CHAPTER

14

Transport

Animation 14.1:T ransport in Plant
Source & Credit: mrgscience

INTRODUCTION

In this chapter our main focus would be to study different processes involved in the transport of nutrients into the cells and removal of the wastes out of the cells. We would also study, essentially in plants and animals, the elaborate mechanism involved not only for the movement of individual molecules but also their mass transport within bodies. The processes involved for getting materials into and out of the cells are diffusion, facilitated diffusion, osmosis, active transport, endocytosis, exocytosis etc.

In animals, the materials move into, within and out of the body, in respiratory circulatory, digestive and excretory systems. In plants the processes of respiration, transportation, photosynthesis, absorption by roots, conduction of water, and the nutrients are involved in movement of the materials into, within and out of the body.

NEED FOR TRANSPORT OF MATERIALS

The living organism is a complex of interactions of physical and chemical reactions involving different elements and molecules. All living cells or living organisms, must obtain and transport certain materials within the body and also transport and remove the wastes out of their bodies or cells.

If there were no transport systems, most of the cells of the body of a complex multicellular organism, would not be able to get the required materials and dispose of their wastes. There are no mass flow systems in unicellular organisms and lower multicellular organisms.

TRANSPORT IN PLANTS

Uptake and Transport of Minerals and Water

The roots of a plant not only anchor the plant body in the soil, but also absorb minerals and water from the soil. There are three types of nutrients needed by the plants, carbon dioxide, water and

A rye plant less than one meter tall has some 14 million branch roots of a combined length of over 600 kilometers.

minerals besides light to carry out photosynthesis. To get these materials, roots must provide large surface area for absorption, which is achieved by extensive branching. The roots bear a dense cluster of tiny hair like structures which are extensions of epidermal cells of roots.

These are the root hairs, which are in fact the sites where most of the uptake of water and minerals takes place.

Plants are able to sythesize all their required compounds, with the help of the minerals and H_20 from soil, $C0_2$ from air, and light energy. Most of the minerals enter the root hairs or epidermal cells of roots along with water in bulk flow, but some are taken in by diffusion, facilitated diffusion, or active transport.

It has been estimated that out of total surface area provided by roots, 67% is provided by the root hairs.

Prosopis trees of leguminoseae family have maximum depth of their roots, which is 50 metres.

Mineral absorption by roots

The minerals available to plants for absorption are dissolved in the soil water. Their concentration vary according to the fertility and the acidity of the soil, besides other factors. When the soil minerals are not in solution but are bound by ionic bonds to soil particles, they are not available to plants.

Processes involved in absorption by roots

The uptake of minerals by root cells is a combination of passive uptake and active uptake, involving the use of energy in the form of ATP. The passive uptake involves diffusion. The minerals they also move down their concentration gradient through plasmodesmata (symplast pathway) to cells of cortex, endodermis, pericycle and then to sap in xylem cells. From here they are pulled up by transpiration pull to different parts of plant.

When inorganic or organic fertilizer is applied to soil, the minerals are absorbed primarily as inorganic ions. The rate of absorption of each mineral by roots is essentially independent of the rates of absorption of water and of the other minerals. Each mineral moves into roots at a rate determined by such factors as its concentration both inside and outside the root, the ease with which it can passively penetrate cell membrane, and extent to which carrier molecules and active absorption are involved.

The **diffusion** of ions along with water also takes place by mass flow along the apoplast pathway. Ions moving in the apoplast can only reach the endodermis, where casparian strips prevent further progress (Fig. 14.1). To cross the endodermis, ions must pass by diffusion or active transport into endodermis cells, entering their cytoplasm, and possibly their vacuoles. The ions then reach the xylem cells. Diffusion of ions can also take the vacuolar pathway where the ions move along their concentration gradient through the cell membranes, cytoplasm, and tonoplast (the membrane of vacuoles), and reach the dead xylem cells.

Most of ions are taken up by the roots by the process of active transport. By this method plants can take a mineral that is in higher concentration inside the root cells than in the soil solution. In this process molecules and ions move from their low concentration to their higher concentration (i.e. against the concentration gradient), through cell membrane, by the use of energy in the form of ATP. Active transport is selective and is dependent on respiration. Some ions move by passive as well as by **active transport.**

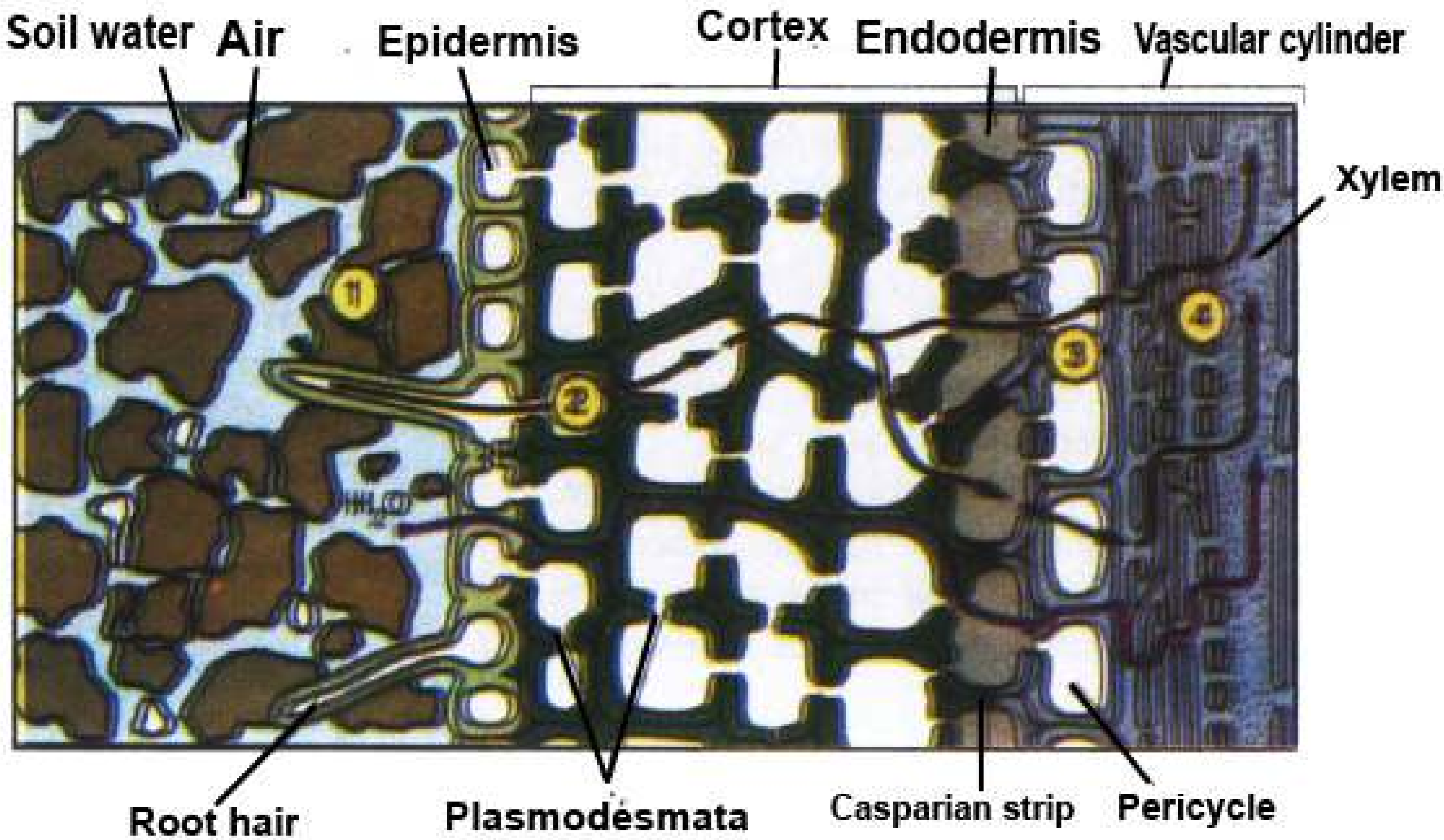


Fig.14.1 Mineral and water uptake by roots. The Casparian strip separates the extracellular space in the root into two compartments: an outer compartment that is continuous with the soil water, and an inner compartment that is continuous with the inside of the conducting cells of the xylem. The black lines show a pathway for both water and mineral; the blue line is an alternative pathway for water alone.

Animation 14.2: transpul
Source and Credit: msseconisseniorbiology

Symbiotic Relationship helps plants acquire nutrients.

One of the important nutrient N_2 is almost always in short supply both in rock particles and in the soil water. Most plants have evolved beneficial relationship with other organisms that help the plants acquire these scarce nutrients. Examples include: Mycorrhize and nitrogen fixing bacteria in root nodules of legumes.

Mycorrhizae help in uptake of minerals

The fungal associations with roots of higher plants, help mineral uptake by the plant.

The fungi facilitate the uptake of phosphorus and trace metals such as zinc and copper.

A root infected with mycorrhizal fungi can transport phosphate at a higher rate than that of an uninfected root.

Mycorrhizal fungi get sugar, and shelter from the plant and in exchange increase the plant's mineral nutrient uptake efficiency. Mycorrhizae are present in 90% families of flowering plants.

Some nutrients are carried from the soil to the epidermal cells of roots through their cell membrane by **facilitated diffusion**. In this type of diffusion, carrier molecules within the cell membrane transport nutrients across the membrane. These carrier molecules are proteins - which are present within cell membrane of epidermal and other root cells.

Uptake of Water by Roots

Normally, the movement of water molecules from a region of their higher concentration to a region of their low concentration through a partially permeable membrane is called **osmosis**. If water moves by osmosis into a cell the process is called endosmosis, and if the water moves out of the cell it is called exosmosis.

The cell wall of epidermal cells of roots is freely permeable to water and other minerals. The cell membrane, however, is differentially or partially permeable to some substances in the solution. The water which enters the epidermal cells moves along the concentration gradient and passes through cortex, endodermis, pericycle and ultimately to xylem cells. (Fig. 14.2)

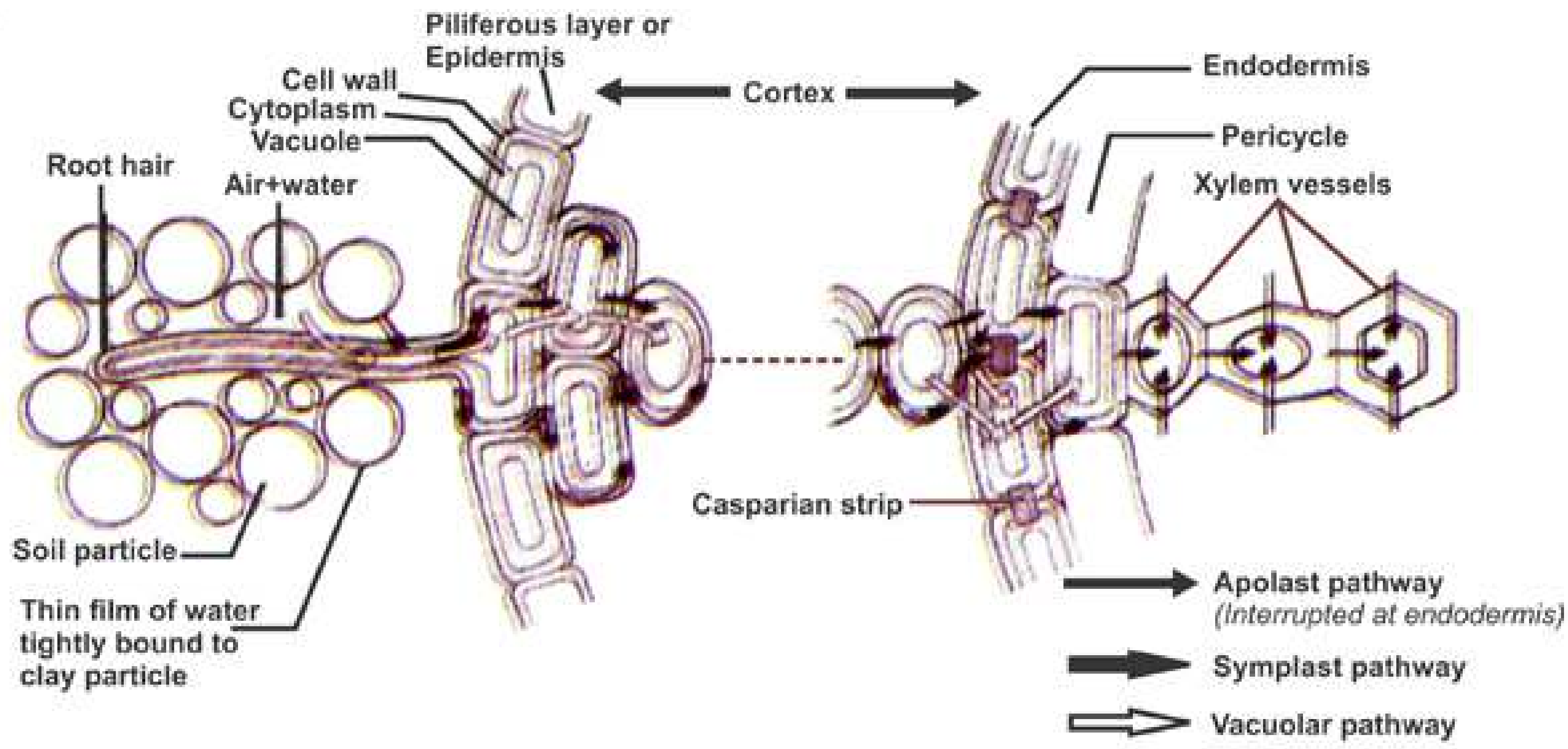


Fig. 14.2 Diagrammatic representation of water and ion movement across a root showing transverse section. The apoplast pathway is of greatest importance for both water and solutes. The symplast pathway is less important, except for salts in the region of the endodermis. Movement along the vacuolar pathway is negligible.

Following are the paths taken by water to reach the xylem tissue:

(i) The apoplast pathway

It is the pathway involving system of adjacent cell walls which is continuous throughout the plant roots. In the roots apoplast pathway becomes discontinuous in the endodermis due to the presence of casparian strips.

(ii) The Symplast pathway

It is the system of interconnected protoplasts in the root cells. The cytoplasm of neighbouring cells (Protoplasts) is connected with one another by Plasmodesmata which are cytoplasmic strands that extend through pores in adjacent cell walls. In the cells of root the cell membrane and cytoplasm (and plasmodesmata) can be regarded as acting together as one partially permeable membrane.

(iii) The vacuolar pathway

In this pathway water moves from vacuole to vacuole through neighbouring cells crossing the symplast and apoplast in the process and moving through cell membranes by osmosis. Water moves passively down a concentration gradient.

Water Potential (Symbolized By Greek Letter Psi = ψw)

Water molecules possess kinetic energy which means that in liquid or gaseous form, they move about rapidly and randomly from one place to another. So, greater the concentration of the water molecules in a system the greater is the total kinetic energy of water molecules. This is called water potential (ψw).

In plant cells two factors determine water potential.
i) Solute concentration (Osmotic or solute potential = ψs)
ii) Pressure generated when water enters and inflates plant cells (Pressure potential = ψp).

Pure water has maximum water potential which by definition is zero.

Water moves from a region of higher ψw to lower ψw .
All solutions have lower ψw than pure water and so have negative value of ψw (at atmospheric pressure and at a defined temperature). So **osmosis** can be defined as:

"The movement of water molecules from a region of higher water potential to a region of lower water potential through a partially permeable membrane".

Osmotic (Solute) Potential = ψs

The osmotic (solute) potential ψs is a measure of the change in water potential(ψs) of a system due to the presence of solute molecules. ψs is always negative. More solute molecules present, lower (more negative) is the ψs.

Pressure Potential (ψp)

If pressure greater than atmospheric pressure is applied to pure water or a solution, its water potential increases. It is equivalent to pumping water from one place to another. Such a situation may arise in living systems.

When water enters plant cells by osmosis pressure may be built up inside the cell making the cell turgid and increasing the pressure potential. Thus the total water potential is sum of ψs and ψp.

ψw	=	ψs	+	ψp
water potential		**solute potential**		**pressure potential**

If we use the term water potential, the tendency for water to move between any two systems can be measured; not just from cell to cell in a plant but also from soil to root from leaf to air or from soil to air. The steeper the potential gradient the faster is the flow of water along it.

The following example would help understand the concept of water potential. Two adjacent vacuolated cells are shown with ψw, ψp and ψs.

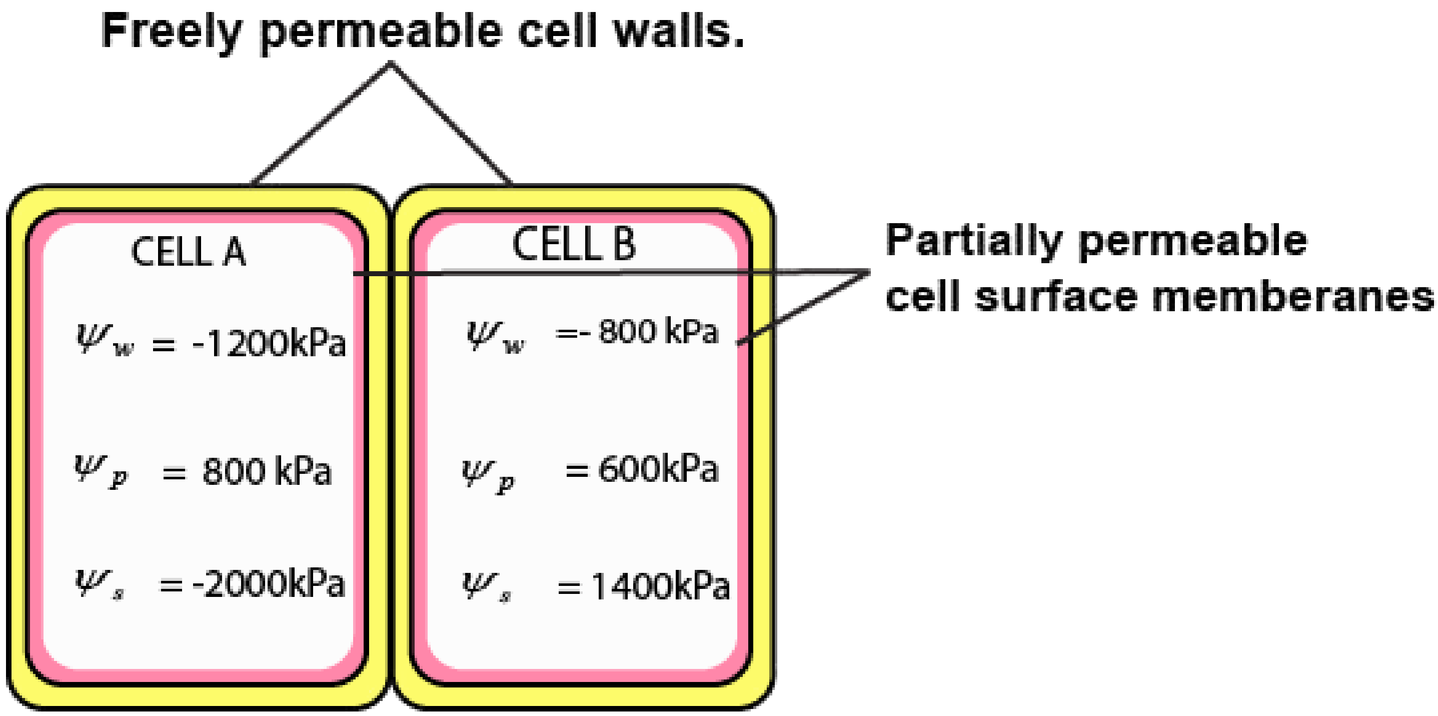


Fig. 14.3 Two adjacent vacuolated cells.

Q. **a)** Which cell has the higher water potential?
b) In which direction will water move by osmosis?
c) What will be the water potential of the cells at equilibrium?
d) What will be the solute potential and pressure potential of the cells at equilibrium?

kPa= 1000 Pascals - which is the pressure exerted by a vertical force of one Newton on an area of 1 metre square.

Plasmolysis and Pressure Potential

Plasmolysis can be defined as the shrinkage of protoplast due to exosmosis of water. When a living cell is placed in a solution having lower water potential than that of the cell, plasmolysis takes place and the cell is called plasmolysed. If this plasmolysed cell is placed in distilled water (which has highest water potential) the water molecules would move from distilled water through differentially permeable cell membrane into the cell, and the cell would become deplasmolysed.

The point at which plasmolysis is just about to happen is called **incipient plasmolysis**. At incipient plasmolysis the protoplast has just ceased to exert any pressure against the cell wall, so the cell is flaccid.

If a plasmolysed cell is placed in distilled water, the one having higher water potential than the contents of the cell, water enters the cell by endosmosis, volume of protoplast increases, and it begins to exert pressure against the cell wall of plant cell. The cell wall is rigid - so the pressure exerted by the protoplast against the cell wall is called **pressure potential**. As the pressure potential of the cell increases due to endosmosis, the cell becomes turgid. Full turgidity i.e. maximum pressure potential is achieved when a cell is placed in pure water or distilled water.

The animal cells cannot withstand higher pressure potential as there is no cell wall around protoplast. Thus the turgid cells burst in a solution of higher water potential. So the animals employ the mechanism of osmoregulation to maintain the amount of water and salts in their cells to constant or nearly constant levels.

ASCENT OF SAP

In the previous pages you have learned that water and dissolved minerals traverse the cortex and endodermis and reach the xylem tissue of roots. (Fig. 14.1,14.2) Actually, water and dissolved minerals are carried or pulled upwards towards the leaves through xylem tissue. This is called ascent of sap. This may involve the following :

(A) Cohesion Tension Theory (B) Root Pressure (C) Imbibition

(A) Cohesion tension theory is one of the most important theories proposed by Dixon. This theory provides a reasonable explanation of flow of water and minerals upwards from the roots to leaves of plants, in bulk flow or mass flow (Fig. 14.5). This depends on the following:

(i) Cohesion: It is the attraction among water molecules which hold water together, forming a solid chain-like column within the xylem tubes. The water molecules form hydrogen bonds between them.

(ii) Tension: It is provided when this water chain is pulled up in the xylem (Fig. 14.4). Transpiration provides the necessary energy or force. Tension is between the molecules of water by hydrogen bonds.

This xylem water tension is strong enough to pull water up to 200 metres (more than 600 feet) in plants.

(iii) Adhesion: It may be added that the water molecules also adhere to the cell walls of xylem cells, so that the column of water in xylem tissue does not break. The composition of cell wall provides necessary adhesion to water molecules that helps water creep up. The cellulose component of cell wall especially has great affinity for water. It can imbibe water.

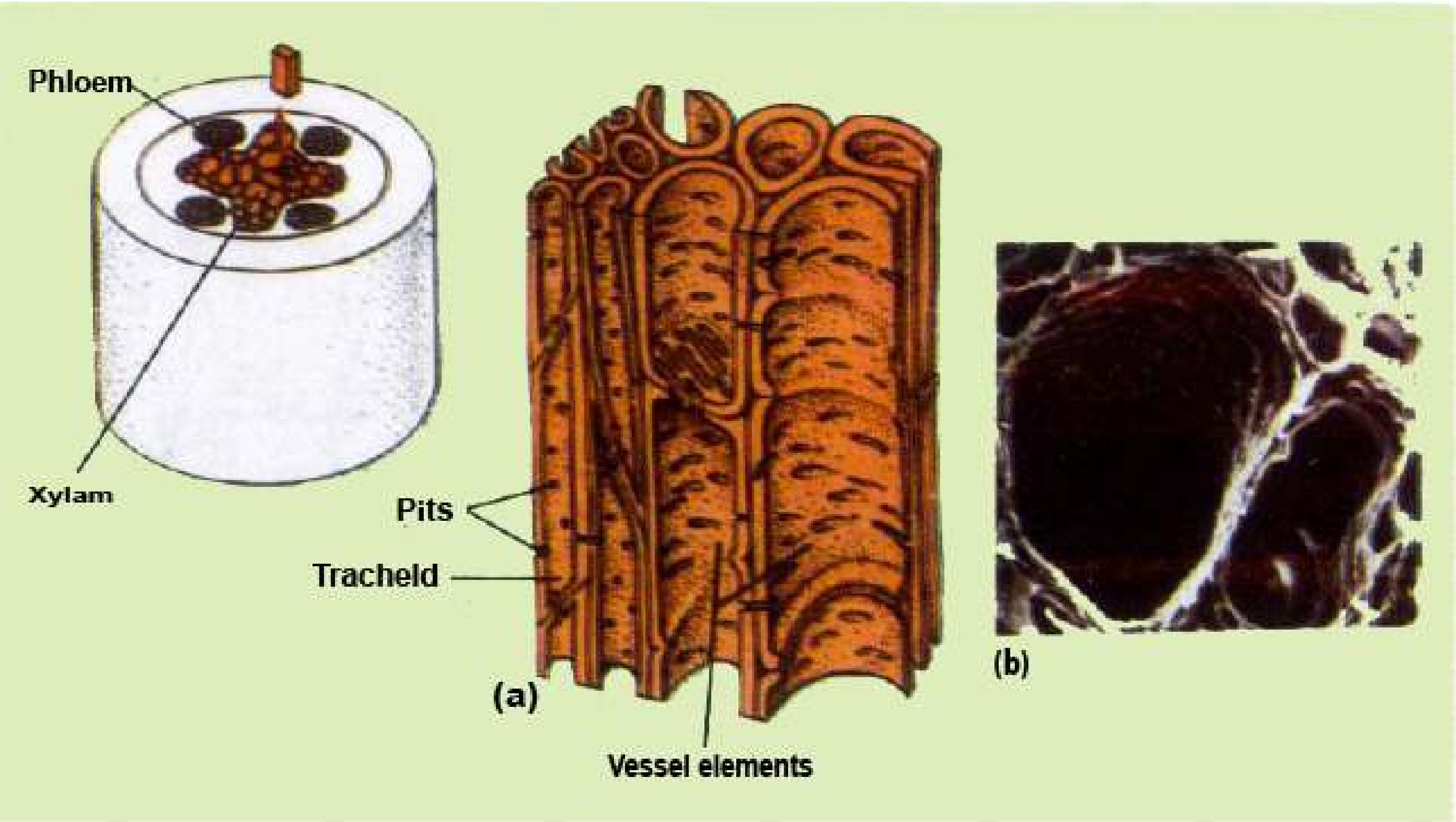


Fig.14.4 (a) Xylem Tissue elements involved in transportation of water and dissolved minerals, (b) Scanning electron micrograph of two large vessel elements of a cucumber root.

(iv) Strong xylem walls: It is essential that the xylem walls should have high tensile strength if they are not to buckle inwards. The lignin and cellulose provides strength to cell wall of xylem vessels (Fig. 14.4).

By cohesion-tension of water molecules, and the transpiration pull providing the necessary energy, the sap (water and minerals) in xylem tissue is pulled upwards to the leaves. Large quantities of water are carried at relatively high speed, upto $8mh^{-1}$ being recorded in tall trees, and commonly in other plants at $1mh^{-1}$.

The total water pulled up in the leaves is transpired, except about 1% which is used by plant in various activities including photosynthesis.

Mechanism of transpiration pull in cohesion tension theory

The evaporation of water from the aerial parts of the plant especially through stomata of leaves is a process called **transpiration**. As a leaf transpires the water potential of its mesophyll cells drops. This drop, causes water to move by osmosis from the xylem cells of leaf into dehydrating mesophyll cells. The water molecules leaving the xylem are attached to other water molecules in the same xylem tube by hydrogen bonds (cohesion of water molecules). Therefore, when one water molecule moves up the xylem, the process continues all the way to the root - where water is pulled from the xylem cells (tracheids and vessels). This pull also causes water to move down its concentration gradient transversely from the root epidermis (root hairs) to cortex by endosmosis and to pericycle. This pulling force or transpiration pull is so strong that it also reduces the water potential of root epidermal cells. Then water in the soil moves from its higher water potential to lower water potential of epidermis of root by osmosis.

Animation 14.3: Transpiration pull
Source and Credit: gifsoup

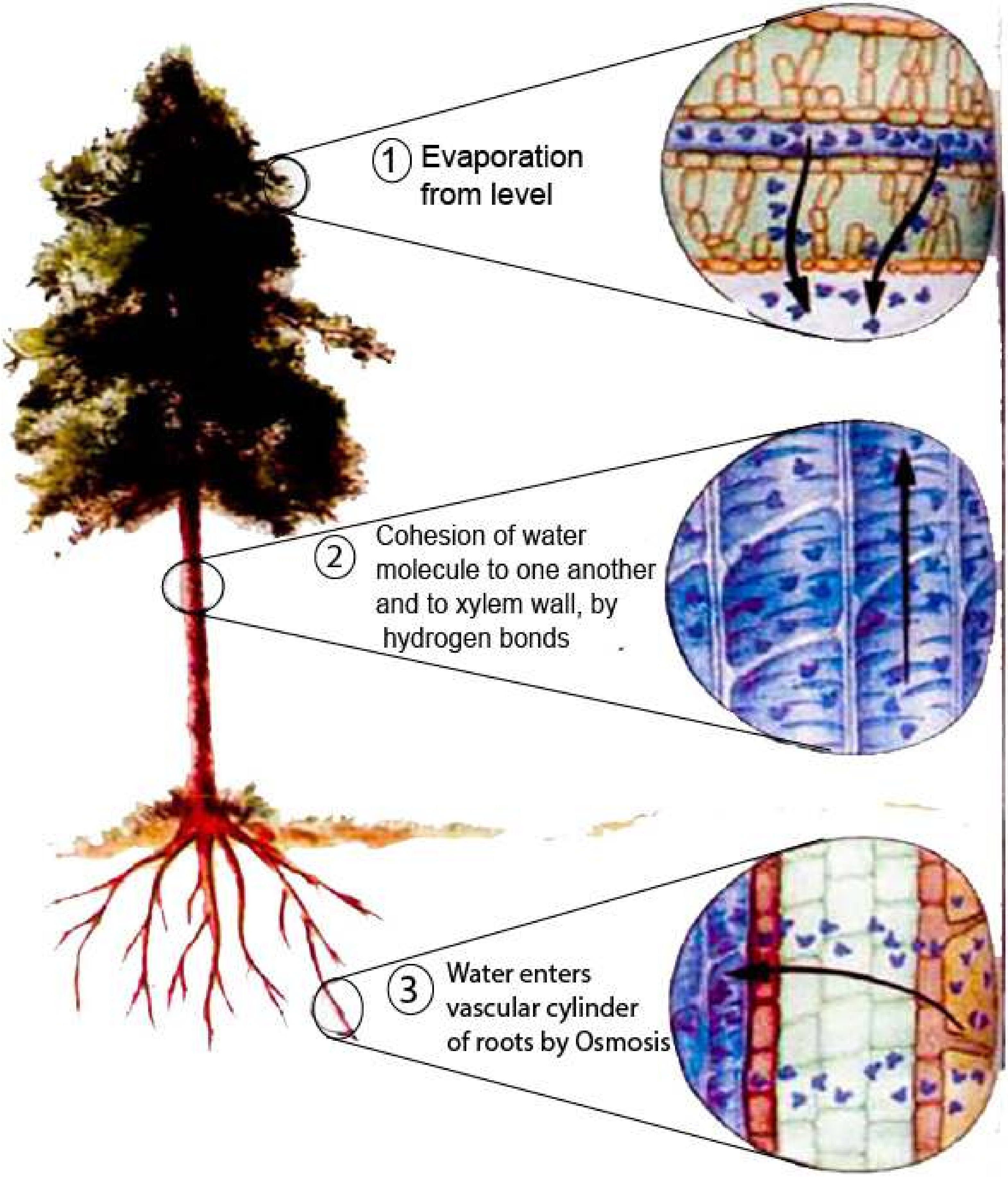


Fig.14.5 The cohesion-tension theory of water flow from root to leaf.

(B) Root pressure : Second force involved in the movement of water and dissolved minerals up in the xylem tissue is the root pressure. Root pressure is created by the active secretion of salts and other solutes from the other cells into the xylem sap. This lowers the water potential of xylem sap. Water enters the xylem cells by osmosis, thus increasing the level of sap in the xylem cells. Water entering the xylem cells, may take apoplast, symplast or vacuolar pathway increasing the hydrostatic pressure in cells, this pushes the water upwards. As a result of root pressure the sap in the xylem does not rise to enough height in most plants. The root pressure is also least effective during the day, when transpiration pull is the active force involved in pulling the sap in xylem cells upwards. It has been estimated that a positive hydrostatic pressure of around 100 to 200 KPa (exceptionally 800 KPa) is generated by root pressure. The pressure mentioned above is not enough to push water upwards to required height in most plants. But it is no doubt a contributing factor in plants which transpire slowly, and are smaller in size.

Closely associated with root pressure is a phenomenon called guttation or exudation. Guttation is loss of liquid water through water secreting glands or hydathodes. The dew drops that can be seen on the tips of grass leaves or strawberry leaves are actually guttation droplets exuded from hydathodes. (Fig. 14.6).

Guttation or exudation is more notable when transpiration is suppressed, and the relative humidity is high as at night. The guttation is in fact due to positive pressure - the root pressure, developed in xylem tissue of roots.

Fig. 14.6 Guttation by stawberry leaves

(C) Imbibition : Another important force in the ascent of sap is imbibition. Sacks in 1874 sugested that the water molecules move along the cell walls of xylem vessels due to imbibition.

The cell wall components especially cellulose, pectin and lignin can take up water and as a result increase in volume, but the components do not dissolve in water, this is called imbibition. The amount of attraction and increase of dry cell walls of plant cells, and of protoplasm for water is often very great and considerable imbibition forces may be developed in plant body. The root cell walls imbibe water from the soil, and this water moves by apoplast pathway already discussed.

Imbibition is a reversible process and when water is lost the original volume of cell wall and of protoplasm is restored. The uptake of water by imbibition is especially important in germinating seeds. The volume of dry seed may increase up to 200 times by imbibition, as a result, the seed coat ruptures and makes the germination of seed effective.

Bleeding : Sometimes it so happens that certain plants, when cut, pruned, tapped or otherwise wounded, show a flow of sap from the cut ends or surfaces quite often with a considerable force. This phenomenon is commonly called **bleeding**.

It is often seen in many land plants in the spring, particularly grape wine, some palms, sugar maple etc.

Although the flow of sap is ordinarily slow, a considerable quantity of the sap within a period of 24 hours comes out of the plant. In some palms when tapped, there may be a flow of sap to the extent of 10-15 litres per day. The sap in such plants contains sugars and water in addition to organic and inorganic substances (e.g. salts).

There are two main factors responsible for bleeding, the hydrostatic pressure in xylem and phloem elements, and the root pressure, which is exerted by the xylem tissues of roots.

TYPES OF TRANSPIRATION

You have already studied the role of transpiration, in ascent of sap.
There are three types of transpiration depending upon the route of escape of water vapours from the aerial parts of the plant.

(i) Cuticular transpiration (ii) Lenticular transpiration (iii) Stomatal transpiration

Animation 14.4: Transpiration
Source and Credit: atmos.uiuc

(i) Cuticular transpiration : The loss of water in the form of water vapours through the cuticle of leaves is called cuticular transpiration. About 5-7% of total transpiration takes place through this route.

The cuticle present on the upper and lower epidermis of leaves is not completely impermeable to water and some water is lost in the form of vapours through cuticle. The thinner the cuticle the greater is the rate of transpiration; although the composition of cuticle is also important. At night, when the stomata are almost closed, cuticular transpiration takes place. Most of the factors which affect rate of transpiration, in general, are also important in controlling the rate of cuticular transpiration.

(ii) Lenticular transpiration : Lenticular transpiration is the loss of water vapours through lenticels present in the stem of some plants. (Fig. 14.7) All plants do not possess lenticels.

The lenticular transpiration is 1-2% of the total transpiration by a plant. These openings, like stomata,are also involved in the exchange of gases between environment. When there is strong light and high temperature,the loss of vapours is rapid because it is governed by diffusion.

Lenticels are aerating pores formed in the bark through which exchange of gases takes place, and water is lost in the form of water vapours (transpiration). Externally, they appear as scars or small protrusions on the surface of stem. Lenticel consists of a loose mass of small, thin-walled cells. At each lenticel the cork cambium forms oval, spherical, or irregular cells, which are very loosely arranged, having lots of intercellular spaces.

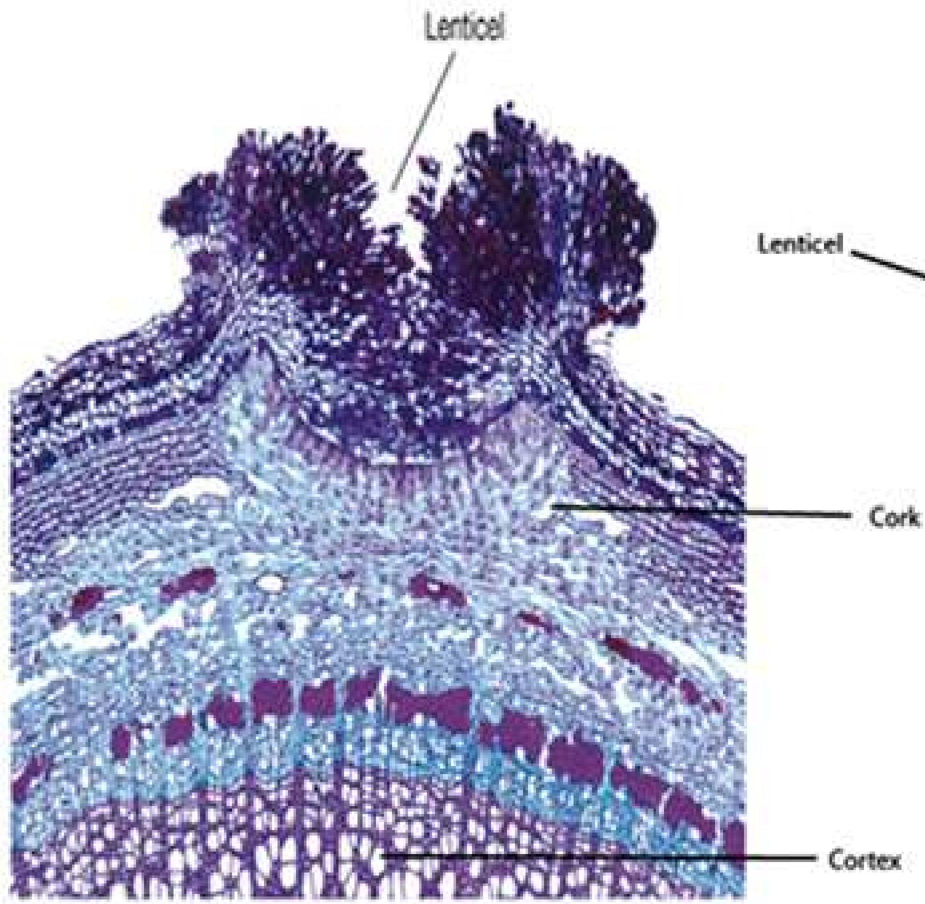


Fig. 14.7 Left : The waterproof outer bark (layer of dark cells on the surface) on this section of stem is interrupted at the center of the lenticel. Thus the more loosely arranged cell layer beneath, with their numerous intercellular air spaces, are exposed to the atmosphere, Right: The individual lenticels can be seen as white areas on the surface of a young stem.

(iii) Stomatal transpiration : It is a type of transpiration in which the water vapours escape through stomata. In isobilateral leaves the stomata are present, in both, upper and lower epidermis e.g. lily and maize leaf. In dorsiventral leaves the stomata are confined to only the lower epidermis.

The guard cells are normally dumble or bean-seed-shaped. The inner concave sides of two guard cells enclose the stoma. This inner side of guard cell has very thick cell wall, but the outer convex side has thin cell wall. The guard cells are the only cells, of leaf epidermis, which are not connected by plasmodesmata to other epidermal cells, and which have chloroplasts - and thus are involved in the process of photosynthesis (Fig. 14.8). When these guard cells are turgid, the stoma between them opens and when the guard cells are flaccid the stoma between them closes. The degree of opening of stomatal pores also affects the rate of transpiration. 90% of total transpiration in a plant is stomatal.

The cells of mesophyll of leaf provide enormous surface ‘area for the loss of water in the form of vapours. The pathway of water vapours loss to the atmosphere, through stomata is shown. (Fig. 14.8)

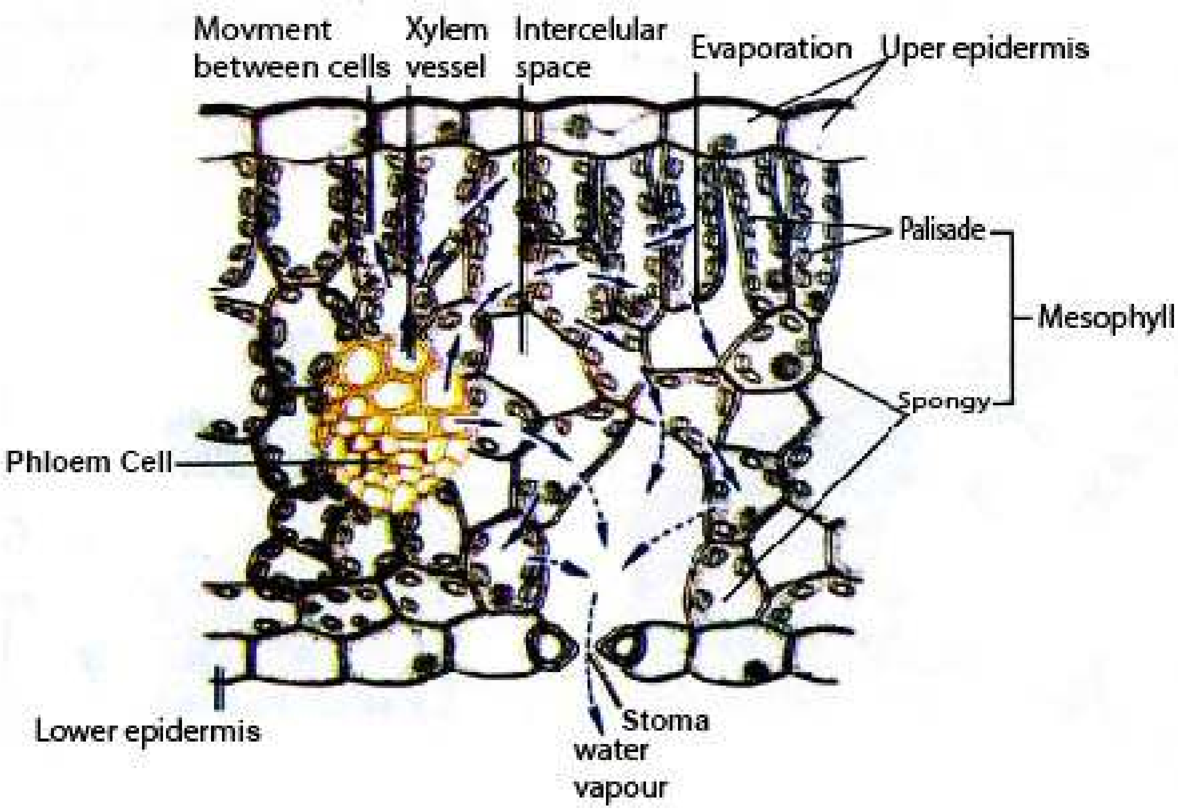


Fig.14.8 The water pathway through the leaf. Water is drawn from the xylem into the cell walls of the mesophyll, where it evaporates into the air spaces within the leaf. By diffusion, water vapour then moves through the leaf air space, through the stomatal pore, and across the boundary layer of still air that adheres to the outer leaf surface. $C0_2$ also diffuses into the leaf through stomata along a concentration gradient.

OPENING AND CLOSING OF STOMATA

The guard cells function as multisensory hydraulic valves (Fig. 14.9). Environmental factors, such as light intensity and quality, temperature, relative humidity, and intracellular CO_2 concentration are sensed by guard cells and these signals are integrated into well-defined stomatal responses.

There are two hypotheses which may explain the opening and closing of stomata.

i) Starch Sugar Hypothesis : The German botanist H. Van Mohl proposed that the guard cells are the only photosynthesising cells of epidermis of leaf and sugars are produced in them during day time when light is available. When sugar level rises i.e. solute concentration increases or water potential decreases - and the guard cells become turgid due to entry of water and they separate from one another, and stoma or pore opnes. During night there is no photosynthesis the sugars are either converted into insoluble starch or are used in respiration, this decreases free sugars in cell. So the osmotic pressure of guard cells is lowered, and water leaves the guard cells, which become flaccid and stoma or pore between them closes. But these processes are not fast enough to account for the rapid rise in turgor, of guard cells.

ii) Influx of K^+ ions : Potassium concentration in guard cells increases several fold, depending upon plant species.

Stomata open due to active transport of potassium ions (K^+) into the guard cells from the surrounding epidermis. The accumulation of K^+ decreases the osmotic potential of guard cells. Water enters the guard cells by osmosis, which become more turgid and stretched and stomata are opened. The stoma closes by reverse process; involving passive diffusion of K^+ from guard cells followed by water moving out by osmosis. What controls the movement of K^+ into and out of guard cells? Level of carbon dioxide in the spaces inside the leaf and light, control this movement. A low level of carbon dioxide favours opening of the stomata, thus allowing an increased carbon dioxide level and increased rate of photosynthesis.

Exposure to blue light, which is also effective in photosynthesis has been shown to acidify the environment of the guard cells (i.e. pumps out protons) which enable the guard cells to take up K^+ followed by water uptake resulting in increased turgidity of guard cells. So in general stoma are open during day and closed at night. This prevents needless loss of water by the plant when it is too dark for photosynthesis.

The plants open their stomata by actively pumping Potassium in guard cells causing water to follow by osmosis. Guard cells become turgid and stoma or pore opens. When Potassium leaves the guard cells (during night) water leaves the guard cells by exosmosis and guard cells become flaccid and stoma or pore between guard cells closes.

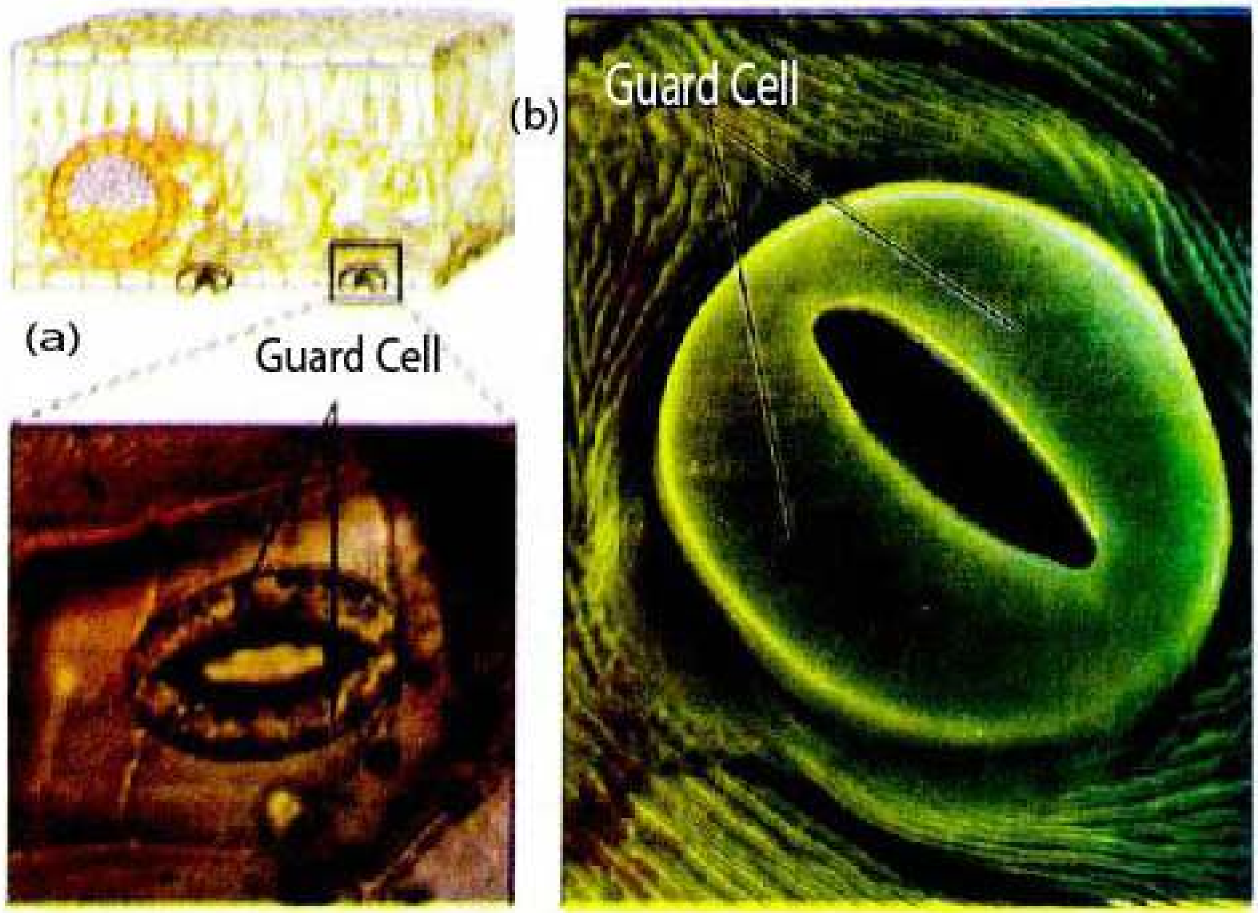


Fig 14.9 Stomata . Stomata seen through (a) the light microscope and (b) scanning electron microscope. In the light micrograph, note that the guard cells contain chloroplasts (the green ovals within the cells) but that the other epidermal cells do not.

Animation 14.5: Stomata
Source and Credit: gifsoup

Factors affecting the rate of transpiration

Rate of transpiration for a plant is very important as the transpiration stream is necessary to distribute dissolved mineral salts throughout the plant. Water is transported to photosynthesizing cells of leaves. Transpiration is also very important as it cools the plant. This is especially important in higher temperatures. If the rate of transpiration is very high, there would be much loss of water from the plant, so at high temperatures the stomata almost close and reduction in the rate of transpiration is effected. This stops wilting of the leaves and of plants (herbaceous plants).

There are some important factors which affect the rate of transpiration in a plant.

(i)	Light	(ii)	Temperature
(iii)	CO2 concentration	(iv)	Humidity and vapour pressure
(v)	Wind and	(vi)	Availability of soil water.

i) Light : The opening and closing of stomata is directly controlled by the light. In strong light the rate of transpiration is much more as compared with that in dim light or no light. As Potassium actively enters the guard cells, when light is available, water follows - and guard cells become turgid, and stoma opens.

ii) Temperature: When the sun-light is strong on a bright and sunny day the environmental temperature is increased. The higher temperature reduces the humidity of the surrounding air. The evaporation of water from the surfaces of mesophyll cells also increases, thus increasing the rate of transpiration.

The rate of transpiration doubles by every rise of 10°C in temperature. Very high environmental temperature, i.e. 40-45°C cause closure of stomata, so that plant does not loose much needed water. If higher temperatures are maintained in the environment for a longer duration and soil water is limited, the plants would wilt and may die.

Hormones are involved in stomatal movement in plants. At high temperature when leaf cells start wilting a hormone is released by mesophyll cells. This hormone is called abscisic acid. This hormone stops the active transport of K^+ into guard cells, overriding the effect of light and $C0_2$ concentration. So K^+ pumping stops. Stomata close.

iii) Carbon dioxide concentration : Low carbon dioxide concentration (such as those that occurs during the day when photosynthesis exceeds respiration), stimulates the active transport of Potassium ions into the guard cells. This transport (as discussed earlier) causes stomata to open and allow $C0_2$ to diffuse in the mesophyll cells of leaves. At night cellular respiration in the absence of photosynthesis raises $C0_2$ levels. This halts the inward transport of K^+, and thus of water, allowing the guard cells to become flaccid and stomata close. Thus transpiration almost stops.

iv) Humidity and vapour pressure : When air is dry, the rate of diffusion of water molecules, from the surfaces of mesophyll cells, air spaces, and through stomata to outside the leaf, increases (Fig. 14.8). So more water is lost, increasing the rate of transpiration. In humid air the diffusion rate is reduced. This decreases the rate of transpiration appreciably.

v) Wind : The air in motion is called wind, which causes increase in rate of diffusion of water molecules. The rate of evaporation from the surfaces of mesophyll cells increases. When air is still, the rate of movement of water molecules (diffusion) is slowed down, thus reducing the rate of transpiration.

vi) Availability of soil water : If there is little water in the soil, less is brought or transported to the leaf cells and less is lost to the environment by transpiration. So when the rate of absorption of water in root cells is reduced, the rate of transpiration is reduced.

Transpiration as a necessary evil

Transpiration has been described as necessary evil because it is an inevitable, but potentially harmful consequence of the existence of wet cell surfaces from which evaporation occurs. Loss of water from the plant can lead to wilting, serious desiccation and often death of a plant if conditions of drought are experienced. There is good evidence that even mild water stress results in reduced growth rate and in crops to economic losses through reduction of yield.

Despite its apparent inevitability it is also of very great importance for the plant.

i) Water is conducted or transported in most tall plants with the courtesy of transportation pull.
ii) Minerals dissolved in water are distributed throughout plant body by transpiration stream.
iii) Evaporation of water from the exposed surface of cells of leaves has cooling effect on plant.
iv) Wet surface of leaf cells allow gaseous exchange.

TRANSLOCATION OF ORGANIC SOLUTES

Organic solutes are transported by phloem tissue.

Phloem Transport

The phloem is generally found on the outer side of both primary and secondary vascular tissue in plants with secondary growth. The phloem constitute the inner bark. The cells of phloem thatconduct or transport sugars and other organic material throughout the plant are called sieve elements.

In addition to sieve elements, phloem tissue also contains companion cells, parenchyma cells, and in some cases fibres, sclereids and latex containing cells. However, only sieve tube cells are directly involved in transport of organic solutes.

Sieve elements are characterised by 'sieve areas' portions of the cell wall where pores interconnect the conducting cells. Some of the sieve areas of sieve tube members are generally formed in end walls of sieve tube members where the individual cells are joined together to form a longitudinal series called a sieve tube. Sieve plate pores of sieve tubes are essentially open channels, that allow transport between cells (Fig. 14.10).

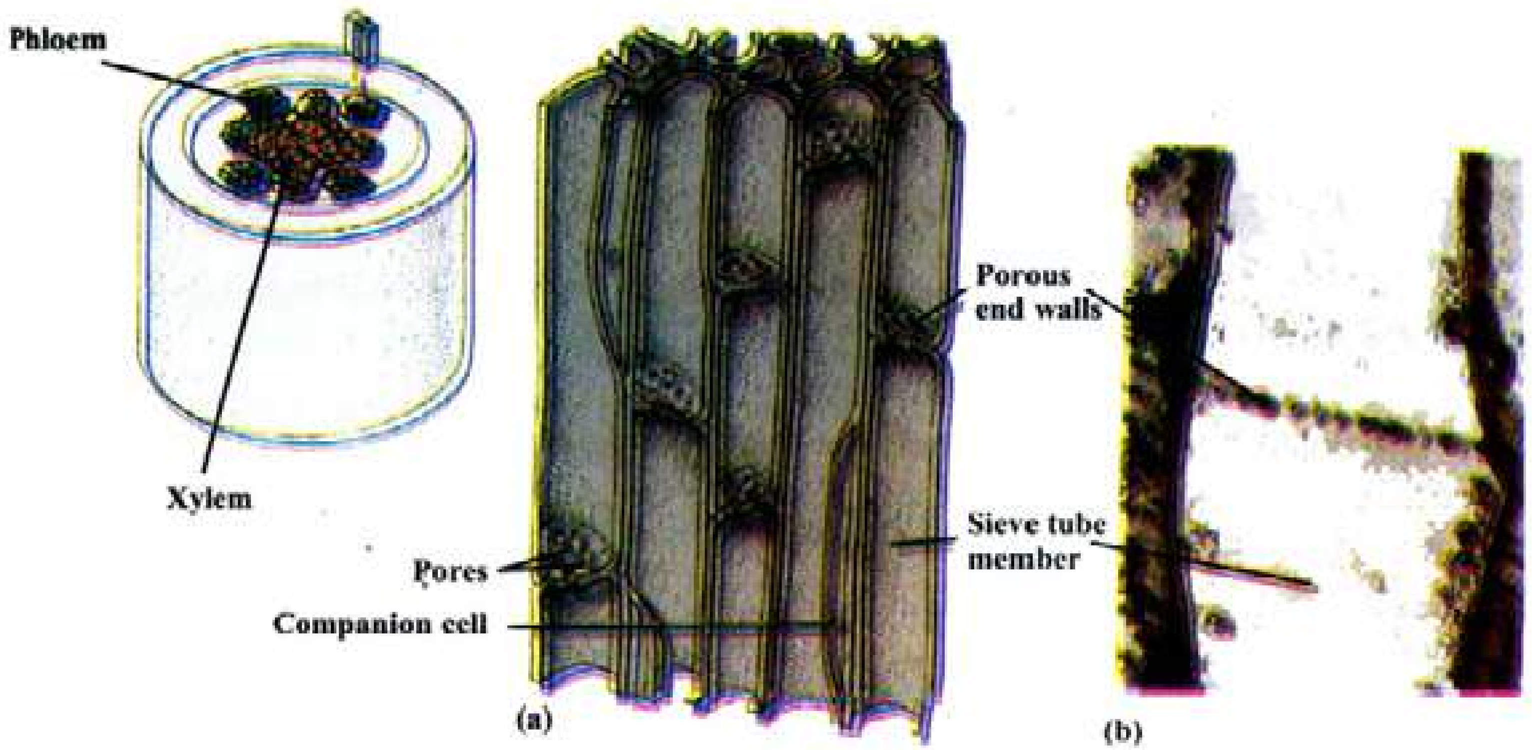


Fig. 14.10 (a) This diagram shows part of the root phloem consisting of sieve tube members stacked end to end. Adjoining end walls have common pores. Each sieve tube member is associated with a companion cell (b) Sieve tube member showing the pores in its end walls. Note the scarcity of cytoplasmic components in these sugar conducting cells.

Each sieve tube member is associated with one or more companion cells. Sieve tubes and companion cells are in communication with each other by plasmodesmata. Companion cells supply ATP and proteins to sieve tubes. The photosynthetic products from photosynthesizing cells, the mesophyll and palisade layer of leaf, pass into sieve tubes, through the companion cell via plasmodesmata.

Patterns of Transport

Phloem transport does not occur exclusively in an upward or a downward direction and is not defined with respect of gravity. Transport or translocation occurs from the areas of supply (sources) to areas of metabolism or storage (sinks).

The areas of sources include any exporting organ typically a mature leaf, or storage organ, that is capable of

i) Storing photosynthate in excess of its own needs.

ii) Storage organ during the exporting phase of its development. In biennials e.g root of beet is a sink in first growing season, but becomes source in the next growing season, when sugars are utilized in growth of new shoots.

iii) Sinks are the areas of active metabolism or storage for example roots, tubers, developing fruits, immature leaves, and even the growing tips of stem and root.

The movement in phloem is from source to sinks in most of the plants during active photosynthesis.

The composition of materials flowing in phloem has been studied by using aphids - the insects which are phloem feeders (Fig 14.11). These insects insert their stylets into stem or leaf and extend them to puncture a sieve tube. The pressure in the sieve tube cell forces sap through aphid's digestive tract and out its posterior end as droplets called "honey dew". The composition of honey dew have revealed that it contains 10-25% dry matter 90% or more of which is sucrose. Nitrogenous compounds are about 1%.

Animation 14.6 Absorptive Root
Source & Credit: cas.miamioh

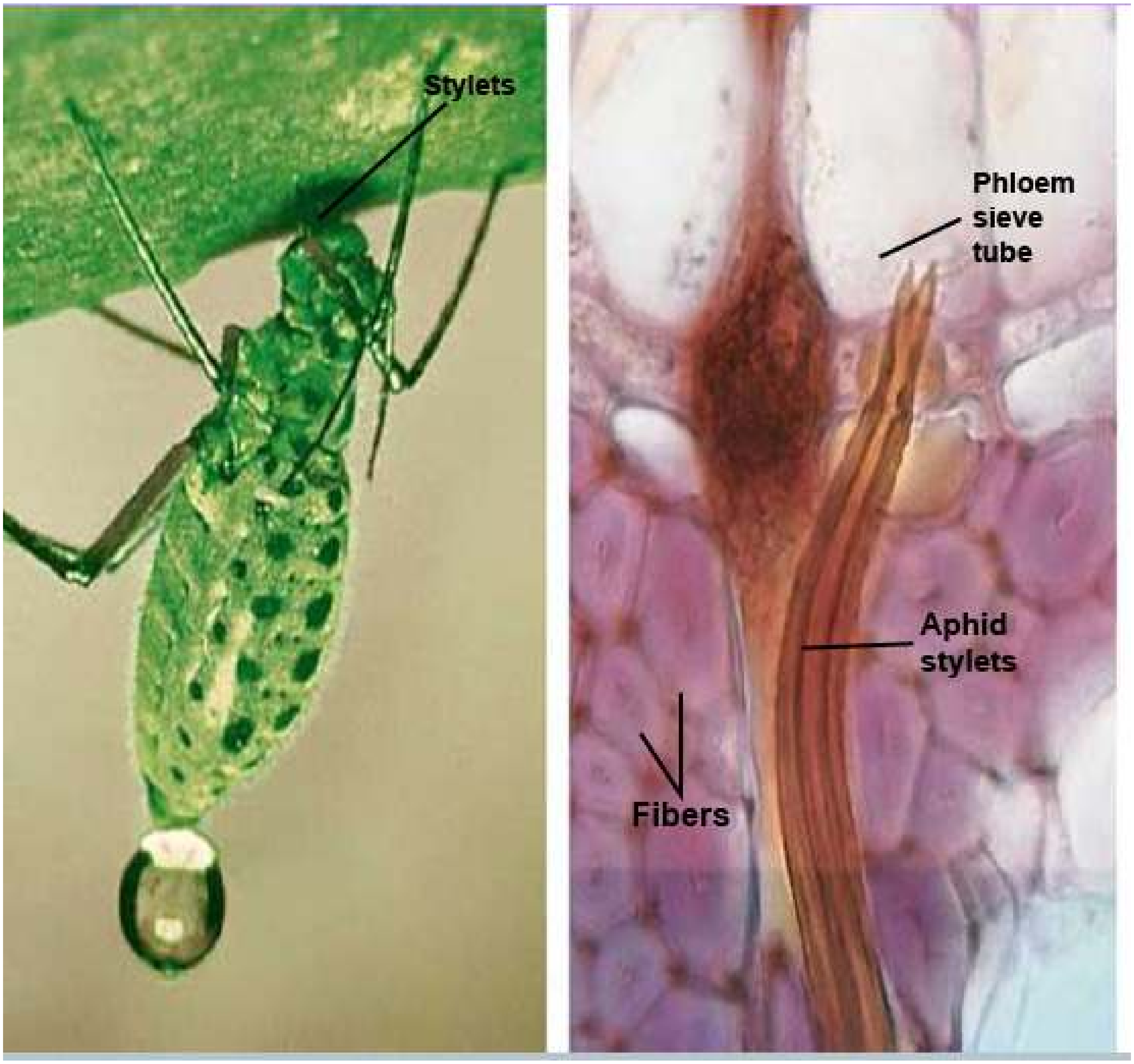


Fig.14.11 Collection of phloem sap using aphids

The Mechanism of phloem translocation/transport

The theory called, Pressure - Flow Theory, is the most acceptable theory for the transport in the phloem of angiosperms. We have considerable evidence to support this theory. There were two main categories of theories to account for movement of sap in phloem. The active theories involving the use of energy for the movement of materials in phloem, and the passive theories in which no use of energy was involved. The active theories have all been abandoned as there is not much evidence to support these theories.

Now we are left with passive theories of transport / translocation. These include:

(i) Diffusion **(ii)** Pressure flow theory

(i) Diffusion: is far too slow, to account for the velocities of sugar movement in phloem, which on the average is 1 metre per hour, while the rate of diffusion is 1 metre per eight years. So we are left with pressure flow theory.

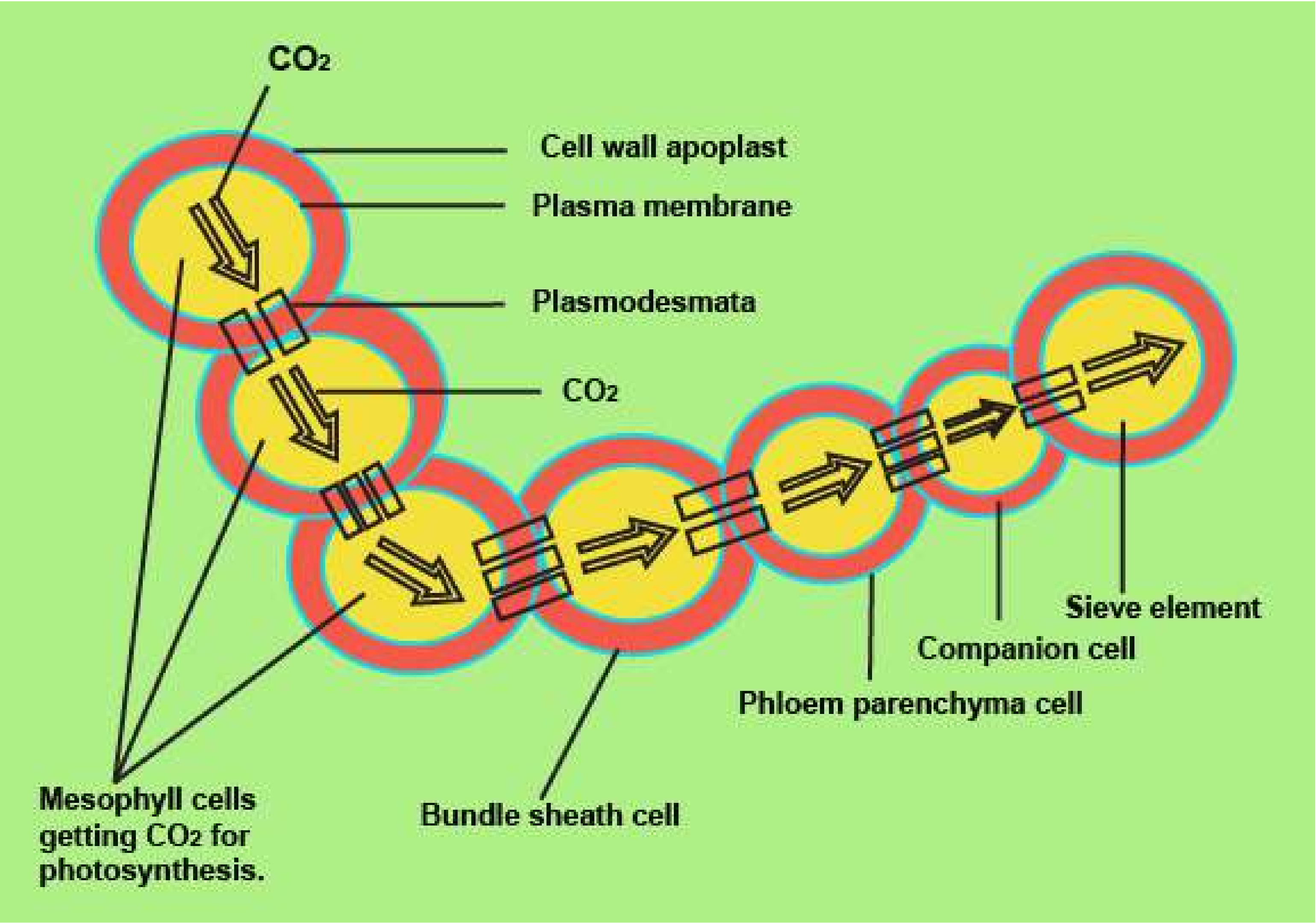


Fig.14.12 Movement of sugars from mesophyll cells to sieve elements.

(ii) Pressure flow theaory: A hypothesis was first proposed by Ernst Munch in 1930. It states that the flow of solution in the sieve elements is driven by anosmotically generated pressure gradient between""source and sink. Now this hypothesis has been given status of a theory. See Fig. 14.13, the following steps,explain pressure flow theory.

(1) The glucose formed in the photosynthesizing cells, is used within the cells (for respiration etc.) and the rest is converted into non-reducing sugar i.e. sucrose. (2) This sucrose is actively transported through the bundle sheath cells to the companion cell of the smallest vein in leaf, a

short distance transport (involving 2 - 3 cells). Thus sucrose diffuses through plasmodesmata to sieve tube cell or sieve element, raising the concentration of sucrose in it. (Fig. 14.12) The pathway taken by sucrose is symplast in most cases; but is some, apoplastic movement does take place. The sucrose is actively transported to the sieve elements. (3) The water moves by osmosis from the nearby xylem in the leaf vein. This increases the hydrostatic pressure of the sieve tube element.

(4) Hydrostatic pressure moves the sucrose and other substances in the sieve tube cells, and moves to sinks e.g. fruits and roots. In the storage sinks, such as sugar beet root and sugarcane stem, sucrose is removed into apoplast prior to entering symplast of the sink.

(5) Water moves out of sieve tube cell by osmosis, lowering the hydrostatic pressure.

In symplastic pathway, sucrose (or sugars) move through plasmodesmata to the receiver cell. Thus according to pressure flow theory, the pressure gradient is established as a consequence of entry of sugars in the sieve elements at the source; and removal of sugars (sucrose) at the sink (Fig. 14.13). The energy driven entry of sugars in sieve tube elements, generate high osmotic pressure in the sieve tube elements of the source causing a steep drop in the water potential.

(6) The presence of sieve plates greatly increases the resistance along the pathway and results in the generation and maintenance of a substantial pressure gradient in the sieve elements between source and sink.

The sieve element's contents are physically pushed along the transportation pathway by bulk flow, much like water flowing through a garden hose.

The pressure flow theory accounts for the mass flow of molecules within phloem. It may be noted that the transpertation of photosynthate or carbohydrates from the mesophyll cells to phloem tissue involves diffusion and active transport (carrier mediated transport). Then in phloem tissue (sieve tubes) the movement of materials is according to pressure flow theory.

Again in the sink cells when the sugar and the carbohydrates are passed from the phloem tissue, diffusion and carrier mediated transport, either passive or active, takes place, (see table 14.1).

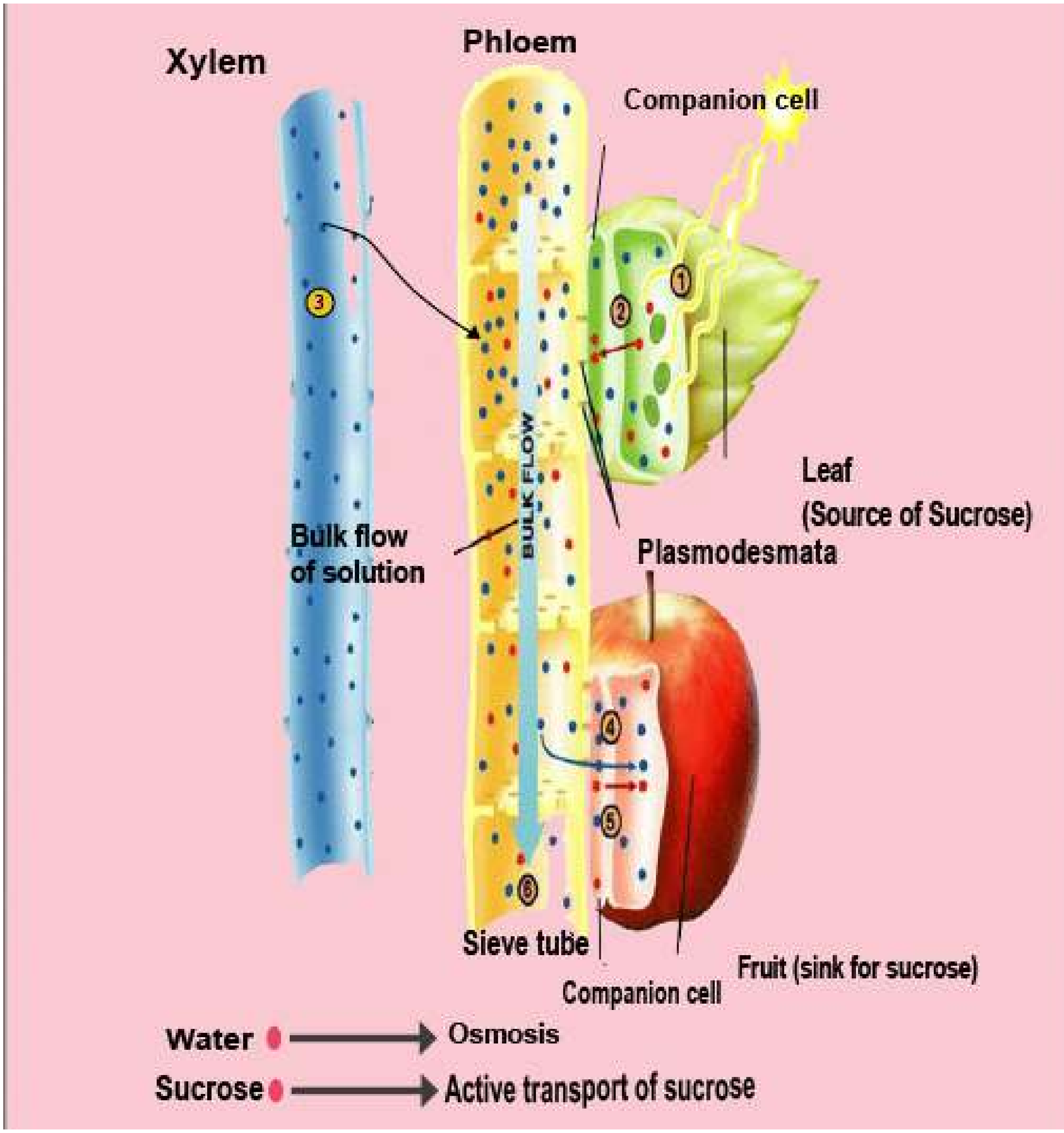


Fig. 14.13 The Pressure-flow theory (1) A photosynthesizing leaf manufactures sucrose (red dots), which (2) is actively transported (red arrow) into a nearby companion cell. The sucrose diffuses to sieve-tube element through plasmodesmata, raising the concentration of sucrose. (3) Water (blue dots leaves nearby xylem and moves into the "leaf end" of the sieve tube by osmosis (blue arrow), raising the hydrostatic pressure. (4) The same sieve tube connects to a developing fruit (sink); sucrose enters the companion cells by diffusion through plasmodesmata. It is then actively transported out of the companion cells and into the fruit cells. (5) Water moves out of the sieve tube by osmosis, lowering the hydrostatic pressure within the tube. (6) High pressure in the leaf end of the phloem and low pressure in the fruit end cause water, together with any dissolved solutes, to flow in bulk from leaf (source) to fruit. (Black arrow).

TRANSPORT IN ANIMALS

Unicellular animals have maximum surface area to volume ratio; and most of the substances move into or out of their bodies by simple diffusion, osmosis, active transport, and facilitated diffusion. So there are no special transport systems involved. Same is true of simple multicellular animals which are aquatic. But complex multicellular animals possess highly organized, and well developed transport system, in the form of blood vascular system.

Transportation in *Hydra*

It is fresh water in habitat. The body is two layered; the outer ectoderm and inner endoderm; in between them is mesogloea which is non-cellular. The outer surfaces of the ectoderm cells are exposed to the water in which the animal lives. Water, dissolved 0_2, and food is taken into the coelenteron(enteron) of Hydra by the movement of tentacles, and flagella which are present in most cells of endoderm.

The materials and food may be absorbed or taken up by endocytosis into endodermal cells. The indigestible and partly digested food is removed by exocytosis from these cells, into digestive cavity (coelenteron). Ectodermal cells get food from endodermal cells by diffusion.

The ectodermal cells directly exchange materials with the surrounding water (Fig 14.14). They also get nutrients from endodermal cells.

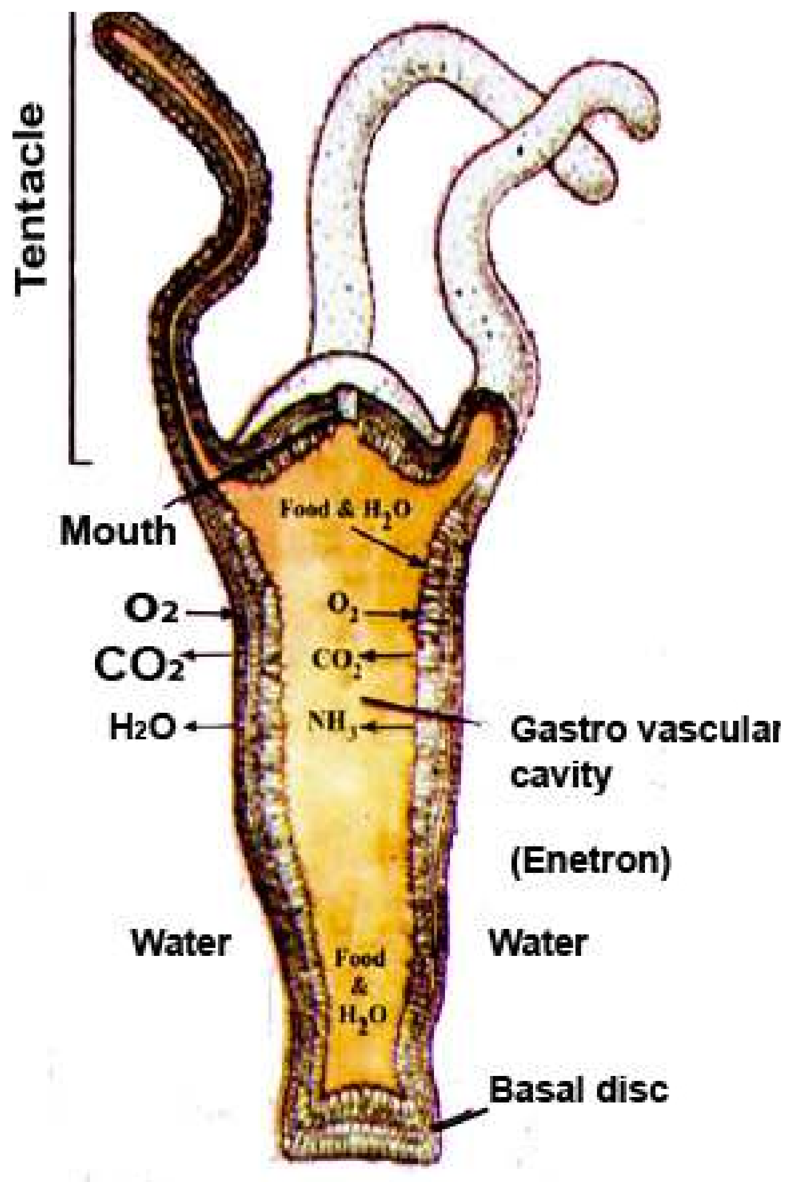


Fig.14.14 Hydra

Transportation in *Planaria*

The body of Planaria is flat, so the most of its cells are exposed to the outer water. Diffusion is the process involved in the movement of materials into and out of the cells.

There is no special transport system in Planaria. The reasons are:

(i) The body of Planaria is flat, and provides greater surface area for the exchange of materials, between the body and the environment.

(ii) Planaria is acoelomate i.e. there is no body cavity and the mesodermal layer or mesenchyme is composed of loosely packed cells between ectoderm and endoderm. Whatever materials, such as 0_2, diffuse in the ectoderm, pass to mesoderm cells and then diffuse into endoderm cells. For the removal of wastes the same route is reversed. Intestinal caecae reach near almost every cell of the body and digested food is provided to the cells by diffusion. The endoderm cells, can also acquire food, water, dissolved minerals, and to some extent 0_2. and remove wastes into the gut.

CIRCULATORY SYSTEM

In the body of larger and complex animals, there is very little exposed surface area to volume ratio. Most of the cells are not exposed to the external environment directly and it becomes very difficult to transport materials by simpl diffusion. Complex animals have evolved transport systems in the form of blood vascular system or circulatory system.

Characteristics of Circulatory System

A circulatory system accounts for rapid mass flow of materials from one part of the body to the other, where diffusion would be too slow.

There are three characteristics of a circulatory system.

(A) A circulatory fluid - the blood.

(B) A contractile pumping device - which may be the modified blood vessel or a heart.

(C) Tubes, which can transport the circulatory fluid (blood) to and from cells of the body These tubes are the blood vessels. Materials must be exchanged between the circulatory fluid and other body cells.

Open and Closed Circulatory System

The circulatory systems of animals are divided into two main types:

a) Open circulatory system: It is observed in animals belonging to Phylum Arthropoda (crustaceans, spiders, insects) and Phylum Mollusca (snails and clams) and group of protochordates, the tunicates.

b) closed circulatory system: It is observed in animals belonging to annelids,cephalopod molluscs (squids and octopus), echinoderms and vertebrates.

The differences between open circulatory system and closed circulatory system would be clear by studying the comparison between circulartary systems of earth worm and cockroach, (see table 14.1).

Animation 14.7: Circulatory System
Source and Credit: technostrikers

Table 14.1 Comparison between closed and open circulatory systems.

Closed circulatory system e.g. Earthworm (*Pheretima*)	**Open circulatory system e.g. cockroach (*Periplaneta*)**
1. Blood always remain in the blood vessels, and does not come in direct contact with other cells of the body.	1. Blood does not remain enclosed in the blood vessels and comes in direct contact with other body cells, and bathes them.
2. Inter connected system of arteries , veins, and capillaries present.	2. There are no typical arteries, veins, and capillaries and for much of the time the blood called haemolymph flows in the cavities or sinuses of body cavity (hoemocoel) around the viscera (perivisceral sinus) and around the nerve cord (perineural sinus).
3. Exchange of nutrients and waste products between the blood and tissues via tissue fluid occurs through capillaries.	3. Exchange of nutrients and waste products between the blood and tissues occurs when blood directly bathes the tissues.
4. The system also transports gases i.e. oxygen and carbon dioxide.	4. This sytem does not transport gases i.e. oxygen and carbon dioxide (these gases are transported by tracheal system).
5. Respiratory pigment haemoglobin is dissolved in blood. Nucleated white blood cells are present.	5. No respiratory pigment and blood is colourless in which nucleated white blood cells float.
6. This is regarded as the most advanced type, having greater efficiency, maintaining the blood pressure and economy of blood volume.	6. This is regarded as primitive having lesser efficiency and does not maintain blood pressure.
7. In earthworm there are 4 or 5 pairs of lateral hearts present on the lateral side of oesophagus in 7th to 13th segments. Hearts pump the blood from the dorsal to the ventral blood vessel.	7. In cockroach the heart is 13-chambered, tubular vessel present in the pericardial sinus and placed in mid-dorsal region below terga in abdominal region. On the side of the pericardial sinus there are alary muscles helping in the flow of blood. Each heart chamber has a pair of lateral openings, the ostia.
8. There are three main longitudinally running blood vessels, dorsal, ventral and sub-neural, which are interconnected through capillaries and commissural vessels.	8. The portion of the tubular dorsal vessel which extends in the thoracic and head region is called the “aorta”. It opens anteriorly in the haemocoel of the head by funnel shaped opening.

9. The dorsal vessel collects blood from the 14th segment backwards. In the first 13 segments it becomes distributing channel and sends its blood to hearts and anterior end of the body. Ventral vessel is the chief distributing vessel with backward flow.The subneural vessel is collecting vessel and the flow of blood is backwards. It communicates with dorsal blood vessel through commissural vessels.	9. The flow of blood from heart to, aorta to, haemocoel in head, to perivisceral sinus, to perineural sinus, to pervisceral sinus, to pericardial sinus, and to heart through ostia.

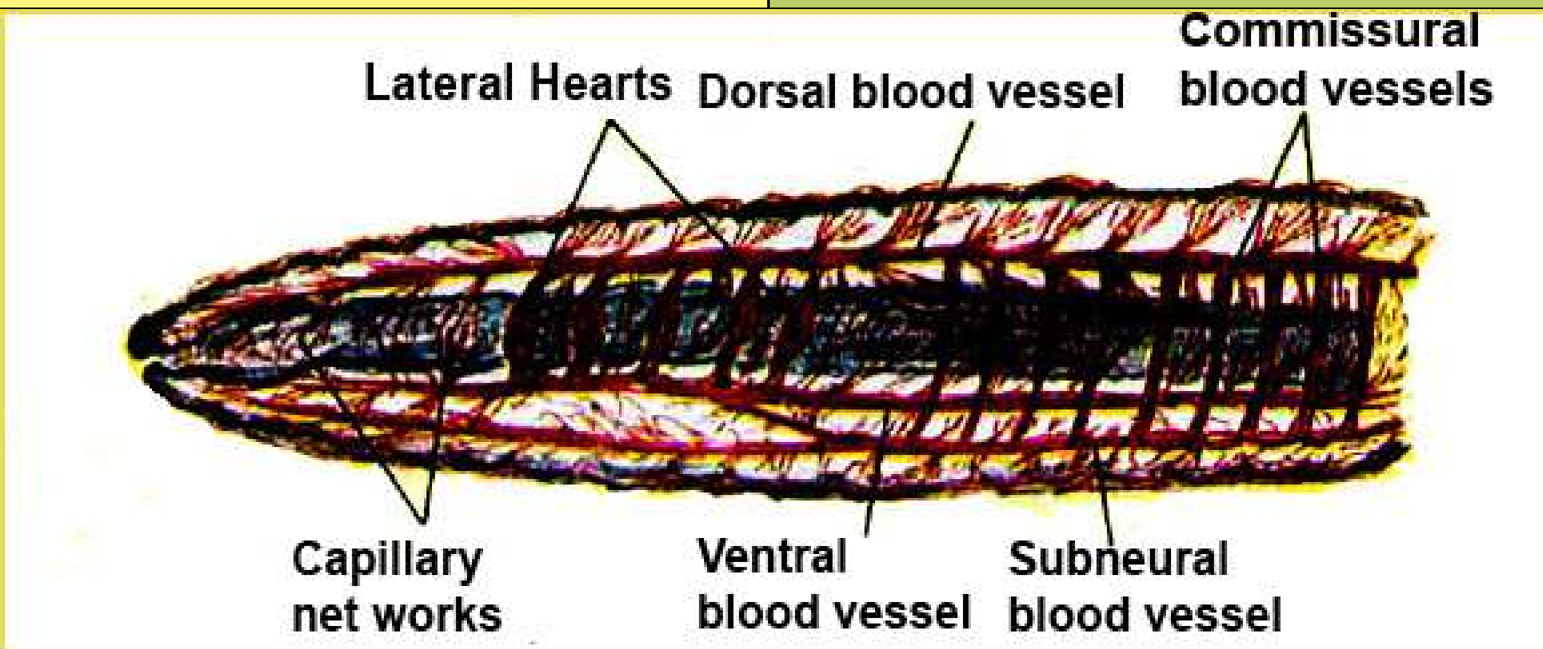


Fig. 14.15 Closed circulatory system of earthworm

Animation 14.8: Closed circulatory system of earthworm
Source and Credit: waterwereld

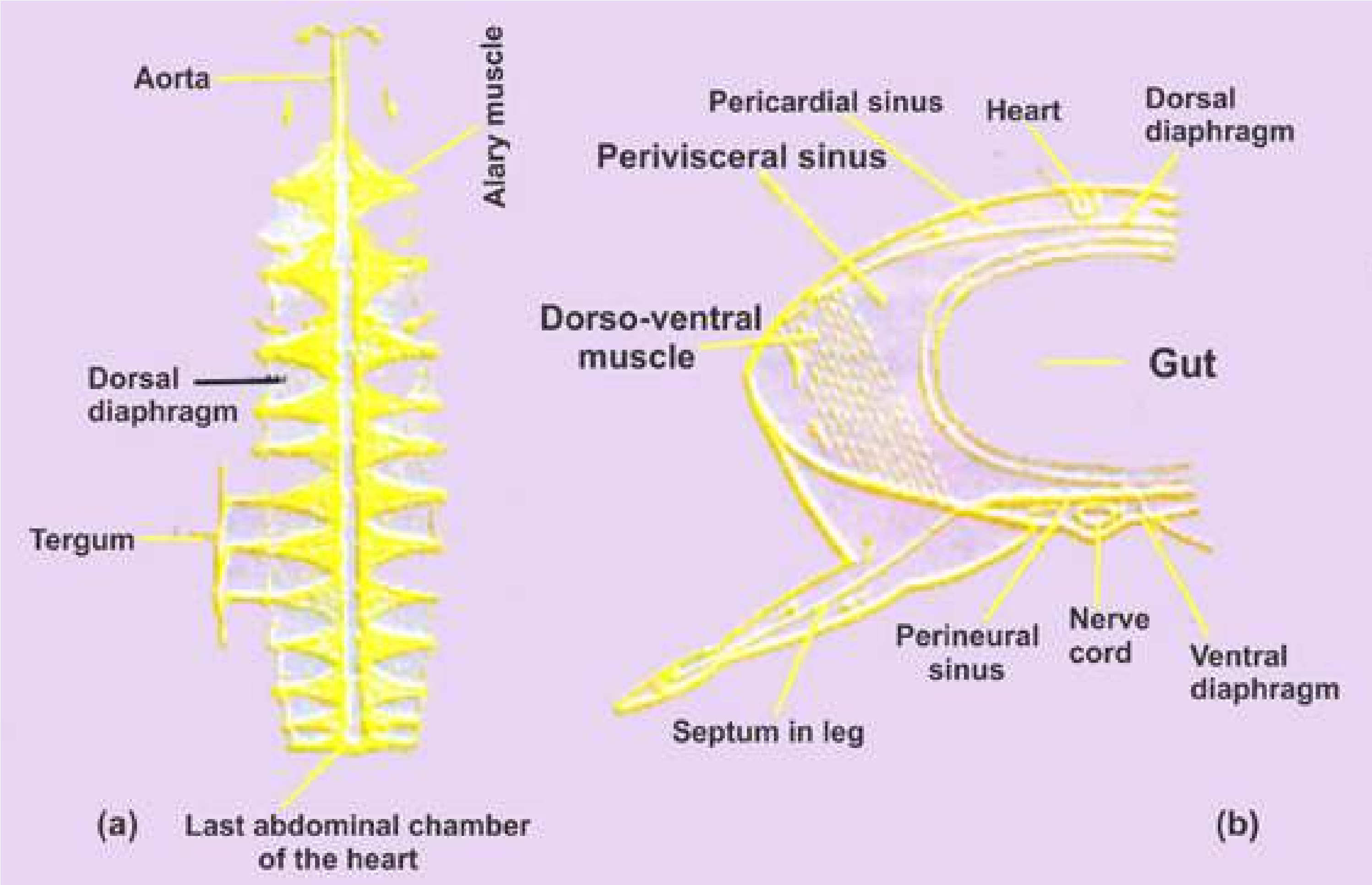


Fig.14.16 Open circulatory system of cockroach, (a) The heart with alary muscle and dorsal diaphragm, (b) T.S of cockroach through thorax showing various sinuses.

Vertebrate blood circulatory system

The components of vertebrate blood vascular system are typical of a circulatory system-blood, heart, blood vessels (arteries, capillaries and veins). All vertebrates have closed circulatory system In addition there is lymphatic system which also aids in transportation.

Heart pumps the blood to different parts of the body via aorta and arteries Arteries break into fine blood vessels, the capillaries. These join to form veins which bring blood back to the heart. The capillaries are sites where exchange of materials between blood and body tissues takes place.

Evolution of vertebrate heart

The heart of fishes have sinus venosus, an atrium, a ventricle, and bulbus arteriosus or conus arteriosus. Sinus venosus receives deoxygenated blood from the body,and then blood is passed to atrium, which on contraction passes it to ventricle. ventricle has thick muscular wall. When the muscles of ventricle contract, they push the blood via conus arteriosus or bulbous arteriosus (proximal swollen portion of ventral aorta).

Thus the heart of fishes works as a **single circuit heart**. The blood flows in one direction only, from sinus venosus to atrium then to ventricle and to ventral aorta via bulbus arteriosus or conus arteriosus to the gills and then to the body. The blood returns to the heart in the sinus venosus The oxygenated blood is supplied from dorsal aorta through coronary arteries,to the heart and is carried back by coronary veins from the heart).

The heart of the fishes never receives oxygenated blood. It is only the deoxygenated blood which passes through different chambers of the heart. (Fig. 14.18 a). The valves present in the heart control the flow of blood in single direction i.e. sinus venosus —> atrium —> ventricle conus arteriosus —> ventral aorta —> gills —> dorsal aorta —» body —» sinus venosus. So the heart of fishes functions as a single circuit heart.

In amphibians the heart is three chambered with regard to auricles and ventricles.There are two auricles and one ventricle. In addition, sinus venosus and truncus arteriosus are also present. Sinus venosus receives de-oxygenated blood from two superior venacavae (precavals) and one inferior vena cava (postcaval) from different parts of the body. This blood passes to the right auricle. The oxygenated blood from lungs is poured via pulmonary veins into left auricle. Both auricles contract simultaneously and blood is passed into the ventricle. There is a complete mixing of oxygenated and deoxygenated blood in the ventricle. When ventricle contracts, it pushes blood via truncus arteriosus, to two carotids, two systemics, and two pulmocutaneous arches. (Fig. 14.19b).

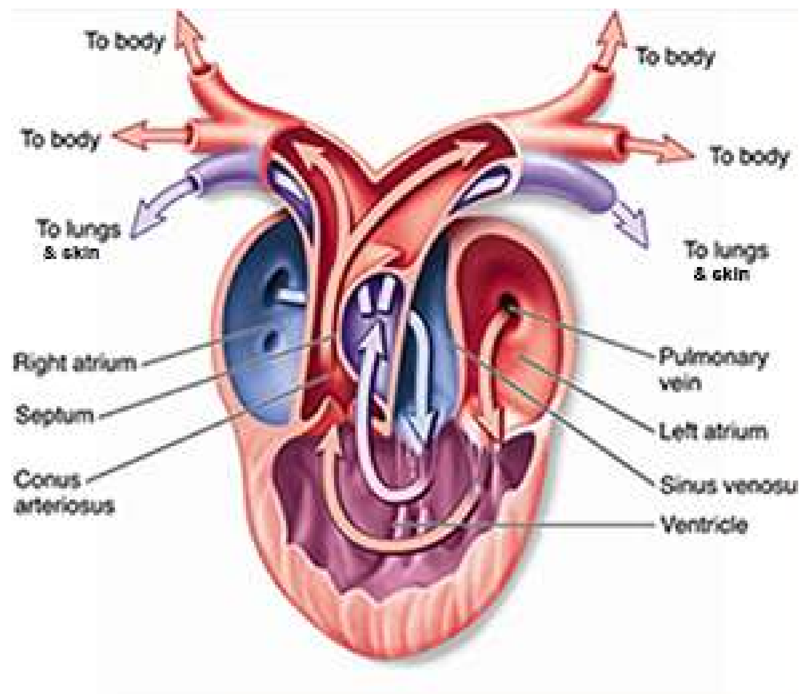


Fig. 14.17 Structure of heart of frog

Animation 14.9: Structure of heart of frog
Source and Credit: multelearn

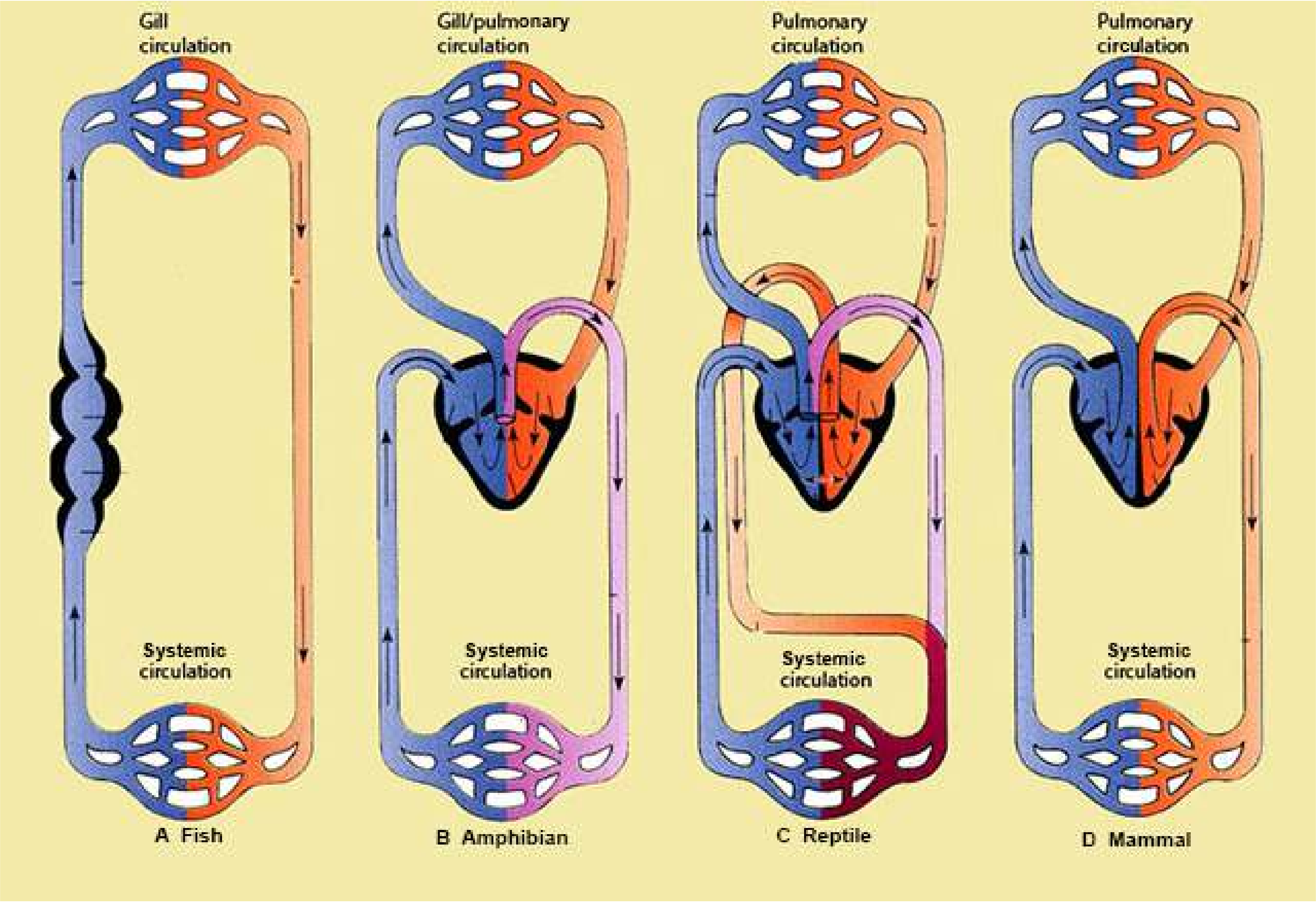


Fig.14.18 A schematic comparison of vertebrate heart and circulation of blood. (A) In modern fish the blood is pumped to the gills, where it picks up oxygen. The oxygenated blood (red) then passes without further pumping to the systemic circulation, where it gives up its oxygen before returning to the heart. (B) In amphibians the blood that has picked up oxygen in the gills and/or lungs returns to the heart, from which it is pumped into the systemic circulation. Extensive mixing (purple) of the pulmonary and systemic flows occurs in the heart. (C) In reptiles the pattern is much the same, except that the ventricles are partially divided, so less mixing takes place. (D) In mammals and birds the two halves of the heart are effectively separated.

The heart of reptiles and all other amniotes practically functions as four chambered heart. There are two auricles in the heart of reptiles. The reptiles have incompletely partitioned ventricle; but in crocodiles, the interventricular septum is complete and heart is four chambered. In all reptiles the left and right systemic arches carry oxygenated blood and arise from a region of ventricle called cavum venosum - into which left ventricle directs its blood. The deoxygenated blood from the right atrium is directed towards the entrance of the pulmonary trunk which is also located or starts from a pocket the cavum pulmonale, on right side of ventricle- in the animals (reptiles) which do not have completely divided ventricle. Although the two systemic arches start from the ventricle separately, they are also interconnected at their base by an opening. The heart of reptiles birds and mammals functions as **double circuit heart.** (Fig. 14.19c).

In the birds and mammals, the heart is four - chambered, and oxygenated and deoxygenated blood does not mix at all. The pulmonary trunk arises from right ventricle and leads to the lungs.

The aortic trunk emerges from the left ventricle and leads to carotid and systemic arches. The left systemic disappears in birds and right systemic, most of it, disappears in mammals. (Fig. 14.19 D).

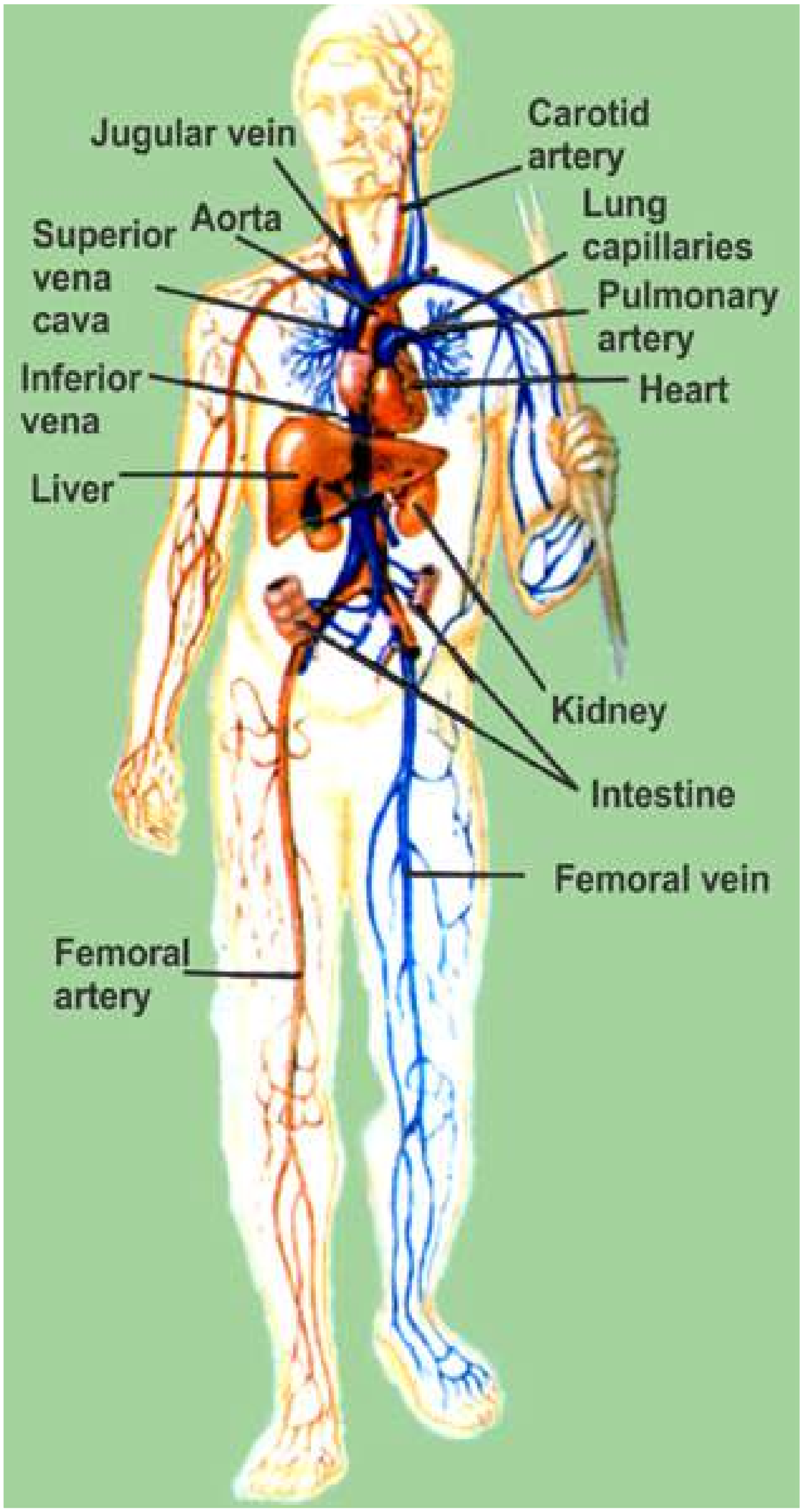


Fig. 14.19 The human circulatory system

In reptile, birds and mammals, as a result of these modifications, all blood returning to the right side of the heart passes to the lungs. After oxygenation, blood returns to left atrium from the lungs via pulmonary veins. Left atrium passes this blood to left ventricle - which on contraction pumps it to different parts of the body, and again blood returns to right atrium (Fig.14.18D). **Pulmonary circulation** is by pulmonary arch carrying deoxygenated blood from right ventricle of heart to lungs, and the blood returns to left atrium after oxygenation via pulmonary veins.

Likewise the systemic arch distributes blood to different parts of the body, and then the blood from the body returns to the heart, in the right atrium via precaval and postcaval. This is **systemic circulation**. So the hearts of amphibians, reptiles, birds and mammals have both pulmonary and systemic circulation.

TRANSPORT IN MAN :

In humans, in addition to blood circulatory system, there is also another transport system, the lymphatic system, described latter in this chapter.

Blood circulatory system

The circulatory system of humans have the same 3 basic components.
(A) Circulating fluid - the blood.
(B) The pumping organ - the heart.
(C) The blood vessels, arteries, capillaries and veins.

(A) The circulatory fluid-the blood

The blood is the medium in which dissolved nutrients, gases, hormones, and wastes are transported through the body. It is made up of two main components, (i) plasma and (ii) cells or cell - like bodies (white blood cells, red blood cells, platelets). The weight of the blood in our body is about 1/12th of our body.

(i) PLASMA : It has been estimated that in a normal person plasma constitutes about 55% by volume of the blood, and cells or cell-like bodies about 45% by volume of the blood.

Plasma is primarily water in which proteins, salts, nutrients and wastes are dissolved. Water constitutes about 90% of plasma, 10% are dissolved substances. Most of the dissolved substances are maintained at a constant or nearly constant level, but others occur in varying concentrations.

The substances dissolved or present in plasma vary in their concentrations, with the condition of the organism and with the portion of the system under examination. The solutes can be divided into six categories:

Inorganic salts (ions) - Plasma proteins - Organic nutrients - Nitrogenous waste products - Special products being transported and gases which are dissolved.

1. Inorganic ions or mineral ions. Together the inorganic ions and salts make up 0.9 per cent of the plasma, of humans, by weight; more than two thirds of this amount is sodium chloride the ordinary table salt. Even if the total concentration of dissolved substances remains the same, shifts in the concentration of particular ion can create serious disturbances. The normal pH of human blood is 7.4; and it is maintained between narrow limits, because the change in pH would affect the chemical reactions of the body.

2. The plasma proteins constitute 7-9 percent by weight of the plasma. Most of these proteins are synthesized in the liver. Some of the globulins, called immunoglobulins or antibodies, are produced in response to antigens, by lymphocytes; and then are passed to plasma, and lymph.

The proteins like prothrombin acts as a catalyst in blood clotting process. Fibrinogen takes part in the blood clotting process. Immunoglobulins play important role in body's defenses against disease.

3. Organic nutrients in the blood include, glucose, fats, phospholipids, amino acids and lactic acids. Some of them enter the blood from the intestine (absorption). Lactic acid is produced in muscles as a result of glycolysis, and is transported by blood to liver. Cholesterol is an important constituent, it is metabolized to some extent, but also serves as precursor of steroid hormones.

4. Plasma also contains nitrogenous waste products formed as a result of cellular metabolism. These products are carried from the liver where they are produced, to the organs from where they are removed i.e. kidneys. Urea and small amounts of uric acid are present in plasma.

5. All the hormones in the body are carried by blood - so they are present in the plasma.

6. The gases such as CO_2, O_2 are present in the plasma of the blood.

Animation 14.10: Blood Circulatory system
Source & Credit: my-ecoach

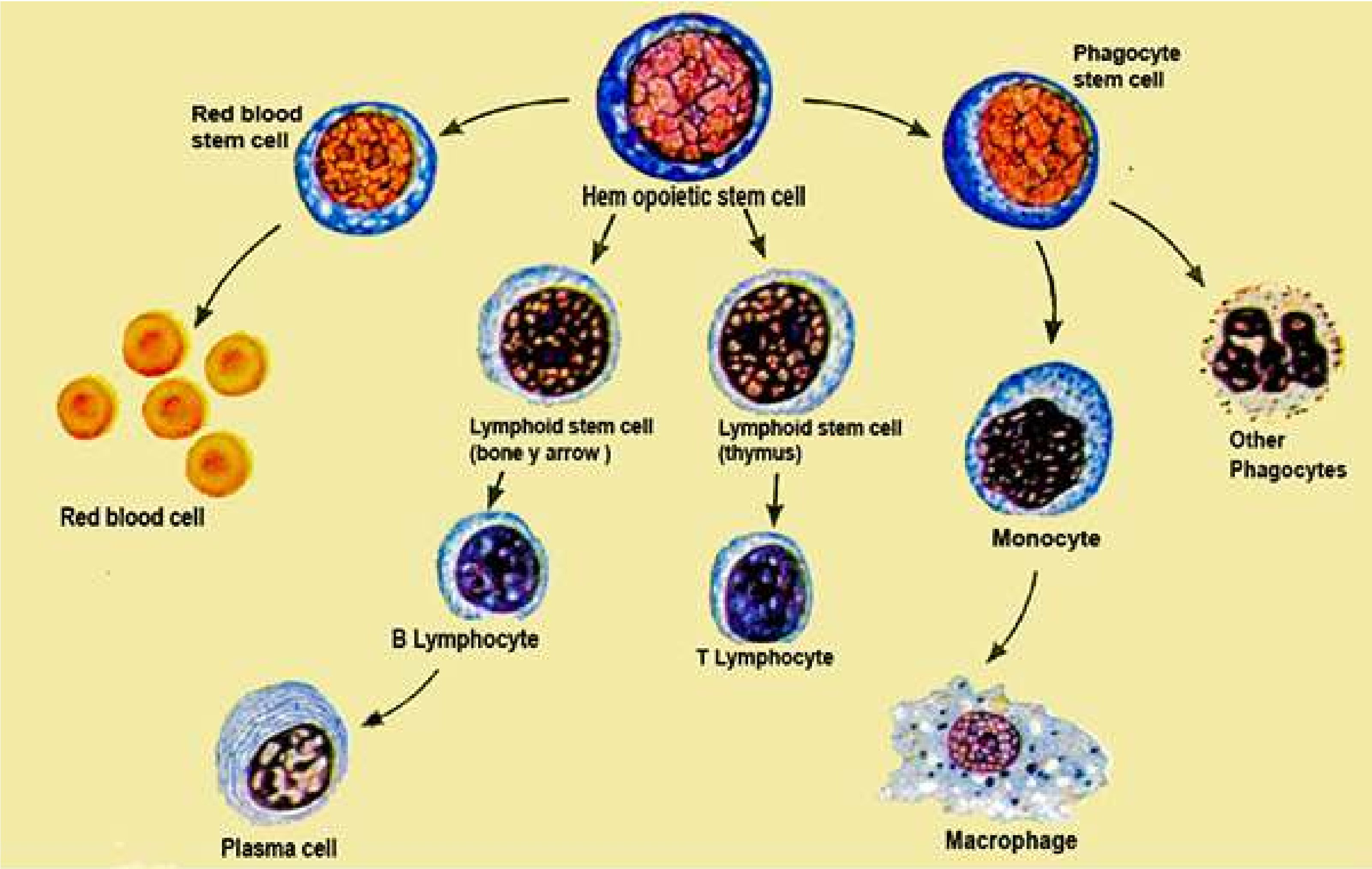


Fig.14.20 Red blood cells (erythrocytes) and white blood cells (leucocytes) develop from stem cells in bone marrow.

(ii) BLOOD CELLS AND CELL LIKE BODIES : These include red blood cells, (Erythrocytes), white blood cells (leucocytes) and platelets.

(a) Red blood cells (Erythrocytes) : These are most numerous of the cells in the blood. A cubic millimeter contains 5-1/2 million of them in males, and 4-1/2 million in females. These cells, when formed, have nucleus, but it is lost before they enter the circulatory fluid or blood. 95% of the cytoplasm of red blood cells is the red pigment, called haemoglobin the remaining 5% consists of enzymes, salts and other proteins. The red cells once mature, do not divide.

Red blood cells are formed principally in the red bone marrow of short bones, such as the sternum, ribs and vertebrae (Fig. 14.20). In the embryonic life, they are formed in the liver and spleen. The average life span of red blood cell is about four months after which it breaks down and disintegrates in the liver and spleen - partly by phagocytes by phagocytosis (Table -14.2)

(b) White blood cells (Leucocytes): These blood cells are colourless, as they do not contain pigments. One cubic millimetre of blood contains 7000 to 8000 of them. They are much larger than the red blood cells. There are at least five different types which can be distinguished on the basis of the shape of the nucleus and density of granules in the cytoplasm (Table 14.2). They can be grouped into two main types, granulocytes and agranulocytes. Granulocytes, include neutrophils, eosinophils and basophils. They are formed in the red bone marrow (Fig. 14.20). Agranulocytes are formed in lymphoid tissue, such as those of the lymph nodes, spleen, tonsils, adenoids and the thymus. Agranulocytes include monocytes and lymphocytes (B and T). Monocytes stay from 10- 20 hours in the blood, then enter tissues and become tissue macrophages, performing phagocytic function (Fig. 14.24) Lymphocytes have life spans of months or even years; but this depends on the body's need for these cells.

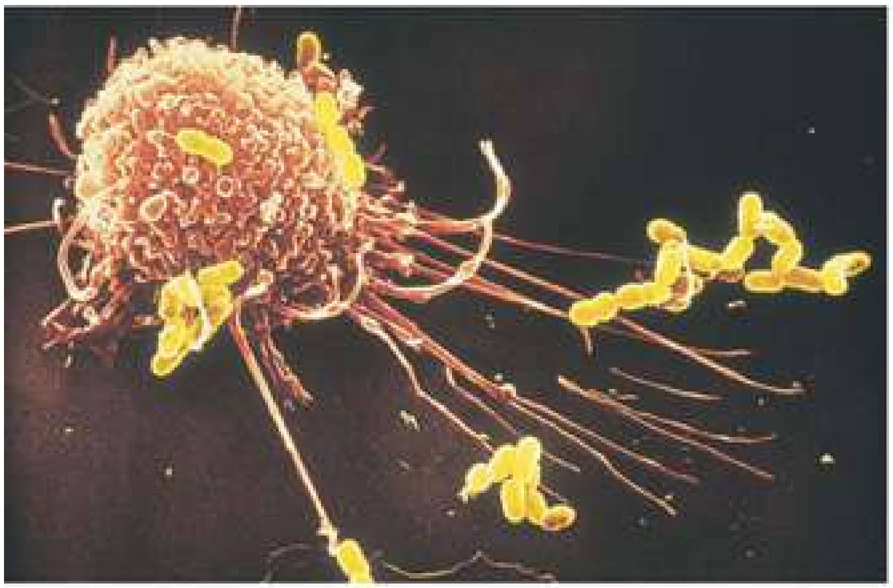


Fig. 14.21 A macrophage in Action

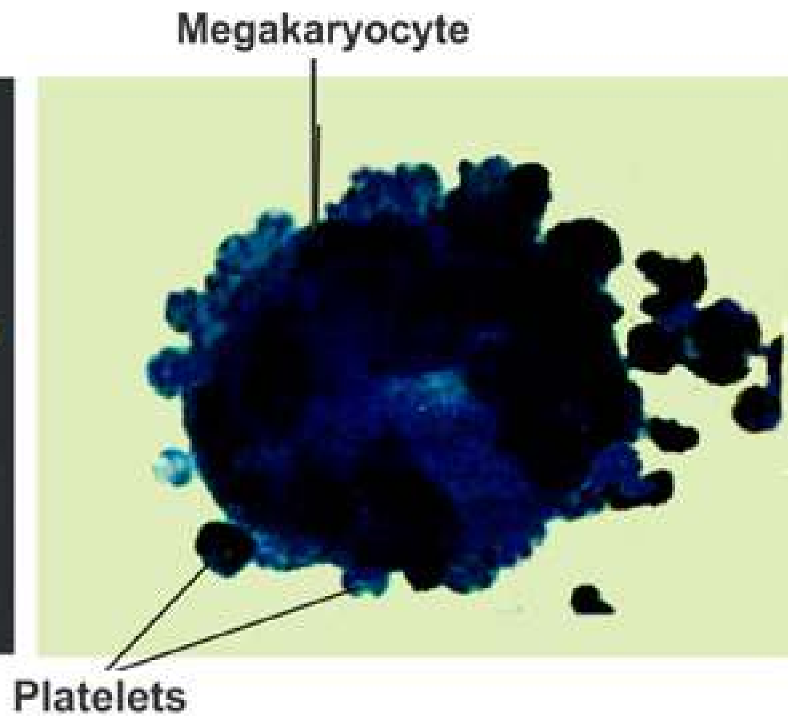


Fig. 14.22 The production of platelets

Animation 14.11: white blood cells
Source and Credit: gifsoup

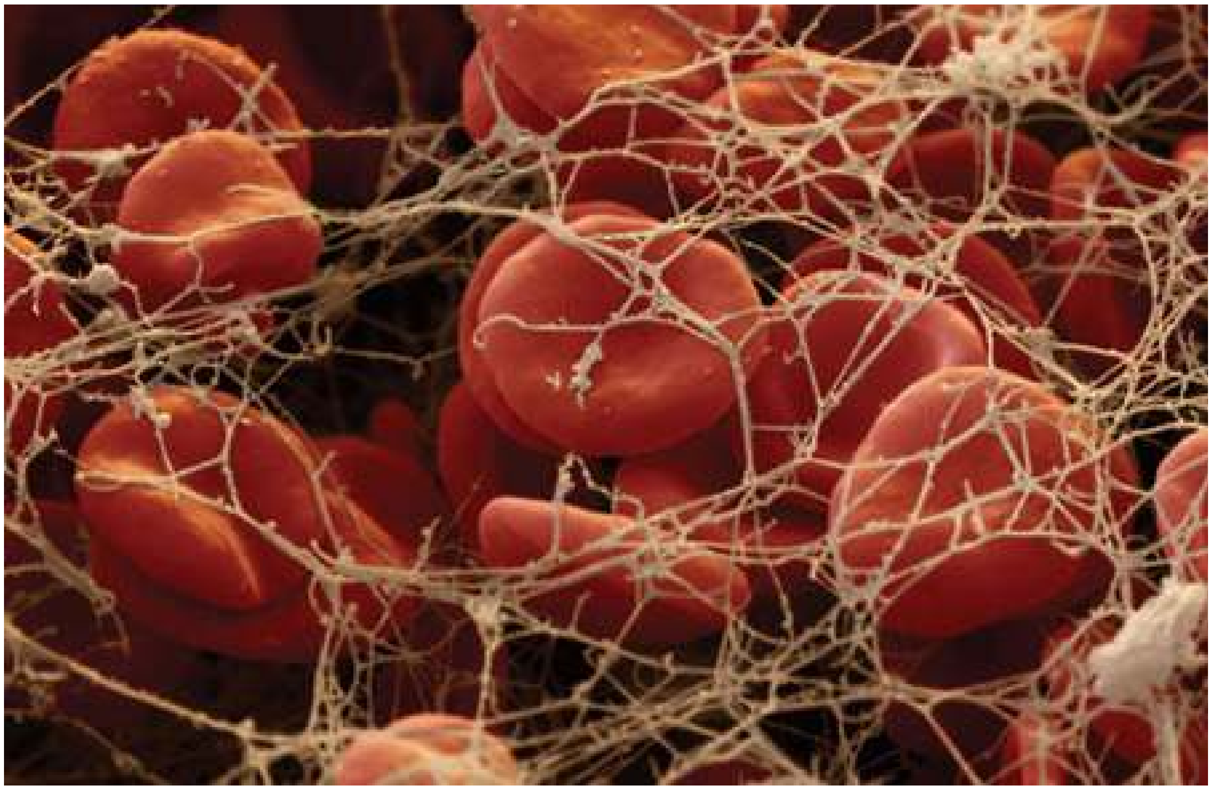


Fig. 14.23 Blood clotting

Animation 14.12: Blood Cells
Source & Credit: imgur

Cell Type		Description	Average Number present	Major Function
Red blood cell (erythrocyte)		Biconcave disc without nucleus, Approximately 8 μ m in diameter	5,000,000 per mm^3	Transports oxygen and a small amount of carbon dioxide.
White blood cell (leucocytes)			7500 per mm^3	
(a) Granulocytes 1. Neutrophil		About twice the size of red cells, nucleus two to five lobed	62% of white cells	Destroys small particles by phagocytosis.
2. Eosinophil		About twice the size of red cells, nucleus bilobed	2% of white cells	Inactivates inflammation-producing substances; attacks parasites.
3. Basophil		About twice the size of red cells nucleus bilobed	Less than 1% of white cells	Releases heparin to prevent blood clots and histamine, which causes inflammation.
(b) Agranulocytes 4. Monocyte		Two to three times larger than red cells, nuclear shape from round to lobed	3% of white cells	Gives rise to macrophage, which destroys larger particle by phagocytosis.
5. Lymphocyte		Slightly larger than red cell, nucleus nearly fills cell	32% of white cells	Functions in the immune response by producing anti bodies.
Platelets		Membrane bounded cytoplasmic fragment of cells in bone marrow called megakaryocytes	250,000 per mm^3	Involved in blood clotting.

Leucocytes protect the body against foreign invaders, and use circulatory system to travel to the site of invasion. Monocytes and neutrophils travel through capillaries and reach the site of wound where bacteria have gained entry. Macrophages and neutrophils feed on bacterial invaders or other foreign cells, including cancer cells (Fig. 14.21). They typically die in the process, and their dead bodies accumulate and contribute to the white substance called pus, seen at infection sites.

Basophils produce heparin - a substance that inhibits blood clotting. These also produce chemicals, such as histamine, that participate in allergic reactions and in responses to tissue damage and microbial invasion. Lymphocytes help to provide immunity against the disease.

(c) Platelets : These are not cells, but are fragments of large cells called megakaryoctyes (Fig. 14.22). There is no nucleus in them. There is no pigment in them. Platelets help in conversion of fibrinogen, a soluble plasma protein, into insoluble form, fibrin. The fibrin threads enmash red blood cells and other platelets in the area of damaged tissue, ultimately forming a blood clot. The clot serves as a temporary seal to prevent bleeding until the damaged tissue can be repaired (Fig. 14.23).

Functions of blood

The overall functions of blood in humans can be listed as follows:

i) The plasma proteins maintain colloid osmotic pressure of the blood (75% by albumins, 25% by globulins and almost none by fibrinogen).

ii) Blood helps to transport materials, in the body including nutrients, water, salts and waste products. All hormones are transported by blood from the endocrine tissues to the target cells.

iii) Gases O_2 and CO_2 are transported by blood.

iv) Blood helps in body defenses against disease, neutrophils and monocytes engulf and destroy invading microorganisms e.g. bacteria.

v) Blood provides immunity by the lymphocytes (pages 325-327).

vi) Blood produces interferon, and antitoxins which are proteins, and protects our body from nucleic acids and toxins of invading organism.

vii) Blood acts as a buffer to maintain the acid - base balance i.e. concentration of H^+ and OH ions of the body.

viii) Helps in maintaining the body temperature, concentration of water and salts, thus helps in homeostosis.

ix) Wall of Blood helps in the exchange of materials between blood and body tissue through blood capillaries via interstitial fluid.

x) Blood helps the body in maintaining the internal environment, by producing heparin, histamines, and also maintaining the amounts of chemicals including water and salts, in the body and maintains body temperature to a constant or nearly constant levels.

xi) Helps in blood clotting process and seals the wounds, that stop entry of pathogens into body.

DISORDERS

There are certain disorders, related to the blood. Some of them are discussed below:

i) Leucaemia (Blood Cancer)

It is the result of uncontrolled production of white blood cells (leucocytes). This is caused by a cancerous mutation of a myelogenous or lymphogenous cell. The Leucaemia is usually characteriszed by greatly increased numbers of abnormal white blood cells in the circulating blood. Myelogenous cells (bone marrow cells) are in the bone marrow - and may spread throughout the body, so that white blood cells are produced in many other organs. These white blood cells are not completely differentiated, and so are defective. Leucaemia may be of different types depending on the type of white blood cells, which are undifferentiated and being produced at a faster, than normal rate. There may be neutrophilic leucaemia, eosinophilic leucaemia, basophilic leucaemia, monocytic or lymphocytic leucaemia. It is a very serious disorder and the patient needs to change the blood regularly with the normal blood, got from donors. It can be cured by bone marrow transplant - which is in most cases effective, but very expensive treatment.

ii) Thalassaemia (G. Thalassa = The sea; haema = blood)

It is also called Cooley's anaemia on the name of Thomas B. Cooley, American pediatrician. It is a genetically transmitted haemoglobin abnormality. It is characterized by the presence of microcytes, by spleenomegaly (enlargement of spleen) and by changes in the bones and skin. The blood of these patients is to be replaced regularly, with normal blood. It can be cured by bone marrow transplant - which is very expensive - and does not give 100% cure rate. Haemoglobin molecule in most cases, does not have (β- chains in it, instead F.chain is present (F is foetal haemoglobin).

iii) Oedema

It means the presence of excess fluid in the tissues of the body. The excess fluid may be in the cells, or outside the cells. The intracellular oedema is caused by osmosis of water into the cells, and cause, depression of metabolic systems (due to lack of nutrition and O_2 in the tissues) especially and the Na-pump.

The extracellular oedema may be the result of :

i) Abnormal leakage of fluid from the blood capillaries or failure of the lymphatic system to return fluid from the interstitial fluid.

ii) Oedma is caused by renal retention of salts and water. Oedema disturbs the exchange and concentration of minerals and ions in the blood and body cells, affects blood pressure, increases heart load etc.

(B) Pumping Organ - The Heart

Structure and action : The heart of humans is located in the chest cavity. The heart is enclosed in a double membranous sac - the pericardial cavity, which contains the pericardial fluid. Pericardium protects the heart, prevents it from over extension.

The wall of the heart is composed of three layers.

(i) **Epicardium** (ii) **Myocardium** (iii) **Endocardium**

Myocardium of the heart is made up of special type of muscles, the cardiac muscles.

These muscles contain myofibrils, and myofilaments of myosin and actin. Their arrangement is similar to those in skeletal muscle fibres, and their mechanism of contraction is essentially the same, except that they are branched cells, in which the successive cells are separated by junctions called intercalated discs. The heart contracts automatically with rhythmicity, under the control of the autonomic nervous system of the body.

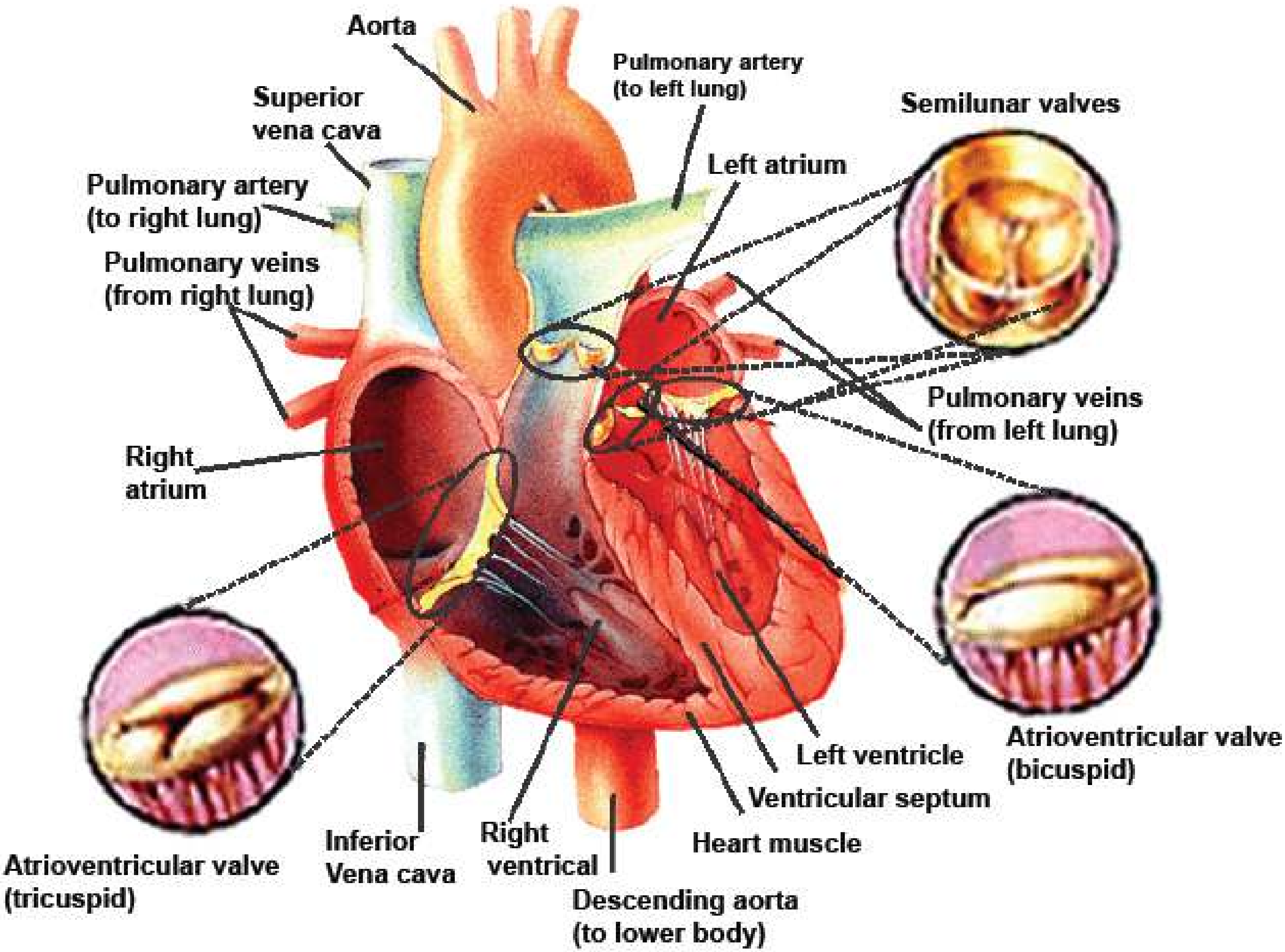


Fig 14.24 The human heart and its valves and vessels.

There are four chambers of the heart: two upper thin-walled atria, and two lower thick walled ventricles. Human heart functions as a double pump, and is responsible for pulmonary and systemic circulation. Complete separation of deoxygenated blood (Right side) and oxygenated blood (left side), in the heart, is maintained. The right atrium receives deoxygenated blood via venae cavae from the body.

The blood is passed on to right ventricle through tricuspid valve (called so because it has 3 flaps). These flaps are attached with fibrous cords called chordeae tendinae, to the papillary muscles which are extensions of the wall of the right ventricle. When right ventricle contracts, the blood is passed to pulmonary trunk, which carries blood via left and right pulmonary arteries, to the lungs. At the base of the pulmonary trunk, semilunar valves are present. After oxygenation in lungs the blood is brought by pulmonary veins to the left atrium, which passes this blood via bicuspid valve (called so because it has two flaps) to the left ventricle. The flaps of bicuspid valve are similarly attached through chordae tendinae, to papillary muscles of the wall of left ventricle. When the left ventricle contracts, it pushes the blood through aorta to all parts of the body (except lungs). At the base of aorta semilunar valves are also present. The valves of the heart control the direction of flow of blood. The wall of left ventricle is thicker (about 3 times) than that of the right ventricle. At the base of aorta, first pair of arteries, the coronary arteries, arise, and supply blood to the heart. The aorta forms an arch, and before descending down gives three branches supplying blood to head, arms and shoulders. The aorta descends down in the chest cavity. It gives many small branches to the chest wall and then passes down to the abdominal region. Here it gives branches, which supply blood to different parts of alimentary canal, kidneys and the lower abdomen.

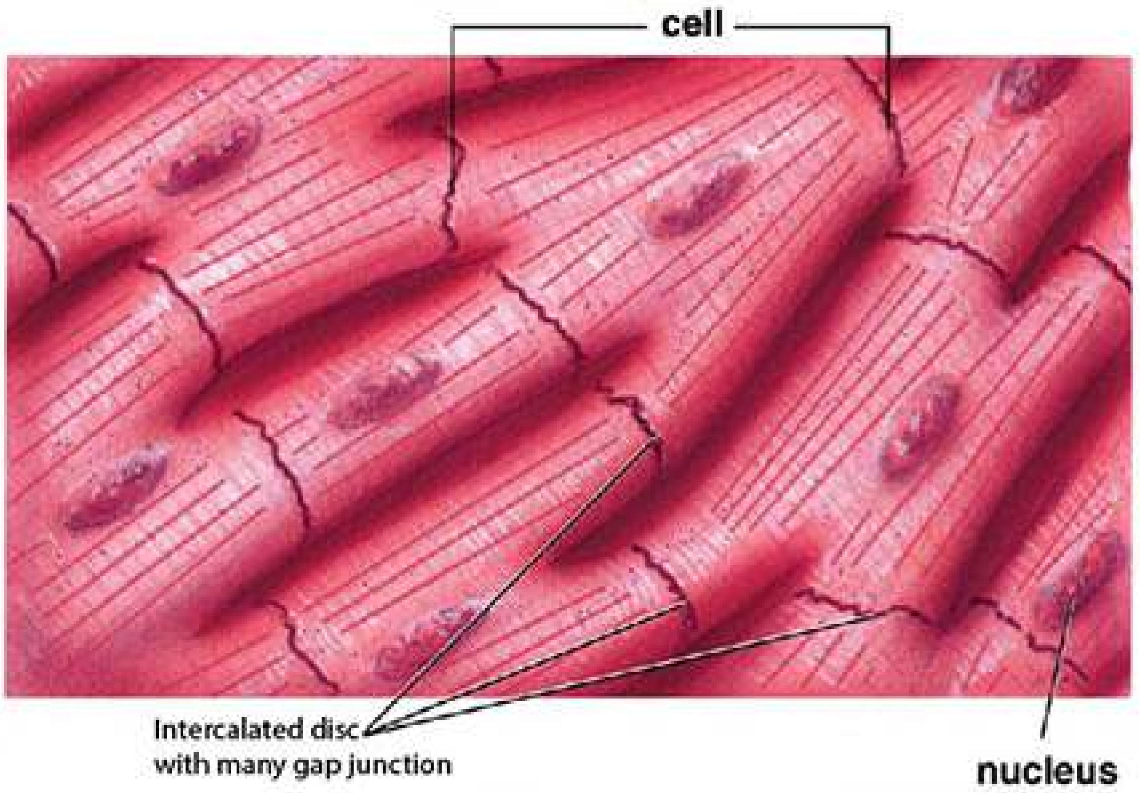


Fig.14.25 The structure of cardiac muscle

The aorta Bifurcates into iliac arteries, each of which leads to supply blood to each legs. The blood from the upper part of the body is collected by different veins, which join to form superior vena cava; which pass its blood to the right atrium. Two **Iliac veins** are formed by veins which collect blood from legs, and unite to from inferior **vena cava**. It receives **renal vein** from each kidney; and **hepatic vein** from the liver, before it enters the right atrium. The liver receives **hepatic portal vein** which is formed by many veins collecting deoxygenated blood with absorbed food from different parts of alimentary canal.

The Cardiac Cycle

It is the sequence of events which take place during the completion of one heart beat. Heart beat involves three distinct stages (Fig. 14.26).

1. Relaxation phase - diastole.

The deoxygenated blood enters right atrium through vena cava, and oxygenated blood enters left atrium through pulmonary veins. The walls of the atria and that of ventricles are relaxed. As the atria are filled with blood, they become distended and have more pressure than the ventricles. This relaxed period of heart chambers is called diastole.

2. Atria Contract - atrial systole

The muscles of atria simultaneously contract, when the atria are filled and distended with blood, this is called atrial systole. The blood passes through tricuspid and bicuspid valves, into the two ventricles which are relaxed.

3. Ventricles contract - ventricular systole

When the ventricles receive blood from atria, both ventricles contract simultaneously and the blood is pumped to pulmonary arteries and aorta. The tricuspid and bicuspid valves close, and 'lubb' sound is made. Ventricular systole ends, and ventricles relax at the same time semilunar valves at the base of pulmonary artery and aorta close simultaneously, and 'dubb' sound is made. (Lubb, dubb can be heard with the help of a stethoscope).

One complete heart beat consists of one systole and one diastole, and lasts for about 0.8 seconds. In one's life, heart contracts about 2.5 billion times, without stopping.

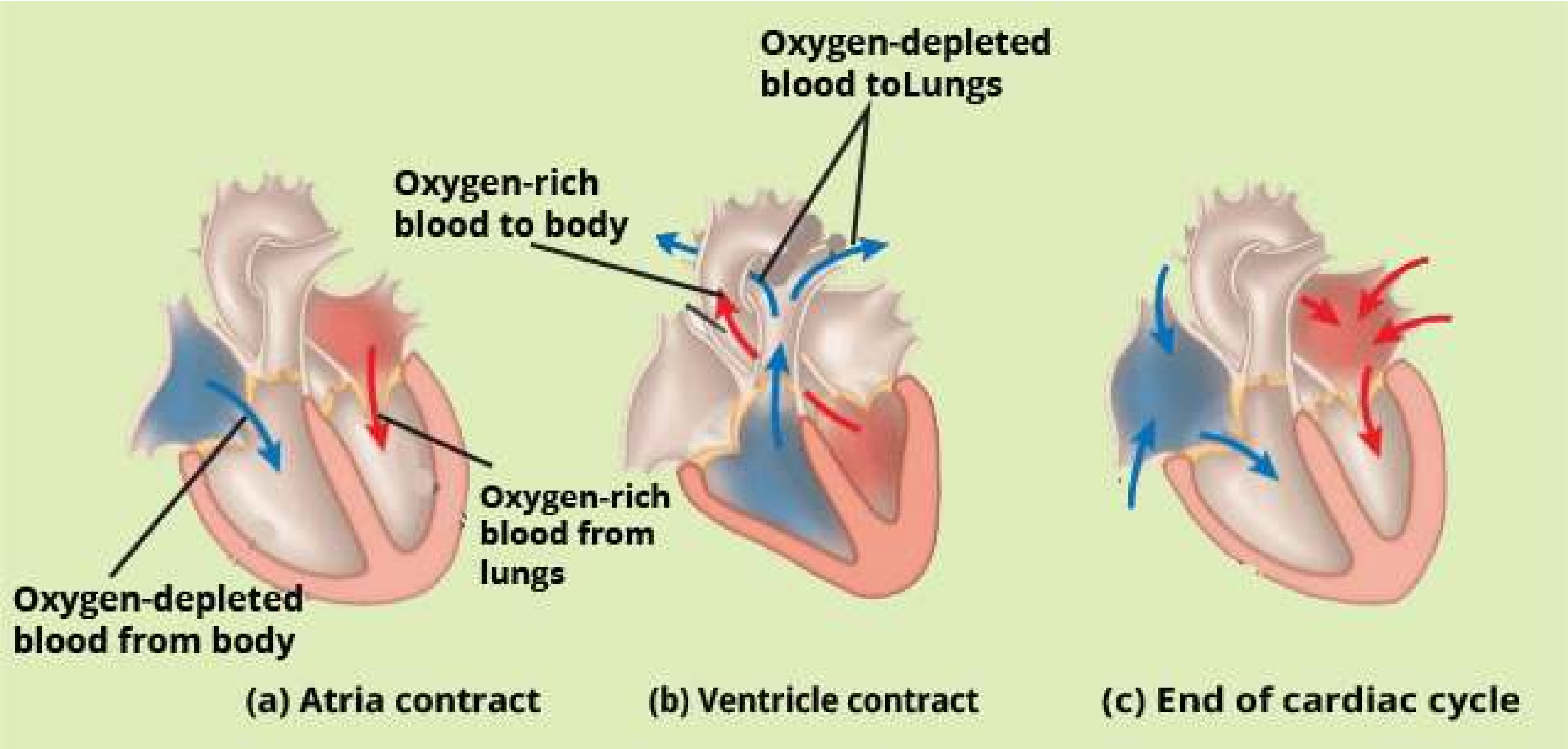


Fig.14.26 The cardiac cycle

Mechanism of heart Excitation and Contraction

The heart beat cycle described above starts when the sino-atrial node (Pace maker) at the upper end of right atrium sends out electrical impulses to the atrial muscles, and causing both atria to contract. The sino-atrial node consists of a small number of diffusely oriented cardiac fibres, possessing few myofibrils; and few nerve endings from the autonomic nervous system.

Impulses from the node travel to the musculature of the atrium and to an atrioventricular node. From it an atrioventricular bundle of muscle fibres propagates the regulatory impulses via excitable fibres in interventricular septum, to themyocardium of the ventricles. There is a delay of approximately 0.15 second in conductance from the S-A node to A-V node, permitting atrial systole to be completed before ventricular systole begins (Fig. 14.28).

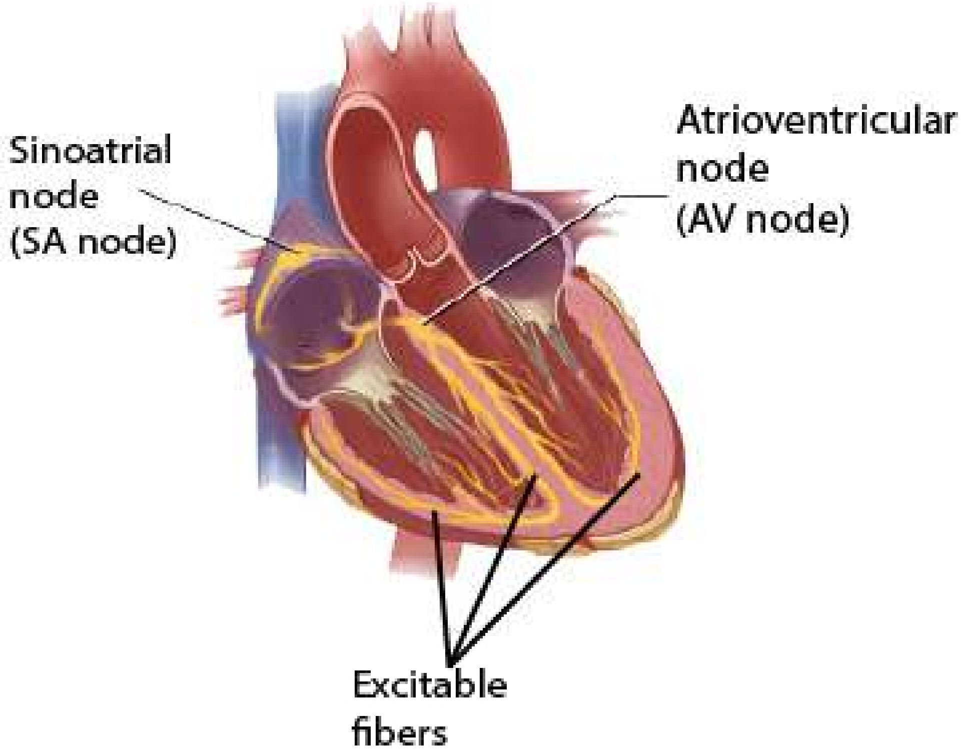
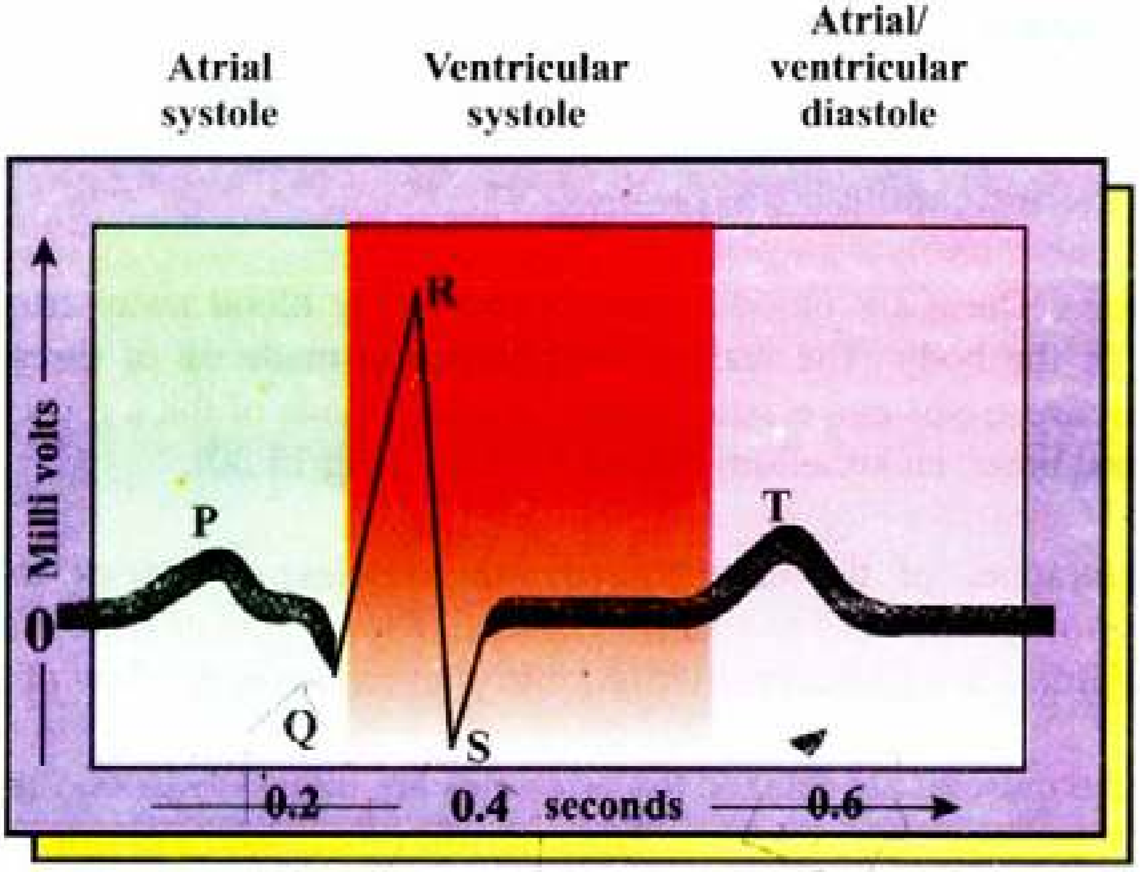


Fig.14.27 The heart's pacemaker and its connections

Animation 14.13: Heart pacemaker
Source & Credit: thevisualmd

Electrocardiogram

As the cardiac impulse passes through the heart, electrical currents spread into the tissues surrounding the heart, and a small proportion of these spread all the way on the surface of the



A normal electrocardiogram (ECG) indicates that the heart is functioning properly. The P wave occurs just prior to atrial contraction; the QRS wave occurs just prior to ventricular contraction and the T wave occurs when the ventricles are recovering from contraction.

body. If electrodes are placed on the skin on opposite sides of the heart, electrical potentials generated by these currents can be recorded. This recording is known as electro cardiogram which is taken by electrocardiograph (E.C.G.) machine. It helps to diagonose the abnormalities in the rhythmicity and conduction system of the heart which may be corrected by the use of artificial pacemaker.

Artificial pace maker

Pacemaker is responsible for initiating the impulses which trigger the heart beat rate. If there is some block in the flow of the electrical impulses, or if the impulses initiated by S.A. node are weak; it may lead to death of the individual. So an artificial pacemaker, which is battery operated producing electrical stimulus is used. For example if A-V pathway is blocked, the electrodes of artificial pacemaker are attached to the ventricle. Then this pacemaker provides continued rhythmic impulses that take over the control of the ventricles.

Blue babies

Failure of interatrial foramen (an opening in the inter-atrial septum) to close or of ductus arteriosus to fully constrict results in cyanosis (blueness of skin) of new bom. This is due to mixing of blood between two atria and the mixed blood is supplied to the body of newborn babies resulting in blueness of skin, thus the name blue babies.

(C) Blood vessels

The third component of the blood circulatory system of humans comprises of the blood vessels; arteries, capillaries and veins.

(i) Arteries : These are blood vessels which carry blood away from the heart to different parts of the body. The wall of the arteries is made up of three layers, outer, (made of connective tissue and elastic fibres), middle (made of thick muscular tissue and elastic fibres) and inner, endothelium (Table 14-3, and Fig 14.30).

The contraction of the circular (smooth muscles) of arteries and arterioles is under the control of nervous and endocrine systems. When stimulated the muscle contracts, constricting the arterioles (vasoconstriction) and thus reducing the flow of blood in them.

When the muscles are relaxed the arterioles are dilated (vasodilation) more blood flows in them, The arterioles themselves divide repeatedly until they form a dense network of microscopic vessels, called capillaries.

Atherosclerosis (G. athere = porridge; skeleoris = hardening): It is coexisting atheroma and arteriosclerosis; atheroma is deposition of hard yellow plaque of lipoid material in the inner most layer of the arteries, which may be due to high level of cholesterol in the blood.Arteriosclerosis is a degenerative arterial change associated with advancing age. Primarily a thickening of middle layer of arteries, and usually associated with some degree of atheroma. So Atherosclerosis causes narrowing and hardening of arteries. This increases the risk of formation of thrombus (see thrombus formation), and if thrombus is formed in the brain or heart it is fatal. (Atherosclerosis is a major condition leading to heart attack.

(ii) Capillaries : These are blood vessels with walls that are only one cell thick (Table 4.3, Fig. 14.29, 14.30). Although the blood appears confined within the capillary walls, the latter are permeable with the result, that water and dissolved substances pass in and out exchanging oxygen, carbon dioxide dissolved food and excretory products with the tissues around capillary. The capillary network is so dense that no living cell is far from a supply of oxygen and food. In the liver, every cell is in direct contact with a capillary. The diameter of a capillary can be altered by nervous stimulation, which tends to close them, and by chemicals, such as histamine, which dilate them. The change in diameter is brought about by a change in the shape of the cells, constituting their walls. The pre capillary sphincters also regulate the amount of blood flowing in capillaries. Thus the amount of blood flowing in a certain tissue is controlled.

The capillaries are the sites where the materials are exchanged between the blood and body tissues. This exchange occurs in three ways.

(i) Active transport and diffusion through the cells lining the capillary wall into the interstitial or extracellular fluid, and then to the body cells, and vice versa.

(ii) Through the intercellular spaces of endothelial lining of wall of capillary to and from the extracellular fluid.

(iii) Materials from the cavity of capillaries are also taken up by endocytosis, and then passed to the other side by exocytosis. Same is true for some materials entering from the interceullar spaces (extracellular fluid) into the blood.

Thus the exchange of materials takes place between blood and tissues via extracellular or interstitial fluid. Capillaries join to form venules, which join to form veins.

(iii) Veins : These blood vessels transport blood from body cells towards heart. The wall of veins has same three layers as are present in arteries. But middle layer is relatively thin and only slightly muscular, with few elastic fibres, (table 14.3 and Fig. 14.30). The semilunar valves are present in the veins. These valves prevent the back flow of blood, as it is moving towards the heart. The pressure of surrounding muscles, when they contract, tends to squash the veins and assist the return of blood towards heart.

Veins join to form larger veins, and ultimately form venae cavae (Inferior vena cava and superior vena cava) which pour the blood into the right atrium of the heart. The oxygenated blood from the lungs is brought to the left atrium by pulmonary veins.

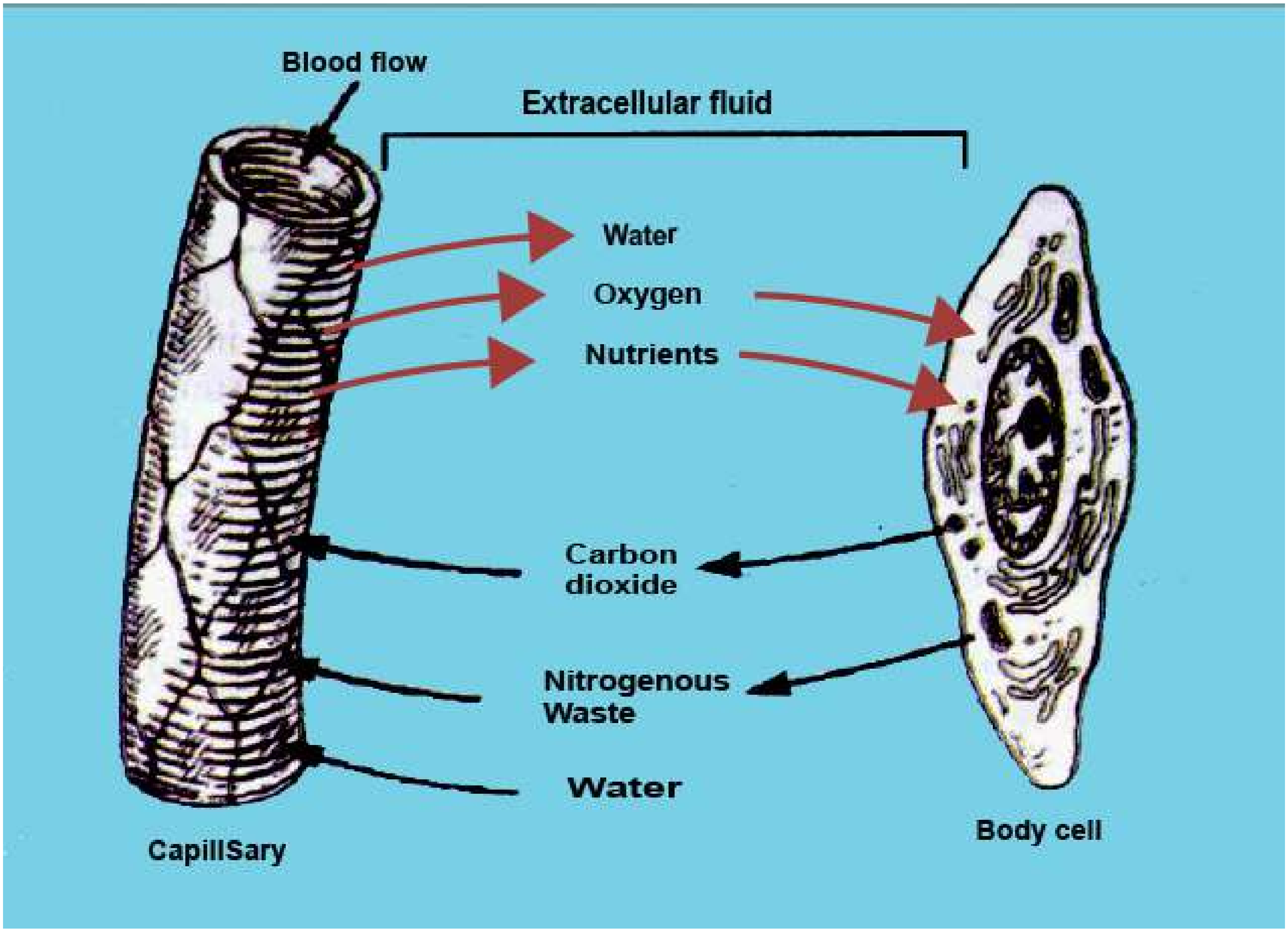


Fig.14.29 The exchange of gases and nutrients in a capillary.

The pressure within capillaries causes a continuous leakage of fluid from the blood plasma into the spaces that surround the capillaries and tissues. This fluid, known as interstitial fluid consists primarily of water, in which the dissolved nutrients, hormones gases, wastes, and small proteins from the blood are present. Large proteins red blood cells and platelets cannot cross the intercellular spaces of capillary wall, so they remain within capillaries. But some white blood cells can squeeze out through the intercellular spaces of capillary wall. Interstitial fluid is the medium through which the exchange of materials between the blood and nearby cell occurs. (Fig. 14.29)

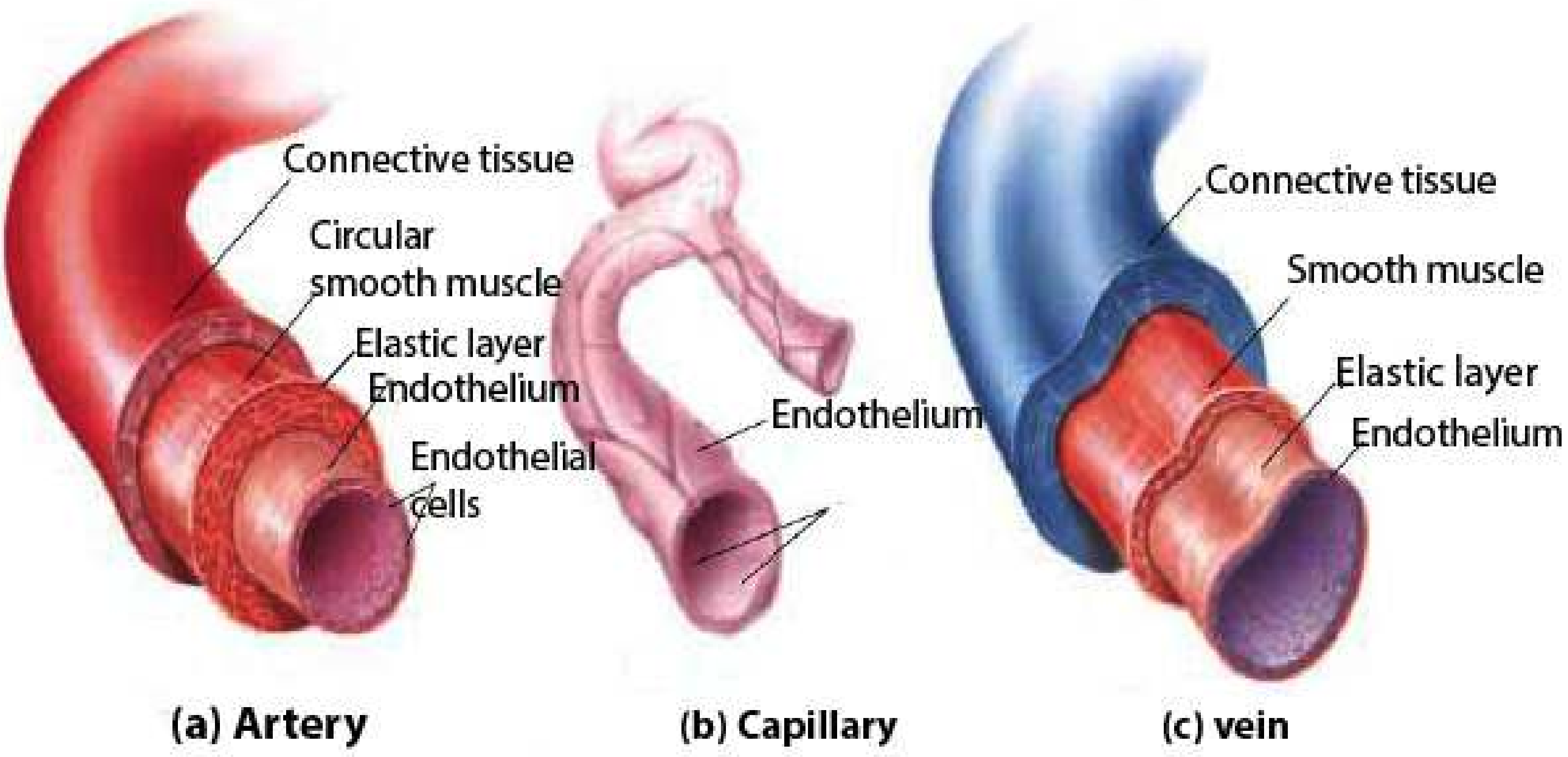


Fig.14.30 Showing the comparison in structure of artery, capillary and vein.

Animation 14.14: Structure of artery
Source & Credit: my-ecoach

Table 14.3 Comparison in structure and function of an artery, capillary and vein

Arteries	Veins	Capillaries
1. These transport blood away from the heart to the various parts of the body through capillaries.	1. These collect blood from body through capillaries and transp ort it towards heart.	1. These link arteries with veins.
2. All arteries carry oxygenated blood except pulmonary arteries.	2. All veins carry deoxygenated blood except pulmonary veins.	2. These have mixed oxygenated and deoxygenated blood.
3. There are no valves in them except at the base of pulmonary trunk and aorta.	3. Valves are present. These prevent the back flow of blood.	3. There are no valves.
4. Have high blood pressure.	4. Have low blood pressure.	4. Falling pressure in these.
5. Wave of blood pressure or pulse due toheartbeat can be detected.	5. No pulse.	5. No pulse.
6. Blood flow rapid. 400-500mm per second in aorta and decreasing in arteries and arterioles.	6 . Rate of blood flow increases from smaller to larger veins.	6. Blood flow slowest less than 1 mm per second.
7. Have smaller bore and thick wall.	7. Have larger bore and thin walls.	7. Larger bore; wall one cell in thickness.
8. Thick muscle layer and elastic fibres present. The elasticity helps changing the pulsating flow of blood.	8. Thin muscle layer and less elastic fibres. So they are less elastic.	8. No muscles or elastic fibres.
9. No exchange of materials.	9. No exchange of materials.	9. Responsible for exchange of materials.

Blood Pressure and Rate of flow of Blood

It is the measure of force with which blood pushes up against the walls of blood vessels. It is the force that keeps blood flowing from the heart to all the capillary networks in the body. This pressure is generated by the contraction of ventricles (ventricle systole) and is the highest in aorta, then gradually reduces in arteries. The walls of arteries are elastic and the flow of blood stretches them, and it is felt as pulse. During diastole, the relaxation phase of the cardiac cycle, the heart is not exerting pressure on the blood in the arteries and pressure in them falls. The pressure reaches its high point during systole (systolic pressure which in normal individuals is 120 mm Hg) and its low point during diastole (diastolic pressure which in normal individuals ranges between 75-85 mm Hg). The blood pressure gradually declines (Fig. 14.31). The decline of the blood pressure in successive parts of systemic circuit, is the result of friction between the flowing blood and the walls of the blood vessels - thus blood moves from a region of higher pressure towards a region of lower pressure.

Several other changes occur along the route of blood flow.

i) The difference between systolic and diastolic pressure continues to diminish until it disappears in the capillaries and veins.

ii) The rate of blood flow tends to fall as the blood moves through the branching arteries and arterioles, the rate is lowest in the capillaries; and increases again in the venules and veins. These changes in rate of blood flow result from changes in the total cross sectional area of the vessel system. The flow of blood in veins is maintained by the contraction of surrounding muscles and the action of semilunar valves which prevent back flow of blood. Muscular activity including breathing movements help normal flow of blood in the body.

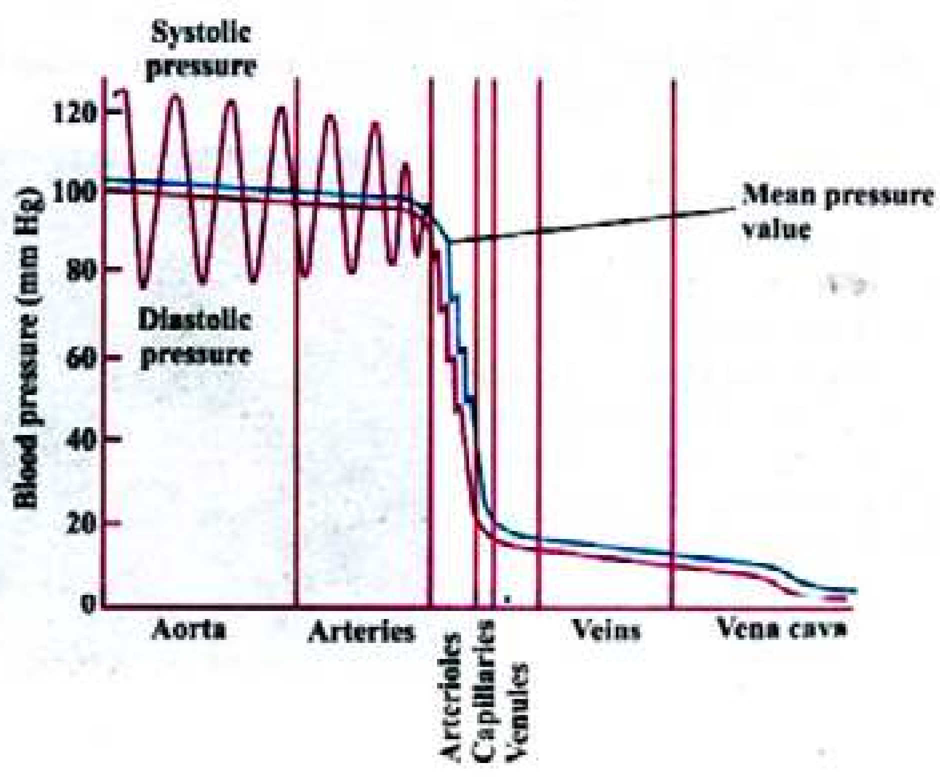


Fig.14.31(a) graph of blood pressure in different parts of the human circulatory system.

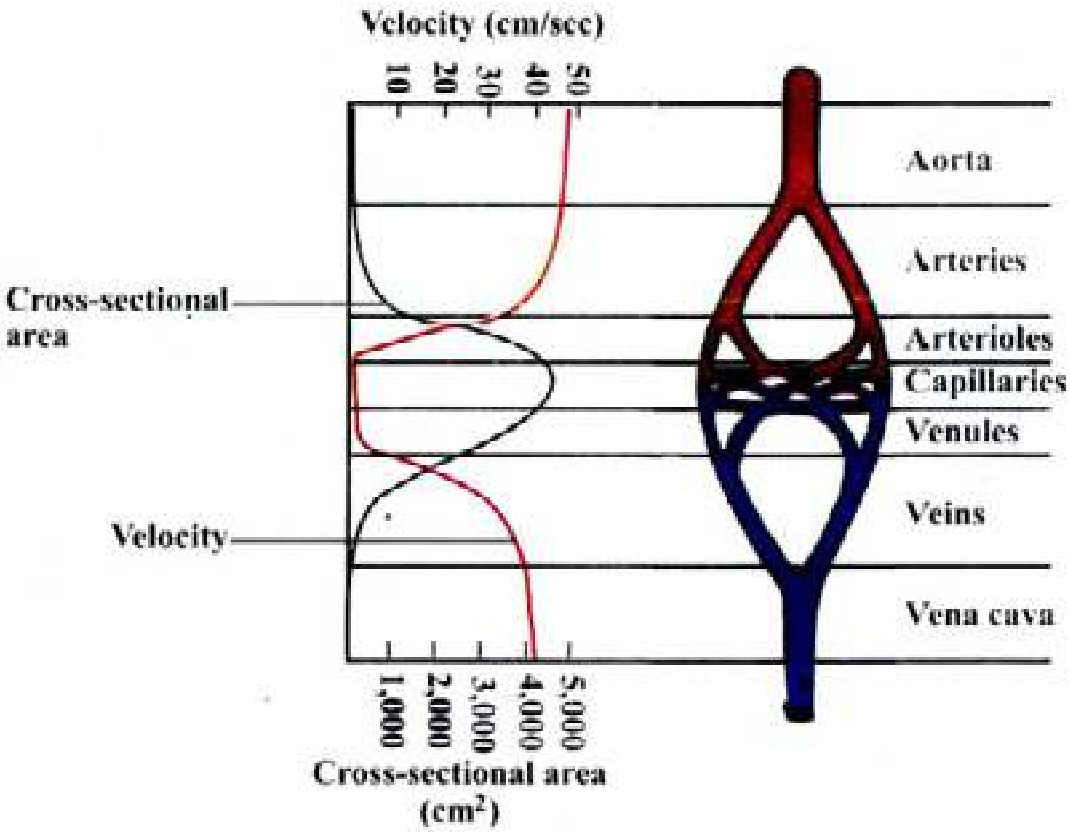


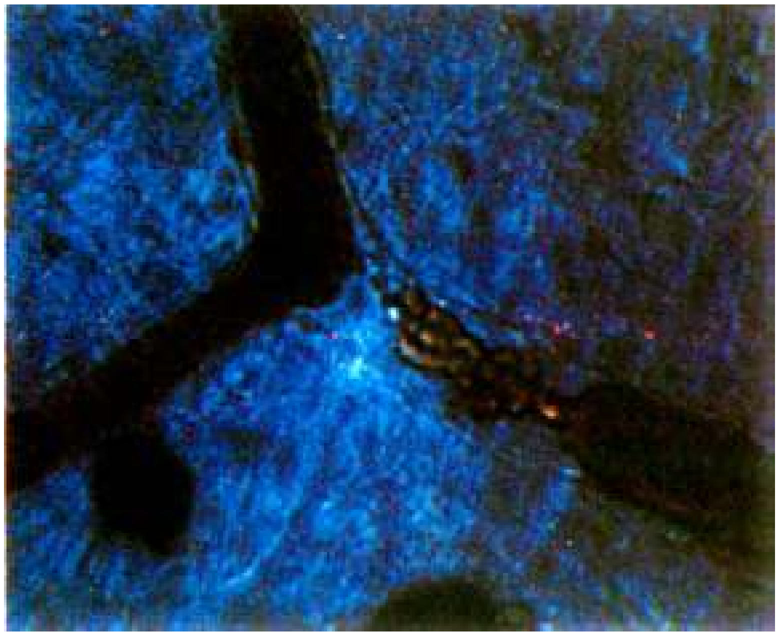
Fig.14.31 (b)Change in the velocity of blood flow in the various parts of a systemic circulatory pathway.

Hypertension

It is a condition of high blood pressure. Prolonged high blood pressure damages the lining of the blood vessels and also leads to weakening of heart muscles (which have become thickened due to the continuous strain imposed on them), with declining efficiency of the pumping action of the heart. Blood may then be retained in the heart and lungs, often leading to fatal condition called congestive heart failure.

Thrombus Formation and Hypertension

Thrombus is a solid mass or plug of blood constituents (clot) in a blood vessel. This mass may block (wholly or only in part) the vessels in which it forms, or it may be dislodged and carried to some other location in the circulatory system, in which case it is called an embolus. Thrombosis is the formation of thrombus (Fig. 14.32). Thromboembolism is leading cause of deaths in western civilization.



14.32 A thrombus in a small blood vessel. The thrombus (tangled red mass) has blocked blood flow near a point where the vessel branches. The blood has pulled away from the left end of the thrombus and is beginning to pull away from the right end also.

Thrombus formation may be due the following:

i) Irritation or infection of lining of blood vessels.
ii) Reduced rate of blood flow, due to long periods of inactivity.
iii) Pneumonia and tuberculosis, emphysema

Heart attack (Myocardial infarction)

Blockage of blood vessel in the heart by an embolus (or by locally formed thrombus) causes necrosis or damage to portion of heart muscles, a condition known as a heart attack or technically myocardial infarction, Heart attack is due to disruptions of control system of the heart with accompanying arrhythmias, especially ventricular fibrillation.

We can avoid the above mentioned situations if we :

i) Avoid too much fatty food (especially rich in cholesterol). Maintain normal body weight.
ii) Control blood pressure by regular walk and exercise.
iii) Do not smoke.

Stroke

If the normal flow of blood is blocked by an embolus (or a locally formed thrombus), in a blood vessel in the brain, and causes necrosis, or death, of the surrounding neural tissue (owing to lack of O_2), the condition is called a stroke or cerebral infarction. The symptoms of the stroke vary depending on the part of the brain that has been damaged.

Haemorrhage

It is the discharge of blood from blood vessels. Especially important is the brain haemorrhage which results from bursting of any of the arteries supplying the brain. When the wall of the arteries becomes hard and loses its elasticity - and higher blood pressures would result in brain haemorrhage. To avoid brain haemorrhage, the blood pressure must be controlled between normal limits.

In almost all the above mentioned problems, it is important to take following preventive measures :

- Taking in of less cholesterol in our food. Maintenance of normal blood pressure.
- Do not become over weight.
- Do not smoke.
- Do regular exercise.
- Avoid stress and tension.

LYMPHATIC SYSTEM

This system is responsible for the transport and returning of materials from the tissues of the body to the blood.

The system comprises lymph capillaries, lymph vessels, lymphoid masses, lymph nodes, and **lymph**- the fluid which flows in the system.

Lymph capillaries end blindly in the body tissues, where pressure from the accumulation of interstitial fluid or extracellular fluid forces the fluid into the lymph capillaries. When this fluid enters the lymph capillaries, it is called lymph. The lymph vessels empty in veins; so lymph is a fluid in transit between interstitial fluid and the blood.

The intercellular spaces in the walls of lymph vessels are larger than those of the capillaries of blood vascular system. So larger molecules, from the interstitial fluid can also enter the lymph capillaries.

Lymph capillaries join to form larger and larger lymph vessels; and ultimately form thoracic lymph duct, which opens into subclavian vein. The flow of lymph is always towards the thoracic duct.

In the intestine, the branches of lymph capillaries, within villi, are called lacteals.

The flow of lymph is maintained by :

Activity of skeletal muscles, movement of viscera, breathing movements and the valves, which prevent back flow of lymph.

Along the pathway, the lymph vessels have, at certain points, masses of connective tissue where lymphocytes are present; these are **lymph nodes**. Several afferent lymph vessels enter a lymph node, which is drained by a single, efferent lymph vessels.

Lymph nodes are present in the neck region, axilla and groin of humans.

In addition, several lymphoid masses are present in the walls of digestive tract, in the mucosa and submucosa. The larger masses spleen and thymus, tonsils and adenoids are all lymphoid masses. These produce lymphocytes.

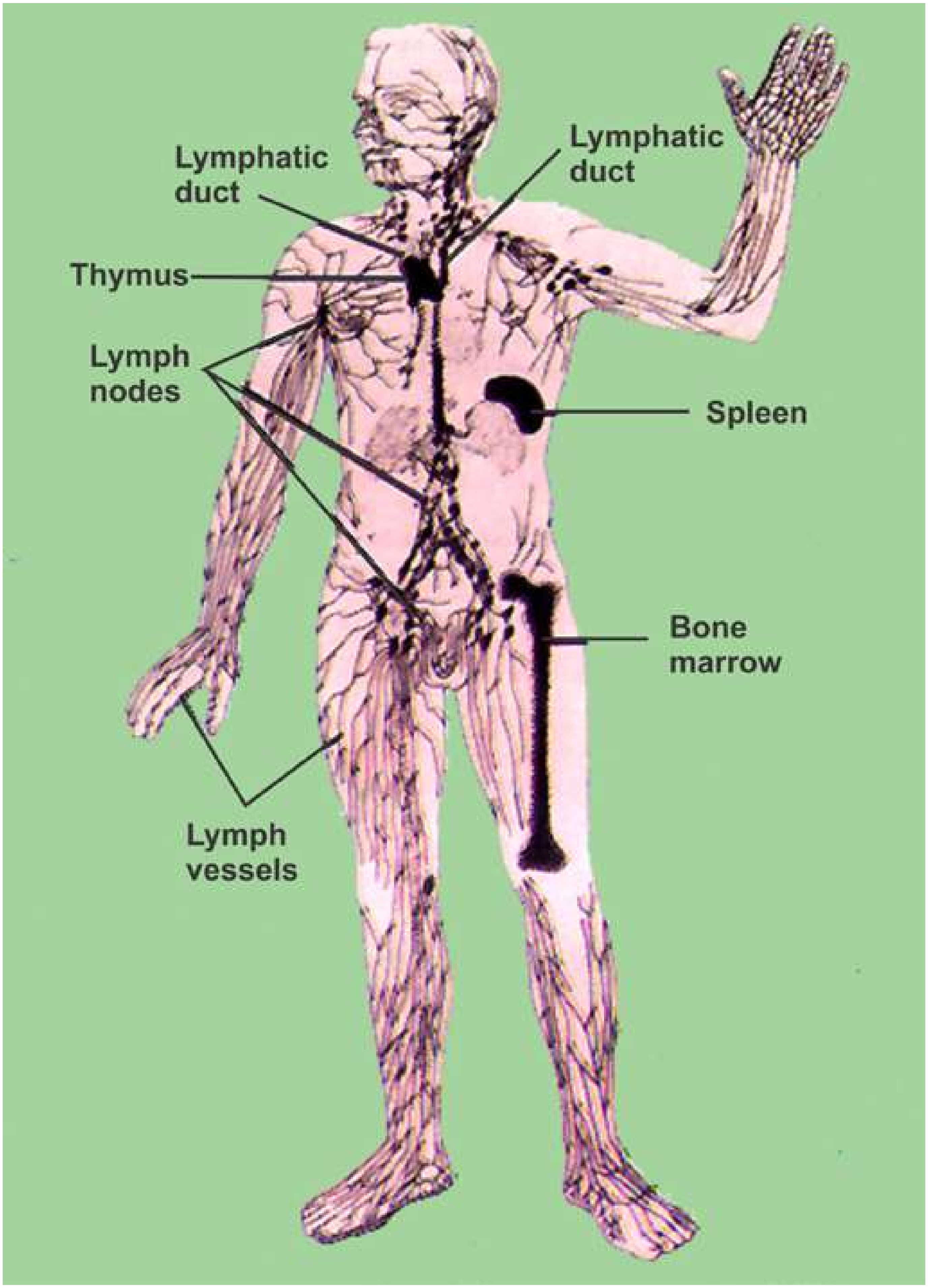


Fig. 14.33 Human lymphatic system.

There are the several functions performed by lymphatic system.

i) In an average person, about three litres more fluid leaves the blood capillaries than is reabsorbed by them each day. It returns this excess fluid and its dissolved proteins and other substances to the blood.

ii) The lacteals of villi absorb large fat globules, which are released by interstitial cells after the products of digestion of fats are absorbed. After a fatty meal these fat globules may make up 1% of the lymph.

iii) The lymphatic system helps defend the body against foreign invaders. Lymph nodes have lymphocytes and macrophages that destroy bacteria and viruses. The painful swelling of lymph nodes in certain diseases (mumps is an extreme example) is largely a result of the accumulation of dead lymphocytes and macrophages.

iv) Just as the lymph nodes filter lymph, the spleen filters blood, exposing it to macrophages and lymphoctyes that destroy foreign particles and aged red blood cells.

IMMUNITY - AND ITS TYPES

Immunity

The capacity to recognize the intrusion of any material foreign to the body and to mobilize cells and cell products to help remove the particular sort of foreign material with greater speed and effectiveness" is called **immunity**.

In animals in addition to physical barriers (skin + mucous membranes) and phagocytes, there is a third mechanism, to defend their bodies against the foreign invaders; this is the **immune system**.

The components of immune system include the lymphocytes (B and T) and the antibodies - which are special type of proteins. These antibodies are immunoglobulins which are synthesized by vertebrates, in response to antigens; and immobilise it, or sets in motion events that ultimately cause its destruction.

Lymphocyte T and B have been named due to their relationship with Thymus gland, and Bursa of Fabricius respectively. The influence of the thymus gland essential in making T-cells immunologically competent.Bursa of Fabricius is lymphoid structure present in the wall ofcloaca of young birds from where B-lymphoctyes were discovered to have role in immune system.

Antigen or immunogen is a foreign substance, often a protein which stimulates the formation of antibodies (Fig. 14.34) **Antibodies** are specific i.e. cause the destruction of the antigen, which stimulated their production. **Antibodies** are manufactured in B-lymphocytes , then secreted in to the lymph and blood where they circulate freely.

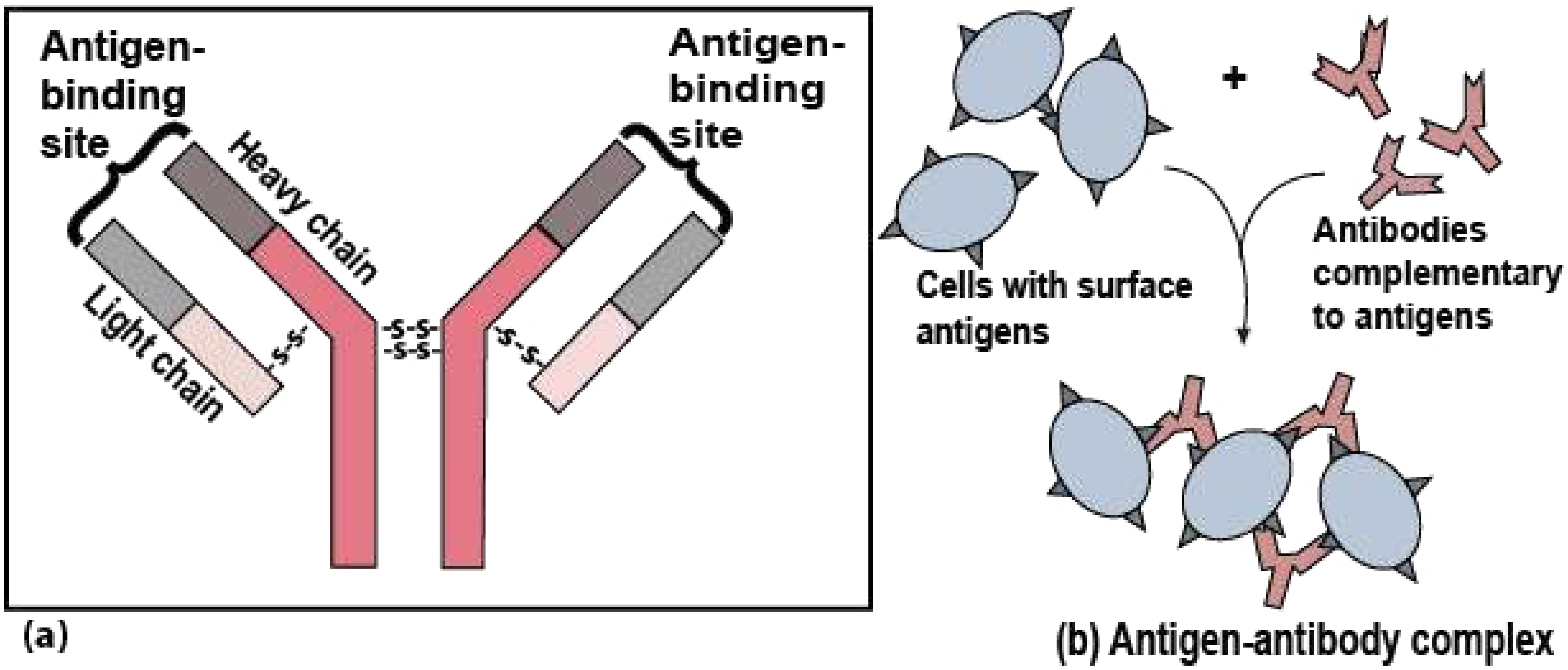


Fig. 14.34 (a) An antibody molecule consists of four polypeptide chains - two identical light chain and two identical heavychains - linked by disulfide (- S - S -) bridges. Variable amino acid sequences (V) in the light chains and upper regions of the heavy chains determine which antigen will bind to that particular antibody. Constant amino acid sequences (C) are the same for all the antibodies in one class (b) Large antigen-antibody complexes will form if there are multiple copies of the antigenic molecule on the foreign cell's surface.

T-cells recognize antigen, then combat micro-organisms and / or effect the rejection of foreign tissues (in case of tissue transplant). This is called **cell-mediated response.**

B-cells recognize antigen and form plasma cell clone. These plasma cells synthesise and liberate antibodies into the blood plasma and tissue fluid. Here antibodies attach to the surfaces of bacteria and speed up their phagocytosis, or combine with and neutralise toxins produced by micro-organisms, by producing antitoxins. This is called **humoral Immune response.**

When we get vaccination, against a specific disease (antigen), we become immune to that infection or disease. If we get vaccination against, polio, smallpox, measles, mumps etc., once in our life time, we are protected or become immune to that infection in our future life.

Types of immunity

Active Immunity : The use of vaccines, which stimulate the production of antibodies in the body, and making a person immune against the disease or infection, is called **active immunity.** But this active immunity has been achieved by artificially introducing, antigens in the body, so it is called **artificially induced active immunity.**

But, when a person is exposed to an infection (antigen) - becomes ill, and in most cases survives then this immunity, developed against that disease is called **naturally induced immunity or auto immune response.**

Antiserum is a serum containing antibodies.

Passive immunity : In contrast to active immunity, in which case antigens are introduced to stimulate the production of antibodies, by artificial or natural method; antibodies are injected in the form of antisera, to make a person immune against a disease,This is called **passive immunity.**

In body, antigen - antibody complexes are formed which are taken up by phagocytes and destroyed. The patient is spared the complications (or possibly death) caused by the infection or venom.

Passive immunity response is immediate, but not long lasting. Because no time is taken for the production of sufficient level of antibodies, (as antibodies are being injected) and after the level of antibodies is reduced or they are used up - No more antibodies production is there.

The method of passive immunization is used to combat active infections of, tetanus, infectious hepatitis, rabies, snake bite venom etc. In the case of snake bite venom passive immunity is produced by the antitoxins so the serum is called antivenom serum.

AIDS *(Acquired Immune Deficiency Syndrome; is a disease caused by a virus. The affected persons suffer from deficiency in their immun system of the body, and the immune system collapses. Thus the* **AIDS** *victim often succumb to a bacterial disease or cancer, that under normal circumstances, the immune system can over come. There is no known cure of the disease. It can spread by blood transfusion and by sexual contact with the infected persons.*

EXERCISE

Q .1 Fill in the blanks :

(i) In the process of facilitated diffusion, the carrier molecules are...................................

(ii) Pure water has a water potential which is equal to ....

(iii) The insects which feed on the phloem of plants are the ....

(iv) The substance produced by basophils which inhibits blood-clotting is ....

(v) The most abundant compound of blood plasma of man i s ....

(vi) .... in 1874 suggested that water molecules move along the cells walls of xylem vessels due to imbibition.

Q.2. Write whether the statement is 'true' or 'false' and write the correct statement if it is false.

(i) The intercellular openings in the blood capillaries are larger than the openings in the lymph capillaries.

(ii) Between the left auricle and the left ventricle in human heart, the valve present is called tricuspid valve.

(iii) The pacemaker of the heart of man is the AV node.

(iv) Each sieve tube member is associated with one or more tracheid cells.

(v) The method of active immunization is used to combat active infections of tetanus and rabies.

Q.3. Extensive Questions

(i) How are minerals and water taken up by roots? Draw the structures involved and the pathways for water and minerals from soil water to xylem, and the transport processes at each step.

(ii) Describe the mechanism of opening and closing of stomata.

(iii) How does the pressure-flow theory explain the movement of sugars through a plant?

(iv) Describe cohesion-tension theory of water movement in xylem. What supplies the cohesion, and what is the source of tension? How do these two forces interact to move water through plant,

(v) Explain, apoplast, symplast and vacuolar pathways, and describe the movement of water and dissolved minerals, through them.

(vi) Explain water potential. What is the relationship of water potential with solute potential and pressure potential?

(vii) Name and describe the general functions of the three major type of cells or cell like bodies found in blood of humans. Which of these cell types is found predominantly in lymph?

(ix) Write a note on immunity and its types.