26 Blood

Blood is the ***fluid tissue***. It is reddish in colour. It is made to flow by the pumping action of the heart.

Adult human contains about 5 litres of blood. The blood is formed of two components, namely a fluid component called ***plasma*** and a cellular component called ***formed elements.***

Plasma

Plasma is the ***liquid*** portion of blood. Out of 5 litres of blood 3.5 litres are plasma. It contains 90% water and the remaining 10% is formed of organic and inorganic substances. These materials include proteins, glucose, nitrogenous wastes, enzymes, hormones, minerals, etc.

There are about 200-300 gms of plasma proteins present in the total volume of blood. There are four different varieties, namely

1. *Serum albumin*
2. *Serum globulin*
3. *Fibrinogen* and
4. *Prothrombin*

Formed Elements of Blood

There are three types of cellular elements, namely

1. *Red blood corpuscles or RBC*
2. *White blood corpuscles or WBC* and
3. *Platelets.*

1. Red Blood Corpuscles (RBC)

The red blood corpuscles are otherwise called ***erythrocytes*** (erythros = ***red***, cyton = ***cell***). Human erythrocyte is a ***non-nucleated*** cell having the form of a ***biconcave disc.*** Erythrocyte contains ***haemoglobin.***

The erythrocytes of birds, amphibia, reptiles, fishes and camels are oval. Erythrocytes of man and other mammals are flattened biconcave circular discs. Mammalian RBC is non-nucleated.

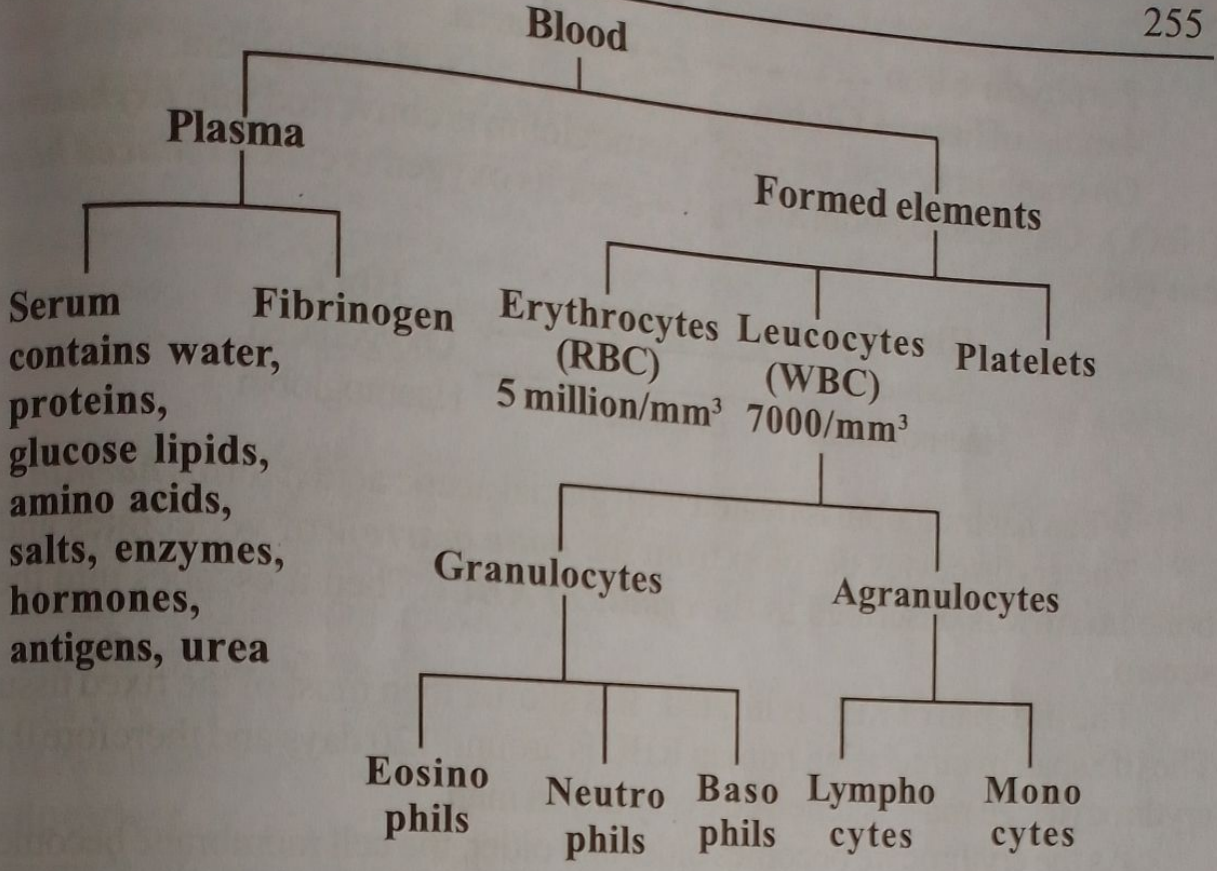

Fig.26.1: Flow chart showing the components of blood.

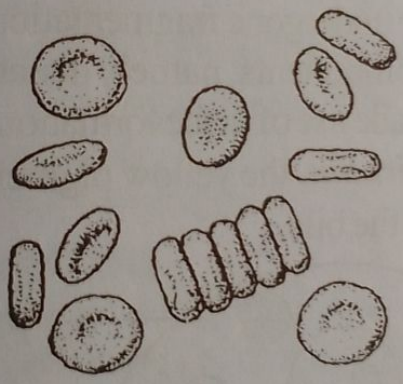

Fig.26.2: Red blood cells.

The number of erythrocytes per cubic millimetre differs in different animals. The normal average cell count of erythrocyte in adult male is about 5 million and in female ***4.5*** million per cubic millimetre blood. In infants, the count is ***6.7*** million, where as in foetus it is ***7.8*** million.

Each RBC is composed of a ***plasma membrane*** and a spongy elastic substance called ***stroma.*** Inside the meshes of the stroma is present the iron pigment ***haemoglobin.***

Haemoglobin is a conjugated protein composed of a protein part ***globin*** and a non-protein pigment ***haem.*** Haem is an ***iron*** containing ***porphyrin***.

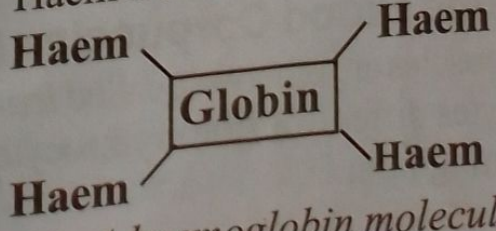

Fig.26.3: A haemoglobin molecule.

Porphyrin + iron ----------► Haem.

4 mols. of haem + Globin ----------► Haemoglobin.

On combining with oxygen, haemoglobin is converted into ***oxyhaemoglobin*** (HbO_2). Oxyhaemoglobin after giving out its oxygen is called ***reduced haemoglobin*** (Hb).

$$\underset{\text{Reduced Haemoglobin}}{\mathbf{Hb + O_2}} \xrightleftharpoons[\text{In tissues}]{\text{In lungs}} \underset{\text{Oxygenated Haemoglobin}}{\mathbf{HbO_2}}$$

When haemoglobin is treated with glacial acetic acid it forms ***haemin crystals.***

The erythrocytes develop from the ***bone marrow*** of vertebrates and so the bone marrow is described as the ***cradle of RBC.*** Then it escapes into the blood stream.

The life span of RBC is limited. It is shorter than most of the fixed tissue cells. The life span of circulating human RBC is around 120 days and therefore 0.83% of erythrocyte cell mass is renewed every day in man.

As the erythrocyte becomes older and older, the cell membrane becomes more and more fragile and the old RBCs are disintegrated in the ***spleen***. So the spleen is said to be the ***grave yard*** for red cells.

Once the erythrocytes have undergone fragmentation, their haemoglobin is broken down into two important components, namely denatured ***globin*** and ***iron.*** The iron is stored in the liver and is made use of in the formation of fresh haemoglobin. The globin part is converted into ***bilirubin,*** the yellow pigment and ***biliverdin***, the green one which are used in colouring the bile.

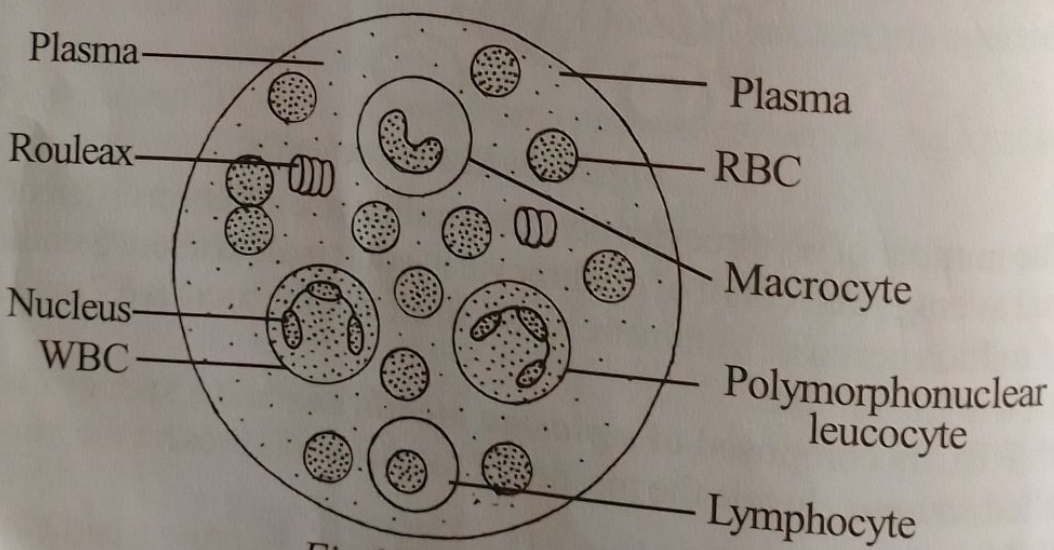

Fig.26.4: Blood of man.

2. White Blood Corpuscles (WBC)

The white blood corpuscles are otherwise called ***leucocytes*** (leucos = *colourless*, cyton = ***cell***). The leucocytes differ from the erythrocytes in the following aspects:

1. They have no haemoglobin.

2. They are bigger in size
3. They are nucleated and amoeboid.
4. They are much less in number and their life span is longer.
5. There are several varieties and they have different functions.

The average total number of WBC is 6000-8000 per cubic mm of blood and the average ratio of WBC to RBC works out to 1:600.

Leucocytosis is the term used to describe increase in the total number of white blood cells in the blood. ***Leucopenia*** means the decrease in the white blood cells count.

Based on their functional aspect, leucocytes are termed as ***phagocytes.*** They protect the body by attacking the invading micro-organisms and devour them. In the new born, the WBC count is very high, about 20000 per cubic millimetre. Throughout infancy and childhood the count remains high.

There are several varieties of leucocytes. Determination of the different varieties of leucocytes is known as ***differential count*** of white blood corpuscles. Leucocytes are of two main types 1. ***Granulocytes*** and 2. ***Agranulocytes.***

1. Granulocytes

They are WBC with granules in the cytoplasm and the nucleus is ***unlobed.*** Granulocytes are produced in the bone marrow and are of three types, namely ***neutrophils, eosinophils*** and ***basophils.***

The increase of granulocytes in the blood is called ***granulocytosis.*** Diminution of granulocytes is called ***granulocytopenia*** and complete disappearance of granulocytes is known as ***agranulocytosis.***

Granulocytes are of the following types:

a. Neutrophils or Scavenger cells

These are about 79% of the total leucocyte count. A neutrophil has a ***granular cytoplasm*** and a ***multilobed nucleus*** (2-7 lobed).

They show ***amoeboid*** movement. When they come across the bacteria, they are engulfed by a process termed as ***phagocytosis.***

During infection and inflammation their number is considerably increased in the circulating blood.

These leucocytes are capable of passing out through the capillaries by a process known as ***diapedesis.*** As these cells are highly phagocytic and devour foreign particles they are also called ***scavenger cells***. The absolute number of neutrophil is 3000-6000 per cu. mm.

b. Eosinophils

These are about 1-4% of the total leucocyte count. The cytoplasm contains coarse ***granules*** which stain with the acid dye like ***eosin.***

The nucleus is ***two*** or ***three lobed.*** The absolute number of eosinophils is 150-400 per cu.mm. They increase during allergic conditions.

The eosinophils are ***amoeboid*** but not phagocytic.

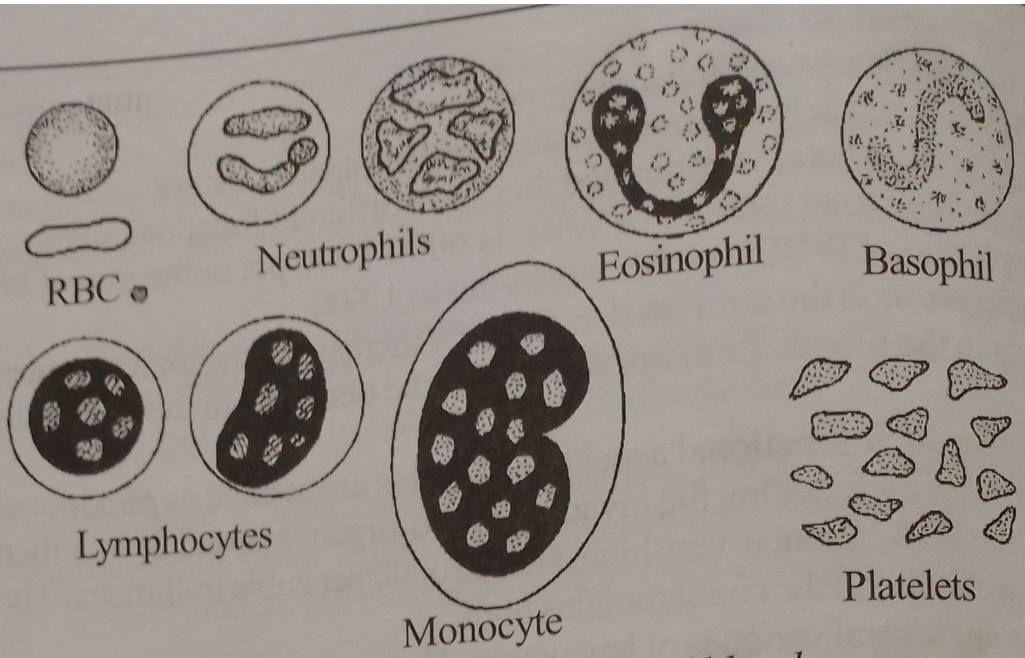

Fig.26.5: Formed elements of blood.

The important functions of eosinophils are to bring about destruction and detoxification of toxins of protein origin.

c. Basophils

Basophils are about 0-4% of the total leucocyte count. The nucleus is lobed and the cytoplasm contains ***granules*** of various sizes which take deep ***basic stains***.

The absolute number of basophil is 0-100 per cu.mm. Basophil has some possible role in local ***anticoagulation*** and formation of ground substance.

2. Agranulocytes

Agranulocytes are produced in the lymph nodes and spleen, and are of two types: ***lymphocytes*** and ***monocytes.***

Lymphocytes

These are about 25-30% of the total leucocyte count and their absolute number is 1500 to 2700 per cu.mm. They have a large nucleus compared to the size of cytoplasm. The cytoplasm is basophilic without any granules. Lymphocytes are divided into two groups, namely small lymphocytes and large lymphocytes.

Monocytes

They are large leucocytes forming about 5-10% of the total leucocyte count. Their absolute number is 350-800 per cu.mm. The nuclei are ***horse-shoe*** shaped. They are motile and have the power of engulfing bacteria.

3. Blood Platelets or Thrombocytes

Thrombocytes are a type of ***formed elements*** in the blood. They are oval to spherical in shape and are 2-3 mm in diameter. They have no nucleus.

The number of platelets in human blood varies from 250,000-450,000 per cu. mm.

The average life span of platelets is about 5-9 days. They are produced in the ***megakaryocytes*** of the bone marrow and are destroyed in the ***spleen*** and other reticuloendothelial cells.

Several functions are performed by the platelets. They initiate blood ***clotting*** and ***repair capillary endothelium.*** Speed of clot reaction or ***syneresis*** is directly proportional to the number of platelets present in the blood. They are also concerned with ***vasoconstriction*** of blood vessels, liberating ***5-hydroxytryptamine.***

Functions of Blood

1. Blood ***transports oxygen*** from the lungs to the tissues and CO_2 from the tissues back to the lungs.
2. It ***transports food*** from the intestine, first to the liver and then to the tissues.
3. It ***transports waste products*** to the kidneys, and to the sweat glands for excretion.
4. It ***transports the hormones*** from the endocrine glands to the target organs.
5. With the help of the plasma proteins, it maintains a ***constant pH.***
6. It helps in maintaining the ***water balance*** of the body.
7. It maintains the ***body temperature*** by transporting the heat from the interior of the body to the surface.
8. It protects the organism from the ***infection of foreign substances.***
9. It prevents its own loss by means of the ***clotting mechanism.***

Blood Cholesterol Level

Cholesterol is a lipid. Man contains 150 to 250 mg per 100 ml of blood.

About 30% occurs as ***free*** cholesterol and 70% as cholesterol ***esters.*** The ester form of cholesterol is also called ***bound*** form.

In children, the cholesterol level is low. It gradually increases with age. After 55 years, there is a tendency to decrease.

In women, the cholesterol level is increased just before ***menstruation.*** During menstruation, it is decreased.

It is increased during ***pregnancy.***

Increase of blood cholesterol level above normal is called ***hypercholesterolaemia.***

Decrease in blood cholesterol level below normal is called ***hypocholesterolaemia.***

High blood cholesterol leads to ***atherosclerosis*** characterised by deposition of cholesterol in the arteries.

Blood cholesterol is a risk factor for ***coronary thrombosis, myocardial infarction*** and ***mortality.***

Blood Urea Level

Urea is a ***nitrogenous waste*** formed from protein metabolism. It is synthesized in the liver by ***ornithine cycle.***

The normal level of urea in the blood is 20 to 40 mg per 100 ml.

Increase in blood urea level is called ***uraemia.*** It occurs during diarrhoea, vomiting, etc.

32 Origin and Conduction of Heart Beat

The rhythmic contraction and relaxation of heart is called heart beat.

The heart beats 72 times/minute.Each heart beat takes 0.8 seconds.

Each heart beat consists of a ***systole*** (contraction) and a ***diastole*** (relaxation).

Origin of Heart Beat

The heart beat is caused by ***impulse*** (electric current).The impulse causes the heart to beat.

The impulse is produced by ***nerves*** or ***muscles.***

In ***Arthropods*** and ***Annelids***, the impulse is produced by ***nerves.*** The nerves supplying the heart produce ***acetylcholine.*** *The acetylcholine initiates the heart-beat. The heart stimulated by nerves is called a* ***neurogenic heart.***

In vertebrates, the impulse for the heart beat originates within the heart muscles. *The heart stimulated by impulse originating in the heart muscle is called* ***myogenic heart.***

In lower vertebrates like ***fishes*** and ***amphibians***, the impulse originates from the muscles of ***sinus venosus.***

In ***birds*** and ***mammals,*** the heart beat impulse arises from a spherical mass of tissue called ***sinuatrial node.***

Sinuatrial node is a small strip of ***cardiac muscle*** with nerve fibres situated in the upper part of lateral wall of right atrium just below the opening of superior vena cava.

It is formed of cardiac muscle cells without ***contractile elements***. These cells are called ***P cells*** (***Pacemaker cells***). These muscle fibres are continuous with the muscle fibres of atrium.

The SA node is innervated by ***Vagus nerve*** (Cranial nerve) and ***parasympathetic nerves***.

When the SA node is ***stimulated***, the heart beat is accelerated.

Destruction of SA node stops heart beat.

Local ***cooling*** of SA node decreases the heart beat rate.

Local ***warming*** increases the heart beat rate.

The SA node generates current at the rate of ***70 to 80 per minute*** (Average 72 per minute).

Conduction of Heart Beat

The transfer of impulse from the pacemaker to other parts of the heart muscles is called conduction of heart beat.

The heart beats when the impulse passes through the heart muscles.

The impulse is conducted throughout the heart by a ***conduction system***. The conduction system includes

1. *Atrioventricular node (AV node)*
2. *Bundle of His*
3. *Right and left bundle branches*
4. *Purkinje fibres*.

The ***SA node*** is situated at the apex of right atrium.

AV node is situated in the right posterior portion of intra atrial septum.

Impulses from SA node are conducted throughout right and left atria.

The impulses reach the AV node through three sets of ***internodal fibres***. They are

1. *Anterior internodal fibres of Bachman*
2. *Middle internodal fibres of Wencheback*
3. *Posterior internodal fibres of Thorel.*

All these internodal fibres originate from ***SA node***, converge towards ***AV node*** and ***interdigitate*** with the fibres of AV node.

The ***bundle of His*** arises from ***AV node***. It divides into right and left branches. They run on either side of the interventricular septum.

Each branch produces many ***Purkinje fibres*** which ramify the entire ventricles.

The velocity of impulse is ***high*** in the ***Purkinje fibres*** and ***less*** in the ***AV node***.

Atrial muscle fibres	*30cm/ second*
Internodal fibres	*100cm / second*
AV node	*5cm / second*
Bundle of His	*12cm / second*
Purkinje fibres	*400cm / second*
Ventricular muscle fibres	*50cm / second.*

In abnormal conditions, the electrical activity of the heart is irregular or slower or faster. This irregular electrical activity of the heart is called ***cardiac dysrhythmia*** or ***cardiac arrhythmia***.

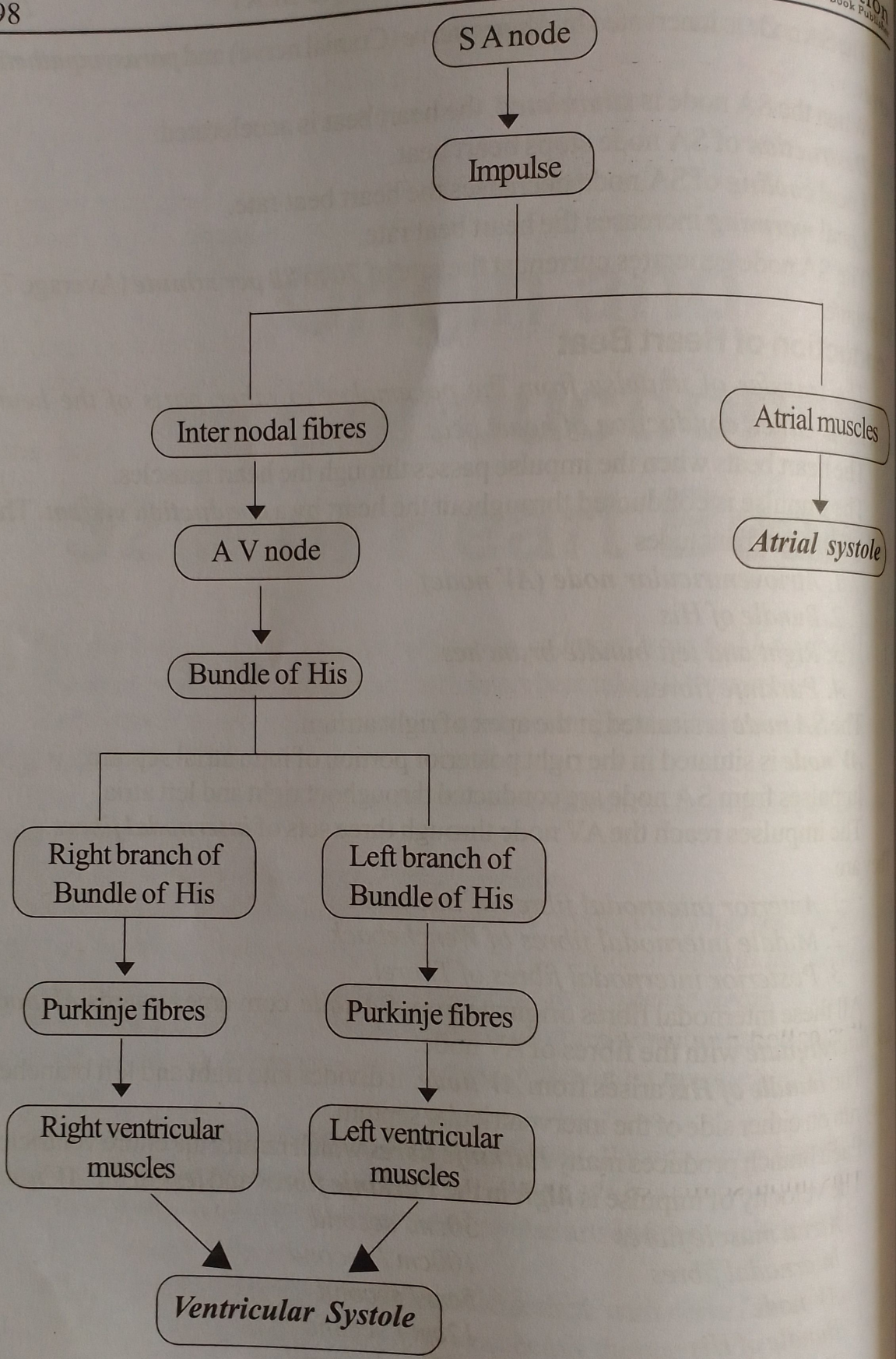

Fig.32.1: Conduction of heart beat.

When the heart beat is too fast, it is called ***tachycardia***. When the heart beat is too low, it is called ***bradycardia***.

Neurogenic Origin

In some animals like Arthropods and some Annelids (*Arenicola* and *Lumbricus*), the heart beat originates by the stimulation of nerves. This type of heart is called ***neurogenic heart.***

The neurogenic hearts are supplied with nerves. These nerves secrete a chemical called ***acetylcholine*** at the nerve endings. The acetylcholine accelerates the neurogenic heart.

Myogenic Origin

In majority of animals like molluscs and vertebrates, the heart beat originates in the muscles of the heart itself. This type of heart is called ***myogenic heart.*** The myogenic heart is inhibited by ***acetylcholine.***

In all vertebrates, the heart beat is initiated by the heart muscles. In lower vertebrates like fishes and amphibians, the heart beat originates from the wall of ***sinus venosus.*** In higher vertebrates like birds and mammals, the heart beat originates from a special kind of muscles called ***sinu-auricular node***. This node is situated in the upper part of the right auricle where the superior vena cava opens. This node is richly supplied with blood capillaries. The impulse for heart beat originates from this node. Hence it is called ***pace maker*** or ***heart of hearts.*** When the pace maker is destroyed the heart beat stops. When the pace maker is stimulated by heat or electric current, the rate of heart beat increases.

Rhythmical chemical changes occur in the sinu auricular node. These chemical changes supply the ***spark*** or ***impulse*** for each contraction.

Highlights

SA node

Sinuatrial node is the impulse generating tissue located in the right atrium near the opening of superior vena cava.

It is called ***pacemaker.***

It is a mass of ***heart muscle*** without contractile elements.

It is made up of heart muscles called ***cardiomyocytes.***

It has the inherent capacity to generate ***impulse (electric current)***.

This impulse makes the heart to ***beat.***

The SA node receives blood supply through ***ramus nodiatrialis*** from the right ***coronary artery.***

It is innervated by ***cranial nerves*** (***vagus nerve***) and ***sympathetic nerves***.

Stimulation of ***vagus nerve, decreases*** the rate of SA node.

Stimulation of ***sympathetic nerves, increases*** the rate of SA node.

When the SA node is ***stimulated***, the heart beat is accelerated.

Destruction of SA node stops heart beat.

34 Blood Pressure

*The **lateral pressure*** that the blood exerts against its walls* is called ***blood pressure***. The blood pressure is caused by the following factors:

1. The contraction of the ventricles.
2. The resistance to the passage of blood through arterioles and capillaries. This factor is commonly called ***peripheral resistance.***

The pressure existing in the arteries is called ***arterial blood pressure***.

The blood pressure is high during systole and it is called ***systolic blood pressure***.

It is low during diastole and it is called ***diastolic blood pressure***.

The difference between these two pressures is called ***pulse pressure.***

The blood pressure is high in the aorta situated near the heart. It gradually decreases as it goes away from the heart. It is low in the capillaries. The blood pressure is minimum in the veins.

For clinical purpose, the blood pressure is measured from the large arteries of the arm. The systolic blood pressure in an ideal man is 120 mm Hg and the diastolic blood pressure is 80 mm Hg.

The systolic blood pressure may vary from 110 to 135 mm Hg and diastolic blood pressure may vary from 70 to 90 mm Hg. Blood pressure is measured in ***millimeters of mercury (mm. Hg).***

When the pressure in a vessel is 50 mm Hg., this means that the force exerted is sufficient to push a column of mercury upto a level of 50 mm height. If the pressure is 100 mm Hg., it will push the column of mercury up to 100 mm.

Sometimes pressure is measured in ***cm. of water.*** A pressure of 10 cm. of water means a pressure sufficient to raise a column of water to a height of 10 cm. One

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** Lateral pressure is that pressure when force is exerted at right angles to the direction of flow at any point within a tube filled with a circulating fluid. Resistance is opposition to force.*

mm. of Hg equals 1.36 cm. of water because the specific gravity of mercury is 13.6 times that of water, and 1 cm is 10 times as great as 1 mm. Dividing 13.6 by 10, we derive the factor 1.36.

Measurement of Blood Pressure

There are two methods to measure blood pressure. They are ***direct method*** and ***indirect method.***

1. Direct Method

Direct method is a ***surgical method***. The artery is exposed and the pressure is measured using a ***mercury manometer.*** A ***cannula*** is inserted into an exposed artery or vein or heart and the other end of the cannula is connected to the U-shaped mercury manometer. The pressure pushes the mercury down in one limb and raises in another limb of the mercury manometer. The difference between the two levels of mercury is approximately equal to the blood pressure.

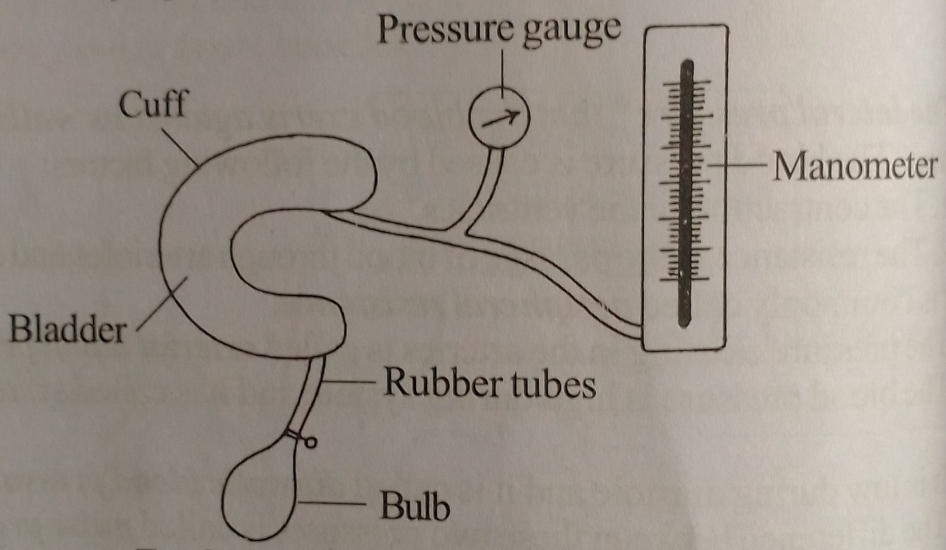

Fig.34.1: Sphygmomanometer.

2. Indirect Method

In indirect method, the pressure is measured without any surgical procedure. In this method the pressure of the brachial artery is measured using an instrument called ***sphygmomanometer***.

- Sphygmomanometer is a clinical instrument used for the measurement of ***blood pressure.***
- It consists of the following components:
  1. A ***cuff*** containing an inflatable rubber ***bladder.***
  2. A rubber ***bulb.***
  3. A ***pressure gauge.***
  4. A ***rubber tube*** connecting the bladder and the bulb.
  5. A ***manometer*** with a column of ***mercury*** and ***calibration.***
  6. A ***rubber tube*** connecting the bladder and manometer.
- A ***stethoscope*** is also required to hear heart beat.
- The cuff is tied around the upper arm.

- The stethoscope is placed under the edge of the cuff above the brachial artery.
- Air is pumped into the bladder until the sound of the pulse in the artery is no longer heard through the stethoscope.
- The air is then released slowly. The point at which the sound reappears is noted on the pressure gauge. This is the ***systolic pressure.***
- The air is allowed to escape further. At one point, a change in the quality of sound is heard, just before it disappears. At this point the pressure is observed in the gauge. This is ***diastolic*** pressure.
- The air is completely let out and the cuff is removed.
- The normal blood pressure of man is 80/120mm Hg. That is, diastolic pressure is 80mm Hg and systolic pressure is 120mmHg.

Resistance of Blood Flow

Resistance is the impediment to blood flow in a vessel. It cannot be measured but can be calculated from blood flow and pressure.

If the pressure difference between two points in a vessel is 1 mm Hg and the flow is 1 ml/sec., then the resistance is said to be 1 ***peripheral resistance unit (PRU).***

The rate of blood flow at rest is close to 100 ml/sec. and the pressure difference from the systemic arteries to the systemic veins is about 100 mm Hg. Therefore, the resistance of the entire systemic system, called the ***total peripheral resistance***, is approximately 100/100 or 1 PRU.

When the blood vessels throughout the body become constricted, the PRU rises to as high as 4. When the vessels become greatly dilated, the PRU can fall to as little as 0.2.

In the pulmonary system, ***the mean arterial pressure*** averages 16 mm Hg and ***mean left atrial pressure*** averages 4 mm Hg., giving a net pressure difference of 12 mm Hg. Therefore, the ***total pulmonary*** resistance at rest is 0.12 PRU. This can increase in disease conditions to as high as 1 PRU and can fall during exercise as low as 0.03 PRU.

Effect of Pressure on Vascular Resistance - Critical Closing Pressure

All blood vessels are ***elastic*** and ***distensible.*** Hence when the blood pressure increases, the diameter of the blood vessels also increase. This in turn reduces the resistance of the vessel. So ***reduction in pressure, increases the resistance.***

As the arterial pressure falls from 130 mm Hg, the flow decreases owing to decreasing diametres of the vessels. When the pressure falls to 20 mm Hg., the blood flow ceases entirely. This pressure at which the blood stops flowing is called ***critical closing pressure***. At this pressure the small vessels, the arterioles, close so completely that all flow ceases.

Vascular Distensibility

The blood vessels are elastic and distensible. The diameter of blood vessels unlike that of metal pipes and glass tubes, increases as the internal pressure increases. Vascular distensibility depends on pressure and is calculated by the following formula:

$$\text{Vascular distensibility} = \frac{\text{Increase in volume}}{\text{Increase in pressure x Original volume}}$$

That is, if 1 mm Hg causes a vessel originally containing 10 ml of blood to increase its volume by 1 ml, then the distensibility would be

$$\text{V.D} = \frac{1}{1 \times 10} = 0.1 \text{ per mm Hg or } 10\% \text{ per mm Hg}$$

Anatomically, the walls of arteries are far stronger than those of veins. Hence the veins are about 6 to 10 times as distensible as the arteries. That is, a given rise in pressure will cause about 6 to 10 times as much extra blood to fill a vein as an artery of comparable size.

Compliance or Capacitance

As the blood vessels are elastic, the walls are stretched and the volume of the vessel is enlarged when the pressure increases. The ratio of change in volume to change in pressure is termed as ***compliance*** or ***capacitance.***

$$\text{Vascular compliance} = \frac{\text{Increase in volume}}{\text{Increase in pressure}}$$

The compliance of a system is related to its size and the elasticity of its walls. The larger the initial volume and elasticity of the walls, the greater will be the compliance of the system.

The venous system is very compiant. Small changes in pressure can produce large changes in volume. The venous system, therefore act as a venous reservoir, because large changes in volume have little effect on venous pressure and therefore the filling of the heart during diastole or capillary blood flow.

The arterial system is less compliant and therefore acts as a pressure reservoir in order to maintain capillary blood flow.

Excretory Products

Animals excrete a wide variety of excretory products. They are the following:

1. Amino acids

Amino acids are the end products of protein metabolism. Excess of amino acids are excreted as such in some animals. Eg. *Unio, Limnaea, Asterias, racentrotus,* etc.

2. Ammonia

Ammonia is formed by the deamination of amino acids. It is toxic and it should be eliminated immediately. It is highly soluble in water with which it forms ***ammonium hydroxide***. Ammonium hydroxide diffuses readily through water and passes rapidly across cell membranes.

$$NH_3 + H_2O \longrightarrow NH_4OH$$

Ammonia is a main excretory product in most of the ***aquatic animals*** like Protozoa, polychaetes, crustaceans, molluscs, teleost fishes, aquatic larvae of insects, amphibian tadpoles, tortoises and turtles.

The animals excreting ***ammonia*** are called ***ammonotelic animals.***

3. Urea

It is derived from ammonia through ***ornithine cycle***. It is less toxic and more soluble in water when compared to ammonia. It is excreted by ***semiterrestrial*** animals which are exposed to scarcity of water. Eg. *Earthworms, shore gastropods, amphibians*, *semi-terrestrial turtles* and *tortoises*, *elasmobranch fishes* and *mammals*.

The animals excreting ***urea*** are called ***ureotelic animals***.

4. Uric acid

Uric acid is less toxic and insoluble in water. It is excreted out as thick ***pastes*** or ***pellets***. It is excreted by true ***terrestrial vertebrates.*** Eg. *Insects, terrestrial snails, terrestrial reptiles* and *birds*.

The animals excreting ***uric acid*** are called ***uricotelic animals.***

5. Trimethylamine oxide

It is a soluble nitrogenous waste, excreted by ***marine teleosts.*** The characteristic odour of the dead fish is due to the presence of this substance in the body.

6. Hippuric acid

It is a ***mammalian*** excretory product. It is derived from ***benzoic acid***. When ***benzoic acid*** is present in the diet, it combines with glycine to form hippuric acid.

7. Guanine

It is excreted by ***spider.*** Its solubility is low and hence it does not require water for excretion.

8. Ornithinic acid

It is excreted by ***birds.*** When benzoic acid is present in the diet, it combines with ornithine to form ornithinic acid.

9. Allantoin

It is formed from uric acid by the catalytic action of the enzyme ***uricase.***

10. Allantoinic acid

It is formed from allantoin by oxidation. It is catalysed by ***allantoinase.***

11. Purines and Pyrimidines

These are formed by the breakdown of nucleic acids. Some animals excrete them as such.

12. Creatine

Mammals excrete creatine. It is synthesized in the ***liver*** from three amino acids, namely arginine, glycine and methionine.

13. Creatinine

Some mammals excrete creatinine. It is derived from creatine.

Origin of Excretory Products

The diet contains proteins in addition to other components. Proteins are digested into amino acids in the alimentary canal. The amino acids are absorbed into the blood and are transported to the cells.

In the cells, amino acids are used for synthetic (anabolism) and destructive (catabolism) processes.

In the process of catabolism, ***ammonia*** (NH_3) is released from amino acids. Ammonia is highly toxic and it must be eliminated from the body as the end product.

Aquatic animals dispose out ammonia as such. But other animals eliminate NH_3 by converting into other products such as urea, uric acid, guanine, etc.

Animals are classified according to the end products produced by them. They are:

Ammonotelic animals
Ureotelic animals
Uricotelic animals
Purinotelic animals
Guanotelic animals

The animals excreting ***ammonia*** are called ***ammonotelic animals***; Eg. *All aquatic animals.*

The animals excreting urea are called ***ureotelic animals;*** Eg. *Amphibians, mammals.*

The animals excreting ***uric acid*** are called ***uricotelic animals***. Eg. *Insects, snails, reptiles* and *birds*.

The animals excreting ***purines*** are called ***purinotelic animals***.

The animals excreting ***guanine*** are called ***guanotelic animals.*** Eg. *Spiders, scorpions.*

Animals are classified based on the product which accounts for 50% or more of the total excreted nitrogen.

Origin of Ammonia

Ammonia is the chief breakdown product of amino acids. It is formed as a result of ***deamination*** chiefly occurs in the liver and tissues.

39 Kidney of Man

Man has two kidneys. They are the ***metanephros*** or advanced kidneys. They are located in the abdomen one on either side of the vertebral column.

The two kidneys are not located at the same level; the right kidney is slightly lower than the left one. This is because the right side of abdomen is occupied by the liver.

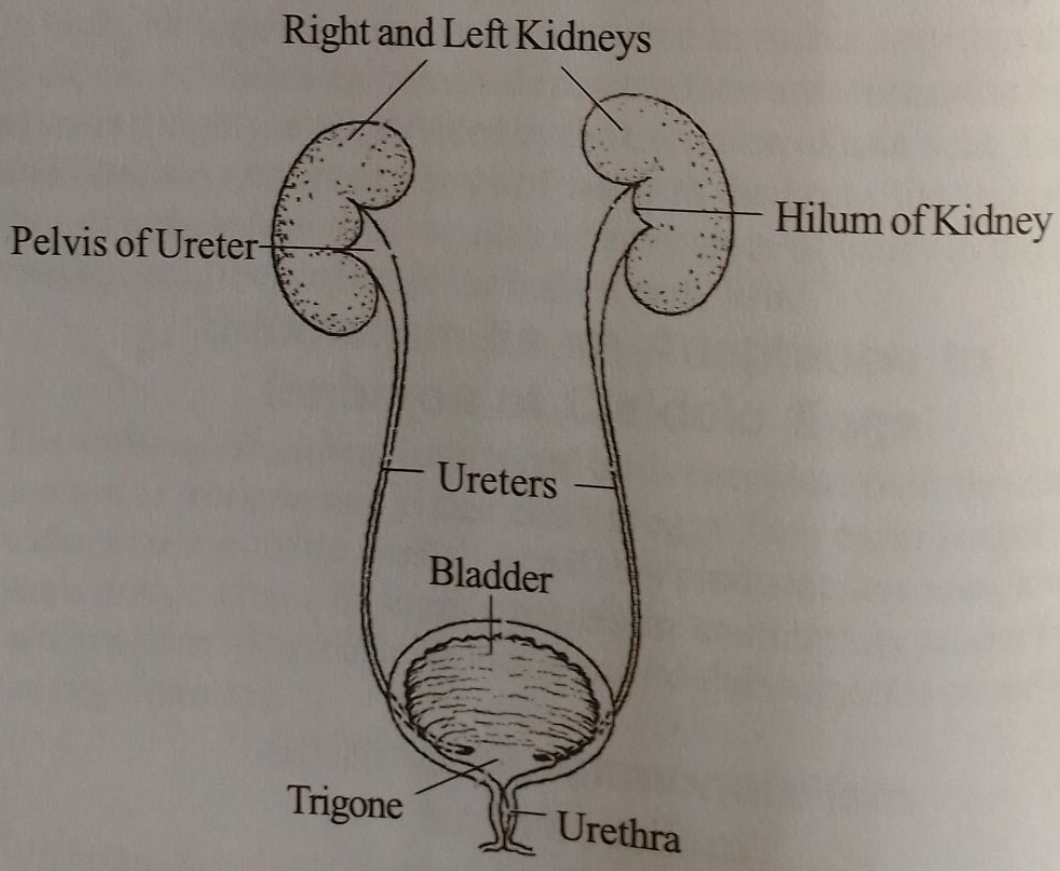

Fig.39.1: Urinary system of Man.

It is ***bean shaped***. The outer surface is convex and inner surface is concave. The inner surface has a deep notch called ***hilus.*** The ureters, renal artery, renal vein and nerves enter the kidney through the hilus.

In a section of the kidney, the peripheral portion appears dark reddish brown and the central portion appears light red. The peripheral area is called ***cortex*** and the central area is called ***medulla.***

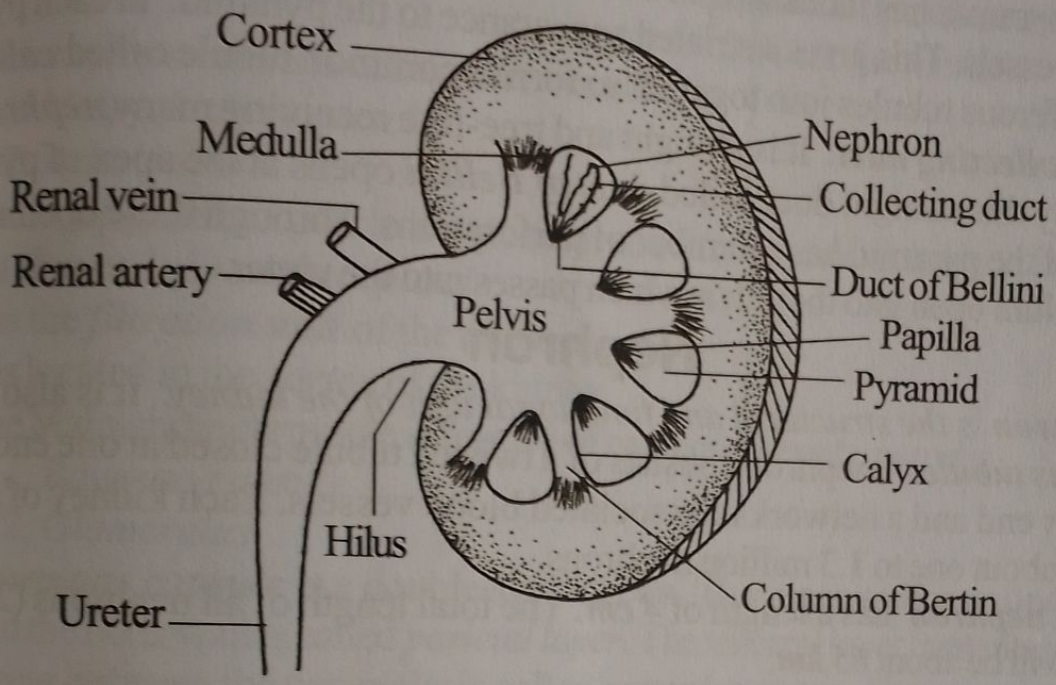

Fig.39.2: Kidney of man.

The ureter entering the hilus expands to form a funnel- like structure called ***pelvis.*** The pelvis is produced into a number of cup-like structures called ***calyces*** (calyx,

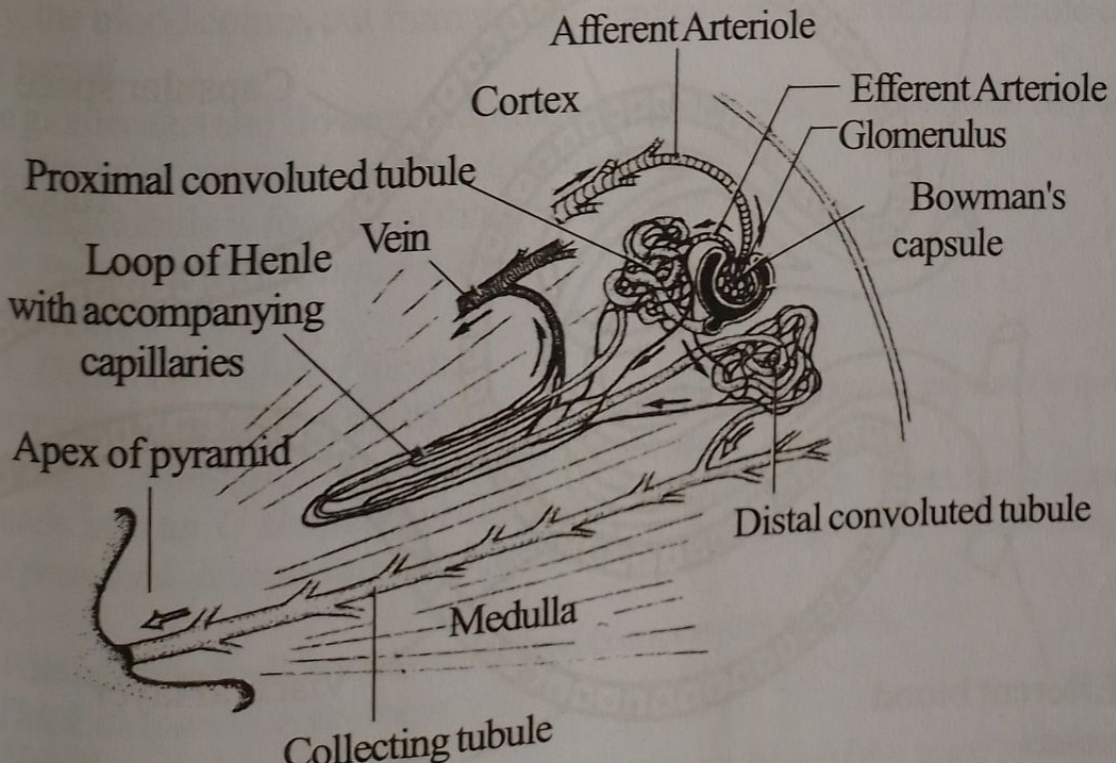

Fig.39.3: A Nephron

sing). The cavity of each calyx is occupied by a cone-like structure called ***pyramid***. The apex of the pyramid is called ***papilla*** or ***area eribrosa.*** It projects into the cavity of the calyx.

Each kidney contains 10 to 15 pyramids. The pyramids are separated by the projections of cortex called ***renal columns of Bertin.***

Each pyramid has thousands of tubules called ***uriniferous tubules*** or ***nephroi*** and blood vessels. This gives a striated appearance to the pyramid. In each pyramid many uriniferous tubules join together to form a common tubule called ***collecting tubule*** or ***collecting duct***. It is straight and tree-like receiving many ***nephroi.***

Finally this straight duct called ***duct of Bellini*** opens at the apex of pyramid. The apex of the pyramid has a number of perforations. Through these openings the ducts of Bellini open into the pelvis which passes into the ureter.

Nephron

Nephron is *the structural and functional unit of the kidney.* It is also called ***uriniferous tubule.*** A nephron consists of a twisted tubule closed at one end, open at the other end and a network of associated blood vessels. Each kidney of man is formed of about one to 1.3 million nephrons.

Each ***nephron*** has a length of ***4 cm***. The total length of all nephrons (2 to 2.6 millions) will be about ***65 km***.

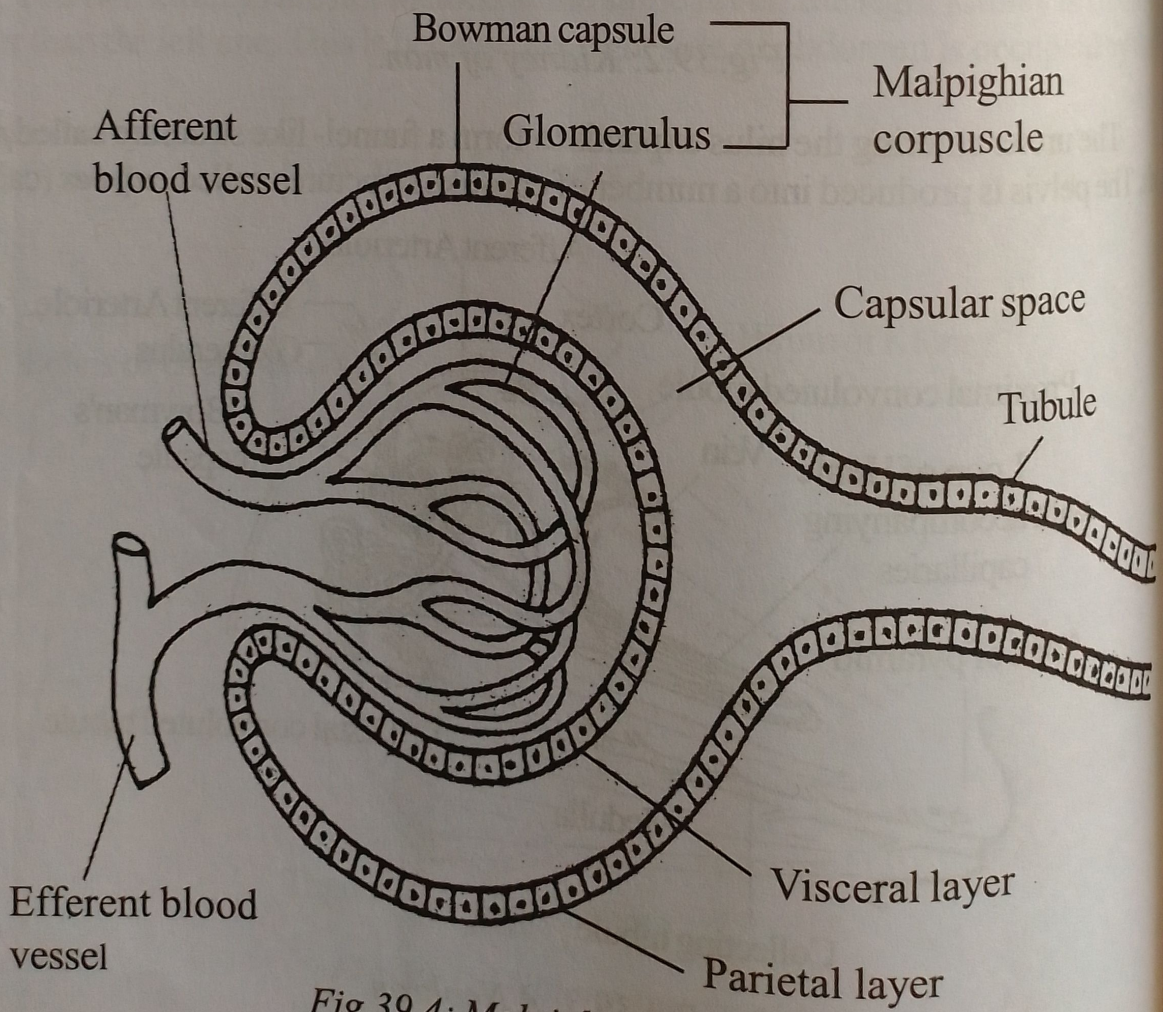

Fig.39.4: Malpighian corpuscle.

The number of nephrons decreases after 45 to 50 year at the rate of 1% every year.

Human kidney has two types of nephrons. They are:

1. *Cortical nephrons* - The Malpighian corpuscles are in the outer cortex. 85% of nephrons are this type.
2. *Juxtamedullary nephrons* - The Malpighian corpuscles remain in the inner cortex near the medulla.

Each nephron consists of two parts namely :

1. *Malpighian corpuscle*
2. *Renal tubule.*

The Malpighian corpuscle is a globular structure located at one end of the nephron. It is also called ***renal corpuscle***.

It is the ***filtration unit*** of the nephron.

It is located in the ***cortex*** of the kidney.

The Malpighian corpuscle is formed of two components, namely

1. *Bowman capsule*
2. *Glomerulus.*

Bowmans capsule is a double-walled cup. The inner wall is called ***visceral layer*** and the outer wall is called ***parietal layer***. The visceral layer contains ***pores***. The space lying between the two walls is called ***capsular space.*** The capsular space of the Bowman capsule is continuous with the lumen of the tubule.

The Bowman capsule can be compared to a ***funnel with a filter paper***.

The cavity of the cup contains a ***network of capillaries*** called ***glomerulus.***

The glomerulus receives blood through a small arteriole called ***afferent vessel.*** Similarly, the blood comes out from the glomerulus through another arteriole called ***efferent vessel.***

The glomerulus and Bowman capsule are together called ***Malpighian corpuscle.***

The Bowman capsule leads into the tubular portion.

The renal tubule is formed of three components.

1. *Proximal convoluted tubule*
2. *Henle's loop*
3. *Distal convoluted tubule.*

The proximal portion of the tubule arising from the ***Bowmans capsule*** is thrown into many coils called ***proximal convoluted tubule.***

It leads into an ***U shaped*** portion called ***Henle's loop.*** It has three regions, namely a proximal ***descending limb,*** a middle ***hair pin bend*** and a distal ***ascending limb.***

The descending limb is made up of two components namely,

Thick descending segment

Thin descending segment.

Thick descending segment is the direct continuation of the proximal convoluted tubule.

The ***thin descending segment*** connects the thick descending segment and the hair-pin bend.

The ***ascending limb*** is made up of two components namely,

1. *Thin ascending segment*
2. *Thick ascending segment.*

Thin ascending segment is the continuation of hairpin bend and it leads into the ***thick ascending segment*** of ascending limb.

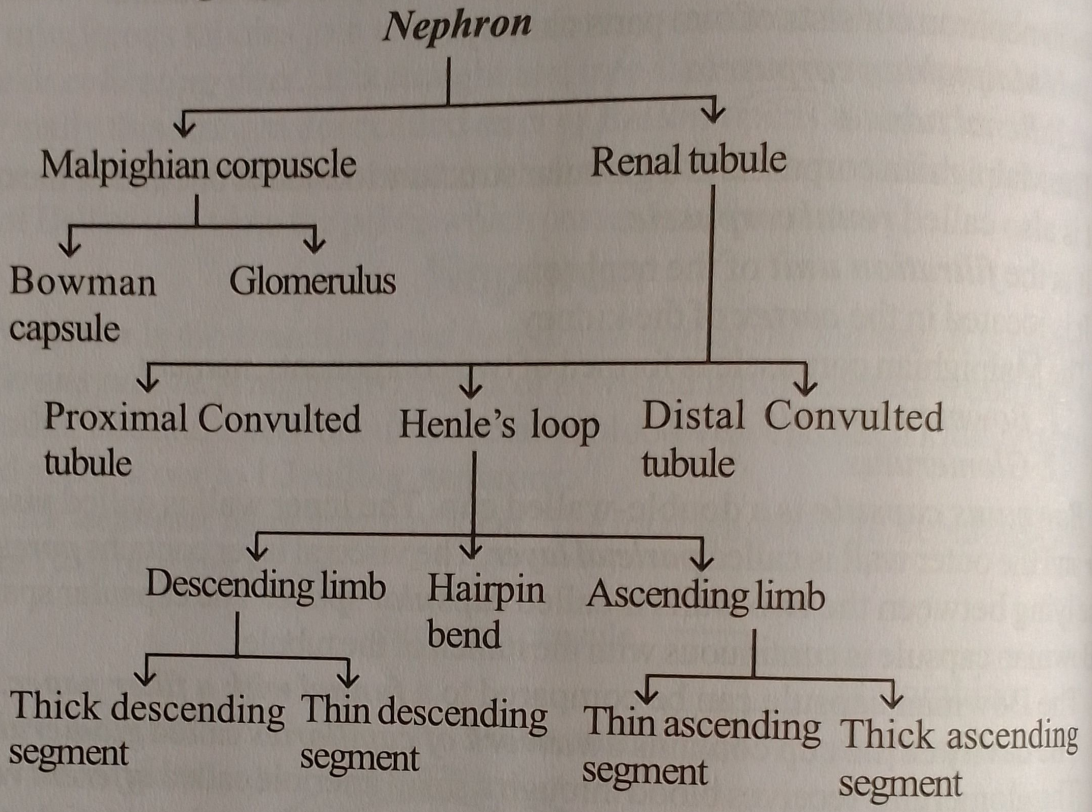

Fig.39.5: Components of a nephron.

The thick ascending limb continues into the ***distal convoluted tubule.***

A group of ***collecting ducts*** unite to form a ***duct of Bellini.***

The ducts of Bellini open into a ***pyramid.***

The pyramids opens into the ***minor calyx.*** Three or four minor calyces unite to form a ***major calyx.***

The major calyces open into the ***pelvis.*** The pelvis leads into the ***ureter.***

The ureter opens into the ***urinary bladder.*** The urinary bladder opens out through the ***urethra.***

The Henle's loop alone remains in the ***medulla.*** The remaining portions of the nephrons remain in the ***cortex.***

Each kidney receives arterial blood through a ***renal artery*** and the venous blood leaves the kidney through ***renal vein.*** The artery divides and redivides to form ***arterioles.*** Most of these arterioles supply the glomerulus as ***afferent vessels.*** They leave the glomerulus as ***efferent vessels.*** The efferent vessels, after leaving the glomerulus, break up into small capillaries which envelope the whole uriniferous tubule. The blood vessels then converge and form a system of veins that merge to form renal vein by which blood leaves the kidney.

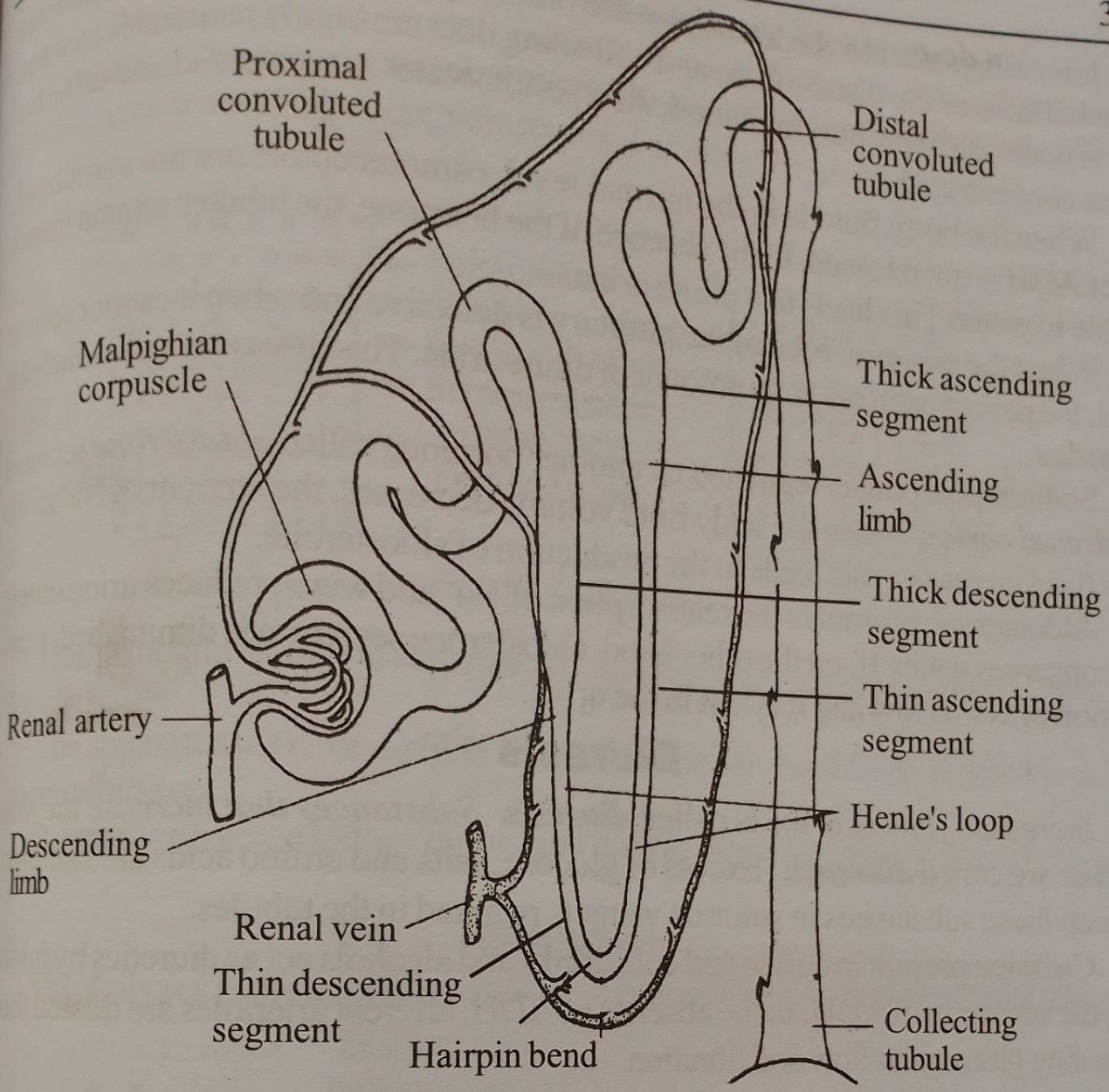

Fig.39.6: Nephron.

Hormonal Regulation of Kidney

When one drinks more water, kidney excretes more water. When one is in the hot sun, the urine will be dark yellow, more concentrated and below normal in amount. This is because when he is exposed to the hot, dry air, the body loses body fluids via sweating; but a considerable fraction of the body fluid is conserved by the kidneys.

Thus the rate of urine formation can be increased or decreased by the kidney according to the demands. How do the kidney know when to excrete water more and when to conserve water?

This is done by the ***hormones.*** The ***hypothalamus*** has special centres for the regulation of body fluids called ***osmoreceptors.*** When the body fluid supply is low, these centres are stimulated and they send out impulses to the posterior lobe of the ***pituitary.***

In response to this stimulus, it secretes a hormone called ***antidiuretic hormone (ADH)*** or ***vasopressin***.

41 Formation of Urine

Urine is the excretory fluid eliminated by the kidney. Formation of urine is a highly sensitive and complex process. It involves three steps. They are,

1. *Ultrafiltration*
2. *Reabsorption* and
3. *Secretion*

1. Ultrafiltration

The straining of blood by the Malpighian corpuscle for minute particles is called ***ultrafiltration.*** *It is the first step in urine formation.*

Malpighian corpuscle functions as the ***filtering apparatus***. The Bowman capsule is like a ***funnel with filter paper***. The ***glomerulus*** provides the *blood* for filtering.

The blood and the capsular space of the Bowman capsule are separated by capillary ***endothelium,*** a ***basement membrane*** and capsular ***epithelium.*** Arterial blood flows in the glomerulus. This blood is filtered by the Bowman capsule and it enters the capsular space. The fluid present in the capsular space is called ***glomerular filtrate.***

The glomerular filtrate exactly resembles a ***cell free*** and ***protein*** free blood. The constituents of glomerular filtrate remain in the same ratio as those of the blood.

In 24 hours, ***180 litres*** of glomerular filtrate is formed. ie. ***125ml***/ minute.

Ultrafiltration is facilitated by the following factors :

- *Pores present in the Malpighian corpuscles.*
- *Blood pressure.*
- *Renal blood flow.*

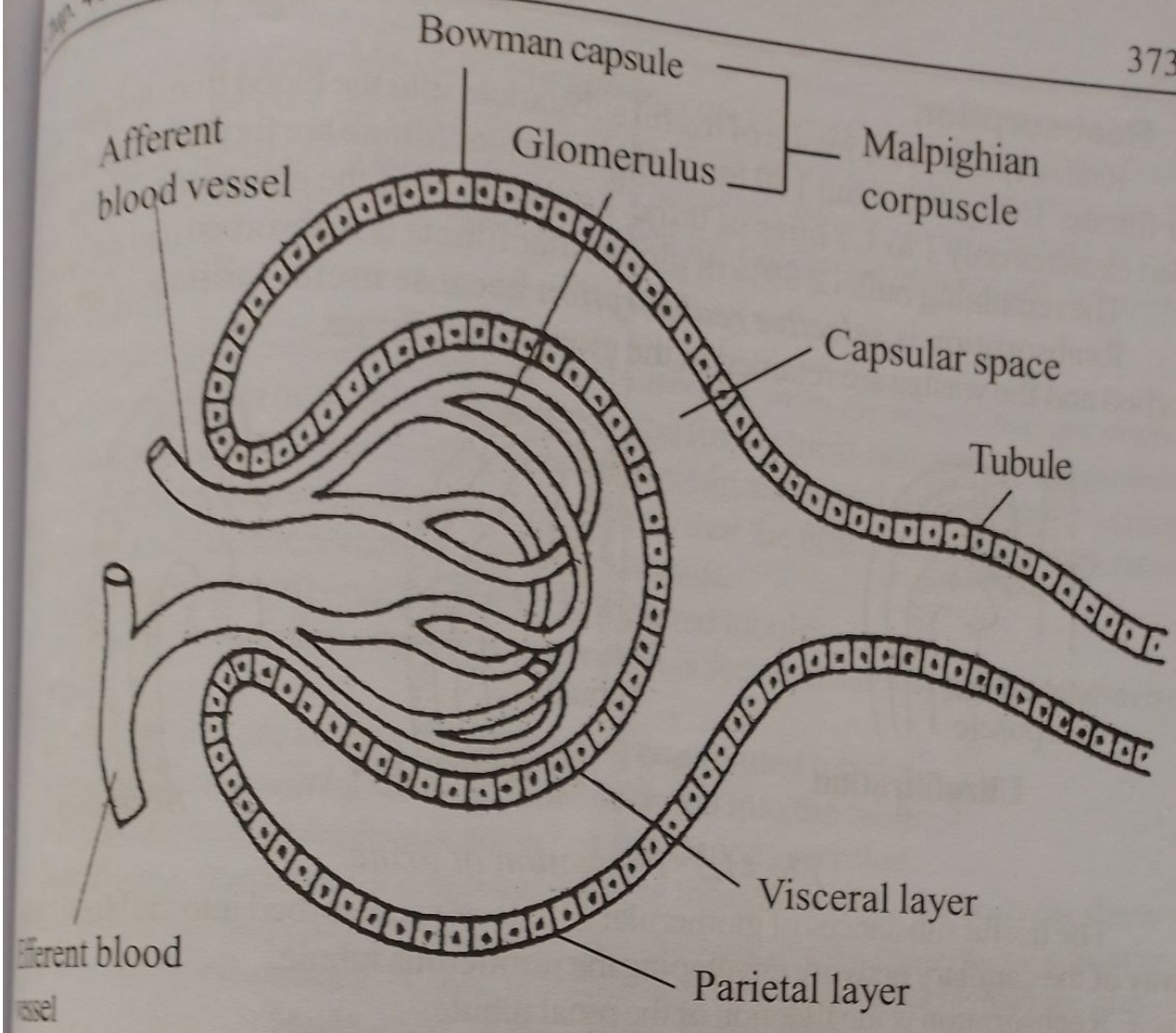

Fig.41.1: Malpighian corpuscle.

- *Osmotic pressure.*
- *Hydrostatic pressure.*
- *Constriction of glomerular arterioles.*
- *Sympathetic stimulation.*
- *Hormonal factors.*

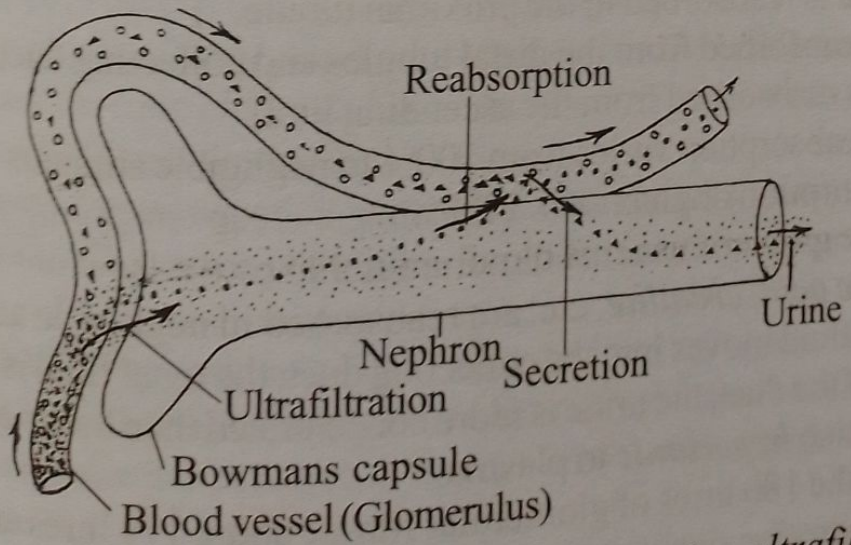

Fig.41.2: Mechanism of urine formation showing ultrafiltration, reabsorption and secretion.

2. Reabsorption

Reabsorption is the intake of useful substances into the blood from the glomerular filtrate. Every day about 180 litres of glomerular filtrate are formed. But a normal man excretes only 1 to 1.5 litres of urine, i.e about 1% of the glomerular filtrate.

The remaining bulk i.e 99% of glomerular filtrate is reabsorbed into the blood.

Reabsorption is ***selective reabsorption*** because useful substances are reabsorbed and the wastes are retained in the glomerular filtrate.

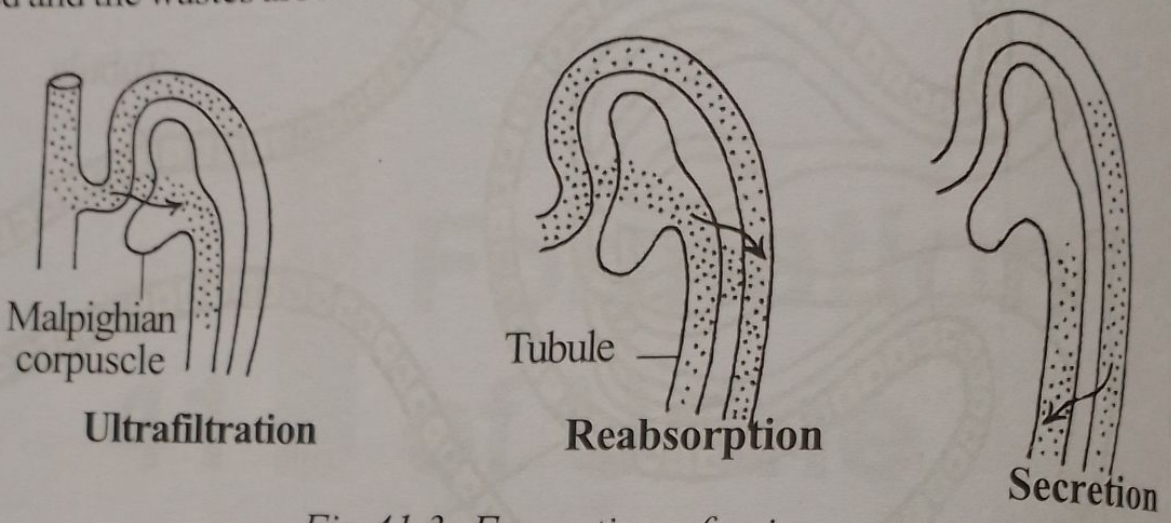

Fig.41.3: Formation of urine.

The useful substances of glomerular filtrate are reabsorbed into the blood by the way of the capillary network enveloping the uriniferous tubule.

Reabsorption is the function of the renal tubule.

The following substances are reabsorbed from the glomerular filtrate of the uriniferous tubule:

1. The ***amino acids, glucose, protein*** and ***phosphate*** are reabsorbed in the first part of the proximal tubule.
2. ***Sodium chloride*** and ***bicarbonates*** are absorbed along the proximal tubule and the distal tubule.
3. ***Potassium*** is reabsorbed in the proximal tubule.
4. ***Water*** is reabsorbed from the distal tubules and collecting duct.
5. ***Sodium*** is reabsorbed from the ascending limb.

The rate of reabsorption varies from 100% to negligible amounts.

1. The reabsorption of glucose is 100%.
2. The reabsorption of water and sodium is 99%.
3. ***Urea, uric acid, creatine***, etc. are reabsorbed in negligible amount.

As the renal fluid moves into the collecting duct, the renal fluid is called ***urine.*** At the end of the duct, the urine is more concentrated than the original glomerular filtrate and is also ***hypertonic*** to plasma.

Thus out of the 180 litres of glomerular filtrate about 179 litres are reabsorbed.

Water reabsorption occurs by osmosis which is a ***passive*** and non-energy requiring process. But the absorption of glucose, amino acids and vitamins is an ***active process.***

The cleaning of the blood by the kidney can be compared to the housewife who wants to clean up a dirty room. To get a clear wash she empties the room of all its portable furniture (table, chairs, pictures and so on) as well as the waste materials. Once the waste has been disposed off all the furnitures are returned to the room again.

3. Secretion

Secretion is *the release of unwanted materials from the blood into the nephron.* The concentration of certain substances in the final urine is higher than that present in the glomerular filtrate. Again urine contains certain additional substances which are not present in the glomerular filtrate. This shows that the urinary epithelium secretes some substances into the lumen of the urinary tubule.

This secretion mainly occurs in the convoluted tubules.

Aminohippuric acid, an excretory product is secreted into the proximal convoluted tubule.

K^+ and H^+ ions are secreted by the distal convoluted tubules.

Potassium, ammonia, urea are also secreted into the tubules.

Creatinine and ***phosphates*** are other substances secreted.

Moreover, a number of foreign substances introduced into the body for therapeutic or diagnostic purposes are also removed from the plasma mainly by the tubular epithelium. Such substances include ***penicillin, phenolsulphonaphthalein,*** etc.

Hair-pin Counter Current Multiplier Theory

This theory was proposed by ***Wirz*** (1951) and ***Bray*** (1960). It explains the formation of concentrated urine. This system operates in the hairpin-like loop of Henle.

In the descending and ascending limbs, the renal fluid flows in the opposite direction and hence the name ***counter current.*** The mechanism of this theory to produce concentrated urine can be summarised as follows:

The entire length of the nephron is permeable to water, with the exception of the ascending limb of the loop of Henle. Sodium is actively pumped from the ascending limb to the interstitial fluid of medulla.

The sodium pumped out of the ascending limb passes into the descending limb by simple diffusion. The sodium again passes into the ascending limb through the loop of Henle.

As a result of this recirculation of sodium, the loop of Henle and the collecting duct are constantly bathed in a highly concentrated fluid. As a result when the renal fluid passes through the collecting duct more water diffuses out from the collecting duct.

In this way, the body is able to excrete a far more concentrated urine. The concentrated urine is produced by the counter-current exchanger mechanism. This mechanism is available only in ***birds*** and ***mammals.***