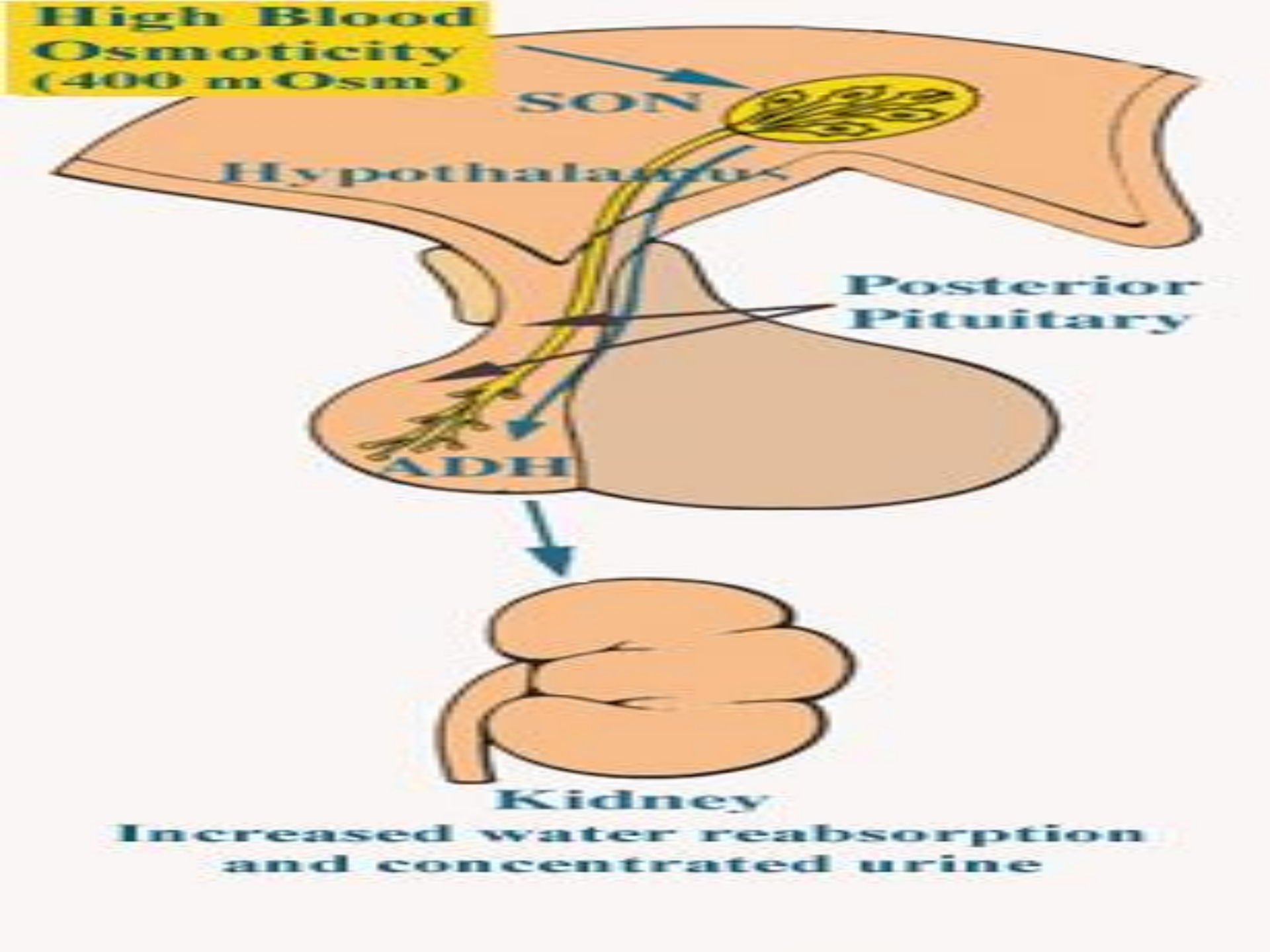
CONTROL OF BLOOD PRESSURE;

1. The Renin Angiotensin Aldosterone System (RAAS).

- When blood pressure falls due to reduced blood volume e.g in haemorrhage and dehydration; the **Juxtaglomerula apparatus (JGA)** in the afferent arteriole of the kidney nephron releases **Renin.** Renin is transported to the liver where it converts **Angiotensinogen** released by the liver , to **Angiotensin 1**.

- The angiotensin 1 is then transported to the lungs where it is converted to **Angiotensin 2** by **Angiotensin converting enzyme (ACE).**
- The angiotensin 2 is a potent vasoconstrictor and constricts blood vessels to increase BP, while at the same time it stimulates the secretion of **Aldosterone** from the zona glomerulosa in the adrenal cortex of the adrenal glands.
- Aldosterone secreted causes kidney reabsorbing tubules to increase sodium and water uptake (reabsorption) into the blood thus increasing blood volume and blood pressure.


Blood pressure rises
Vasoconstriction
Salt/water retention
Thirst
Aldosterone
Angiotensin II
Angiotensin-converting enzyme
Angiotensin I
Renin
Angiotensinogen
Blood pressure falls


High Blood Osmoticity (400 m Osm)
SON
Hypothalamus
Posterior Pituitary
ADH
Kidney
Increased water reabsorption and concentrated urine

- The RAAS plays a vital role in long term control of BP. However, other factors are also involved in BP control especially short term moment to moment control of BP fluctuations.
- These factors include;

2. Chemo receptors.

3. Higher centers in the brain.

4. Baro receptors.

2.Chemoreceptors;

- These are nerve endings in the carotid and aortic bodies and are sensitive to detect changes in CO2 levels,O2 and H+(acidity).

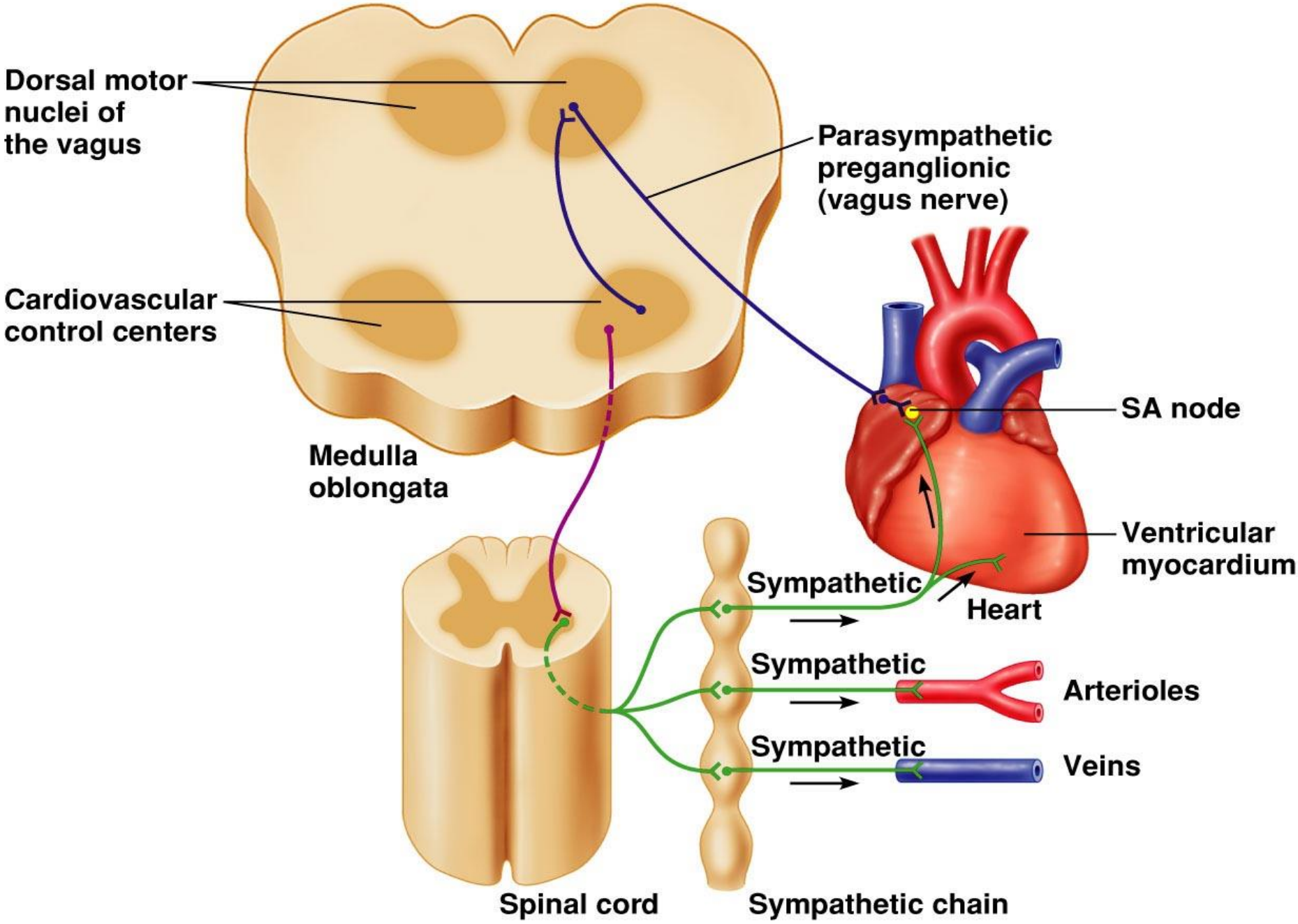
- A rise in H+ (acidity) and hypoxia stimulate these chemo receptors which signals the cardiovascular center in the brain which in turn activates sympathetic blood flow to the heart and thus BP is increased.

- The reverse stimulates the chemo receptors which signals the CVC to stimulate sympathetic nerve flow to the heart and BP is reduced

3.Higher centers in the brain.

- The hypothalamus in the brain controls body temperature and influence CVS which adjust blood vessel diameter.

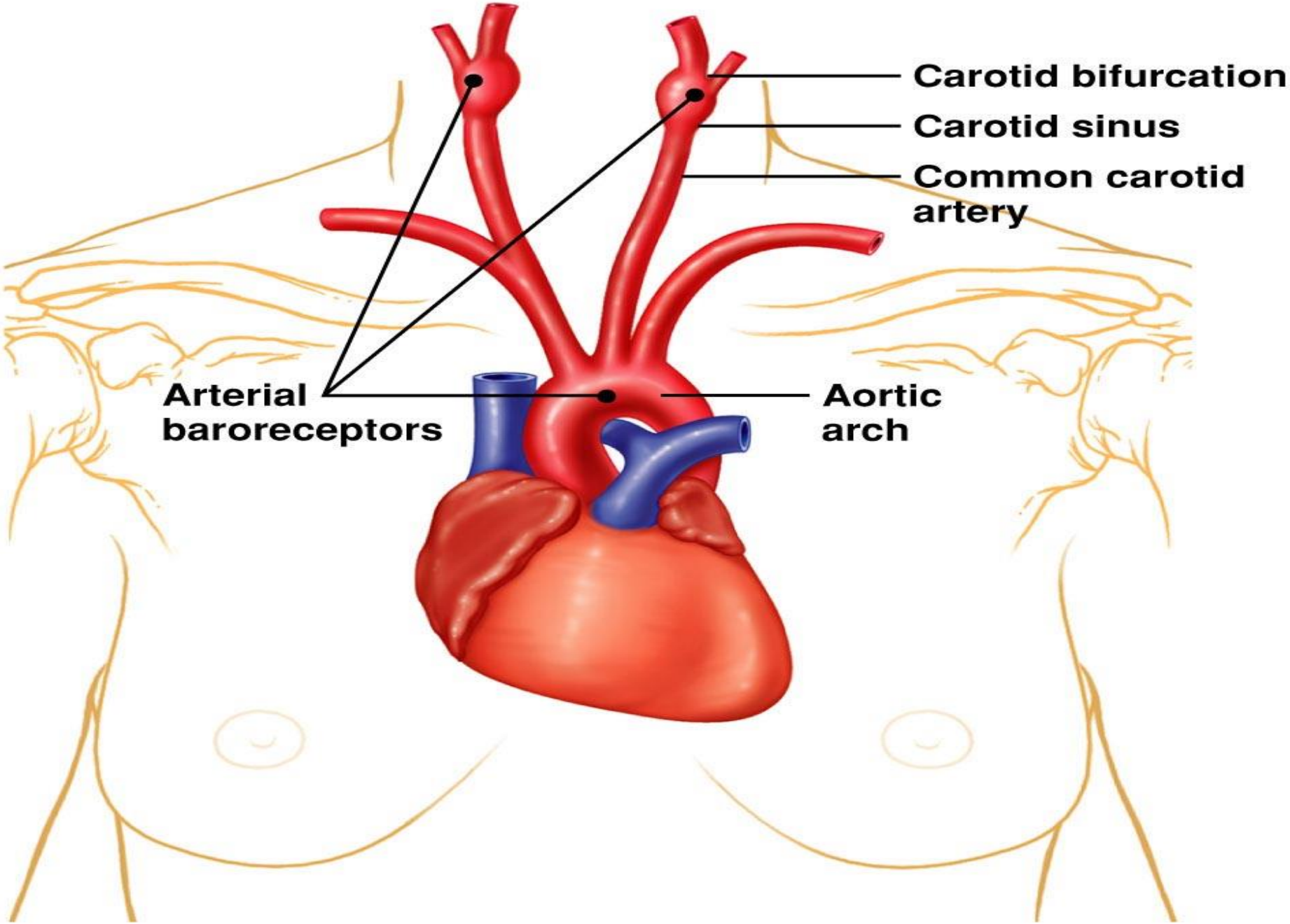
- Other emotional state in the body such as fear, anxiety, pain and anger stimulates changes in the BP.



4.Baroreceptors.

- These nerve endings are sensitive to pressure(stretch) changes within the blood vessels. They are located in the arch of the aorta and carotid bodies.
- A rise in BP stimulates these baro receptors which stimulate the CVC in the pons thus increases parasympathetic activity to the heart resulting to reduced heart rate and reduced force of contraction. The blood vessels also dilate.

- Reduction in the BP stimulates these baroreceptors which signals the CVC in the pons to increase sympathetic activity to the heart thus there results to increased heart rate and increased force of contraction with vasoconstriction.




ADULT

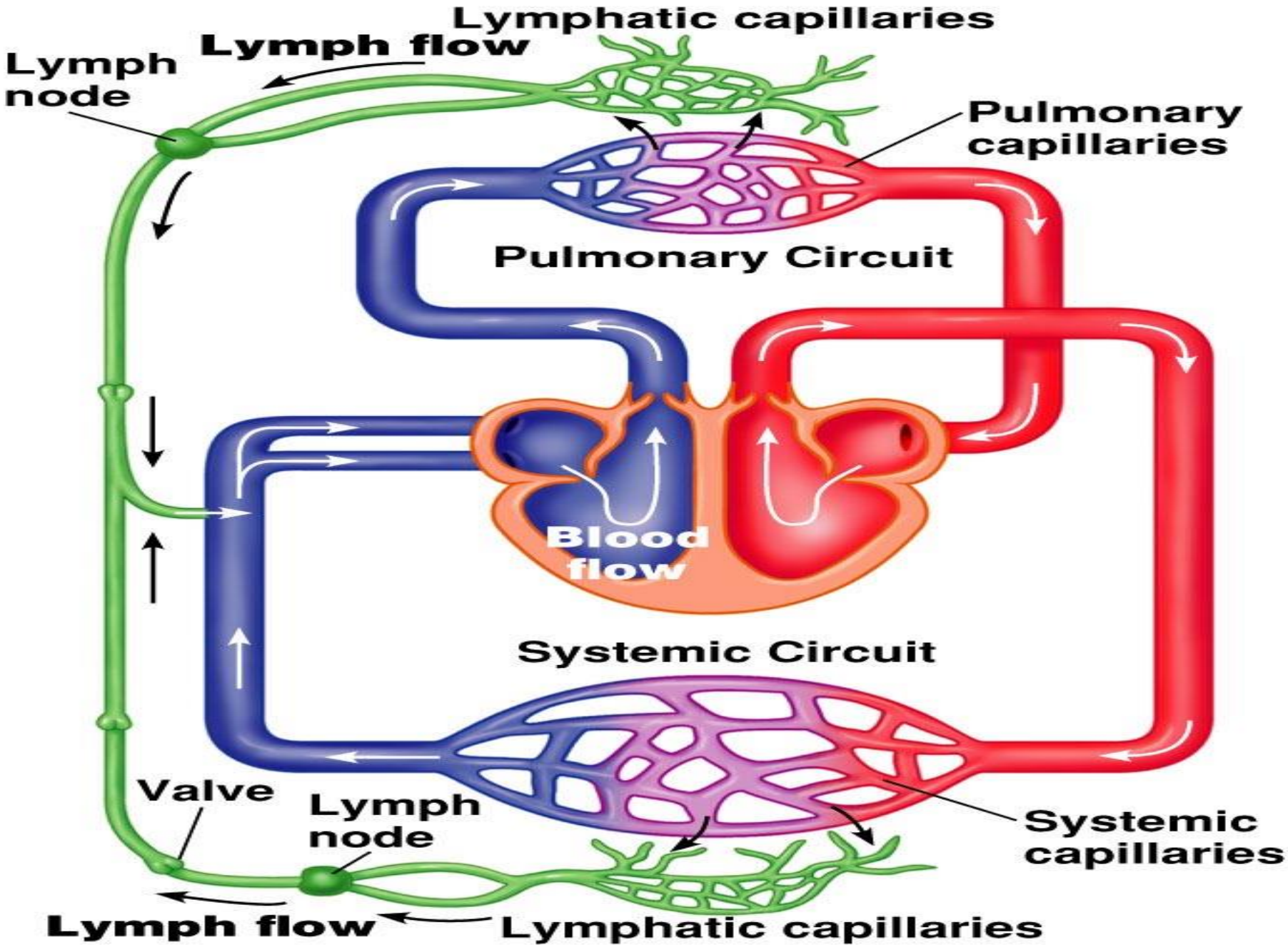
BLOOD CIRCULATION.

Blood vessels;

- The major blood vessels are;

1. Arteries.
2. Arterioles.
3. Capillaries.
4. Venules.
5. Veins.

- All arteries and arterioles carry oxygenated blood except pulmonary artery in the heart.
- All veins carry deoxygenated blood except pulmonary vein in the heart

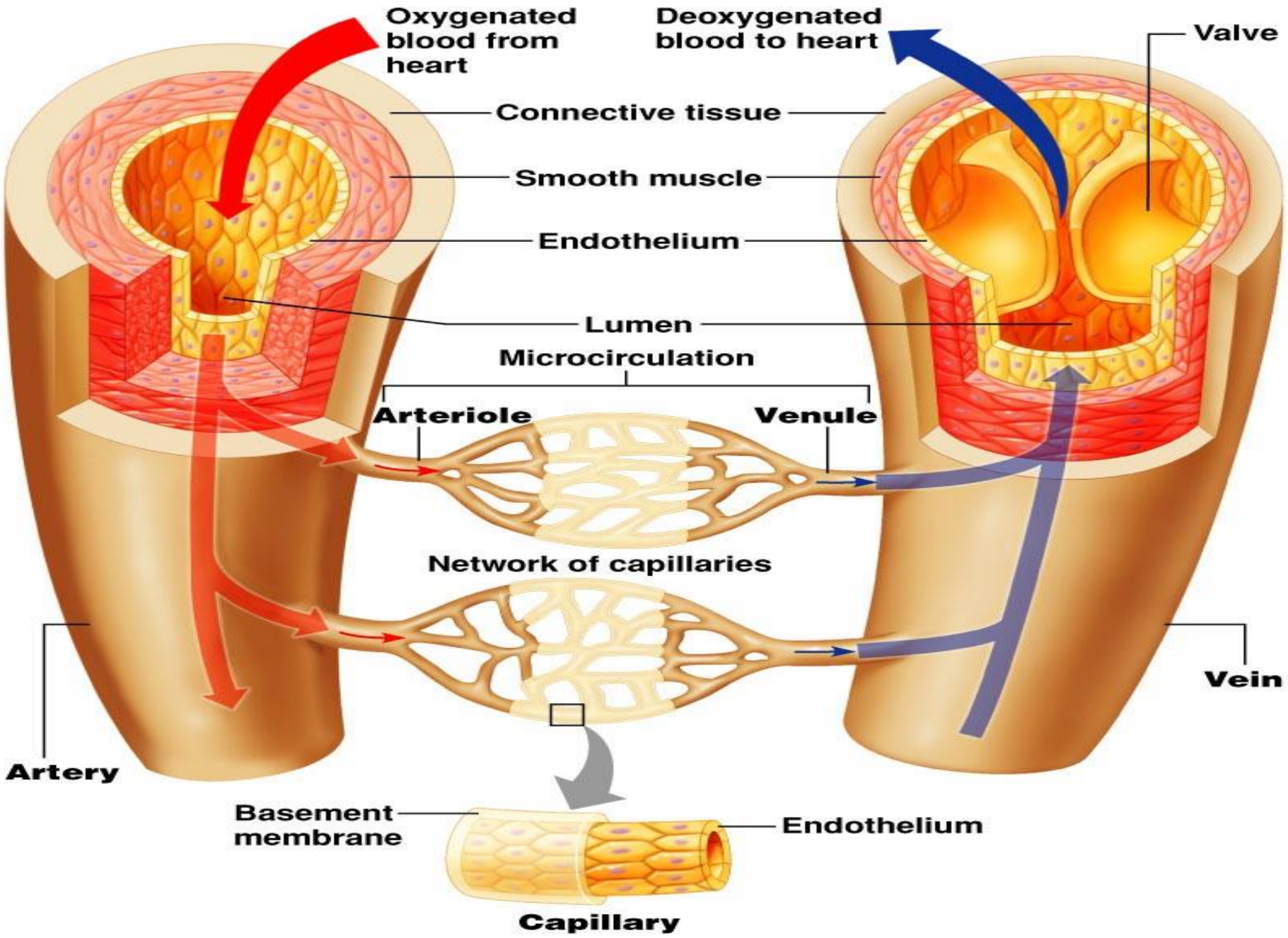


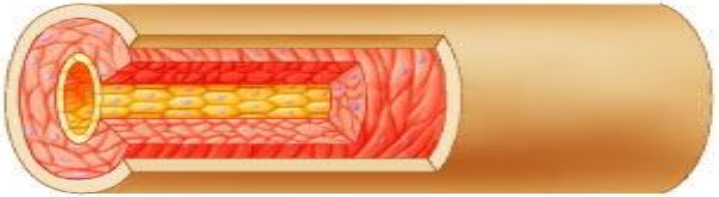
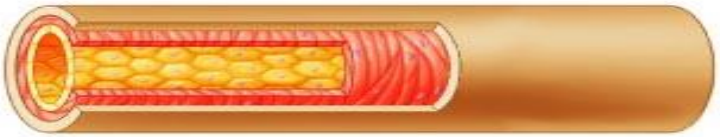
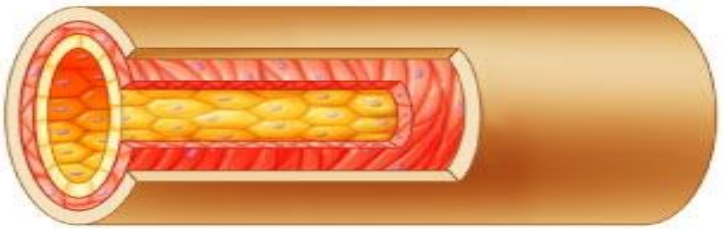
STRUCTURE OF BLOOD VESSELS;

- Blood vessels consist of three layers of tissues;

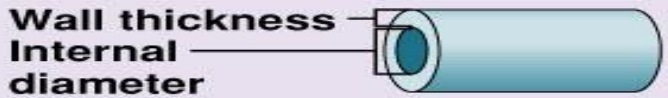
1. Tunica adventitia-Outer fibrous tissue layer.
2. Tunica media-Middle smooth and elastic muscle layer.
3. Tunica intima-Inner squamous epithelium layer(endothelium).

- Arteries have thicker walls than veins though both consist of the same three layer tissue



Average internal diameter (mm)	Average wall thickness (mm)		Special features
4.0	1.0	 Artery	Muscular, highly elastic
0.03	0.006	 Arteriole	Muscular, well innervated
0.008	0.0005	 Capillary	Thin-walled, highly permeable
0.02	0.001	 Venule	Thin-walled, some smooth muscle
5.0	0.5	 Vein	Thin-walled (compared to arteries), fairly muscular, highly distensible

= Endothelium
= Smooth muscle
= Connective tissue



- **Anastomoses;-**These are links between adjacent arteries supplying an area of the body.This is to help provide collateral circulation and thus maintain blood supply to a particular area in case one artery is damaged i.e occluded or ligated.
- **End arteries;-**These are arteries beyond anastomoses e.g arteries that end into tissues.
- **Arterioles;-**These are smaller arteries that break up from the main arteries and further divide into capillaries which have thin and usually one cell thick walls which permit exchange of materials between them and the tissues adjacent to them.

- **Sinusoids;**-These are wider incomplete walled capillaries found in certain tissues and organs such as liver and bone marrow which permit faster exchange of substances between the blood and these tissues.
- Veins have thinner walls than arteries and carry blood at a lower pressure. They posses valves to inhibit backflow of blood due to the relatively low pressure of blood in thee vessels.
- Valves are formed by folds of tunica intima and strengthened by connective tissues and are numerous in veins of limbs especially the lower limbs.
- **Venules** are smaller veins.

- Veins are capacitance vessels capable of distending and holding more volume of blood.

- The opening(lumen) of blood vessels can be adjusted via nervous stimulation of the Autonomic Nervous System from the vasomotor center in the medulla oblongata.

- Arteries respond more to nervous stimulation than veins due to their relatively thicker walls with more smooth muscles.

PERIPHERAL RESISTANCE

- Resistance to blood flow in a vessel is determined by;

1. Diameter of the blood vessel.

2. Length of the blood vessel.

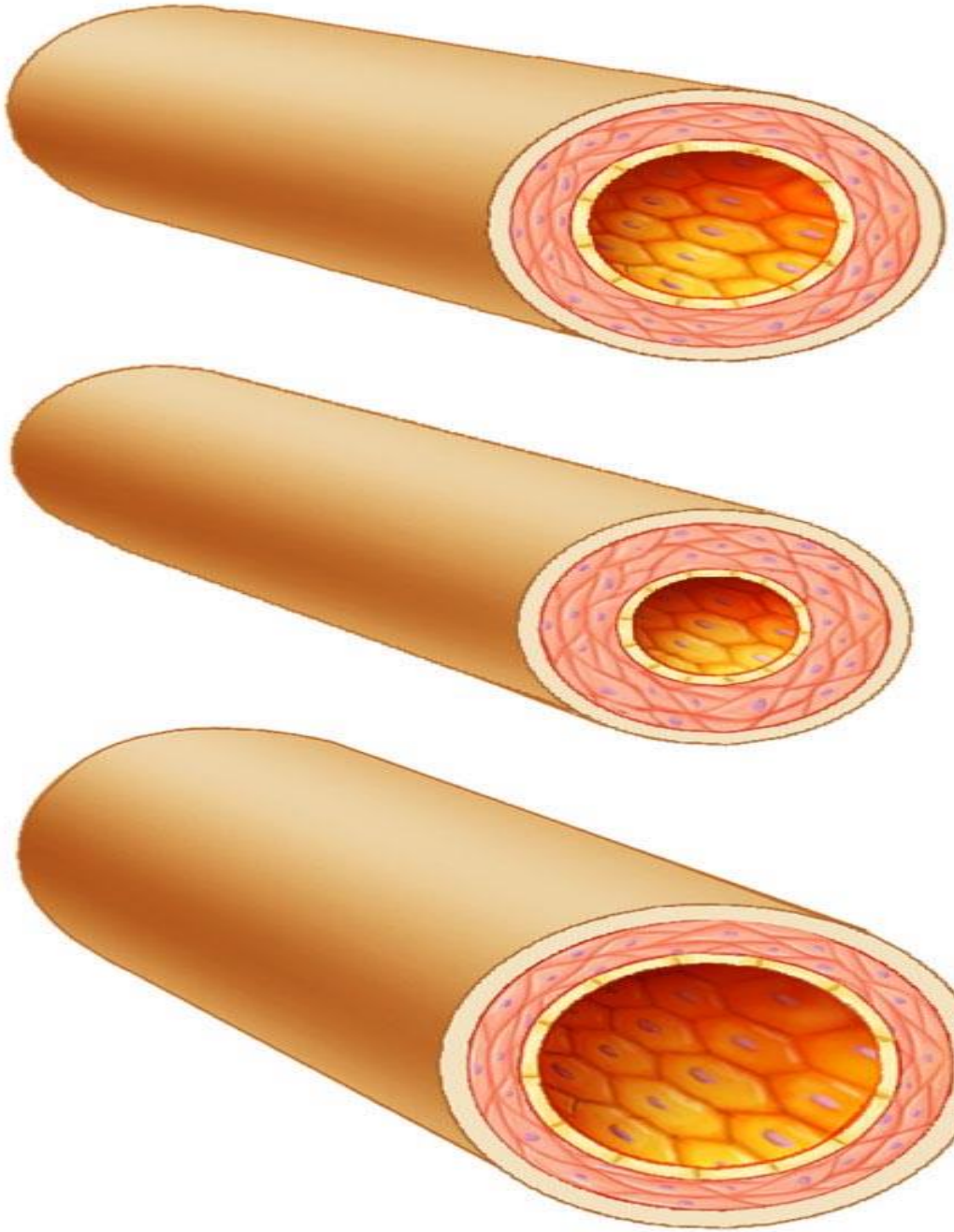
3. Viscosity of the fluid involved.

- Blood vessel diameter is mostly determined by sympathetic nerves as most blood vessels lack parasympathetic nerve supply.

- Sympathetic nerve supply normally constricts/narrows the blood vessels(vasoconstriction) while a reduced stimulation of the blood vessels by the same nerve on the blood vessels causes vasodilatation.
- Under optimal conditions, there is usually moderate sympathetic nervous stimulation.
- The blood vessels of brain and skeletal muscles respond less to sympathetic nerve supply.

AUTOREGULATION OF BLOOD FLOW

- Most organs control blood flow to their tissues according to need.More active tissues receive more blood compared to less active tissues.
- Increase in activity of a particular organ at a particular time results to increased blood supply to that organ at that particular time e.g after a meal,the GIT receives more blood due to increased metabolic activity in the GIT .



Rest, arteriolar tone

Contraction of smooth muscle causes vasoconstriction

Relaxation of smooth muscle causes vasodilation

Mechanisms of autoregulation.

1. **Tissue temperature;**

- Increased metabolic activity increases temperature which in turn causes vasodilatation and increased blood supply.

2. **Hypoxia;**

- Increased CO2 stimulates vasodilatation resulting to increased blood supply to a particular area.

3. **Metabolic wastes;**

- Release of metabolic wastes e.g CO2 and lactic acid results to increased blood flow to enhance easy elimination of these wastes.

4. **Vasodilator chemicals**;

- Release of vasodilator chemicals e.g Nitric acid, Bradykinins etc stimulates vasodilatation resulting to increased blood flow to a particular.

5. **Vasoconstrictor chemicals;**

- These reduces blood supply due to the resulting vasoconstriction when these chemicals are released e.g –Angiotensin II.

  -Catecholamines.

MECHANISMS OF MATERIALS EXCHANGE ACROSS BLOOD/CAPILLARY WALL

1) Exchange of materials across the capillary walls is mainly through;

i. Osmosis.

ii. Diffusion.

iii. Active transport.

2) Gaseous exchange;-This is mainly via diffusion against a concentration gradient e.g O2 from high concentration in the capillary to low concentration in the tissues via tissue fluid, while CO2 from high concentration in the tissues to low concentration via tissue fluid in the capillary.

REGIONAL BLOOD CIRCULATION;

- Blood circulation in the body mainly involve;

1. **Pulmonary circulation.**

- Involve flow of blood from the heart to the respiratory system and back to the heart.

2. **Systemic circulation.**

- Involve flow of blood from the heart to the other parts of the body(systems and organs) other than the respiratory system.

CORONARY CIRCULATION

- Blood flow through the coronary circulation is controlled almost entirely by **local metabolites,** with sympathetic innervation playing only a minor role.
- The most important local metabolic factors are **hypoxia** and **adenosine.** For example, if there is an increase in myocardial contractility, there is increased O_2 demand by the cardiac muscle and increased O_2 consumption, causing local hypoxia. This local hypoxia causes vasodilation of the coronary arterioles, which then produces a compensatory increase in coronary blood flow and O_2 delivery to meet the demands of the cardiac muscle (i.e., active hyperemia).
- An unusual feature of the coronary circulation is the effect of **mechanical compression** of the blood vessels during systole in the cardiac cycle. This compression causes a brief period of occlusion and reduction of blood flow. When the period of occlusion (i.e., systole) is over, reactive hyperemia occurs to increase blood flow and O_2 delivery and to repay the O_2 debt that was incurred during the compression.

CEREBRAL CIRCULATION

- The cerebral circulation is controlled almost entirely by **local metabolites** and exhibits autoregulation and active and reactive hyperemia.
- The most important local vasodilator in the cerebral circulation is **CO_2** (or H^+). An increase in cerebral P_{CO_2} (producing an increase in H^+ concentration and a decrease in pH) causes vasodilation of the cerebral arterioles, which results in an increase in blood flow to assist in removal of the excess CO_2.
- It is interesting that many circulating vasoactive substances *do not affect* the cerebral circulation because their large molecular size prevents them from crossing the blood-brain barrier.

PULMONARY CIRCULATION

- The pulmonary circulation is controlled by **O_2**. The effect of O_2 on pulmonary arteriolar resistance is the *exact opposite* of its effect in other vascular beds.
- In the pulmonary circulation, **hypoxia causes vasoconstriction.**
- Regions of hypoxia in the lung cause local vasoconstriction, which effectively shunts blood *away from* poorly ventilated areas where the blood flow would be "wasted" and *toward* well-ventilated areas where gas exchange can occur

RENAL CIRCULATION

- The renal blood flow is tightly **autoregulated** so that flow remains constant even when renal perfusion pressure changes.
- Renal autoregulation is independent of sympathetic innervation, and it is retained even when the kidney is denervated (e.g., in a transplanted kidney).
- Autoregulation is presumed to result from a combination of the myogenic properties of the renal arterioles and tubuloglomerular feedback.

SKELETAL MUSCLE CIRCULATION

- Blood flow to skeletal muscle is controlled both by **local metabolites** *and* by **sympathetic innervation** of its vascular smooth muscle.
- Incidentally, the degree of vasoconstriction of skeletal muscle arterioles is a major determinant of **TPR** (total peripheral resistance) because the mass of skeletal muscle is so large, compared with that of other organs.

- At **rest,** blood flow to skeletal muscle is regulated primarily by its **sympathetic innervation.** Vascular smooth muscle in the arterioles of skeletal muscle is densely innervated by sympathetic nerve fibers that are vasoconstricting (α_1 receptors). There are also β_2 receptors on the vascular smooth muscle of skeletal muscle that are activated by epinephrine and cause vasodilation.
- Thus, activation of α_1 receptors causes vasoconstriction, increased resistance, and decreased blood flow.
- Activation of β_2 receptors causes vasodilation, decreased resistance, and increased blood flow. Usually, vasoconstriction predominates because norepinephrine, released from sympathetic adrenergic neurons, stimulates primarily α_1 receptors.
- On the other hand, epinephrine released from the adrenal gland during the fight-or-flight response or during exercise activates β_2 receptors and produces vasodilation

- During **exercise,** blood flow to skeletal muscle is controlled primarily by **local metabolites.** Each of the phenomena of local control is exhibited: autoregulation and active and reactive hyperemia.
- During exercise, the demand for O_2 in skeletal muscle varies with the activity level, and, accordingly, blood flow is increased or decreased to deliver sufficient O_2 to meet the demand. The local vasodilator substances in skeletal muscle are **lactate, adenosine,** and **K^+**.
- Mechanical compression of the blood vessels in skeletal muscle can also occur during exercise and cause brief periods of occlusion. When the period of occlusion is over, a period of reactive hyperemia will occur, which increases blood flow and O_2 delivery to repay the O_2 debt.

SKIN CIRCULATION

- The blood vessels of the skin have a dense **sympathetic innervation,** which controls its blood flow.
- The principal function of the sympathetic innervation is to alter blood flow to the skin for **regulation of body temperature.** For example, during exercise, as body temperature increases, sympathetic centers controlling cutaneous blood flow are *inhibited*. This selective inhibition produces vasodilation in cutaneous arterioles so that warm blood from the body core can be shunted to the skin surface for dissipation of heat.
- Local vasodilator metabolites have little effect on cutaneous blood flow

- The effects of vasoactive substances such as histamine have been discussed previously. In skin, the effects of histamine on blood vessels are visible. **Trauma** to the skin releases **histamine,** which produces a **triple response** in skin: a red line, a red flare, and a wheal. The **wheal** is local edema and results from histaminic actions that vasodilate arterioles and vasoconstrict veins. Together, these two effects produce increased P_c, increased filtration, and local edema.

- Read and make notes on fetal circulation.

FETAL CIRCULATION

- Fifty-five percent of the fetal cardiac output goes through the placenta.
- The blood in the umbilical vein in humans is about 80% saturated with O_2, compared with 98% saturation in the arterial circulation of the adult. The **ductus venosus** diverts some of this blood directly to the inferior vena cava, and the remainder mixes with the portal blood of the fetus. The portal and systemic venous blood of the fetus is only 26% saturated, and the saturation of the mixed blood in the inferior vena cava is approximately 67%. Most of the blood entering the heart through the inferior vena cava is diverted directly to the left atrium via the patent foramen ovale. Most of the blood from the superior vena cava enters the right ventricle and is expelled into the pulmonary artery.

- The resistance of the collapsed lungs is high, and the pressure in the pulmonary artery is several mm Hg higher than it is in the aorta, so that most of the blood in the pulmonary artery passes through the **ductus arteriosus** to the aorta. In this fashion, the relatively unsaturated blood from the right ventricle is diverted to the trunk and lower body of the fetus, while the head of the fetus receives the better-oxygenated blood from the left ventricle. From the aorta, some of the blood is pumped into the umbilical arteries and back to the placenta. The O_2 saturation of the blood in the lower aorta and umbilical arteries of the fetus is approximately 60%.