UNIVERSITY OF MEDICAL SCIENCES, ONDO

DEPARTMENT OF PHYSIOLOGY

PHS 223

CARDIOVASCULAR SYSTEM (2 UNITS)

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OUTLINE

- Definition and functions of the CVS
- Cardiac muscle
- Cardiac myoelectrophysiology
- Conductive tissues of the heart
- Cardiac cycle
- Circulation of blood
- Cardiac output and regulation
- Blood pressure (hypertension and hypotension)
- Hemodynamics and microcirculation (pulmonary, cerebral, coronary, splanchnic and muscle circulation)
- Shock and cardiovascular changes in exercise

DEFINITION AND FUNCTIONS OF CARDIOVASCULAR SYSTEM

➢The cardiovascular system is made up of:

- a muscular pump (the heart)

- network of blood vessels through which blood from the heart is taken or conveyed to all body parts and through which blood is returned to the heart.

- Blood

- It is also referred to as the circulatory system.

THE HEART

- Is a muscular organ that pumps blood throughout the circulatory system. Heart weighs about 250-350 gm in an adult.
- It is situated in between two lungs in the mediastinum.
- It is made up of four chambers i.e. two atria and two ventricles.
- The musculature of ventricles is thicker than that of atria.

VALVES OF THE HEART

- There are four valves in human heart.
- Two valves are in between atria and the ventricles called atrioventricular valves.
- Other two are the semilunar valves, placed at the opening of blood vessels arising from ventricles, namely systemic aorta and pulmonary artery.
- Valves of the heart permit the flow of blood through heart in only one direction.

FUNCTIONS OF THE CVS

- Transport of oxygen from the lungs to the tissues.
- Transport of carbon dioxide from the tissues to the lungs for excretion.
- Transport of digested food substances, electrolytes and vitamins (nutrients) from the gastro intestinal tract to all body parts.
- Transport of waste products of cellular metabolism from the tissues to the kidneys and other excretory organs (lungs and skin).
- Transport of hormones from the endocrine glands to their target organs.
- Temperature regulation.
- Transport of blood cells e.g. leukocytes and immune substances that defend the body against foreign agents like bacteria, viruses, fungi and cancer cells.

FUNCTIONAL ANATOMY OF THE HEART

Physiology of cardiac Muscle

- The heart is composed of three major types of cardiac muscle
  - Atrial muscle
  - Ventricular muscle

- Specialized excitatory and conductive muscle fibers.

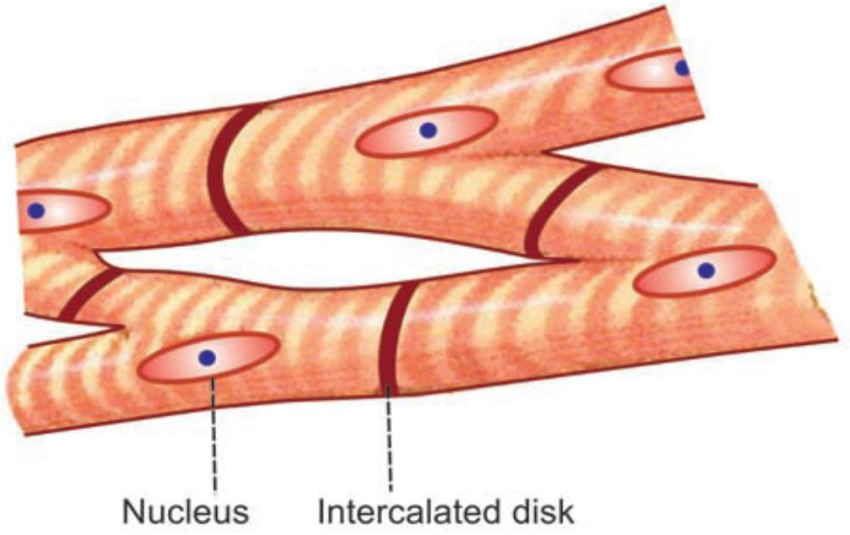
- The atrial and ventricular muscle contract like skeletal muscle, but the duration of contraction is much longer.

- Specialized excitatory and conductive fibers contract only feebly because they contain few contractile fibrils.

- They exhibit either automatic rhythmical electrical discharge in the form of action potentials or conduction of the action potentials through the heart.

- Thus providing an excitatory system that controls the rhythmical beating of the heart.

- Cardiac muscle fibers are arranged in a latticework, with the fibers dividing, recombining, and spreading again.
- Cardiac muscle is striated like the skeletal muscle.
- Myofibrils of cardiac muscle contain actin and myosin filaments similar to those found in skeletal muscle.
- These filaments lie side by side and slide along one another during contraction like in the skeletal muscle.



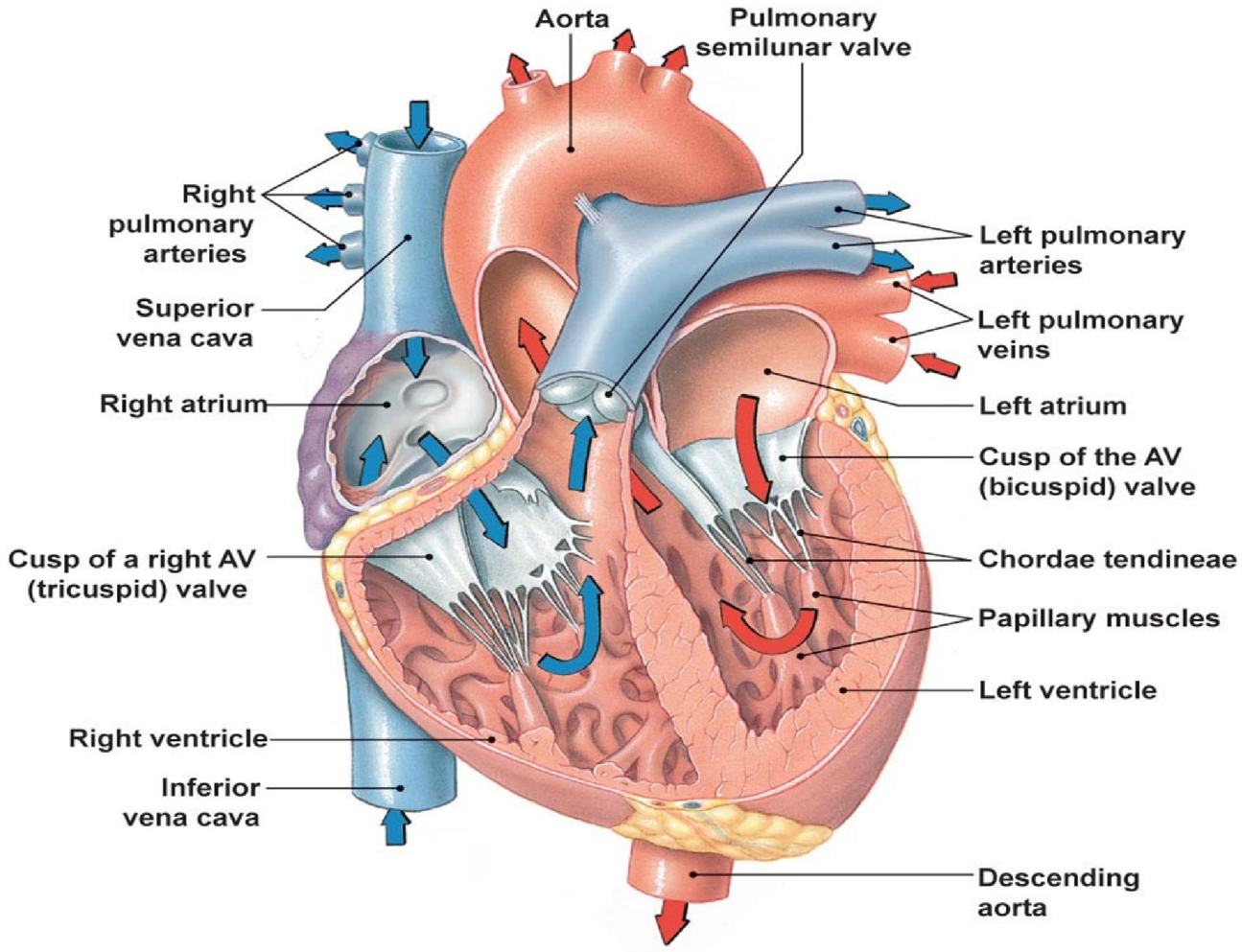
CARDIAC MUSCLE AS A SYNCYTIUM.

- The dark areas crossing the cardiac muscle fibers are called intercalated discs (cell membranes that separate individual cardiac muscle cells from one another).
- Cardiac muscle fibers are made up of individual cells connected in series and in parallel with one another.
- At each intercalated disc the cell membranes fuse with one another to form "communicating" junctions (gap junctions) that allow free diffusion of ions.
- Thus, cardiac muscle is a *syncytium* of many heart muscle cells where the cardiac cells are interconnected
- Therefore, when one of the cells becomes excited, the action potential spreads to all of them, spreading from cell to cell throughout the latticework interconnections.

FUNCTIONAL ANATOMY OF THE HEART

Chambers

- 4 chambers
  - 2 Atria
  - 2 Ventricles
- 2 systems
  - Pulmonary
  - Systemic



FUNCTIONAL DIVISIONS OF THE CIRCULATION

➢Heart has 2 pumps (Right and left)

- The right pump
- It is a low pressure pump
- Consists of the right atrium and right ventricle
- Right atrium receives deoxygenated blood from the superior and inferior venae cavae
- The blood is passed to the right ventricle
- The right atrium and right ventricle is separated by tricuspid or right atrioventricular valve
- The wall of the right ventricle is about 3-4 mm thick
- The blood is pump out of the right ventricle through the pulmonary arteries into the lungs

- Backflow of blood from the pulmonary trunk into the right ventricle is prevented by the pulmonary valves
- The left pump
- It is a high pressure pump
- Consists of the left atrium and left ventricle
- The left atrium receives oxygenated from the lungs
- The blood passes from the left atrium into the left ventricle through the mitral (bicuspid or left atrioventricular valve)
- The wall of the left ventricle is about 8-10 mm thick
- The left ventricle pumps out blood through the aorta into the systemic circulation
- Backflow of blood from the aorta into the left ventricle is prevented by the aortic valve

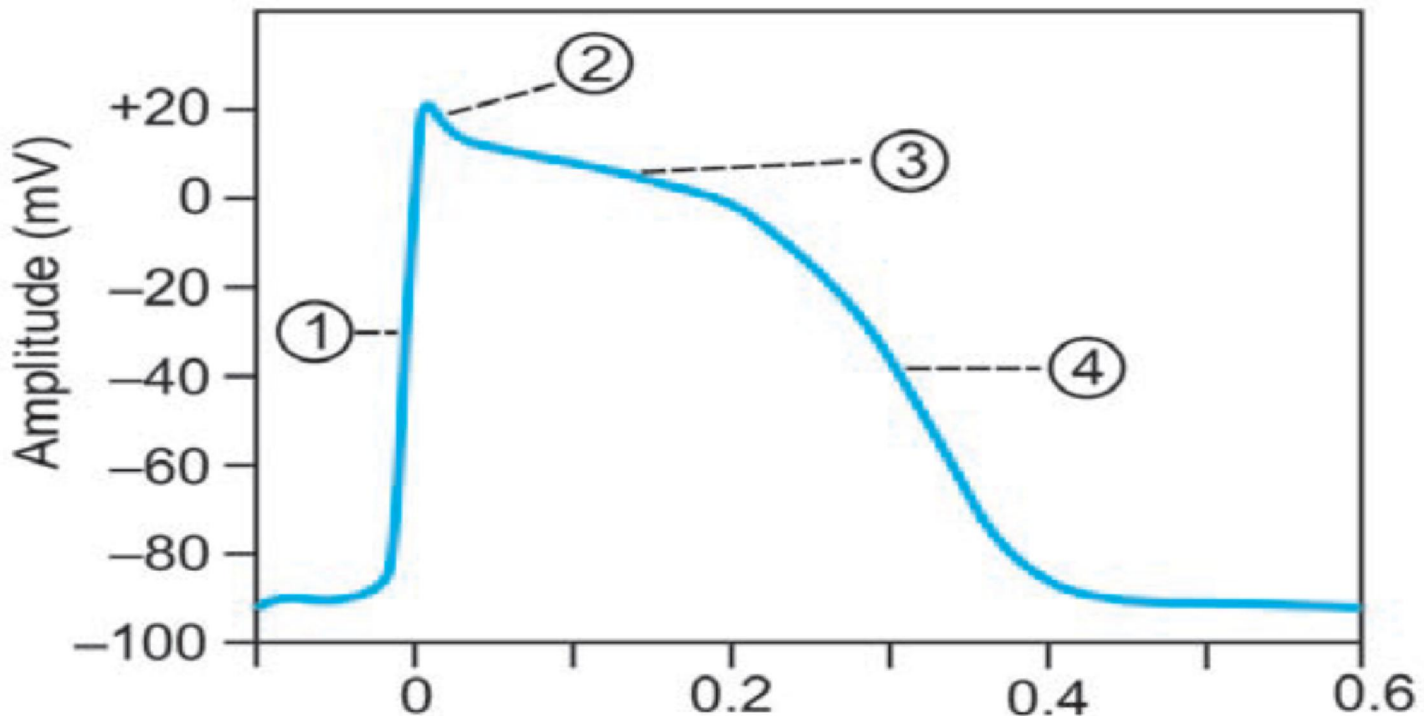
ELECTRICAL POTENTIALS IN CARDIAC MUSCLE

ACTION POTENTIAL

- Action potential in cardiac muscle is different from other tissues' such as skeletal muscle, smooth muscle and nervous tissue.

- Duration of the action potential in cardiac muscle is 250-350 millisec (0.25-0.35 sec).

- The action potential recorded in a ventricular muscle fiber is shown in the figure below



Action potential in ventricular muscle.
1 = Depolarization 2 = Initial rapid repolarization 3 = Plateau 4 = Final repolarization

- The RMP is similar to that in skeletal muscle, at about -90 mV.
- The action potential recorded in a ventricular muscle fiber, averages about 105 millivolts.
- That is the intracellular potential rises from a very negative value, about -90 mV, between beats to a slightly positive value, about +20 mV, during each beat.
- After the initial spike, the membrane remains depolarized for about 0.2 second, exhibiting a plateau.
- Followed at the end of the plateau by abrupt repolarization.
- The presence of this plateau in the action potential causes ventricular contraction to last as much as 15 times as long in cardiac muscle as in skeletal muscle.

- In mammalian hearts, depolarization lasts about 2 ms.
- The plateau phase and repolarization last 200 ms or more.
- Repolarisation will not complete until the contraction is almost over.

MECHANISM OF CARDIAC ACTION POTENTIAL

- The mechanisms depend on trans-membrane ion gradients and voltage-sensitive changes in membrane permeability, or conductance to those ions.
- Three ions are involved i.e. Na^+, Ca^{2+} and K^+
- Sodium channels: depolarization first opens (activates) Na^+ channels, increasing Na^+ conductance.
- This leads to an inward Na^+ current which causes further depolarization.

- Sodium conductance then declines because of depolarization-induced inactivation of Na^+ channels.
- The cell then remain refractory to stimulation until these are returned to their resting, closed state following repolarization.

- Calcium channels: they open in response to depolarization.
- They are activated more slowly than the Na^+ channels, but once they open, calcium ions flow into the cell.
- The inward Ca^{2+} current keeps the membrane depolarized and this maintain the plateau in the action potential.

- Potassium channels: the potassium conductance initially decreases after depolarization.

- During plateau, there is less outward K^+ current than normal.
- This makes it easier for the inward Ca^{2+} current to maintain depolarization.
- After 200 ms, K^+ conductance rises, increasing outward current.
- The K^+ current repolarizes the membrane.

CONDUCTIVE TISSUE OF THE HEART

SA Node

Internodal fibres

AV Node

Bundle of His or AV Bundle

Rt & Lt Bundle Branches

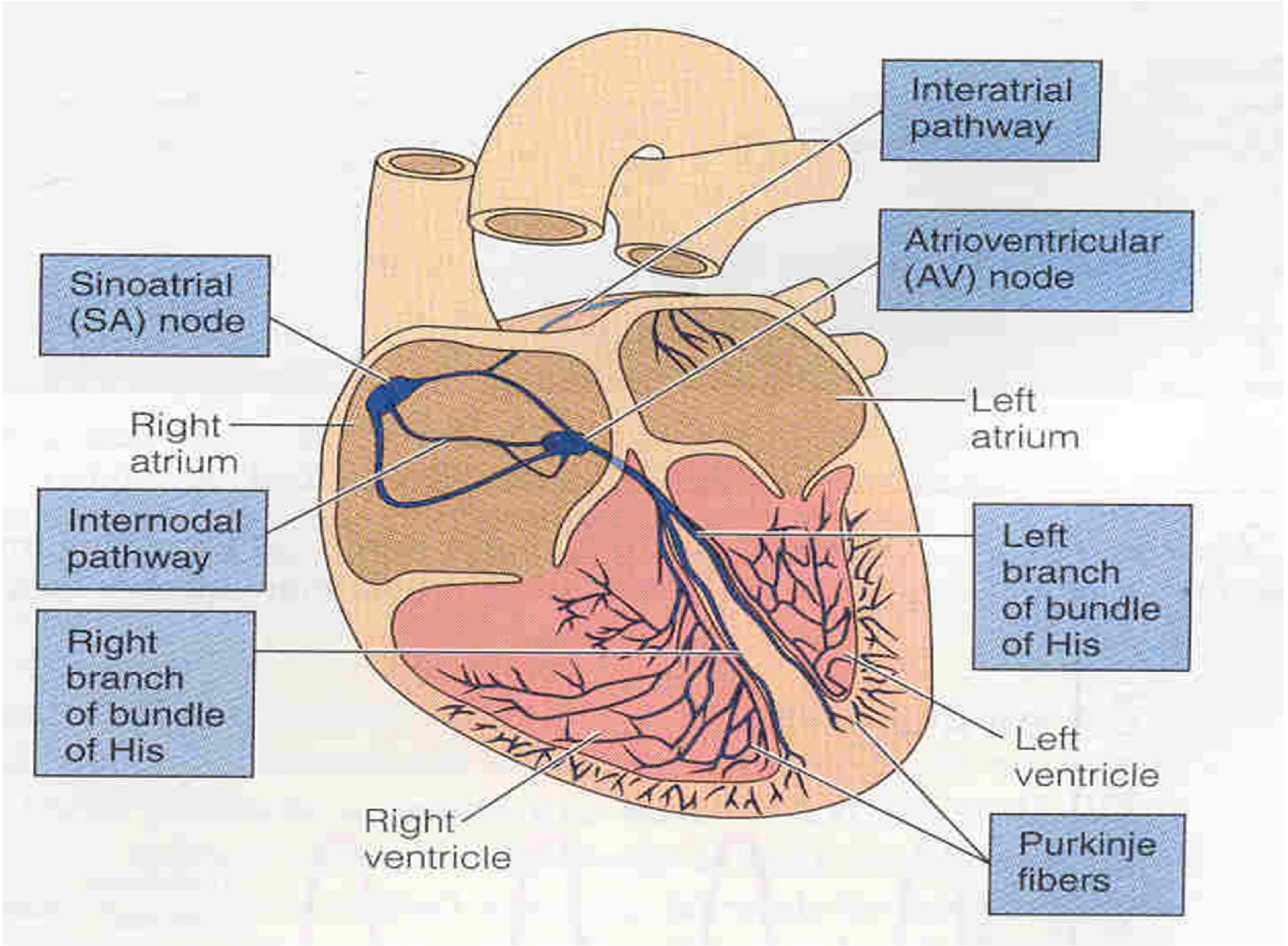
Purkinje fiber

Ventricle

CONDUCTIVE TISSUE OF THE HEART

- Conductive tissue of the heart controls cardiac contraction.
- Action potential originates in SA node and spread to both Atria through intercalated disc and gap junction.
- From atria action potential can not pass to ventricle due to fibrous Skeleton of heart which separates atria and ventricles.
- Therefore specialized conducting tissue is required (it is composed of modified Myocardial cells) to conduct the impulse.

CONDUCTIVE TISSUE OF THE HEART



CONDUCTIVE TISSUE OF HEART

Anatomical Locations

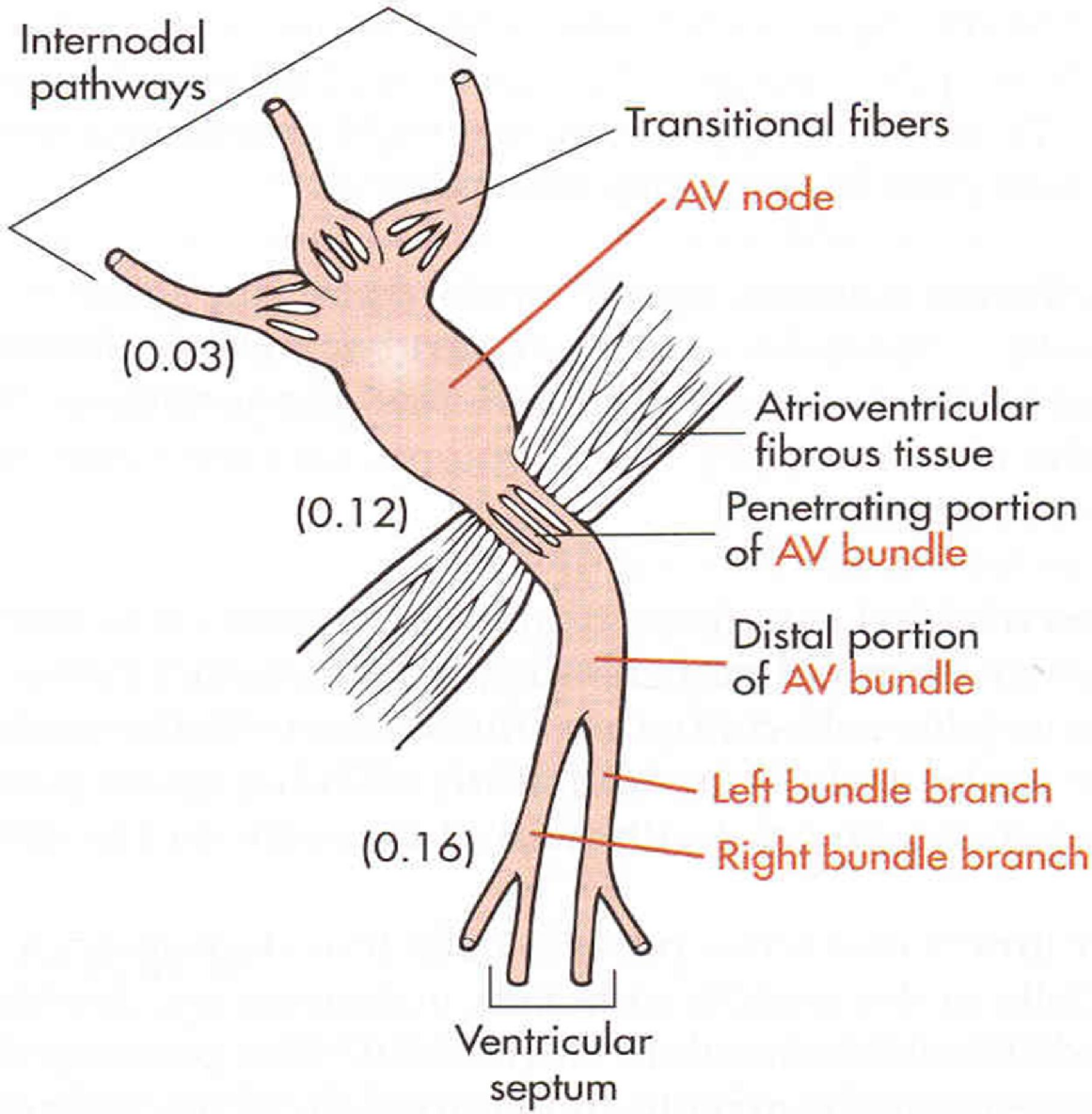
- SA node
- SA node: It is pace-maker because it has pace-maker potential or pre-potential -automatic depolarization. Normal rhythmical impulse is generated.
- SA node is situated in the right atrium near the opening of superior vena cavae. It is supplied by right vagus nerve.
- Internodal fibers: Conduct impulse from SA node to AV node where the impulse from the atria is delayed before passing into the ventricles.
- Internodal Fibers: Anterior, Middle and Posterior (Bachman, Wenchkeback, Thorel).
- AV node
- It is situated at right posterior part of inter atrial septum.
- It is supplied by left vagus.

- Bundle of His (Atrioventricular Bundle)

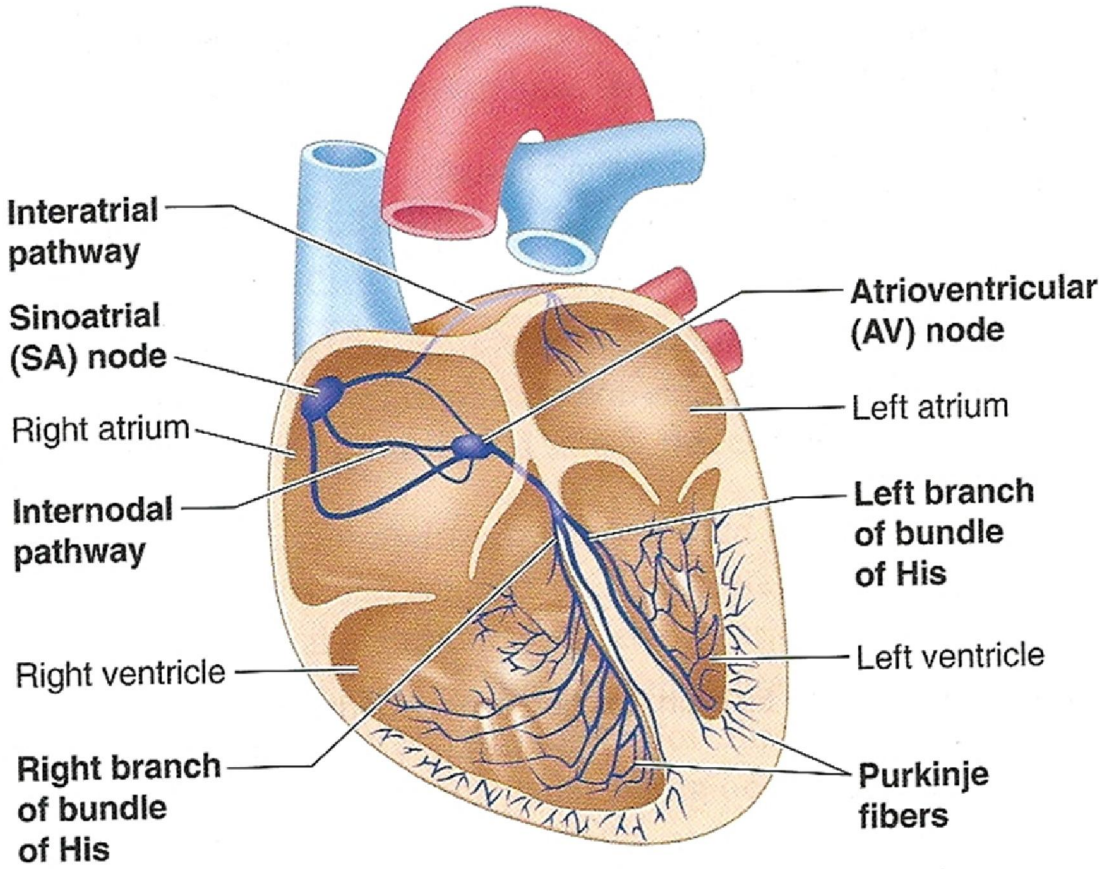
  It is a tract of specialized cardiac cells that originate at AV Node and passes through the fibrous ring at the top of interventricular septum.

- After passing through fibrous ring, it divides to form right bundle branch and left bundle branch that travel down along the sides of interventricular septum and lye sub-endocardially.

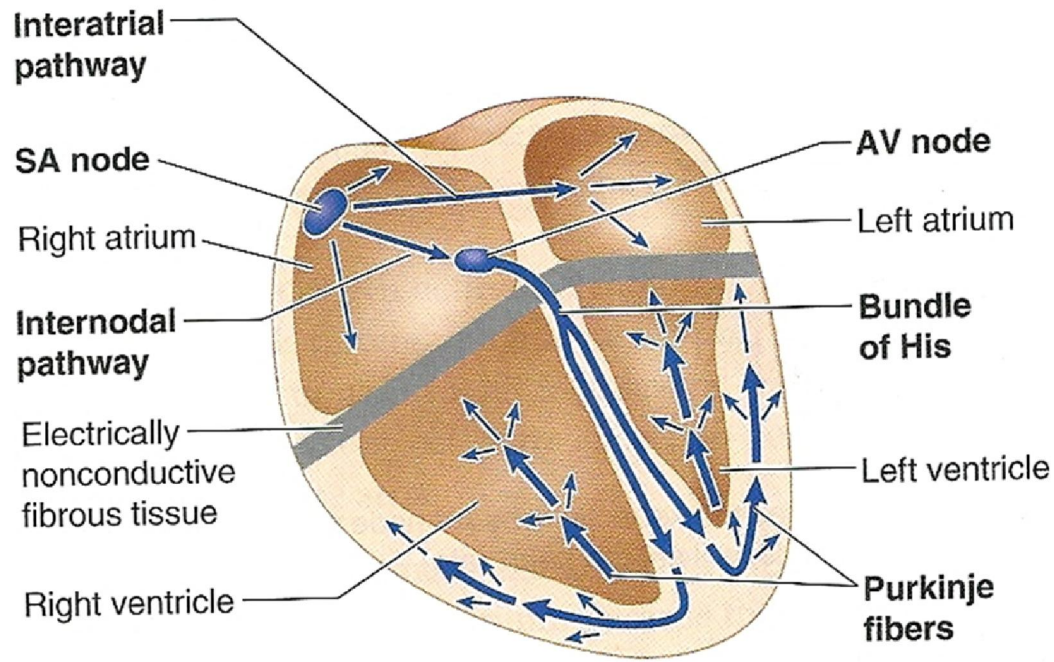
- It conducts impulse from the atria into the ventricles.


Internodal pathways
Transitional fibers
AV node
(0.03)
Atrioventricular fibrous tissue
(0.12)
Penetrating portion of AV bundle
Distal portion of AV bundle
Left bundle branch
(0.16)
Right bundle branch
Ventricular septum

- PURKINJE FIBERS
- Purkinje fibers originate from bundle branches.
- They conduct cardiac impulse to all parts of the ventricles.



(a) Specialized conduction system of the heart



(b) Spread of cardiac excitation

● **FIGURE 9-8 Specialized conduction system of the heart and spread of cardiac excitation.** An action potential initiated at the SA node first spreads throughout both atria. Its spread is facilitated by two specialized atrial conduction pathways, the interatrial and internodal pathways. The AV node is the only point where an action potential can spread from the atria to the ventricles. From the AV node, the action potential spreads rapidly throughout the ventricles, hastened by a specialized ventricular conduction system consisting of the bundle of His and Purkinje fibers.

NORMAL RATE OF ACTION POTENTIAL DISCHARGE IN AUTORHYTHMIC TISSUES OF THE HEART

TISSUE	ACTION POTENTIAL PER MINUTE
SA node (normal pace maker)	70-80
AV node	40-60
Bundle of His and Purkinje fibres	20-40

CONDUCTIVE TISSUE

➢Why SA-Node is a Pace-maker?

- Because its discharge rate is high 70-80/min.
- This 70-80 action potential/min drive rest of the heart, therefore, it is known as pace-maker of the heart.
- It has pre-potential.

Other auto-rhythmic tissue are firing at slow rate.

- They can work as pace-maker, if SA-Node is not functioning e.g. if AV Node takes over as pace-maker, heart rate will be about 50/min.
- Any pace-maker other than SA-Node is called ‘Ectopic Pace-maker’.

SPREAD OF CARDIAC EXCITATION

- Impulse arise at SA-Node and spread to the atria (via gap junction)– Atrial Syncytium, therefore, both atria depolarize at the same time.
- Impulse (AP) goes to AV-Node by Internodal pathway.
- AV-Node is the only point of electrical contact between atria and ventricle (as atria and ventricle are separated by fibrous ring which is non-conductive).
- AV-Node
- At AV-Node, there is delay of 0.1 sec (100 milli-sec).
- This delay is important because it allows the atria to contract and empty their blood into the ventricle, before impulse reaches the ventricle and causes ventricular depolarization and contraction.

- Ventricular Excitation
- After AV delay of 0.1sec, impulse (AP) travels quickly via right bundle branch and left bundle branch (branches of Bundle of His) to Purkinje Fibers, then to the ventricles.
- Both ventricle depolarize, then contract at same time.
- Conduction in Purkinje fiber is fastest 3-5 meter/sec, therefore, both ventricle depolarize quickly and at the same time.

CONDUCTION SPEED IN CARDIAC TISSUE

TISSUE	CONDUCTION RATE (m/s)
SA node	0.05
Atria pathway	1
AV node	0.05
Bundle of His	1
Purkinje system	4
Ventricular muscle	1

CONDUCTION OF IMPULSE

- In Atria – 1 Meter/ sec
- AV Node slow conduction – 0.03 to 0.05 Meter / sec

  There is delay of 0.1 sec in AV node
- Purkinje fiber - 3 to 5 Meter / sec

- Slowest Conduction at AV – Node
- Fastest Conduction - Purkinje Fibers

➢**Why Conduction is slow at AV-Node**

- Because there are less gap junctions.
- Diameter of the fiber is small.

APPLIED – HEART BLOCKS

There are three types of heart blocks:

- First degree heart block: Every impulse is conducted but very slowly, therefore, there is increase in conduction time.
- Second degree heart block: Some impulses are conducted and other are not conducted.
- Third degree heart block: Complete heart block, no conduction occurs from SA Node to the ventricle through AV node, therefore, atrial rate is separate (75/min) from the ventricular rate which follows the Purkinje fibers and is about 30/min.

✓**IMPORTANT**

If ventricular rate is very slow e.g. complete heart block, we need artificial pace-maker (implanted device which generates impulse).

EFFECT OF SYMPATHETIC AND PARASYMPATHETIC ANS

- Sympathetic ANS: It increases conduction as it decreases delay at AV node.
- Parasympathetic: slows the conduction as it increases delay at AV node.

BLOOD PRESSURE (Hypertension and Hypotension)

- It is the force of blood against the inner walls of blood vessels anywhere in the cardiovascular system.
- The term "blood pressure" usually refers to arterial blood pressure.
- Arterial blood pressure is expressed in four different terms.

- Systolic blood pressure (systolic pressure): maximum pressure exerted in arteries during systole of the heart i.e. during ventricular contraction, arterial pressure is at its highest.
- Normal systolic pressure is 120 mmHg (ranges between 110 and 140 mmHg).
- Diastolic blood pressure (diastolic pressure): minimum pressure in the arteries during diastole of heart i.e. when ventricles are relaxing, arterial pressure is at its lowest.
- Normal diastolic pressure is 80 mmHg (ranges between 60 and 80 mmHg).

- Pulse pressure: difference between systolic and diastolic pressure.
- Normal value is 40 mmHg.
- Mean arterial blood pressure: the average pressure existing in the arteries.
- Not arithmetic mean of systolic and diastolic pressures.
- It is diastolic pressure + one-third of pulse pressure.
- Normal value is 93 mmHg.

➢ The arterial blood pressure exists because heart forces blood into elastic aorta where it has some difficulty in escaping as a result of peripheral resistance in smaller vessels, especially the arterioles.

➢ Therefore, pressure produced at any time depends on both the cardiac output (C.O.) and peripheral resistance (P.R.) i.e. B.P.= C.O. × P.R.

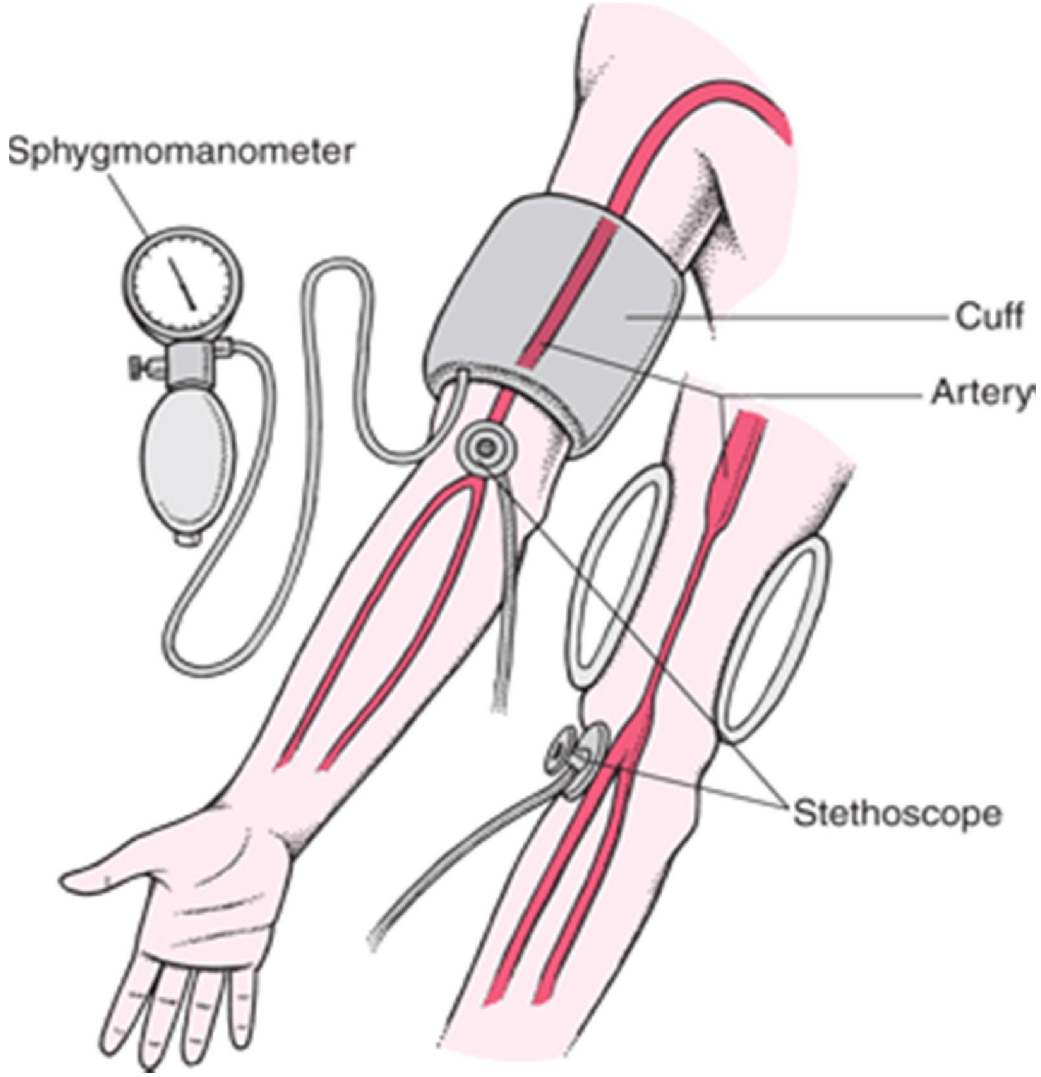
- Variation in blood pressure can occur by changing peripheral resistance or cardiac output or changing both.
- Therefore, all factors affecting cardiac output and peripheral resistance will influence arterial pressure.

- Assignment: Write short notes on factors that can influence arterial blood pressure.

MEASUREMENT OF ARTERIAL BLOOD PRESSURE

- Arterial blood pressure can be measured both directly and indirectly.
  - Directly: a fluid-filled cannula is inserted into an artery.
  - The pressure is recorded with a manometer or an electrical pressure transducer.
  - It not often used in human but in experimental animals because it is invasive i.e. it involves entry into the body by cutting or by inserting the cannula.

- Indirectly: arterial blood pressure is measured indirectly clinically using a sphygmomanometer



- Two methods are used in measuring arterial blood pressure (i.e. palpation and auscultation).
- The 2 methods are usually combined during sphygmomanometry.
- In palpation, radial pulse is palpated, palpating fingers are kept on radial pulse while pressure in sphygmomanometer is increased.
- The reading of the mercury manometer at the point when radial pulse can no longer be felt is the systolic pressure.
- The cuff pressure is then increased by about 50 mm Hg above the point of disappearance of the radial pulse.
- The auscultatory method is then carried out.

- In the auscultatory method,
- Cuff is inflated/tightened until cuff pressure is greater than systolic pressure
- Blood flow in arm ceases
- No pulse (heard+felt) because high pressure in cuff completely collapses the artery.
- Pressure in cuff is reduced → listen for pulse sounds
- Systolic Blood Pressure = first soft tapping sounds (first Korotkoff sound)
- Diastolic Blood Pressure = no more tapping sounds, constant flow (last korotkoff sound)
- Expressed: "Systolic over Diastolic"

REGULATION OF ARTERIAL BLOOD PRESSURE

- Arterial blood pressure may vary even under physiological conditions.
- Arterial blood pressure can be restored to normal level in the presence of well organized regulatory mechanisms in the body.
- The various mechanisms include:
  - Nervous or short term regulatory mechanism.
  - Renal or long term regulatory mechanism
  - Chemical mechanism

- Nervous mechanism or short term regulation:
  - It is a rapid mechanism (a short term control of BP).
  - Restores blood pressure to normal within few minutes in case of alteration in blood pressure.

- It involves the vasomotor centre (collection of nerve cells in the medulla oblongata that receives information from sensory receptors in the circulatory system).
- Vasomotor centre regulates blood pressure by causing vasoconstriction and vasodilation.
- Actions of vasomotor centre depend on impulses received from structures like baroreceptors, chemoreceptors and respiratory centres.

➢Baroreceptors are located in the carotid sinus and wall of aorta.

➢In increased ABP, baroreceptors are activated and send stimulatory impulses to nucleus solitaries which acts on vasoconstrictor and vasodilator areas of vasomotor centre.

➢Vasoconstrictor area is inhibited and vasodilator area is excited.

➢Inhibition of vasoconstrictor area reduces vasomotor tone causing vasodilation and decreased peripheral resistance.

- Excitation of vasodilator area increases vagal tone causing decreased rate and force of heart contraction, decreased cardiac output and decreased peripheral resistance.
- Arterial blood pressure is brought to normal level.

- In decreased ABP, baroreceptors are inactivated, no vasoconstrictor centre inhibition or vasodilator area excitation.
- Then blood pressure rises.

- Chemoreceptor are situated in carotid body and aortic body.
- They are sensitive to lack of O_2 and excess CO_2 and H^+ concentration in blood.
- In decreased ABP, blood flow decreased causing decreased O_2 content and excess CO_2 and H^+.

- These factors stimulate the chemoreceptors.
- Chemoreceptors send impulses to the vasoconstrictor centre which increases blood pressure and blood flow.

- Renal mechanism: kidney play important role in in long term regulation of ABP.
- This is achieved in 2 ways i.e.
  - By regulating ECF volume.
  - Through renin-angiotensin system.
- By regulating ECF volume: direct regulation - fluid loss through urine
  - high pressure/volume -- release more water and salt (sodium) through diuresis and natriuresis
  - low pressure/volume --conserve water

➢Through renin-angiotensin system

- low blood pressure -->
- release of renin -->
- formation of angiotensin II--> vasoconstriction
  - Constriction of arterioles to increase P.R. and blood pressure.
  - Constriction of afferent arterioles to reduce G.F. and increase water retention and blood pressure
- release of aldosterone --> Na^+/water reabsorption (by kidney).

➢Chemical mechanism

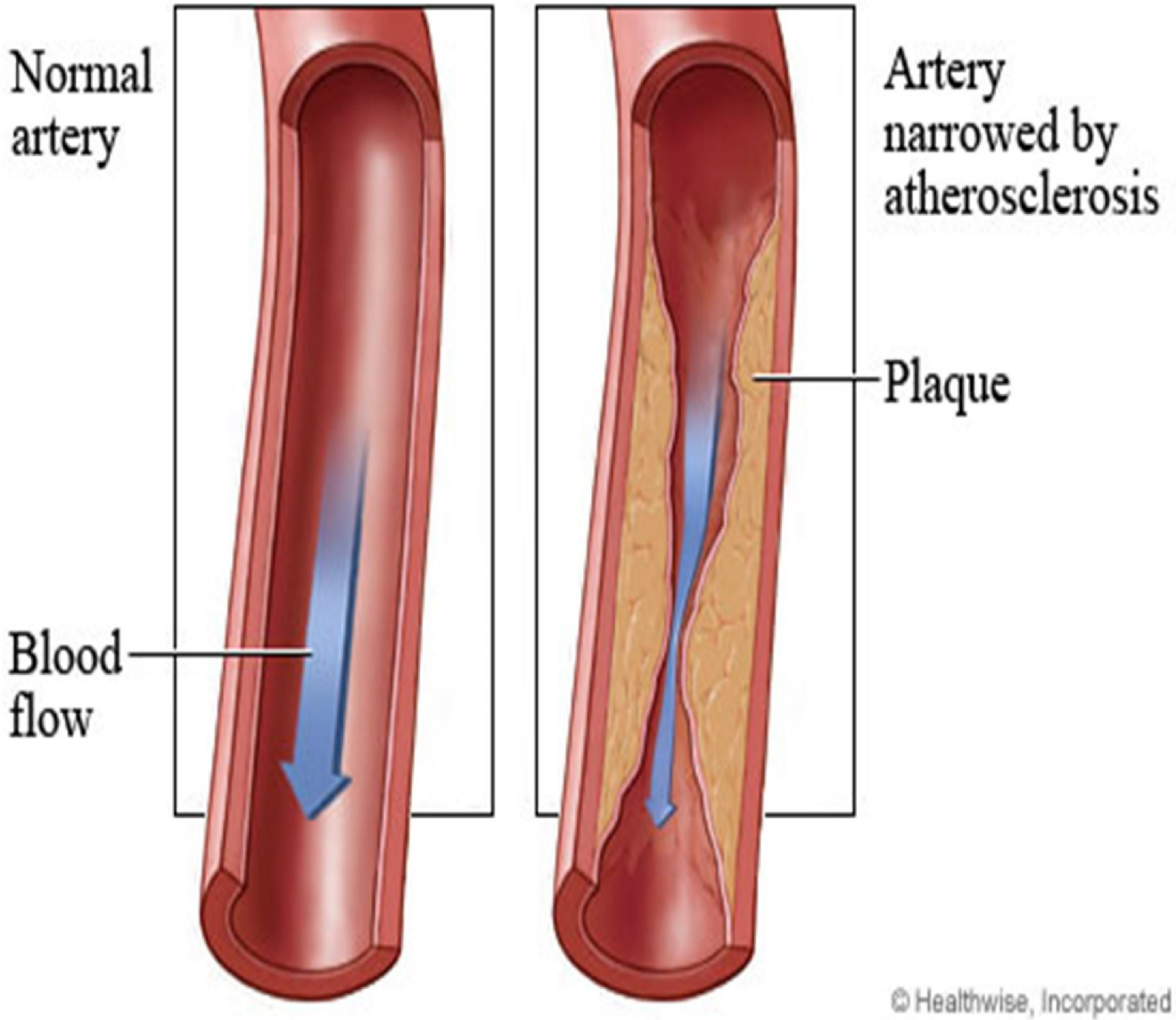
- Hormones of adrenal medulla - "fight-or-flight" response to fear; release of norepinephrine and epinephrine from adrenal medulla; causes vasoconstriction and increased BP.
- Atrial natriuretic factor (ANF) - secreted by the atria of the heart, promotes general decline in blood pressure kidney releasing more Na^+ and water, reducing fluid volume.
- Antidiuretic hormone (ADH) - released by the hypothalamus, causes increase in blood pressure by getting the kidneys to conserve water in the body; e.g. during hypotensive situations

- Hypotension (below normal blood pressure, < 100/60)
  - Factors - age, physical conditioning, illness
  - Orthostatic hypotension - generally in elderly, drop in blood pressure during postural changes.
  - Chronic hypotension - ongoing low blood pressure
- Low blood protein levels (nutrition)
- Addison's disease (hypoadrenalism or adrenal insufficiency), where insufficient amount of hormone like aldosterone is produced.
- Hypothyroidism (affecting adrenal gland function).
- Also sign of various types of cancer

➢Hypertension (above normal blood pressure at rest, > 140/90)

- factors - weight, exercise, emotions, stress.
- Chronic hypertension - ongoing high blood pressure

- Prevalent in obese and elderly
- Leads to heart disease, renal failure, stroke
- Also leads to more arteriosclerosis
- Primary hypertension - unidentified source
  - high Na^+, cholesterol, fat levels
  - clear genetic component (in families).
  - diuretics - promote water removal.
  - NE blockers - slow vasoconstriction
- Secondary hypertension - identifiable disorder
  - kidney disorders.
  - endocrine (hormone) disorders.
  - arteriosclerosis


Normal artery
Artery narrowed by atherosclerosis
Plaque
Blood flow
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