Lecture 11: Digestive System (Part-I)

Introduction: The collective processes by which a living organism takes food which are necessary for their growth, maintenance and energy needs is called **nutrition**. The chemical substances present in the food are called **nutrients**.

DIFFERENT MODE OF NUTRITION IN ORGANISMS: It is important to know the different modes of nutrition in all living organisms in order to understand energy flow within the ecosystem. Plant produces high energy organic food from inorganic raw materials. They are called autotroph and the mode of nutrition is known as **autotrophic nutrition**. Animals feed on those high energy organic food, are called as heterotrophs and their mode of nutrition is known as **heterotrophic nutrition**

Heterotrophic nutrition further sub-categorise in **holozoic**, **parasitic**, and **saprophytic** mode of nutrition based on the pattern and class of food that is taken inside.

Holozoic Nutrition: It involves taking entire organic food and this can be in the form of whole part of plant or animal. Most of the free living protozoans, humans and other animals fall under this category.

Saprophytic Nutrition: The organism fulfils the requirement of food from the rotten parts of dead organisms and decaying matter. The organisms secrete digestive enzymes outside the body on their food and then take in digested food. It is a kind of extra-cellular digestion. Examples: Housefly, Spiders etc.

Parasitic Nutrition: The organism fulfils the requirement of food from the body of another organism. The parasites are of two distinct types, one which lives inside the host and the other which lives outside. The internal parasites usually multiply inside the body cavity of host and most of the times are life threatening while the other lives outside and can play the role of vectors in spreading diseases. Example of internal parasites are plasmodium, tapeworms etc. while the example of external parasites may include mostly fleas and insects.

DIFFERENT STEPS OF NUTRITION

Ingestion: The act of taking food inside by the organisms is called ingestion. Most of the animals consume solid food, excepting a few (mosquitoes, flies and spiders suck in liquid food). Different animals use different organs for this purpose. For example Amoeba, a unicellular organism can ingest food from its body surface. In Hydra, the food is taken inside with the help of tentacles. In vertebrates like frogs, birds and mammals, well-developed organs and methods are present to ingest food.

Feeding involves procurement as well as ingestion of food. Depending upon the nature of food, feeding may be of three types in animals.

Microphagy: This method is also known as filter feeding. Food particles smaller in size pass through filter along with water. The food particles are trapped and utilized whereas water is removed through body. Examples of organisms which show microphagy are paramecium, sponges, crustaceans, certain fishes and birds, blue whales, etc.

Macrophagy: This method involves the feeding of food particles which are large in comparison to the size of the organism. Organisms swallow whole food without chewing. Example of organisms which shows macrophagy are amoeba, hydra, certain amphibians, reptiles, fishes and birds.

Liquid feeding: Leeches, tape-worm, mosquitoes, bugs, spiders, flies, bats and mil-sucking young mammals shows different feeding behaviour where they ingest liquid food, known as liquid feeding or fluid-feeding.

We have listed some mode of feeding that organism exhibits

- Filter feeding: feeding particles suspended in water.
- Deposit feeding: feeding particles suspended in soil.
- Bulk feeding: feeding all of an organism.
- Fluid feeding: feeding fluid of other organisms.
- Ram feeding and suction feeding: ingesting food particles via the fluids around it.

Mechanism of ingestion in unicellular organisms (such as amoeba)

When food particles come in contact with the cell surface of amoeba, it slowly engulfs the whole food with the help of pseudopodia. This process takes place in approximately 2 min.

Different modes of ingestion reported in amoeba are as follows:

- **Circumvallation:** With the help of pseudopodia food cup form to engulf active prey like Paramecium.
- **Circumfluence:** Amoeba rolls over the inactive prey.
- **Import:** Food particles like algal filaments passively sink into the body; when it comes in contact.
- **Invagination:** A sticky and toxic substance is secreted by pseudopodia, which kills the prey and then taken by invagination
- **Pinocytosis:** Certain channels present on the body surface of amoeba to ingest liquid food.

Digestion of food in Unicellular Organism (Amoeba): Ingested food remains in food vacuole. The food vacuole is then transported deeper into the cytoplasm where they fuse with lysosome that contains amylase and certain proteinases. After digestion solid food is converted into liquid diffusible form and readily absorbed by cytoplasm through diffusion process. The undigested food is egested by exocytosis. The complete steps of nutrition are shown in Figure 11.1.

Mechanism of Digestion in multi-cellular organism (such as Hydra)

Hydra is a fresh water diploblastic animal. Its body composed of two layer. Outer layer is protective and sensory epithelium and inner layer is gastrodermis act as a nutritive epithelium. The central body cavity known as coelenteron act as digestive tract.

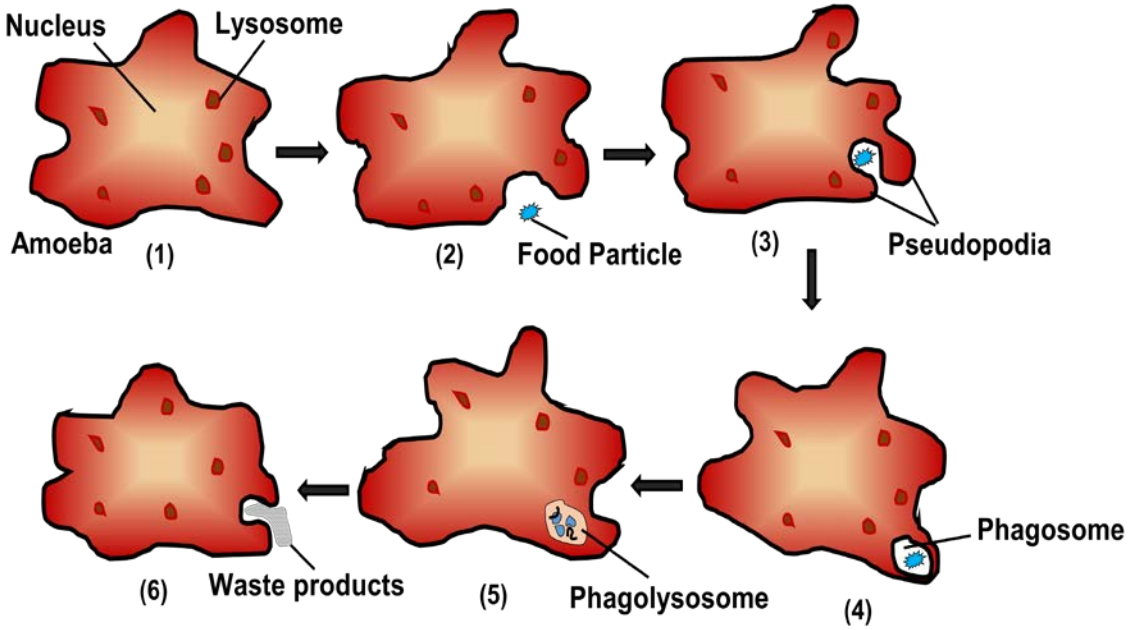


Figure 11.1 : Steps of Digestion in Amoeba.

Hydra catches the prey with the help of tentacles, a protrusion just outside the mouth. The circumference of mouth can extend according to the size of food particle. Thus it can swallow comparatively large animal. Soon after ingestion, digestion process starts with the help of enzymes secreted by granular glands, which appears just after ingestion. The undigested food is then egested through mouth. The complete mechanism of nutrition in hydra is shown in Figure 11.2.

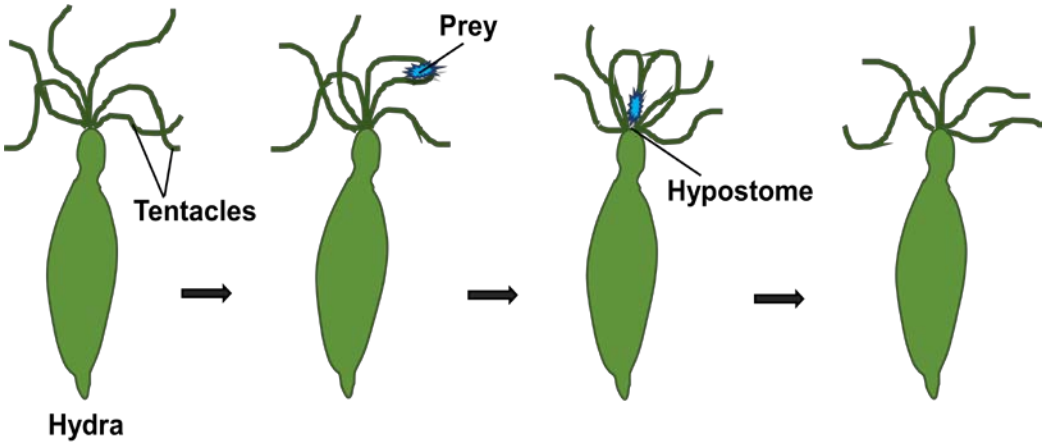


Figure 11.2 : Steps of Digestion in Hydra.

Mechanism of Digestion in sponges:

Sponges don't have distinct digestive system. They engulf food by the support of water flow system. They show filter feeding behaviour, where food particle filter out of the water passing through them. Only particle smaller than 50 micrometre can enter through *ostia*. Sponges consume food by phagocytosis with the help of *pinacocytes* or *archaeocytes*. Food particles smaller than 0.5 micrometre can catch and consumed by *choanocytes*.

Mechanism of Digestion in Lower Vertebrate such as Cockroach:

Cockroach searches the food with the help of antennae, maxillary and labial palps. These appendages bear sense organs. With the help of labium and labrum, the pro-legs pick up and bring food to the pre-oral cavity. Mandibles contain teeth which help in mastication of food in pre-oral cavity. The lacinia present in the maxillae also helps in mastication. The food is mixed with saliva in pre-oral cavity. The saliva of cockroach contains amylase, chitinase and cellulose which digest carbohydrate partially in pre-oral cavity. Food from pre-oral cavity is then transported to esophagus and then into the crop. Crop is analogous to stomach of human, which store food for some time and also digestion takes place. Then food reaches to gizzard for crushing into fine particles, which then passes to midgut. Most of the digestion carried out in midgut. Digested food is absorbed by the inner lining of midgut through diffusion. The undigested food passes to hindgut. Water and electrolytes absorb here and undigested liquid food is converted to semisolid faeces, which the passed out through anus in the form of small dry pellets. The complete digestive system of cockroach is shown in Figure 11.3.

MECHANISM OF DIGESTION IN HIGHER VERTEBRATE (SUCH AS HUMAN):

(1) INGESTION: The amount of food that an individual ingest in depend on the intrinsic desire for food (known as *hunger*) and the type of food that an individual seeks is determined by appetite. For maintaining an adequate supply of nutrition to the body these mechanisms are important. In most of the higher animals there are mainly two mechanism of ingestion: 1) *Mastication or chewing* and 2) *Deglutition or swallowing*.

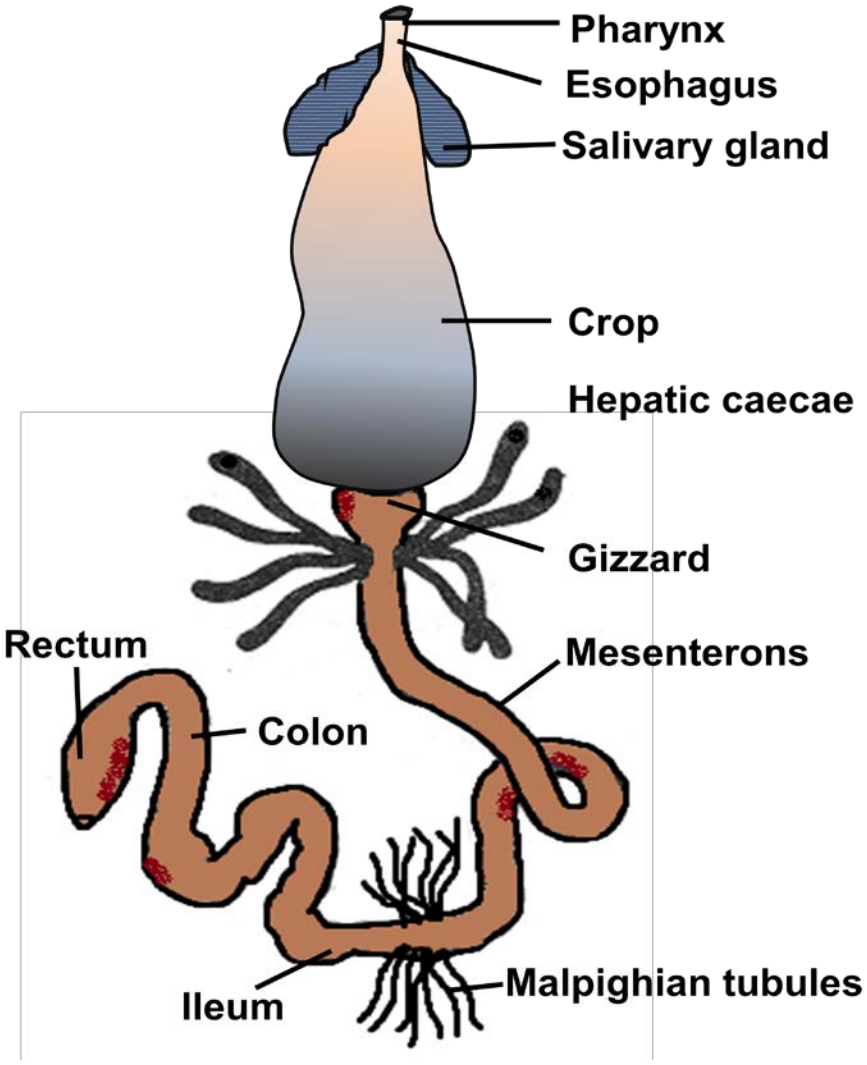


Figure 11.3 : Digestive System of Cockroach.

Mastication or chewing: The foods engulfed or captured by most of the mammals are mechanically broken into smaller pieces. The teeth are perfectly designed for chewing. The anterior teeth (incisors) provide a strong cutting action and the posterior teeth (molars) a grinding action. Jaw bones and muscles help them in doing this work. In herbivores animal (e.g. sheep, cow and horse) the premolar and molar teeth have well developed ridges for effective grinding of the food. In carnivores animals (e.g. tiger, cat, dog) the canine teeth are sharp and large for tearing the flesh. Chewing process is mainly caused by chewing reflex. The presence of bolus in mouth first initiates reflex inhibition of the muscles of mastication, which causes the lower jaw to drop. The drop of lower jaw initiate a stretch reflex of the jaw muscle that in turn initiate rebound contraction, which automatically raise the jaw upward to closure of the teeth. But again bolus compress against the lining of mouth, which inhibit the jaw muscles once again, allowing the jaw to drop again and rebound another time; this is repeated again and again.

Chewing is important for proper digestion of any king of food (except liquid food) but it is most important of fruits and raw vegetables because there indigestible cellulose membrane around the nutrients causes hindrance for digestion. Chewing also increase the surface area of food so that enzymes can act properly and increase the rate of digestion.

Deglutition or swallowing: Swallowing is a complicated process because pharynx is involved both in respiration and swallowing. The pharynx is converted into food tract only for few seconds at a time without compromising respiration.

Swallowing can be divided into three stages:

1) Voluntary stage: initiation of swallowing process.
2) Pharyngeal stage: involuntary movement of food from pharynx to esophagus.
3) Esophageal stage: involuntary movement of food from esophagus to stomach.

Lecture 12: Digestive System (Part-II)

Digestion involves the breaking of complex organic food molecules into simpler one by hydrolysis. Carbohydrates, proteins, fats and nucleic acids are large complex organic food molecules. They are insoluble and polymeric in nature. During digestion different enzymes helps in breakdown of these complex polymers into soluble monomers which are required for energy generation.

The different steps of digestion involve:

1) Movement of food through the alimentary tract
2) Secretion of digestive juices and digestion of food
3) Absorption of water, various electrolytes, vitamins and digestive end products.

Human digestive system mainly consists of two parts: 1) Alimentary tract and 2) secretory glands

1. **Alimentary tract:** It provides continual supply of nutrients, vitamins, electrolytes and ater. The following steps involved to achieve this.
    a. Movement of food through tract
    b. Secretion of digestive juices
    c. Digestion of food components
    d. Absorption of digestive product and water
    e. Excretion of unabsorbed food.

Figure 12.1 shows the complete alimentary tract. It comprises the following parts.

a) **Mouth:** Human mouth consists of vestibule and oral cavity. The slit like space between cheeks and gums is known as **vestibule**. The cavity surrounded by palate, tongue and teeth is known as **oral cavity** or **buccal cavity**. Mouth is the first passage of food where large piece of food is fragmented to small pieces with the help of teeth and mixed with saliva. Tongue manipulates food during chewing and mixing with saliva. This mixture of food with saliva, **bolus**, is then moved inward through pharynx into Esophagus. This process is known as **deglutition** or **swallowing**.

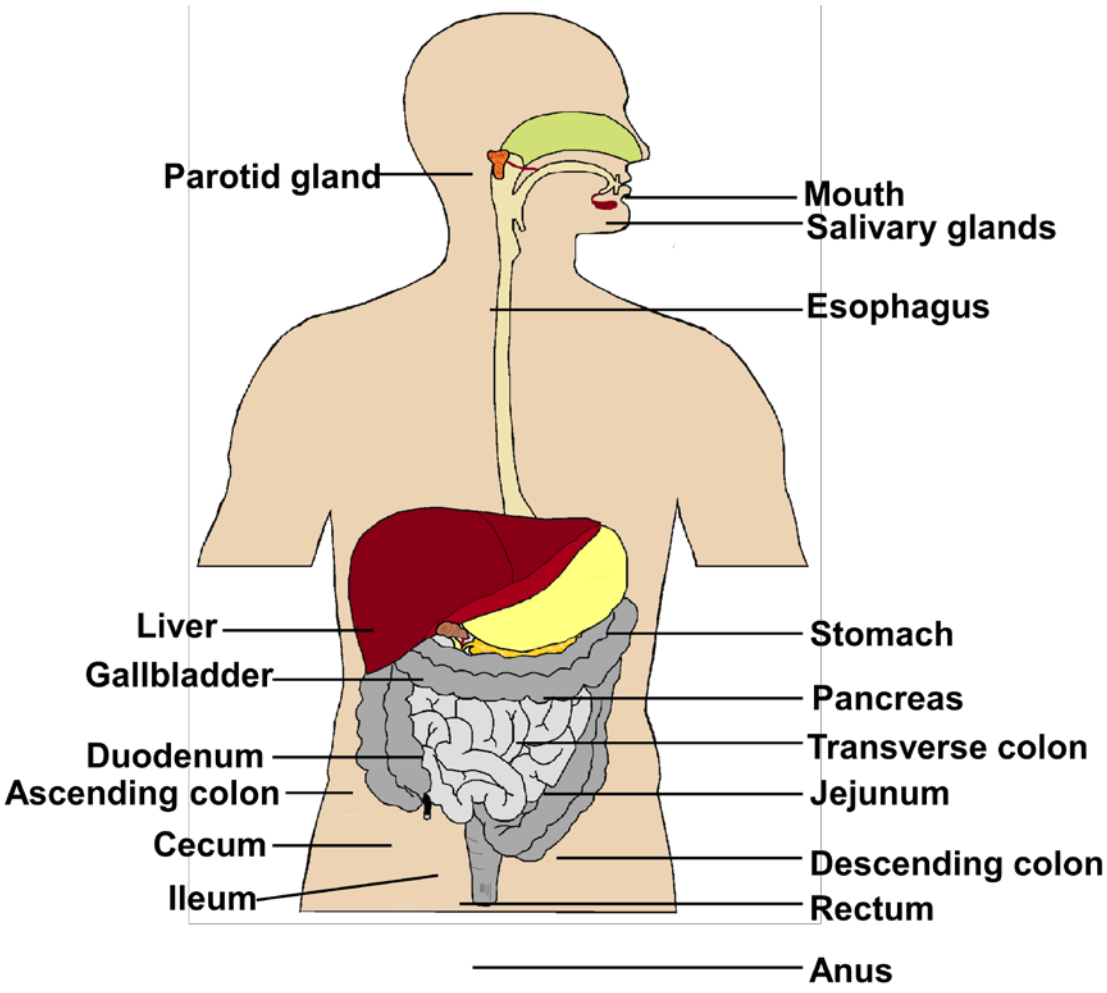


Figure 12.1: Human alimentary tract.

b) Esophagus: It is also known as **food pipe** or **gullet**, is about 25 cm long. It presents behind the trachea and heart. Its primary function is to conduct food from pharynx to the stomach. Food in esophagus is pushed is pushed downward by involuntary muscle contraction of circular muscle, this movement is called as **peristalsis**. Due to contraction of the longitudinal muscles lower part of esophagus become short which pushes its wall outward so that it can receive the bolus. The circular muscles of esophagus then relax. The contractions are repeated in a wave that moves downward to the stomach as shown in Figure 12.2. The cardiac sphincter lies between esophagus and stomach allows the conduction of bolus into stomach. The sphincter closes again. Medulla oblongata controls the peristalsis.

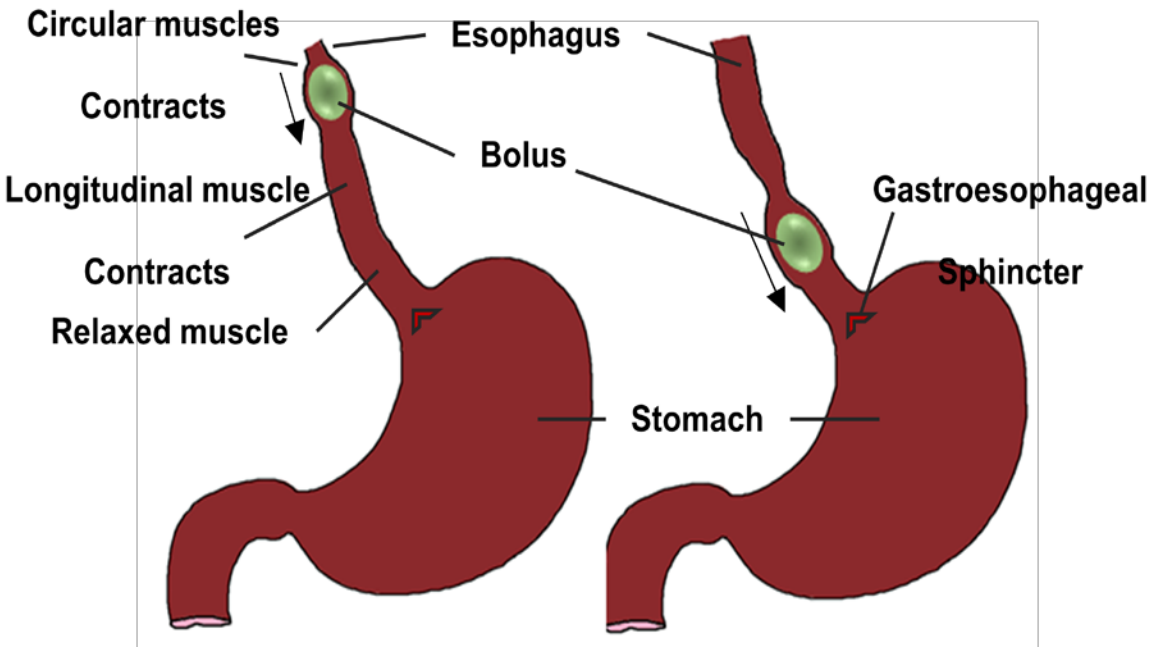


Figure 12.2: Peristalsis.

c) Stomach: It is the widest organ of the alimentary canal. Figure 12.3 shows the anatomy of the stomach and Table 12.1 give the detail of enzymes. It is divided into two major parts 1) the **body** and 2) the **antrum**. Physiologically we can divide it into 1) the *orad portion* (first two third of the body) 2) the *caudad portion* (remainder portion of body and antrum).

As food enters in the orad portion of stomach, it forms concentric circles. When food stretches the wall of stomach, vagovagal reflex travels from stomach to brain and back to stomach. Due to which the tone of muscular wall of stomach body reduces and the wall starts bulging out so that it accommodate greater quantity of food. In the completely relaxed stomach 0.8 to 1.5 litres food can occupy. After mixing of food with the stomach secretions, the resulting mixture is called **chyme**, further passes down the gut. Partial digestion of food (protein and fats) takes place here. It produce castle's intrinsic factor which is required for the absorption of vitamin B_{12} to be absorbed through intestinal wall.

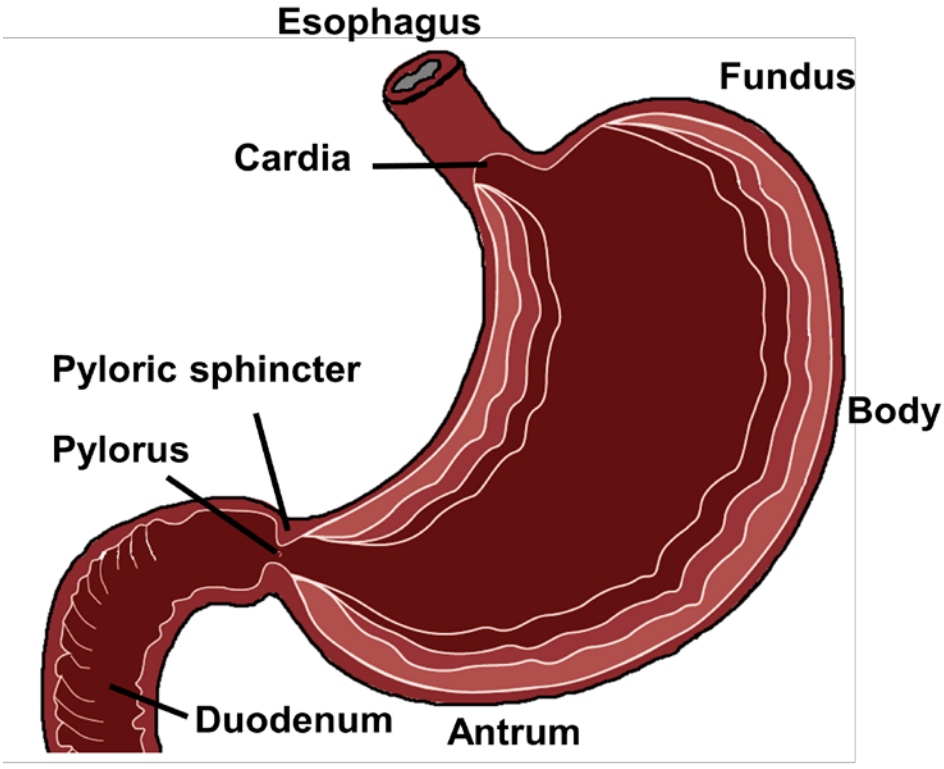


Figure 12.3: Physiological anatomy of the stomach

d) **Small intestine:** It comprises three parts viz. **duodenum, jejunum** and **ileum**. Due to its small diameter, it is named so. The length of small intestine is correlated with the height of person but not with the weight. It is about 6.25 meters long. Thus, it is the longest part of alimentary tract. Chyme is conducted through small intestine by peristaltic movement. When chime stretches the intestinal wall, it elicits localized concentric contractions spaced at intervals cause segmentation of small intestine. In such a way chyme moves toward the anus at a speed of 0.5 to 2.0 cm/s. Movement in proximal parts is faster than terminal portion. During movement of chyme through small intestine complete digestion of proteins, carbohydrates, fats and nucleic acids occurs.

e) **Large intestine:** Its diameter is always larger than small intestine but it varies from one region to another. It is about 1.5 m long. It is divided into three parts: **cecum, colon** and **rectum**. Cecum is a pouch type structure. The outgrowth of cecum is a vestigial body known as *vermiform appendix*. The cecum is more developed in herbivorous mammals than carnivorous. The junction of ileum with cecum is guarded by the **ileocecal valve**. The function of this valve is to prevent backflow of fecal contents from colon to ileum. The valve can resist back pressure of at least 50 to 60 cm of water.

The main functions of colon are

i) Absorption of electrolytes and water from chyme.
ii) Temporary storage of fecal matter.

The proximal region of colon concerned mainly with absorption and distal region with storage. The colon has three longitudinal bands called *teniae coli* and small pouches called *haustra*. Thus the mixing movement in colon is called as **haustration**. The movement in colon are sluggish.

The lower portion of descending colon is sigmoidal in shape and opens into rectum. It is 20 cm long and terminates in the 2 cm long anal tract. When a mass movement propels feces into rectum, the desire for defecation occurs.

The opening of anal tract is called *anus*. The anus has two sphincter. Internal anal sphincter composed of smooth muscle fibre and external anal sphincter composed of striped muscle fibre (voluntary in nature). The moderate quantities of vitamin B complex and vitamin K also found by bacteria in large intestine.

Table 12.1: Site of digestion and final products.

Macromolecule	Digestion starts	Digestion complete	Final products
Carbohydrate	Mouth	Duodenum	Glucose
Protein	Stomach	Duodenum	Amino acids
Fat	Duodenum	Duodenum	Fatty acids & glycerol
Nucleic acid	Duodenum	Jejunum	Nitrogenous bases + pentose sugar + inorganic phosphate

2. **Secretary Glands:** The primary function of secretary glands is the secretion of digestive enzymes for digestion of food and mucus for lubrication and protection of tract. Most digestive secretion occurs in precise amount only in response to the presence of food in alimentary tract. We have discussed major digestive glands.

a) **Salivary glands:** The major gland of salivation are **parotid, submandibular** and **sublingual** glands. Along with this there are many small *buccal glands*. A Healthy individual secretes about 0.8 to 1.5 litres of saliva daily. Saliva mainly composed two major type of proteins. A) **Ptyalin** (an α-amylase) - for digestion of starch, B) **Mucin** – for protection of surface. Parotid glands are larges salivary glands situated near ears. The parotid glands secrete mainly ptyalin, whereas submandibular and sublingual glands secrete both ptyalin and mucin. The small buccal glands secrete only mucus. The pH of saliva is between 6 to 7 which favours the digestive action of ptyalin.

The esophageal glands secretes only mucous which provide lubrication for swallowing.

b) Gastric glands: The entire surface of stomach lining contains mucus- secreting cells. The stomach mucosa has two types of tubular glands: *Oxyntic glands* (gastric glands) and *pyloric glands*. The oxyntic glands secrete hydrochloric acid pepsinogen, intrinsic factor and mucus. The pyloric gland secretes mainly mucus for protection from stomach acid. They also secrete gastrin hormone.

c) Liver: It is larges gland of the body, mainly secrete bile normally between 0.6 to 1 litre/day. Bile serves two major function.

i) Fat digestion and absorption: Along with the enzymes for fat digestion bile acids in bile helps to emulsify the large fat particles of food into many small particles, the surface of which attacked by lipase enzymes secreted in pancreatic juice. Bile acids aid in absorption of end product digested fat through the intestinal mucosal membrane.

ii) Excretion of waste products from blood: An important waste product bilirubin, an end product of haemoglobin digestion and excesses of cholesterol are excreted out with the help of bile.

A pear shaped structure attached to the posterior surface of the liver stores 30 to 60 ml bile secreted by the liver.

d) Pancreas: The pancreas is soft lobulated large compound gland whose internal structure is similar to salivary gland. It lies parallel to and posterior to stomach. *Pancreatic acini* secrete digestive enzymes whereas large amount of sodium bicarbonate solution are secreted by small ductules and larger ducts. The mixture of enzymes and sodium bicarbonates passes through a long pancreatic duct. Pancreatic duct joins with hepatic duct before it empties into duodenum through the *papilla of vater*.

Pancreatic secretion contains enzymes (Table 12.2) for digesting all three major food component: carbohydrate, protein and fats.

Table 12.2: List of pancreatic enzyme

Pancreatic enzyme	Substrate
Trypsin Chymotrypsin Carboxy peptidase	Protein
Pancreatic amylase	Carbohydrate
Pancreatic lipase Cholesterol esterase Phospholipase	Fats

e) Intestinal glands: These are formed by modification of surface epithelium of small intestine. The two main intestinal glands are *Brunner's gland* and *Crypts of Lieberkühn*.

i) Brunner's glands are found only in first few centimetres of duodenum. They secrete large amount of alkaline mucus to protect the duodenal wall from highly acidic gastric juice and to neutralize hydrochloric acid.

ii) Crypt of Lieberkühns are small pits located all over the entire surface of the small intestine, lies between the intestinal villi. They are covered by epithelium composed of two types of cells. 1) *Goblet cells*: secrete mucus. 2) *Enterocytes*: secrete water and electrolyte, also reabsorb the water and electrolyte along with the end product of digestion over the surface of adjacent villi. At the base of these crypts, *paneth cells* and *argentaffin cells* are present.

Paneth cells found mainly in duodenum are rich in zinc and contain acidophilic granules. Argentaffin cells synthesize secretin hormone and 5-hydroxytryptamine.

Table 12.3: List of digestive enzymes in human

Enzyme	Substrate	Site of action
Ptyalin (salivary amylase)	Starch	Mouth
Pepsin	Proteins	Stomach
Gastric Lipase	Little amount of fats	
Renin	Casein	Child's stomach
Pancreatic amylase	Starch	
Trypsin	Proteins	
Chymotrypsin	Proteins	
Elastase	Protein (Elastin)	
Carboxypeptidase	Large peptides	
Pancreatic lipase	Fats (Triglycerides)	
Nuclease	Nucleic acids (DNA, RNA)	Small Intestine
Enterokinase	Trypsinogen	
Aminopeptidase	Large peptides	
Dipeptidase	Dipeptides	
Disaccharidase	Disaccharide	
Intestinal lipase	Fats	
Nucleotidase	Nucleotide	
Nucleosidase	Nucleoside	

Absorption is the process by which simpler nutrients (monosaccharide, amino acids, fatty acids etc.) pass from alimentary tract into blood and lymph. It can be occur by simple diffusion, facilitated diffusion, osmosis and active transport.

Absorption starts from stomach but it is poor absorptive area because here junction between epithelial cells are tight junction and villi are absent on its inner wall. Little amount of water, salts, alcohol, few drugs and moderate amounts of sugar are absorbed through stomach. Absorption of nutrients mainly occurs in small intestine. Vitamins produced due to bacterial digestion and water absorbed in large intestine.

Intestines absorbs collective amount of ingested fluid and fluid secreted in gastrointestinal secretions. Throughout the inner wall of small intestine many folds called *valvulae conniventes* (also known as *folds of kerckring*) present, which increase the surface area for absorption. The valvulae conniventes covered by small protrusions known as *villi* (singular '*Villus*'). Figure 12.4 shows the longitudinal section of the villus.

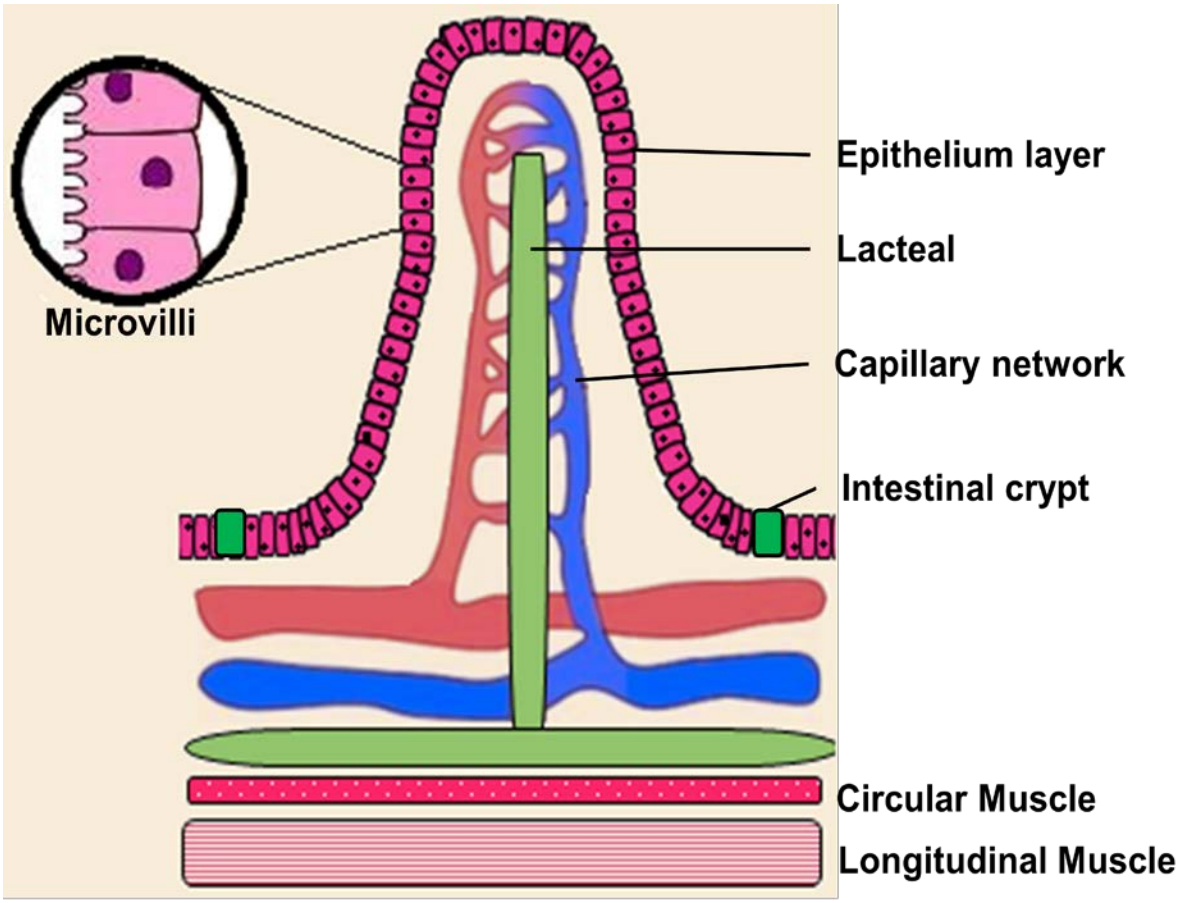


Figure 12.4: Longitudinal section of the villus.

Absorption of Monosaccharides: Absorption of glucose and galactose occur through active transport. Sodium pump on the cell membrane helps in its active transport. Fructose is absorbed by facilitated diffusion. Glucose, galactose and fructose are absorbed into the blood capillaries. Galactose is the most rapidly transported monosaccharide.

Absorption of amino acids: Amino acids are absorbed by active transport coupled with active sodium transport. They also enter the blood stream.

Absorption of fatty acids and glycerol: Fatty acids and glycerol are insoluble in water thus they can't enter in blood stream directly. In intestinal lumen, bile salts and phospholipids incorporates fatty acids and glycerol into small, spherical water soluble droplets known as micelles. Fat soluble vitamins and sterols along with fatty acids and glycerol are absorbed by diffusion by the help of micelles into intestinal cells, where they are resynthesized in the endoplasmic reticulum and are converted into small droplets known as *chylomicrons*. Latter most of them released into lymph present in *lacteals* (lymphatic capillaries).

Absorption of water: Osmosis helps in the absorption of water in small intestine through epithelial cells surface and villi into the blood capillaries. In order to maintain the osmolality, electrolytes and digested food absorb along with water.

Absorption of electrolytes: Sodium can move in and out of epithelial cells by diffusion process and in mucosal cells it moves by active transport. Many others ions such as potassium, calcium, magnesium, iron and phosphate absorbed by active transport. Whereas chloride ions can be absorbed through diffusion or active transport. Vitamin D and parathyroid hormone enhance the absorption of calcium.

Absorption of vitamins: Most water soluble vitamins (Vitamin B complex, Vitamin C, Vitamin P) absorbed by diffusion. Castle's intrinsic factors play an important role in reabsorption of vitamin B_{12}.

Assimilation and egestion:

Finally, all absorbed nutrients transported by blood and lymph further transferred to blood circulation. With the help of blood nutrients reach to target body cells, where it become integral component of protoplasm and used for energy, growth and repair. This process is known as **assimilation**.

The excess of monosaccharide stores in liver and muscles in the form of glycogen by the process called *glycogenesis*. Excess of amino acids are converted into glucose and then to fat through an irreversible reaction and then stored. Most of the fats stored in subcutaneous layers and mesenteries.

Another important step is **egestion**, the process by which undigested food materials eliminated through anus in the form of faeces. Egestion occurs by peristalsis movement. After absorption of water in colon, chyme converted into semisolid faeces. When faeces enters into rectum, wall of rectum feels distension which induces desire of defecation due to a *defecation reflex*. Due to this reflex peristalsis initiated in the sigmoidal colon and reaches to anus through rectum. Involuntary action of internal anal sphincter and voluntary action of external anal sphincter thus helps in defecation.

Lecture 13: Nervous System (Part-I)

Introduction: Nervous system is the most complex system in human. Its uniqueness is due to vast complexity of thought process and control action it can perform (Figure 13.1). It co-ordinate physiological functions in human. Nervous tissue originates from ectoderm and is specialized for receiving stimuli and transmitted message. The nervous tissue consists of highly specialized cells called the **neurons**. Thus neurons are functional unit of nervous system. The detail structure of a neuron is shown in Figure 13.2.

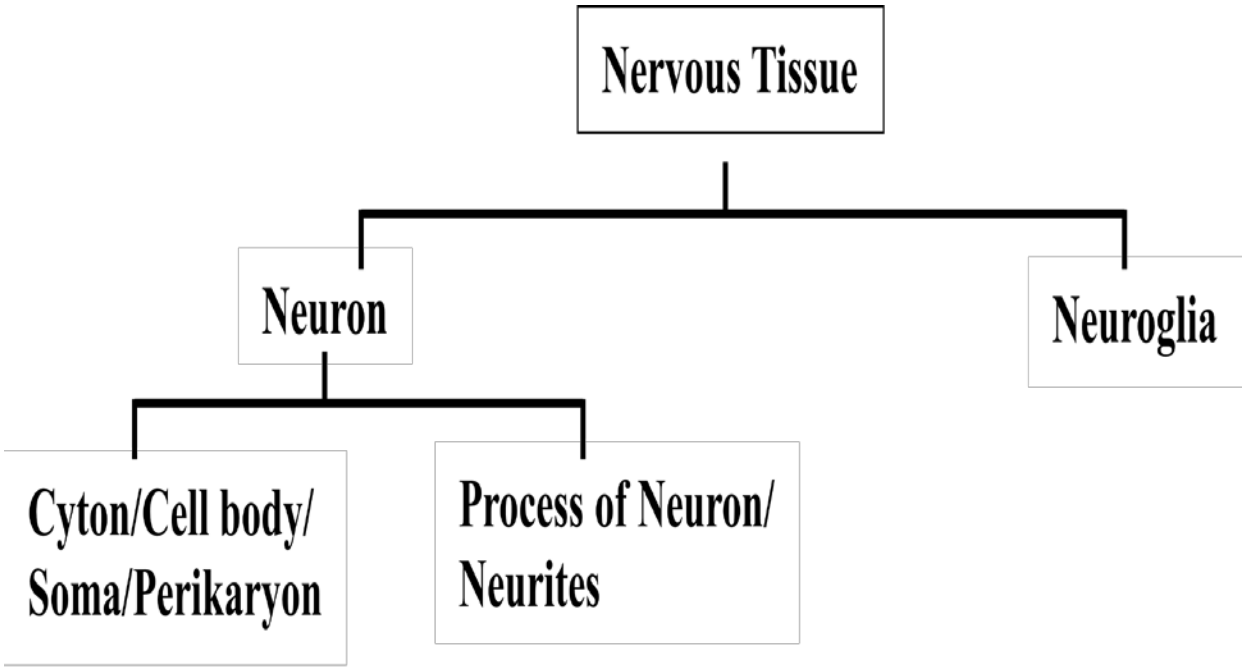


Figure 13.1: An Over-view of Nervous System in animals.

A neuron is mainly divided into two parts: 1) Cell body or cyton and 2) Cell process.

1. **Cyton:** It is broader part of neuron which contains uninucleated cytoplasm. Except centriole, all type of cell organelles is found in cytoplasm. Due to absence of centrioles, neurons can't divide. Some other cells organelles like *neurofibril* and *nissl's granule* found in neuron, which help in transfer of impulse to cyton. Nissl's granule is formed by coiling of endoplasmic reticulum around the ribosome.

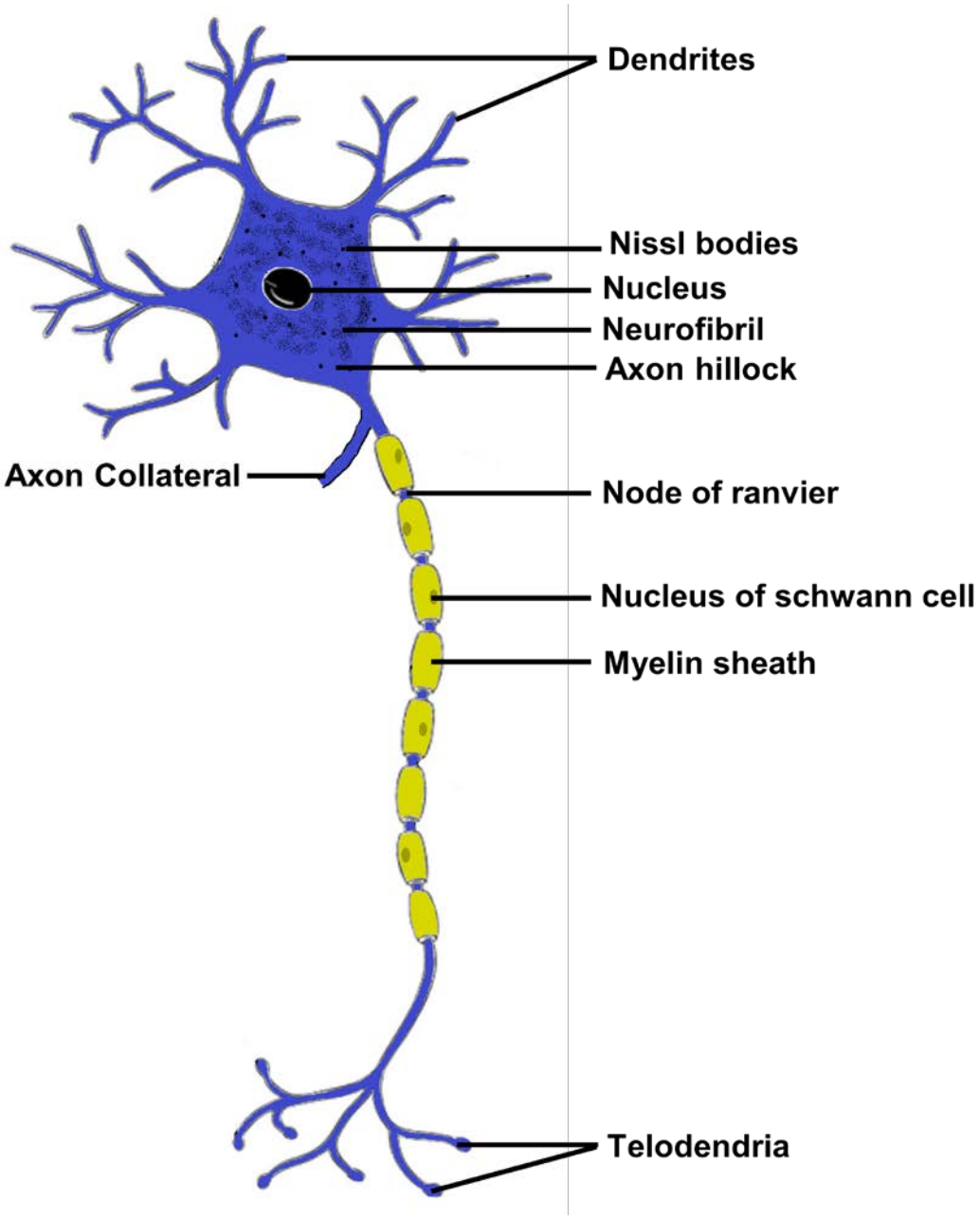


Figure 13.2 : Structure of a typical Neuron.

2. **Cell process:** *Dendron* and *axon* are cell process of neuron. Fine branches of Dendron called dendrites, contains some receptor points, so that Dendron receive the stimuli and produce centripetal conduction. Axon is the longest cell process of neuron. Axon is covered by axolemma. Part where axon arises from cyton called *axon hillock.* Cytoplasm of axon is called axoplasm which only contains neurofibrils and mitochondria. The terminal end of axon is branched and vesicular, called *telodendria*.

Some neurons are covered by layer of sphingomyelin (a phospholipid) called as *myelin sheath* or *medulla*. Myelin sheath is covered by thin cell membrane which is called as *neurilemma* or *schwan cell*. Myelin sheath act as insulator and prevent leakage of ions.

Structural classification of neuron

Neurons are grouped structurally according to the number of processes extending from cyton.

1. **Unipolar neuron:** Single process arises from cyton. e.g. nervous system of embryo. Some times this single process further divided into two processes. One of these act as axon while other act as dendrite. These kind of neurons are termed as pseudo-unipolar. e.g. Dorsal root ganglia of spinal cord and granule cells of olfactory bulbs.
2. **Bipolar neuron:** Two distinct process arise from cyton, an axon at one end and dendrite at another end. These type of neuron found in retina, olfactory epithelium, vestibular and cochlear ganglia.
3. **Multipolar neuron:** These types of neuron have one axon but many dendrons. Motor neurons and interneuron are multipolar.

Neurons of hydra and amacrine cell of retina have no definite cell process. These types of neurone are known as **apolar neuron**.

Functional classification of neuron

Functionally neurons can be divided into three categories based on the direction of nerve conduction.

1. **Afferent or sensory neurons:** Nerve conduction from receptors to the central nervous system.
2. **Efferent or motor neurons:** Nerve conduction from the central nervous system to the effector organs.
3. **Association neurons or interneurons**: They lie between motor and sensory neuron, mostly confined within the central nervous system.

Physiology of Nerve.

The two main properties of nervous tissue are excitability and conductivity. Excitability is the ability of nerve cell and nerve fibres to enter into state of excitation in response to stimulus. The transmission of excitation in a particular direction is called conductivity. The initiation and conduction of nerve impulse is shown in Figure 13.3.

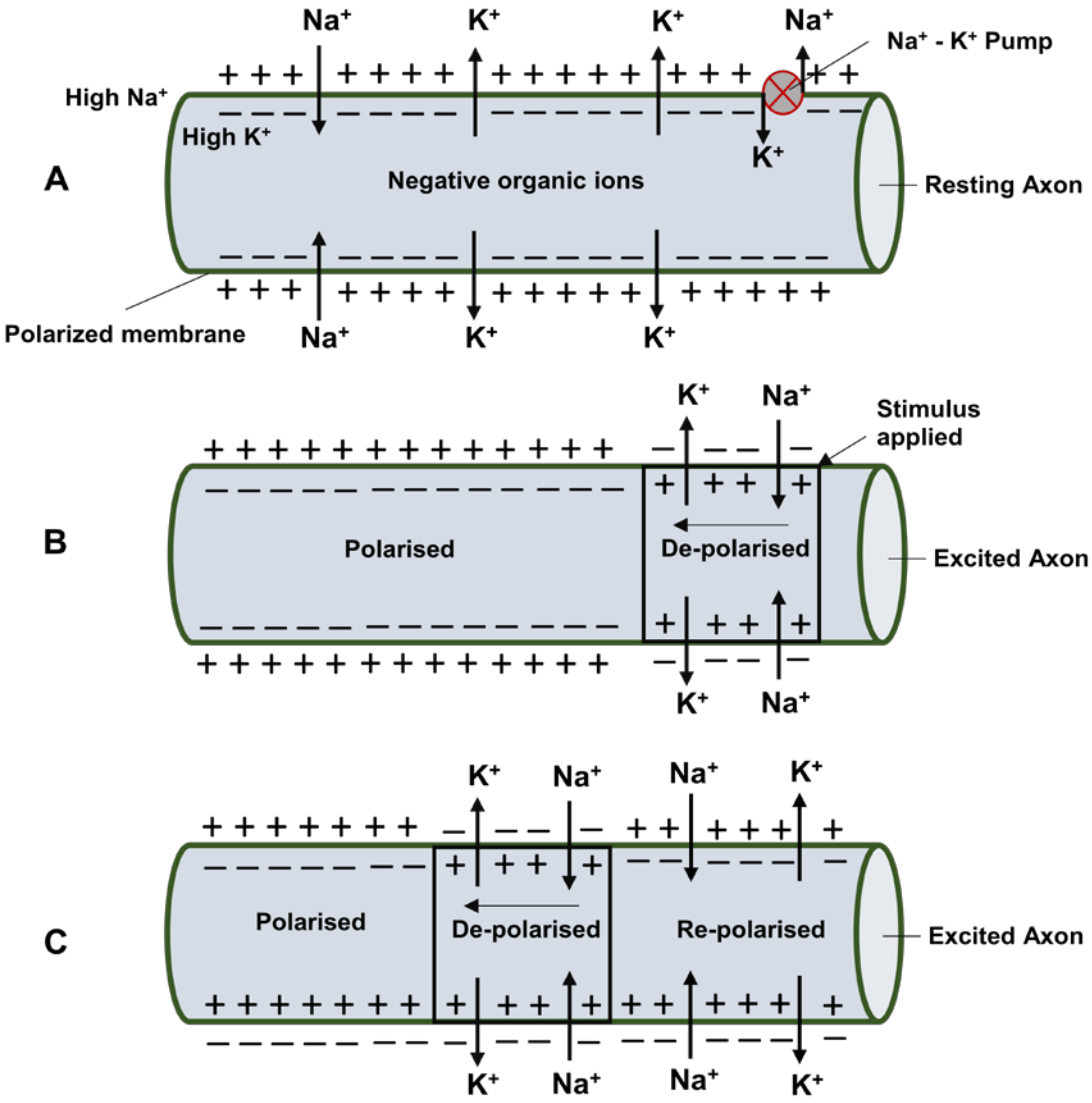


Figure 13.3 : Initiation and conduction of nerve impulse.

The resting membrane potential

The cell membrane of nerve cell is said to be polarized when negative potential exists more inside the cell with respect to outside. The potential difference across the cell membrane at rest is called resting membrane potential and it is approx. -65 mV. The resting membrane potential is maintained by active transport of ions against their electrochemical gradient by sodium potassium pump and also by passive diffusion of ions. For active transport, there are carrier proteins located in the cell surface membrane. They are driven by energy supplied by ATP and coupled by removal of three sodium ions from the axon with the help of uptake of two potassium ions. The

passive diffusion of ions opposes the active movement of ions. The rate of diffusion depends on the permeability of the axon membrane for the ions. Potassium ions have more permeability than that of sodium ions. Therefore loss of potassium ions is more than the gain of sodium ions. This leads to the net loss of potassium ions from the axon and generation of negative charge within the membrane.

Action Potential or exciting stage

The event of depolarisation initiates a nerve impulse or spike. This nerve impulse is also known as *Active potential*, generated by change in sodium ion channel. These channels are known as voltage gated channel. At resting stage these channels remain close due to binding of calcium ions. An action potential is generated by a sudden opening of the sodium gates. Opening of gate increases the permeability of membrane for sodium which then enters inside by diffusion. This increase in positive ions inside the axon drops the negative potential inside axon. A change of -10 mV in potential difference from resting membrane potential is known as spike potential, sufficient to trigger a rapid influx of sodium ions; which leads the generation of action potential.

First, the negative resting potential is cancelled out, at this point the membrane is completely depolarised then the potential difference is developed across the membrane. The potential difference at 30 mV is corresponds to the maximum concentration of sodium inside the axon.

Repolarisation

A fraction of second after the sodium gates open, depolarisation of membrane causes opening of potassium gates therefore potassium diffused out of the axon. This causes less positive charge inside with respect to outside. Thus due to repolarisation, potential changes from 30 mV to -65 mV. The neuron is now prepared for receiving another stimulus and to conduct as described before. Now it’s necessary to restore normal resting potential by expelling sodium ions out and taking potassium ions inside. The time taken for restoration is called *refractory period* because during this period membrane can’t receive another impulse. All the three state of neuron is shown in Figure 13.4.

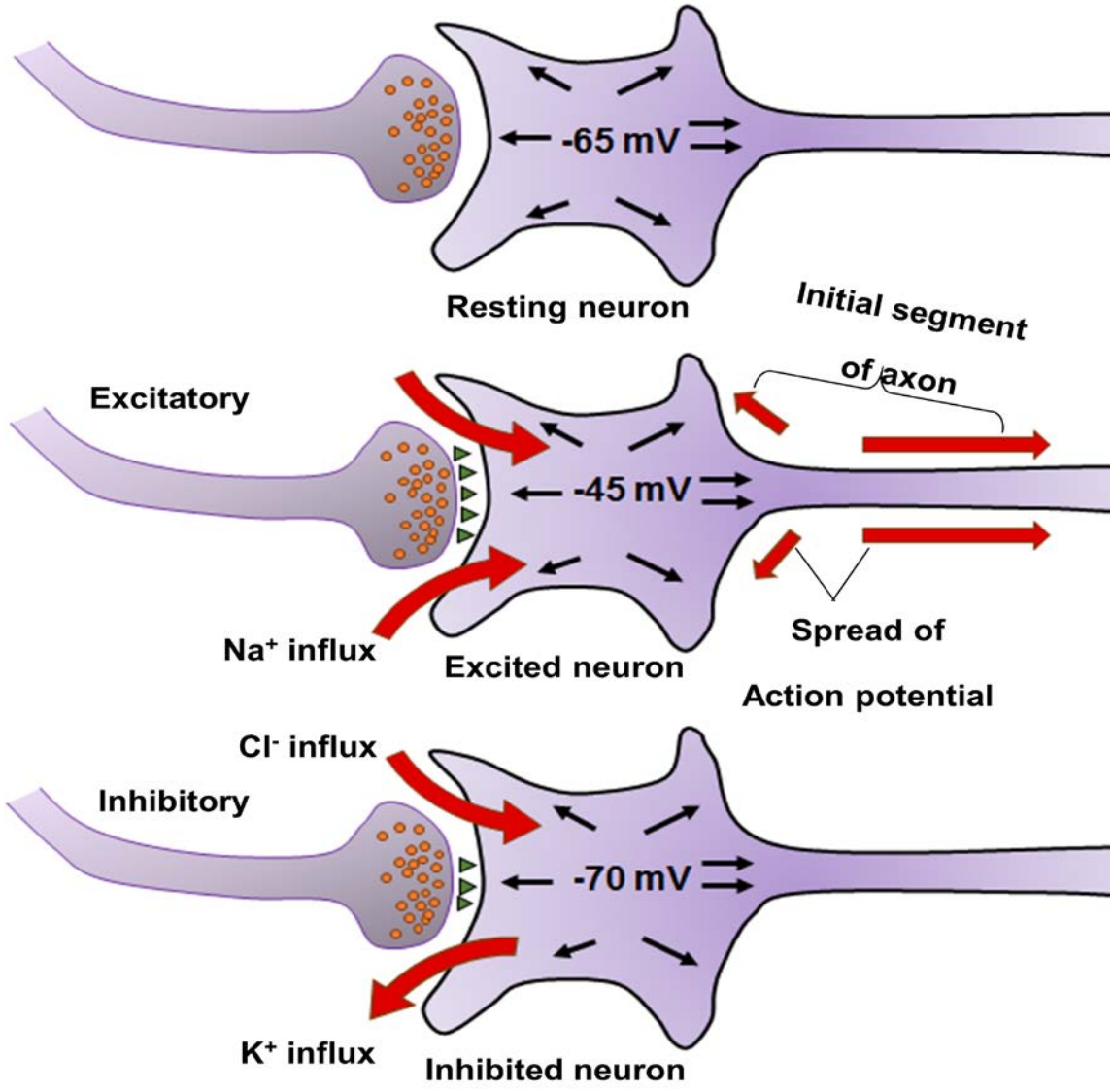


Figure 13.4: The three states of neuron.

The Synapse and Synaptic transmission

The area of functional contact between two neurons for transmission of information is known as *synapse*. In a synapse, membrane of telodendria is called as pre-synaptic membrane and membrane of dendron of other neuron is known as post-synaptic membrane and the space between these two membranes is known as synaptic cleft.

When action potential develops in pre-synaptic membrane. It becomes permeable for calcium ions and Ca^{2+} enters in pre-synaptic membrane. When vesicles burst by the stimulation of Ca^{2+} it release acetyl choline (Ach). Then Ach reaches the post

synaptic membrane via synaptic cleft and bind with receptors, which develop excitatory post synaptic potential. The process of synaptic transmission is shown in Figure 13.5.

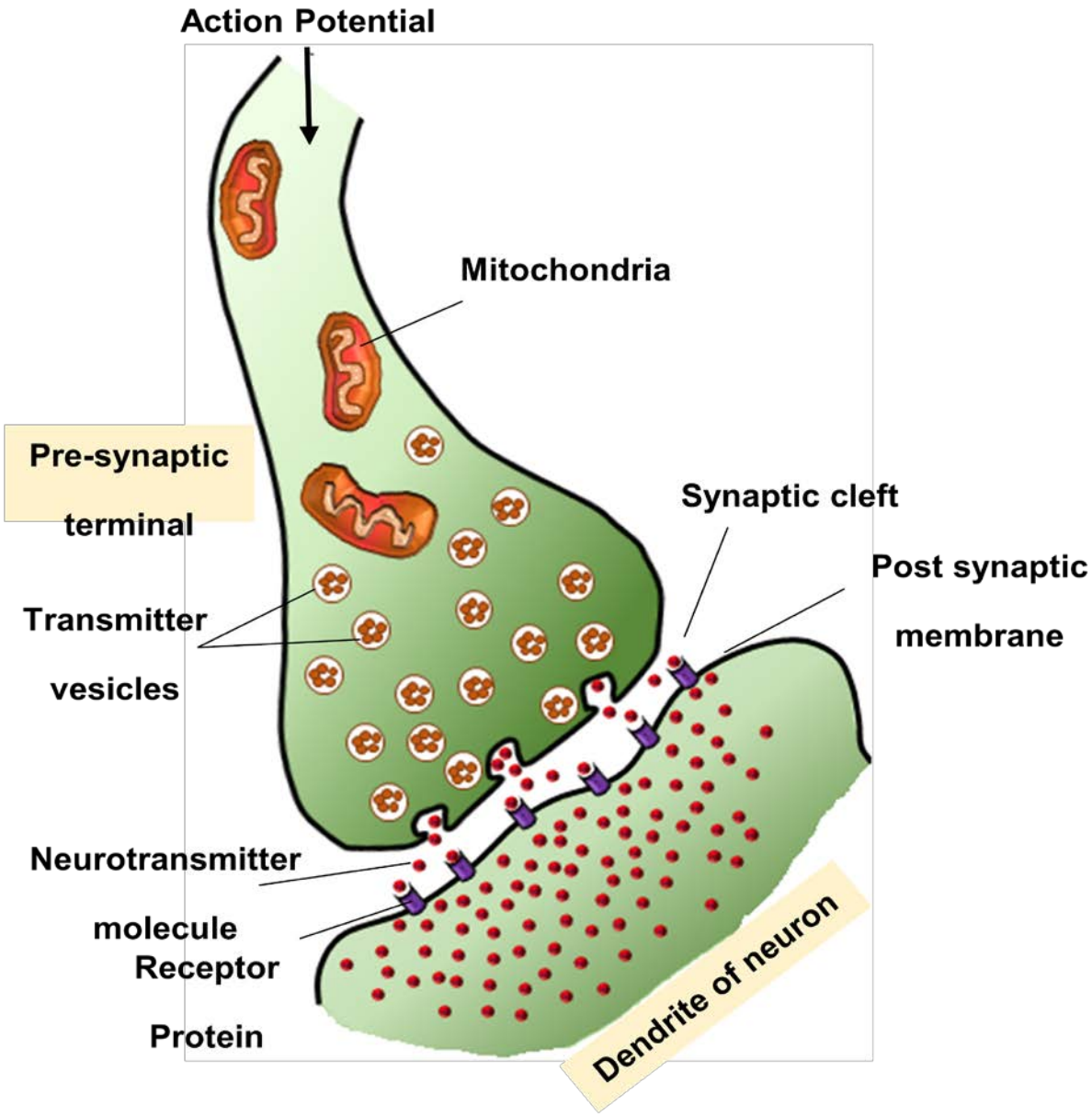
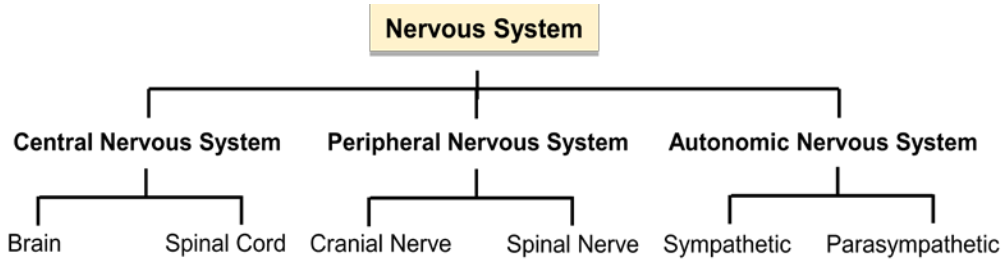


Figure 13.5: Transmission of nerve impulse at a synapse.

Lecture 14: Nervous System (Part-II)

The origin of human nervous system is ectodermal. The whole nervous system is divided into three parts.



Central Nervous System: It comprises the brain and the spinal cord.

1. Brain

Brain accommodate in the skull while spinal cord is enclosed by the vertebral column. To support brain and protect it from external pressures, it is surrounded by a covering of triple membrane of connective tissue called the *meninges*. The three layers of meninges are *duramater*, *arachnoid* and *piamater*. The innermost layer, piamater is thin, delicate and highly vascular. It is firmly adhere to the brain. The middle layer is arachnoid membrane, which is thin and highly folded structure in front of *cranial venous sinus*. The villi like folding helps to reabsorb the *cerebrospinal fluid* (CSF). The outermost layer is very thick, strong and non-elastic called duramatter, is made up of collagen fibre. The space between duramater and arachnoid is known as sub-dural space which is filled by serous fluid. The space between arachnoid and piamater is known as sub-arachnoid space and is filled by CSF.

CSF is lymph like clear and alkaline fluid whose function is to provide support as well as to protect the brain. It also helps in exchange of metabolic substances between the brain and blood capillaries. CSF mainly present in ventricle of brain, sub-arachnoid space and spinal cord.

The human brain is divided into three parts-

a. **Fore brain or Prosencephalon:** It includes cerebrum, diencephalon and olfactory lobes.
b. **Mid brain or Mesencephalon:** It consists of corpora quadrigemina and crura cerebri.
c. **Hind brain or Rhombencephalon:** It includes cerebellum, pons varolii and medulla oblongata.

a. **Fore brain**

Cerebrum: It is the largest and most advanced part of brain which comprises of two cerebral hemispheres on the dorsal surface. A longitudinal groove is present between both cerebral hemisphere known as *median fissure*. Both hemispheres are somewhat connected with curved thick nerve fibres called *corpus callosum*. The outer portion of cerebrum is called the cerebral cortex which is made upcontains numerous cell bodies and relatively few myelinated axons. This gives as overall grey appearance and hence called as**grey matter**. The surface of cortex is highly folded. The upward folds are called as **gyri** consecutive with the downward grooves called **sulci**. Beneath the grey matter there are millions of myelinated axon tracts and contains relatively very few cell bodies which give an opaque white appearance. Hence they are collectively called as **white matter**. Each cerebral hemisphere is divided into four lobes: **frontal** or **anterior**, **parietal** or **middle**, **temporal** or **lateral** and **occipital** or **posterior lobe**. Central sulcus separates frontal lobes from parietal lobes. Lateral sulcus or sylvian sulcus separate temporal lobe from frontal lobe and parietal lobe. Occipital lobe is separated by parietal lobe by parieto-occipital sulcus (Shown in Figure 14.1).

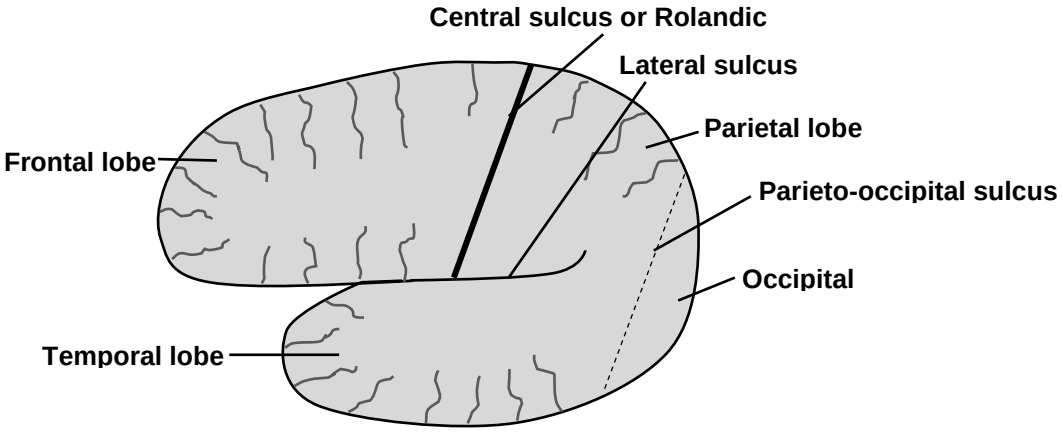


Fig. 14.1: Dorsal surface of cerebral hemisphere

There are three main functional area of each cerebral hemisphere.

1. **Sensory area:** They receive impulse form receptors.
2. **Association area:** They interpret the input, store the input and initiate a response. This area is involved in memory, learning and reasoning.
3. **Motor area:** They transmit impulse to the effector organs.

Diencephalon: It is small and posterior part of fore brain, covered by cerebrum. It consist of thalamus, hypothalamus, epithalamus and metathalamus.

i. **Thalamus:**It is a major part of diencephalon and represents upper lateral wall. It accepts all sensory impulses from the all part of body (except olfaction) and send those to the cerebral cortex. Thus it acts as **relay centre**. In lower animals thalamus act as sensory centre because cerebral cortex is less develop.
ii. **Hypothalamus:** It is called the **master gland**. It represents lower lateral wall of diencephalon. Pituitary gland is attached with its middle part. A web like structure is found on anterior surface of hypothalamus known as **optic chiasma**. In mammalian brain, **corpus albicans** is found on the posterior part of hypothalamus.
iii. **Epithalamus:** It represents the roof of diencephalon. Pineal gland is found in this region.
iv. **Metathalamus:** It represents the floor of diencephalon. It consist medial geniculate body (related to hearing) and lateral geniculate body (related to vision).

b. Mid Brain

It is small and contracted part of brain. Two longitudinal myelinated nerve fibres called **cerebral penducles**or **crura cerebri**located at the anterior part of mid brain. Four spherical projections called *optic lobe* or *colliculus* are located at the posterior part of mid brain. Inferior optic lobes are related to acoustic reflex action.

c. Hind Brain

Cerebellum: It is second largest part of brain. Human cerebellum is made up of 3 lobes. Lateral lobes are large and spherical, called as cerebellar hemisphere. It control regulation and coordination of voluntary muscles.Cerebellumhelps to maintains the body balance of a person.

Medulla Oblongata: It is tubular and cylindrical in shape present at the posterior part of brain. It controls all the involuntary activities of the body e.g. respiration, metabolism, secretory actions of different cells etc.

Pons varolii: It is small spherical projection which is situated below the mid brain and upper to the medulla oblongata. It consists of many transverse and longitudinal nerve fibres. Transverse nerve fibers are joined with cerebellum, whereas longitudinal fibre are join cerebrum to medulla oblongata. It regulates the breathing reaction through pneumotaxic centre.

Midbrain, medulla oblongata and pons varolii are situated on one axis called **brain stem**. The side view of a human brain is shown in Figure 14.2 which shows major parts of brain.

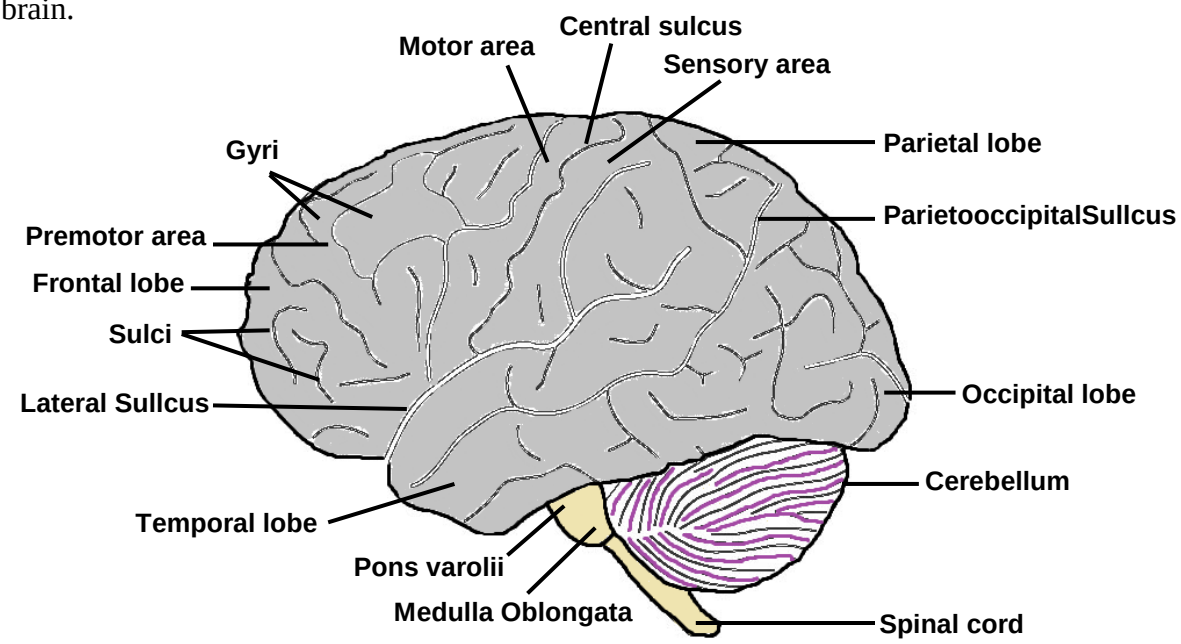


Figure 14.2: Side view of human brain

Table 14.1: Different areas of brain and their functions.

Name of Area	Location	Function
Prefrontal cortex	Frontal lobe	Site of intelligence, knowledge and memory
Premotor area	Frontal lobe	Writing centre, associated movement of eye, head & body, control complex movement of jaw, tongue, pharynx and larynx
Motor area	Frontal lobe	Analysis of all type of voluntary muscle
Frontal eye field	Frontal lobe	Opening and closing of eyelid and conjugate movement of eye
Broca's area or motor speech area	Frontal lobe	Analysis for speak
Auditory area	Temporal lobe	Analysis for sound
Olfactory area	Temporal lobe	Analysis for smell
Wernicke's area	Temporal lobe	Analysis for communication
Gustatory area	Parietal	Analysis for taste
Somesthetic area	Parietal	Analysis for touch, pain, pressure etc.
Angular gyrus	Parietal	Analysis for writing (associated with speech)
Occipital area	Occipital	Analysis for vision

2. Spinal Cord

Spinal cord is continuation of medulla oblongata which comes out from *foramen of magnum* and continues in *neural canal* of vertebral column. It is also covered by duramater, arachnoid and piamater. Narrow space between duramater and vertebra is known as *epidural space*. The outer part of spinal cord is of white matter while inner part is of grey matter. The grey matter projects outside and forms the dorsal and ventral horn. Dorsal and ventral horn continues in a tube like structure known as root of dorsal and ventral horn. In the root of dorsal horn, ganglia are present known as *dorsal root ganglia*. Sensory neurons are found in the dorsal root ganglia whose axon extend and get embedded into grey matter of spinal cord. These sensory neurons make synapse with ventral root neuron. Motor neurons are found in ventral root whose cyton is found in ventral horn while its dendrons are embedded into grey matter of spinal cord. Both sensory and motor nerve fiber combined and comes out from *intervertebral foramen* and form spinal nerve.

Spinal cord acts as bridge between brain and organ of the body. It regulates and conducts the reflex action as well as it provides relay path for the impulses coming from brain.

Reflex Action

Reflex actions are involuntary actions, completed very quickly as compared to normal actions.

Reflex actions are of two types:

a. Cranial reflex: These actions are completed by brain. These are slow actions e.g. watering of mouth to see good food.
b. Spinal reflex: These actions are completed by spinal cord. These are fast actions e.g. withdrawal of arm at the time of pinching by any needle.

Peripheral Nervous System

All nerves arise from brain and spinal cord are included in peripheral nervous system. Nerves arises from brain is termed as cranial nerve whereas nerves arises from spinal cord is termed as spinal nerves. All reptiles, birds and mammals have 12 pairs of cranial nerve. Amphibians and fishes have only 10 pairs of cranial nerves. In human, I, II, and VIII cranial nerve are pure sensory in nature. III, IV, VI, XI and XII cranial nerve are motor nerve and rest others out of 12 cranial nerves are mixed type of nerves.

Table 14.2: List of human cranial nerves

Name	Origin	Distribution	Nature	Function
Olfactory	Olfactory epithelium	From olfactory lobe to temporal lobe	Sensory	Smell
Optic	Retina	Leads to occipital lobe	Sensory	Sight
Oculomotor	Midbrain	Four eye muscle	Motor	Movement of eyeball
Trochlear	Midbrain	Superior oblique eye muscle	Motor	Rotation of eyeball
Trigeminal a. Ophthalmic	Pons varolii -	Skin of nose, eyelid, forehead, scalpe, conjunctiva,	Mixed Sensory	Sensory supply to concerning

b. Maxillary c. Mandibular	- -	lachrymal gland. Mucous membrane of cheeks and upper lip and lower eyelid Lower jaw, lower lip, pinna.	Sensory Mixed	part - Muscle of mastication
Abducens	Pons varolii	Lateral rectus eye muscle	Motor	Rotation of eyeball
Facial	Pons varolii	Face, neck, taste buds, salivary gland	Mixed	Taste (anterior 2/3 part of tonge), facial expression, saliva secretion
Auditory	Pons varolii	Internal ear	Sensory	Hearing and equilibrium
Glossopharyngeal	Medulla oblongata	Muscle and mucous membrane of pharynx and tongue.	Mixed	Taste (posterior 1/3 part of tounge), saliva secretion
Vagus	Medulla oblongata	Larynx, lungs. Heart, stomach, intestines	Mixed	Visceral sensations and movements
Accessory spinal	Medulla oblongata	Muscles of pharynx and larynx	Motor	Movement of pharynx and larynx
Hypoglossal	Medulla oblongata	Muscles of tongue	Motor	Movement of tounge.

In human, there are 31 pairs of spinal nerves. Each spinal nerve is of mixed type and arise from the roots of the horns of grey matter of the spinal cord.

Spinal nerves are divided into 5 groups according to its position:

1. Cranial spinal nerve – 8 pairs
2. Thoracic spinal nerve – 12 pairs

3. Lumber spinal nerve – 5 pairs
4. Sacral spinal nerve – 5 pairs
5. Coccygeal nerve – 1 pairs

Autonomic nervous system

The autonomic nervous system controls activities inside the body that are involuntary e.g. heart rate, sweating, peristalsis etc. It consists of motor neurons passing to the smooth muscle of internal organs. Autonomic nervous system plays an important role in maintaining homeostasis. It is divided into two parts: 1) Sympathetic and 2) Para-sympathetic.

Sympathetic system is related with such intuitive reaction which increases the protection of body in adverse atmospheric condition along with energy consumption. Whereas para-sympathetic system is linked with those reactions in which energy is conserved.

Measurement of nerve conduction

A **nerve conduction study** (NCS) is a medical diagnostic test. It is used to estimate the function and the capability of electrical conduction, of the motor nerves and sensory nerves of the human body. Nerve conduction velocity (NCV) is frequently measured during this test.

NCS laterally with electromyography measure nerve and muscle function. Diagnosis of defective spinal nerve compression, or any other neurologic disorder or injuries are undertaken for study by NCS process. Evaluation of numbness of limbs, weakness of the legs and arms as well tingling or burning sensation in certain areas of the body are the central area of diagnosis.. Nerve conduction study mainly comprise of the following studies.

1. **Motor NCS:** It is performed by electrical stimulation of a peripheral nerve and recording from a muscle to which these nerve supplies. Latency is defined as the time taken for the electrical impulse to travel from the stimulation to that muscleand is usually measured in milliseconds. The target muscle generates a response whose size is called the amplitude. Motor amplitudes are measured in millivolts. Determination of NCV across different segments of the nerve is a

primary goal of the Motor NCS study. It is done by the stimulation of two or more different locations along the same nerve.With the help ofthe difference in latencies from the two points of stimulation as well as the distance between the different stimulating electrodes, one can calculate the NCVs across different segments.

2. **Sensory NCS:** It is similar to Motor NCS and is performed by electrical stimulation of a peripheral nerve and but here the recording is done from a truly sensory portion of the nerve. Sensory latencies are measured milliseconds but sensory amplitudes are much smaller than the motor amplitudes (microvolt). Sensory NCV is calculated in the same way as motor NCVs.
3. **F-wave study:** The motor and sensory segments are concerned about nerve conduction velocities in sections/segments of limb whereas the F-wave latency is used to derive the conduction velocity of nerve between the limb and spine.In a typical F wave study, a strong electrical stimulus is applied above the distal portion of a nerve. The resulting the impulse travels both in both directions: one towards the muscle fibre and the other back to the motor neurons of the spinal cord. These directions are referred to as orthodromic and antidromic, respectively. The *orthodromic* stimulus on reaching the muscle fibre elicits a strong M-response indicative of muscle contraction. Meanwhile the*antidromic* stimulus on reaching the motor neuron cell bodies excites a small portion of the motor neurons causing them to backfire resulting in orthodromic wave which travels back down the nerve towards the muscle. This reflected stimulus evokes a smaller response of the muscle fibres resultingin a second CMAP called the F wave.

   The limb length, D(in millimetres)is taken into account for calculations of Conduction velocity.
4. **H-reflex study:** This studyis similar to F-wave study and evaluates conduction between the limb and the spinal cord. Although a subtle difference exists in that here the impulses going toward the spinal cord are in sensory nerves while the impulses coming from the spinal cord are in motor nerves.

The interpretation of nerve conduction studies is a complex affair and expert medical practitioners such as neurologists, physiatrists or clinical neurophysiologists are routinely involved. NCS have proven to be very helpful in diagnosis of many diseases related to the nerves. The process is non-invasive, albeit sometimes it can be painful due to minor electrical shocks. Although the low amount of electrical current is considered safe, patients with a harbouring electrical devices such as permanent pacemaker are advised to avoid this kind of test or tell the examiner prior to the test.

Electro-encephalograph (EEG)

In 1929, Hens Berger is credited to have found some electrical activity when he connect a galvanometer to human scalp. It gave birth to electro-encephalography. EEG is an electrically operated instrument having array of 16-30 electrode, which when attached to the scalp for short time gives electric wave signals. It operates by detecting the brain's electrical charge which is maintained by billions of neurons. The Neurons are electrically charged due to continuous pumping of ions by membrane transport proteins across their membrane. Neurons constantly exchange ions with the extracellular fluid, e.g. to maintain resting membrane potential. When many ions having similar charge are pushed out of several neurons at the same time, they can push their neighbours, who further apply force to their neighbours, and so on such that a wave forms. When the wave of ions reaches the electrodes attached to the scalp, they can give or take electrons on or from the metal of the electrodes. Since metal can conducts these electrons easily, voltages difference between any two electrodes can be measured by a voltmeter. Recording these voltages for a specific time gives us the EEG. A schematic of typical EEG frequency display system is shown in Figure 14.3.

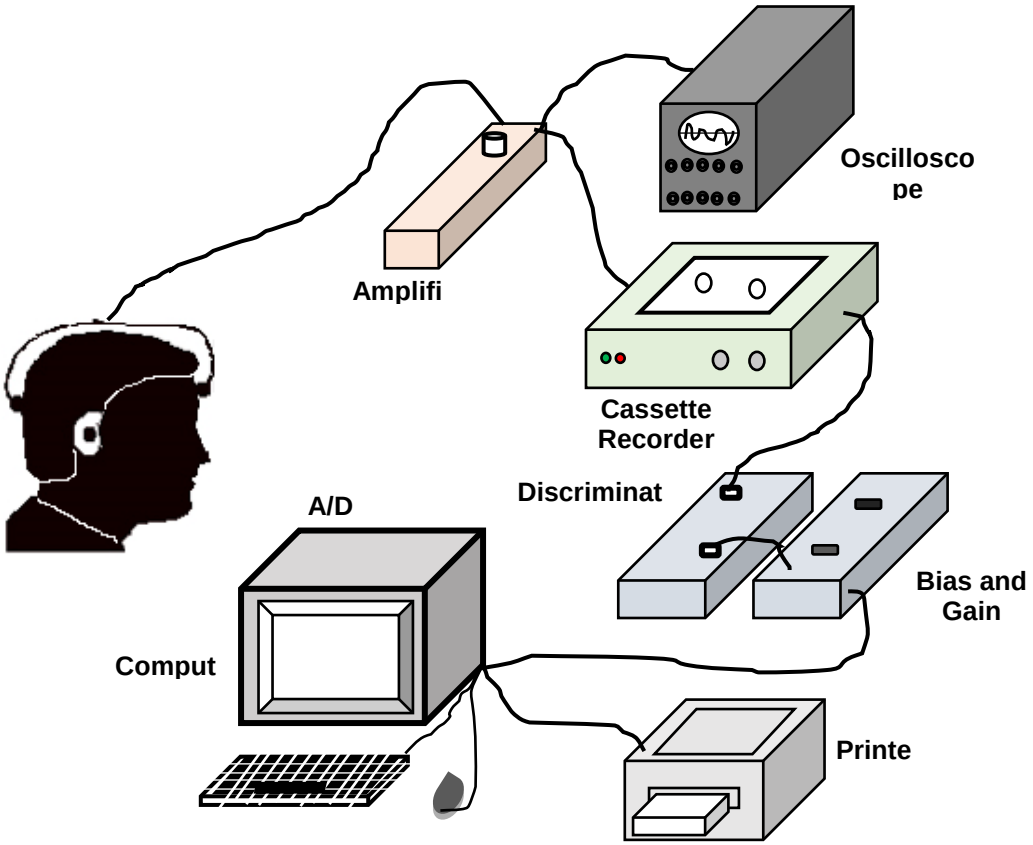


Fig. 14.3: EEG frequency display system

Wave patterns form during EEG recording

Delta waves: The frequency of Delta wave is below 4 Hz. It is the highest in amplitude and the slowest waves. It originate normally in adults during sleep. It is also seen normally in babies. It can also be observed in patients during coma.

Theta waves: The frequency of theta wave range from 4 Hz to 7 Hz. It is seen normally in young children. It may be seen in older children and adults under stress or during meditation. Excess theta for age represents abnormal activity.

Alpha waves: The frequency of alpha wave range from 7 Hz to 14 Hz. An awake but resting person produces alpha wave. Hans Berger termed “alpha wave” when he saw the first rhythmic EEG activity. This was the "posterior basic rhythm" seen in the occipital regions of the brain. It arises with closing of the eyes and with relaxation, and weakens with eye opening or mental labour. In addition to the posterior basic rhythm, there are

other normal alpha rhythms such as the “mu rhythm” which arises when the hands and arms are indolent.

Beta waves: The frequency of beta wave range from 15 Hz to about 30 Hz. During extreme mental activity, beta wave initiates from frontal and parietal regions. Beta activity is closely linked to motor behaviour and is generally weakened during active movements. An alert wide awake person shows unsynchronised beta wave.

Gamma waves: The frequency of gamma wave is nearly 30–100 Hz. Gamma rhythms represent binding of different populations of neurons together into a network for the purpose of carrying a certain motor function.

Mu waves: The frequency of mu wave is 8–13 Hz. It partly overlaps with other frequencies. It denotes the synchronous firing of motor neurons in rest state.

Deviations from normal pattern indicate brain disorder and change in physiological state of brain. EEG can diagnose epilepsy, brain tumour, abscess, sleep disorders, metabolic and drug effects on brain.

Lecture 15: Muscular System (Part-I)

Introduction: Locomotion is important to all organisms for various purposes like to find food, to mate, to escape from predators, for survival purpose, etc. and altogether, they influence in locomotive organ evolution process in animals. Locomotive organs are different in nature from one species to other. Muscles play important role in movement of the animals. In higher animals along with muscles, bones also associate for the movement. Animal movements can differentiate as walk, run, swim, fly, crawl and jump. Bacterial movement can classify as flagellar, spirochaetal and gliding movement. Single cell organisms also show crawling like movement often called amoeboidal movement as well as they show cillary movement, flagellar movement. Nature of movement is different in plants in which roots, branches, leaves move in response to environmental abiotic factors but overall the plant is non-movable. Here we discuss the different types of locomotion or movement and their mechanisms briefly.

Definition: Locomotion can defined as an ability to move from one place to another.

The organs which helps for the locomotion is called as locomotive organs. Ex: limbs, flagella, cilia, etc.

Locomotion in single cell organisms

Prokaryotic and eukaryotic single cell organism do movement for their survival, growth and reproduction.

Bacterial movements

Bacteria are single cell prokaryotic organisms. They show three different types of movements. They are

1. Flagellar movement
2. Spirochaetal movement and
3. Gliding movement.

Mechanism of these movements are partially understood.

Flagellar movement

Bacteria can move in liquids with help of flagellum. Depends on number of flagella, arrangement over cell surface, bacteria were named differently like monotrichous,

lophotrichous, amphitrichous and peritrichous. According to the arrangement they are classified into different classes and those bacteria are motile.

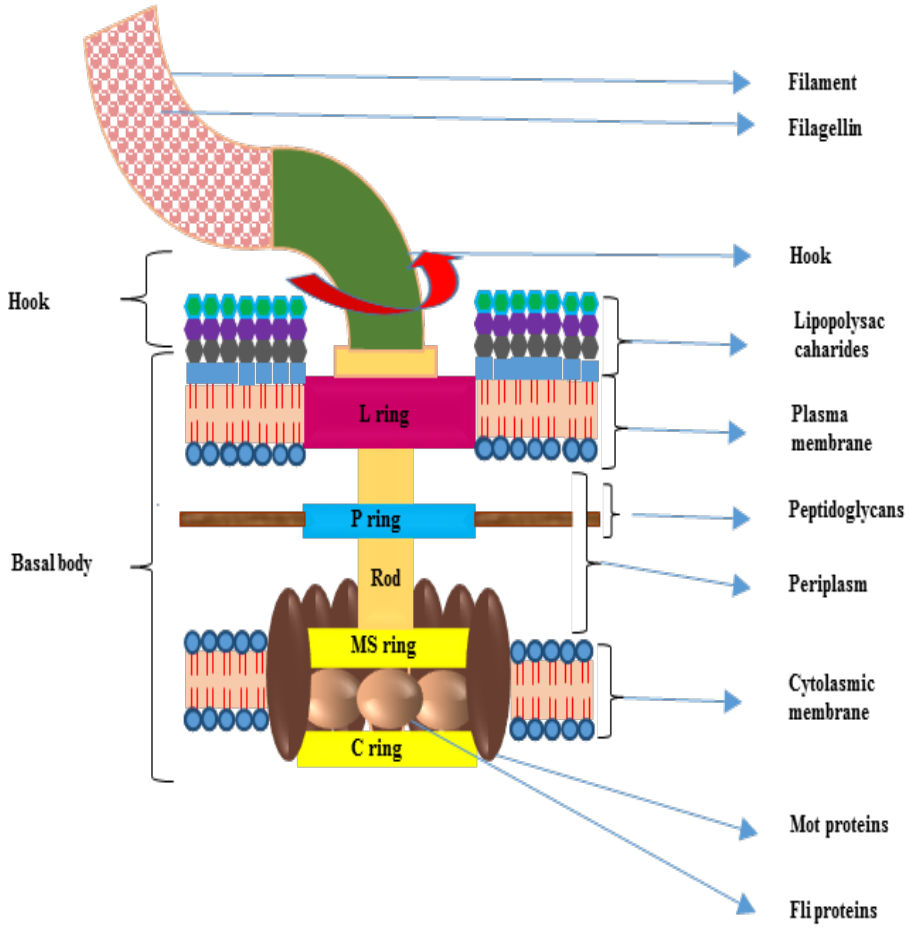


Figure 15.1 : Structure of Flagellum

Flagellum (Figure 15.1) is a lash-like cell surface appendages and it consists of protein flagellin. It generally divided into 3 portions and they are basal body, hook and filament. Basal body areimplanted in cell wall. Basal body of the flagellum has M (motor) ring, S(stator) ring and C ring. M and s ring together bind with peptidoglycan layer of the bacteria whereas c ring present in the cytoplasmic region. Basal body is connected with the filament by hook. Flagellum can rotate either clockwise or anticlockwise. Further basal body has around 40 proteins including ‘mot’ proteins and ‘fli’ proteins which are essential in the active movement through proton pumping mechanism. Ex. for flageller bacteria Vibrio, Spirillum, Salmonella,Klebsiella, etc.

Spirochetal movement:

Spirochetes are Class V bacteria. The movement of Spirochetes is called as spirochetal movement. Spirochetes are long right handed helically shaped bacteria. Axial fibrils and periplasmic flagellum,present in the periplasmic region of the bacteria,overlapped together and run one sub-polar end to other of the Spirochetes (Figure 15.2). The mechanism of Spirochetal movement is not clear, however the proposed anticlockwise rotation of the flagellum can lead the bacterial movement. Classical example for this type movement is Treponemapallidum.

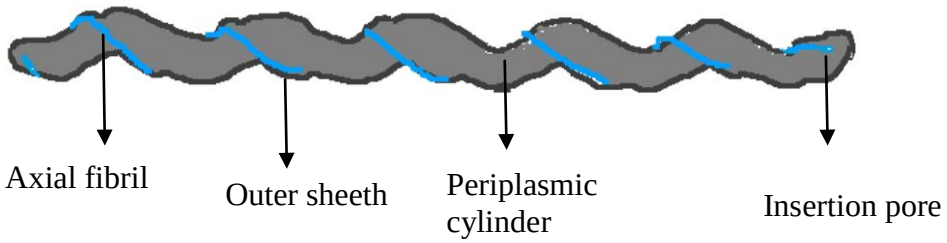


Figure 15.2 : Structure of Spirochetes

Gliding movement:

Group of gliding bacteria show non flagellum based gliding movement. Fimbriae like appendages (pili), present at polar region, involve in the gliding movement with the help of motor system A and S along chemosensory system 'Frz'. Here coordinated movement of two different motor system, known as S and A system, response for the motility of bacteria (Figure 15.3).But their mode of action is unclear. Ex. Myxococcus, cyanobacterium, Oscillatoria.

Figure 14.3 : Gliding movement of *Treponema Pallidum*

But other hypotheses like generation of contractile waves or surface tension or pushing by secreted slime was also proposed as possible mechanisms of gliding.

Eukaryotic single cell movement

Both single cell life forms as well as multicellular life forms are exist in eukaryotes. According to the life form they adopt their own mode of locomotion.

Protozoan are single cell eukaryotes. Theyare following different type of locomotion according their life form. Amoeba is a single cell protozoa. It can migrate with the help of pseudopodia and this movement is called as amoeboid movement. Most of the time amoeba move to get the food. Various hypotheses regarding the amoeba movement:front contraction hypothesis, tail contraction hypothesis, ectoplasmic contraction theory, cytoplasmic streaming, sol-gel theory, etc., Here we discuss the simple ameboidal locomotive sol-gel theory.

The simple mechanism of amoeba movement (Figure 14.4) as follows

1. Swelling of the plasmagel results pseudopodia in response of semipermeable membrane turgidity.
2. Movement of plasmasol towards the pseudopodia with simultaneous contraction of plasmagel
3. Gelation of plasmosol results enlargement of pseudopodia
4. Adhesion to the food particle.

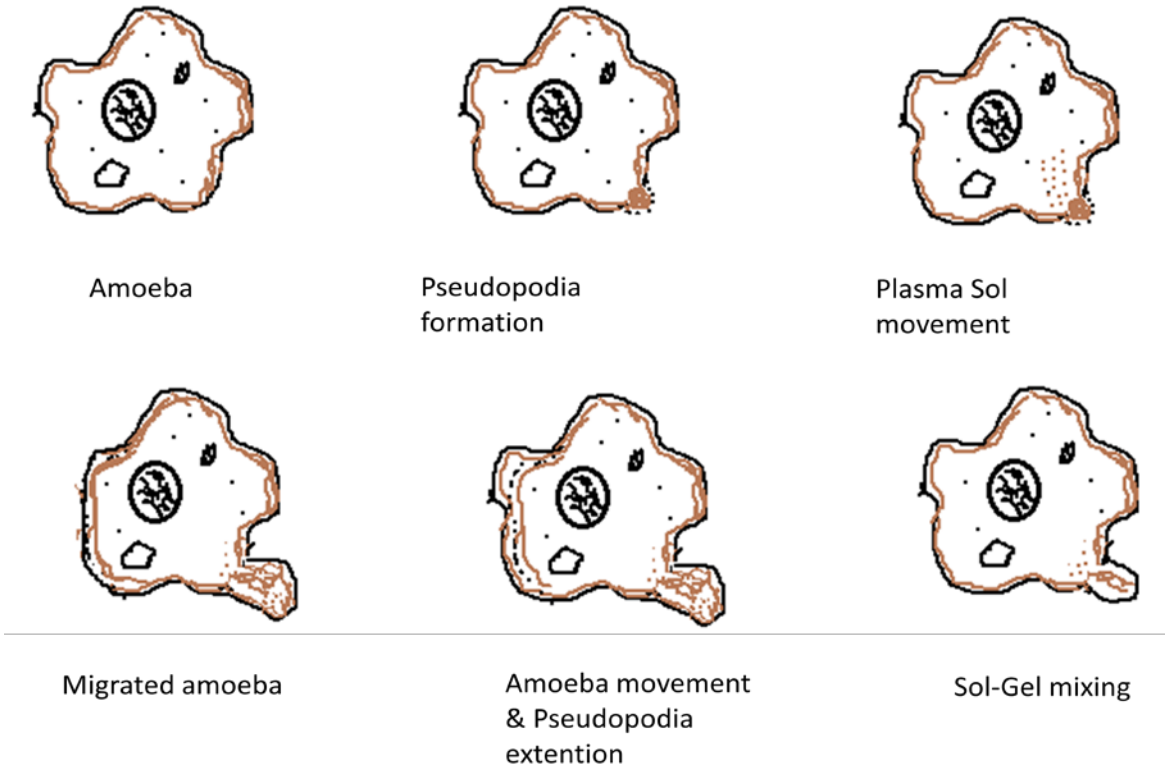


Figure 14.4 : Sol-Gel Ameoba movement

Most of non-flagellated cells often follow the amoeboid movement. Ex. Macrophages

Euglenoid movement

Euglena is another single cell eukaryotic organism. Euglena contains flagella as well as pellicular structure. Euglena can move by waving the flagella. Pellicular structure of the euglena also help them to move. Adjacent pellicular strips move very quickly thus by changing own shape euglena can move without the help of flagella.

Paramesium (ciliary) movement

Paramesium is one more single cell eukaryotic organism which show cilia movement. Dense hair like cilia is present on entire outer surface of the euglena. In a coordinated manner, cilia move one after one all over the body result the paramecium movement.

Movements in animal cells

Animals, insects, birds, reptiles and fishes are multicellular eukaryotes. They migrate in three different modes. They are amoeboid movement, ciliary movement and muscular movement.

Amoeboid movement: In animal cell migration is possible by cytoplasm streaming which followed by the formation of pseudopodia. In animal cells, microfilament involvement is observed in amoeboid movement.

Ciliary movements: Cilia is the short form of the flagella present in ciliated epithelium. Coordinated movements of cilia helping those cells to migrate. The function of cilia almost similar to flagellum.

Muscular movement: In higher organisms, muscles based movement is very common. Coordinated function of muscles, skeletal and neural systems results the muscle movement.

Locomotion in lower animals

In lower animals skeletal system is underdeveloped or absent. In such condition they have to use muscles or specialized locomotive organs for the locomotion. Ex. Earthworms, snails, snake, fishes, etc.

Locomotion in Earthworm:

Long tube like structured earthworm moves underground by means of waves of muscular contraction. During muscular contraction body segments are alternatively shorten and lengthen. A special type S-shaped setae ring present in all segments of the earthwork except first, last and clitellum which help to anchor the surrounding soil. Mucus lubrication secretion make easier of their movement in soil.

Locomotion in Snake:

Snakes also use muscles for their locomotion. Four types of locomotion were identified in snakes. They are lateral undulation, rectilinear movement, concertina movement and sidewinding. In common lateral undulation mode, wave like muscle reflexion from head to tail results the locomotion.

Locomotion in Sea-anemone:

Bilateral sea-anemone moves by radial operation of radial pedal. Sea-anemone creeps in the direction of plane of symmetry.

Locomotion in fishes

Fishes swim by using their specialized locomotive organ fins. While moving the fins, the generated thrust help to move to the fish. With the help of multiple fins fishes can control the direction of movement.

Locomotion in cockroach

Cockroaches have wings as well as legs. Primarily they use the legs for the locomotion and as well as they can use the wings too for the locomotion.

Locomotion in Higher animals:

Large number of animals use limbs for their movement in which muscles are attached endoskeleton or exoskeleton. In vertebrates endoskeleton muscle system is present in which muscles are attached external portion of the bones (Figure.15.5.a). But in arthropods exoskeleton muscle system is present in which muscles are attached inside of the skeleton system (Figure 15.5.b)

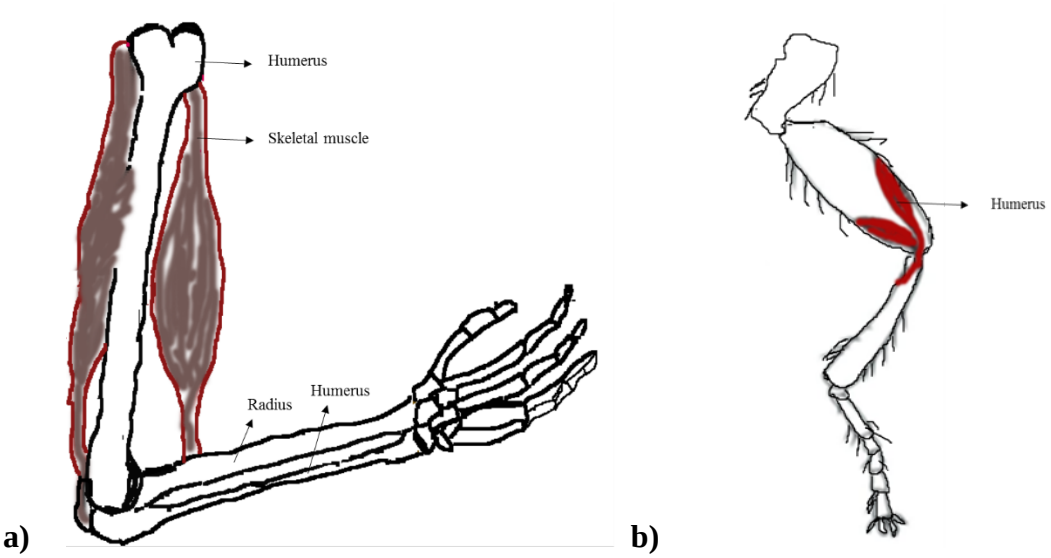


Figure 14.5 : Exoskeleton and endoskeleton system

In birds, limbs are developed into wings as well as legs. Such differentiation is absent in vertebrates (Figure. 14.6).

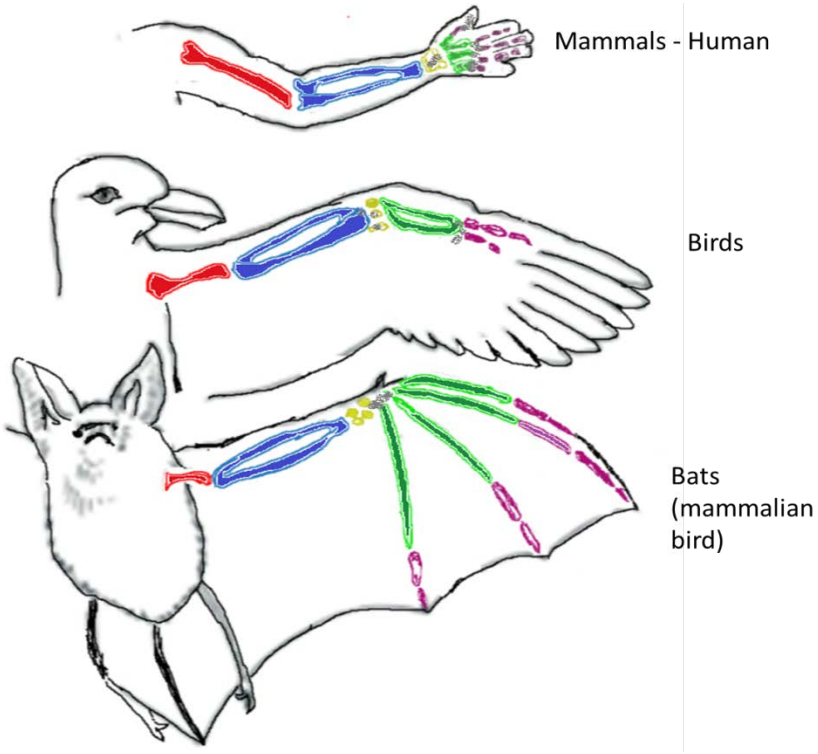


Figure 14.6 : Modified limb systems

Most of the insects use limb system for their movement but they follow different mode of locomotion according to their systems.

Movements in plants:

Plants also show movements like phototrophism, gravitrophism.

In response to light, plant grow towards the light. This phenomenon is called as phototropism. Whereas signalling molecules have their own roles in this process. Auxin is one them. It triggers shoot growth. Stems show positive phototropism and roots show negative phototropism.

The growth in response to gravity is called as geotrophism. Roots show positive geotrophism and stems show negative trophism. Here again auxin plays an important role in geotrophism.

Plant movement against contact stimuli is called as thigmotropism. Climbing plants such as vines are the examples for thigmotropism. When the plant touches some surface, the cell which contact the surface secrete the auxin to the untouched neighbour cell and induce them to grow long. This results bending around the object.

Lecture 16: Muscular System (Part-II)

Introduction: Muscle is one type of tissue among four different tissues. Muscle is a specialised type of tissue and it originating from mesoderm. Muscles alone contribute around 40 to 50 percent body weight of the human. Excitability, contractility, elasticity and extensibility are the special characteristic nature of the muscle cells.

Based on their location, muscles are classified into three categories:

1. Skeletal muscles,
2. Visceral muscles and
3. Cardiac muscles.

Skeletal Muscles: Muscles which are associated with skeletal components are known as skeletal muscles. Microscopically their appearance is look like striped. Hence they are also called as striated muscles. These muscle activities are regulated voluntarily by the nervous system. The principle action of skeletal muscle is locomotion and it can modulate body shape.

Visceral muscles: Visceral muscle present in inner walls of hollow visceral organs of the body. Example includes, alimentary canal, reproductive tract, etc. Unlike skeletal muscle, they are smooth in appearance. They are involuntary in nature so nervous system cannot control voluntarily. Visceral muscle involves in food transport in digestive tract and gamete transport through the genital tract.

Cardiac muscles: Heart consists of cardiac muscles in which cells assemble in a branching pattern. Like skeletal muscles, they are also striated. Activity wise, they are involuntary in nature thus nervous system cannot control the cardiac muscles directly. The different between these muscle forms is given in Table 16.1.

Table 16.1: Difference Between skeletal, visceral and cardiac muscle.

	Skeletal Muscle	**Visceral Muscle**	**Cardiac Muscle**
Location	Around bone all over the body	Inner walls of alimentary canal, reproductive tract	Heart
Morphological appearance	Striped	Smooth	Striped with cross linking
Nerve control	Involuntary	Voluntary	Involuntary
Function	Movement	Transport	Pumping
Contraction types	Short twitch and long tetranic	Concentric, eccentric, isometric and isotonic	Long tetranic
Elasticity	Elastic in nature	Elastic in nature	Elastic in nature
Diameter	10 to 80 µM	1 to 5µM	~ 10µM

Structure of skeletal muscle:

Muscle cells are also termed as muscle fibres. (Figure 16.1) They are long, cylindrical and multinucleated cells. Muscle fibres were organised in three levels. They are epimysium, endomysium and perimysium. Muscles are covered by thick and tough connective tissues called as epimysium. Epimysium separates one muscle from another. Collagen fibres of the eipmysium are wavy in appearance and it has connection with the perimysium. Each perimysium covers 100 to 150 muscle fibres and forms fascicles. Interstitial space between muscle fibres is around 1 µm which allow development of the tunnel in the perimysium thus arteries, veins and nerves can pass through it. In perimysium, collagen fibres are arranged as wavy forms with cross links which helps to improve the strength and stability of the muscle fibres. Endomysium consists of loose connective tissues and they additionally add up the strength of the muscle fibres. Endomysium also connects with the perimysium for the stability.

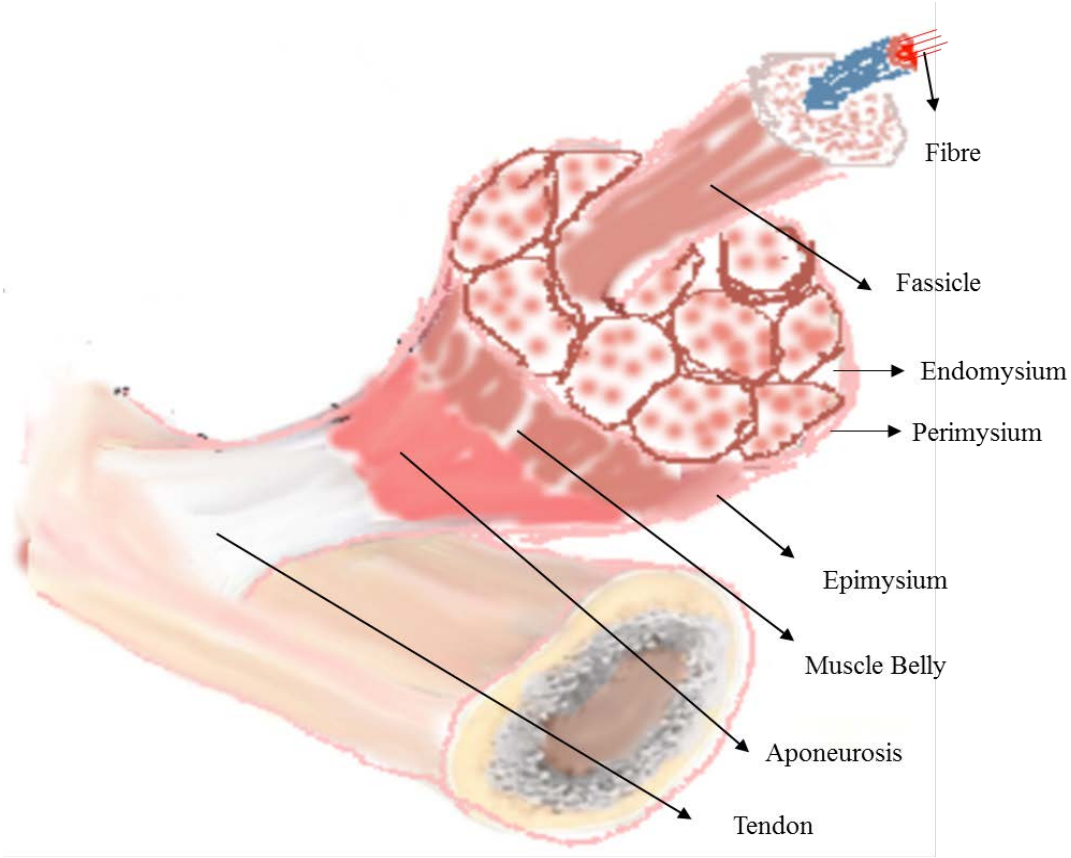


Figure 16.1: Organization of muscle fibre

Muscle fibres are lined by the plasma membrane (sarcolemma) enclosing sarcoplasm. Muscle fibres contains multiple nucleus (syncytium) and the sarcoplasm contains relatively higher amount of glycogen granules, myoglobin. Moreover high amount of calcium stored in endoplasmic reticulum. Parallel arrangement of myofilaments in sarcoplasm is one of the characteristic nature of the muscle fibre. Two types of myofilaments, known as myofibril present in the muscle fibres (Figure 16.2). Based on the thickness, myofibril termed as thin and thick myofilament which is made up of actin and myosin filaments respectively. Actin filament otherwise termed as 'I' band or isoelectric band whereas myosin filament termed as 'A' band or anisotrophic band. Actin and myosin fibrils are arranged alternatively and run across the muscle fibres longitudinally. Z – line and M – line, which are fibres with elastic in nature present in between I band and A band respectively. The portion in between to A band is termed as sarcomere which is the functional unit of the muscles which is responsible for contraction.

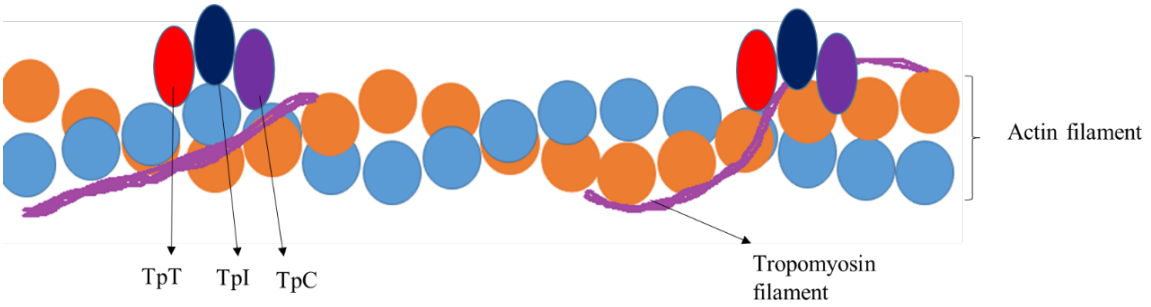


Figure 16.2: A thin myofilament

Actin: Actin is one of the major muscle proteins, which is a polymeric in nature. G-actin is the monomer unit of the actin filament and it is globular in nature. Its molecular weight is around 43 kda. Number of actin monomer units polymerize and form multimeric fibrous F-actin. Two F-actins coil around each other to form α-helice (Figure. 16.3). Thickness of F-actin filament is around 6-7 nm and it consists of 14 G-actin molecules per turn. Association with tropomyosin and troponin, F-actin forms I band of the myofibril. Troponin masks the active binding sites for myosin on actin filaments.

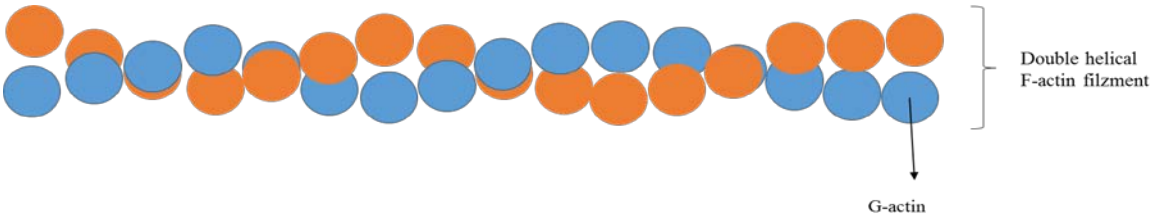


Figure 15.3: Actin Fibre

Myosin: Myosin is another major muscle protein. It is a hexameric protein. It consists of two heavy chains and four light chains. Molecular weight of the heavy chains and light chains are around 200 kda and 15 to 27 kda respectively. Heavy chain forms dimeric filaments by coiling α-helically each other except N terminal (Figure 16.4). Unwound N terminal of myosin is globular in nature and it serves the binding sites for other light chains as well as F-actin. N terminal of the myosin has ATPase activity. Carboxy terminal of myosin filament meet together at H zone whereas N terminals meet together at the margins of A band.

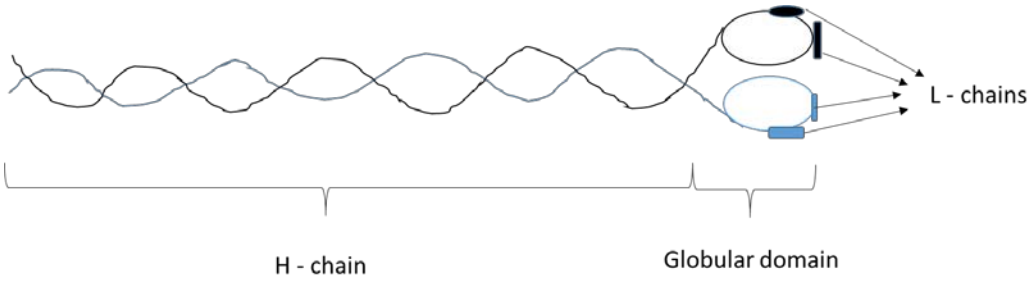


Figure 16.4: Myosin fibre

Tropomyosin: Tropomyosin is a rod like fibrous molecule. Its molecular weight is around 66 kda. It made up of two different α and β peptides and both are α-helical in nature. Double stranded tropomyosin run parallel with thin filaments in grooves of the F-actin strands.

Troponin: Troponin is a globular protein and exit as three interconnected protein system. They are (a) TpT (tropomyosin binding protein), (b) TpC (calcium binding protein) and (c) TpI (actin and TpC binding protein). Troponin lie on thin filaments with an interval of 38.5 nm, but the rest attached with F-actin and tropomyosin.

Polymerization of desmin results intermediate filaments which is predominantly present in Z line. A-α-actinin is a homodimeric protein and often anchors the ends of f-actin molecule to the Z line.

Neuromuscular junction in skeletal muscle:

Neuromuscular junction is a connective region of efferent nerve fibre of nerve system and muscle fibre of muscle system through synapses. The entire junction is covered by a cell, which known as Schwann cell, for insulation purpose. An invaginated membrane

appearance present in this junction is called as synaptic gutter where axon neuronal end. Sub-neuronal clefts surround the axon terminal and it increases the surface area for synaptic transmitters. (Figure. 16.5)

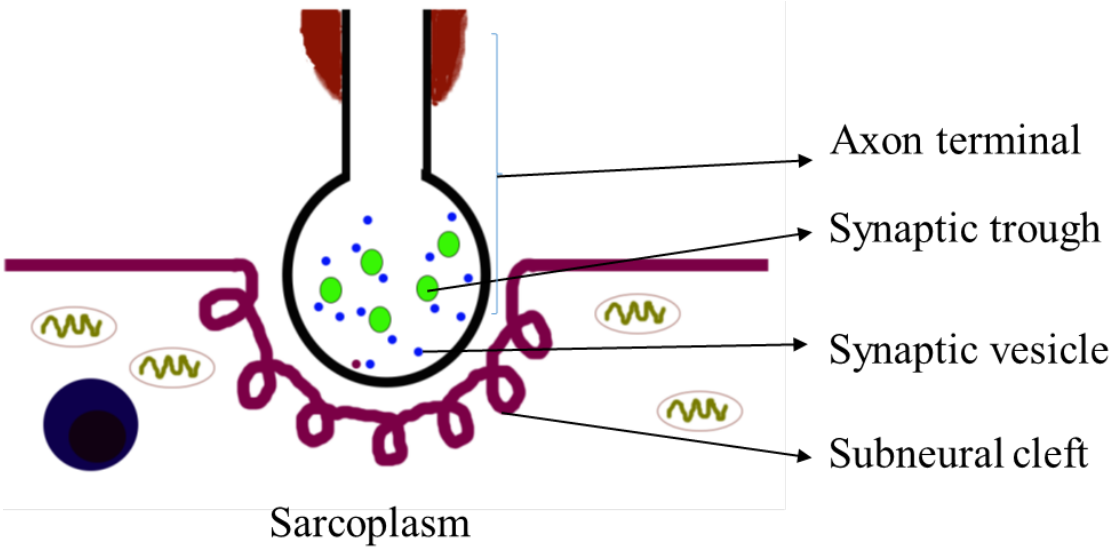


Figure 16.5: Neuromuscular junction

Structure of Visceral muscle

Visceral muscle or smooth muscles are fusiform in shape (Figure 16.6). They mostly present free in nature i.e., single fibre form. It has greater elasticity than the muscle fibre. Contractility and extencity are also higher than muscle fibre. Myosin, actin, troponin, tropomyosin, calponin, caldesporin are some of the protein present in the smooth muscles.

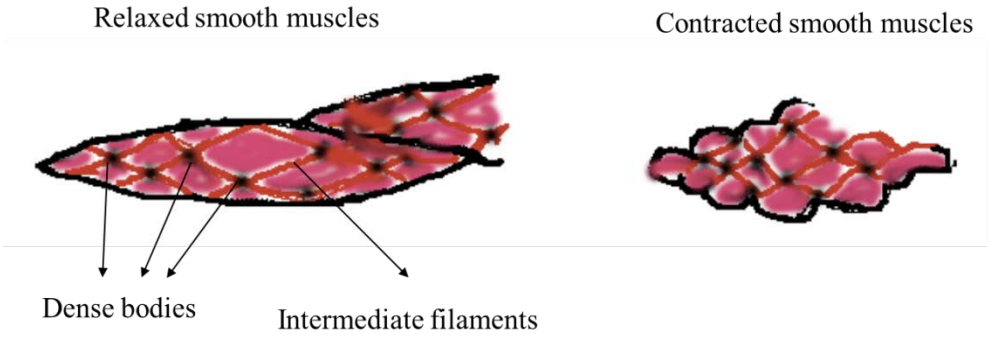


Figure 16.6: Structure of smooth muscle

Neuromuscular junction in smooth muscle:

Branches of autonomous nerve fibres innervate the smooth muscle in a diffuse manner. The junctions are not connected directly with muscle, but they secrete the neurotransmitters at external space of muscle fibre. Secreted neurotransmitters diffuse through the muscular fibre membrane to transmit the signal.

Structure of Cardiac muscle:

Cardiac muscles having many features as like skeletal muscle. Cardiac muscle cells are separated by a dark area which called as intercalated discs (Figure 16.7). They are striated and interconnected. Gap junctions and desmosomes also present in the cardiac muscle. Interconnected cardiac cells called as syncytium. Heart consists of two syncytium, known as atrial syncytium and ventricular syncytium.

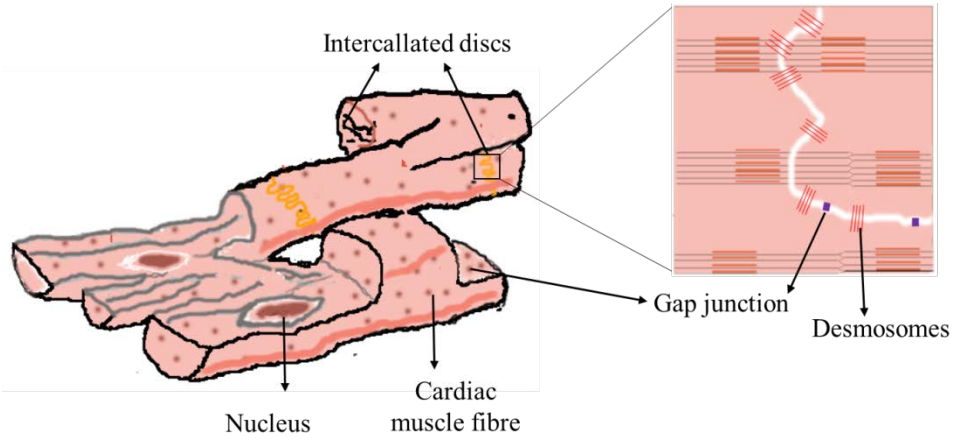


Figure 16.7: Structure of cardiac muscle

Lecture 17: Muscular System (Part-III)

Introduction: In human well developed limb system exists for the locomotion. Together muscle-skeletal-nerve system coordination results the locomotion. Here we discuss the different types of muscle contraction and their mode of action.

Types of muscle contraction in human:

Three types of muscles present in human which we discussed in previous lecture. Skeletal muscles are mainly involving in the locomotion by contraction. Contraction of the skeletal muscle underlie in two different class. They are Twits contraction and tetranic contraction. Voluntary muscles contractions are differentiated as concentric, eccentric, isometric and isotonic contraction. Cardiac muscle contraction can be include in tetranic contraction but molecular level difference can be seen (Figure 17.1).

Twitch contraction: It is a very short timed muscle contraction. In response to stimuli, muscle contract and relax but before reaching the peak muscle start to relax.

Tetranic contraction: In comparison to twitch contraction, tetranic contraction is a longer contraction. In response to stimuli, muscles contract, stabilize and then relax in a sequence manner. Duration of the stable condition vary depend on the strength of the stimuli.

Concentric contraction: In order to overcome the resistance with generated energy, muscle contracts and shortens. This contraction can be seen in bicep contraction, angle change in joints.

Eccentric contraction: Due to the lack of energy generation to overcome the external response, muscle contract and lengthen.The response is slightly delayed one when compare to the concentric contraction.

Isometric contraction: No variation can find in muscle length in response to the external force. So there is no movement.

Isotonic contraction: The excessive force on the muscle initially contracts and later increases the muscle length. The muscle length increase in response to the external force.

General mechanism

In response to signals action potential generated from the brain reach to the muscle cells through the neurons. At the end of the axon terminal, it secretes a small amount of neurotransmitter, acetylcholine. Acetylcholine diffuses from the membrane receptors which present on the muscle membrane to transmit the signal. Acetylcholine binding leads to the opening of sodium channels results influx of sodium inside the cell.

Sodium influx generate an action potential in the muscle fibre and it travels along the muscle cell membrane. This action potential depolarizes the muscle membrane which results the release of calcium ions from sarcoplasmic reticulum to the sarcoplasma. Calcium mediated attraction in between the actin and myosin lead to the sliding alongside each other. This sliding movement results the muscle contraction. After a fraction of second, calcium pump actively transfer the calcium from sarcoplasm to sarcoplasmic reticulum. This removal of calcium from the sarcoplasm results the muscle relaxation.

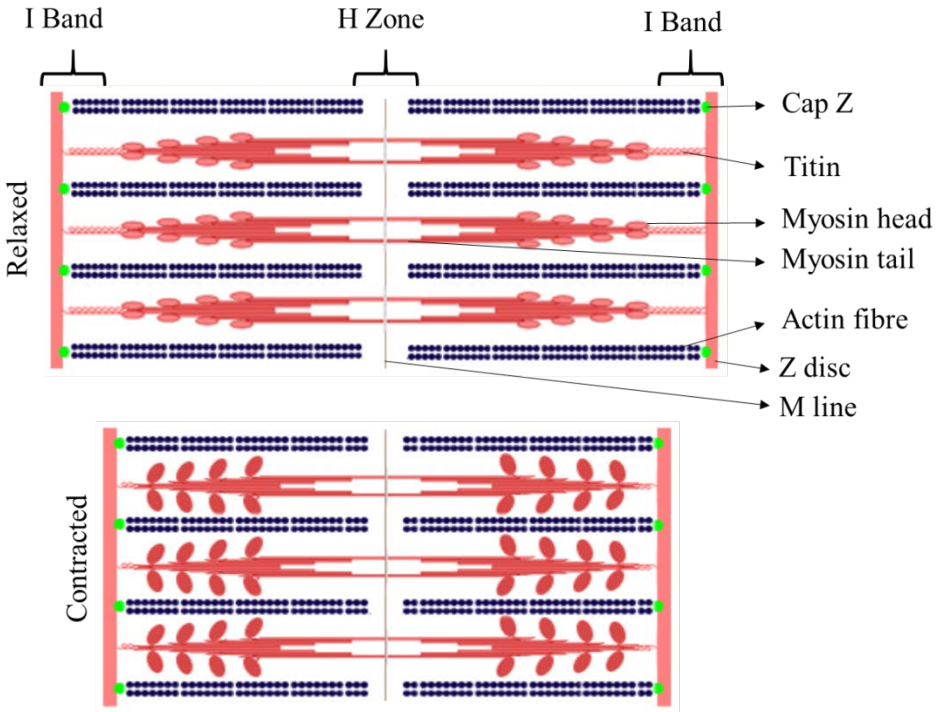


Figure 17.1 : Skeletal muscle contraction

Molecular mechanism:

Muscle contraction mechanism is described by sliding filament theory. This theory described by Andrew F Huxle, Rolf Niedergerke, Hugh Huxley and Jean Hanson in 1954. Muscle contraction is a cyclic repetitive process. In which, actin filament slide over myosin and generate tension in the muscle.

Action potential from CNS reaches neuromuscular junction and release the acetylcholine near to muscle fibre. Acetylcholine diffuse the synapse where it binds to the nicotinic acetylcholine receptors. After binding, receptors get activated on neuromuscular junction and it lead to the opening of the sodium/potassium channel. It results in sodium influx and potassium outflow from the cell. Sodium/potassium movement from the muscle cell generate an action potential which leads to the depolarization of the inner muscle fibre.

Depolarization in the inner muscle fibre activates L-type voltage dependent calcium channels (Ex. Dihydropyridinereceptors) in the sarcoplasmic reticulum. This channels are closely resembles the calcium release channels such as ryanodine receptors. Activation of voltage gated calcium channels presence in the sarcoplasmic reticulum start to release the calcium.

The released calcium binds to the troponin C which present in the myosin fibril and modulates the tropomyosin allosterically. In normal condition tropomyosin do not allow the myosin to bind on thin fibres. But in presence of calcium, troponin (troponin T), it undergoes the allosteric modification and troponin loose the affinity over thin filament. It results in tropomyosin migration from the thin filament. Immediately, myosin binds strongly with the freed area of thin filament. This process is an energy coupled process, so myosin utilizes the ATP energy by cleaving into ADP and inorganic phosphate. Actin also involve in this process, here it helps to release the inorganic phosphate from the myosin. The overall results in sarcomere shortening. In this state, the distance in between the Z band shortens. The movement of myosin was observed around 10 to 12 nm per power stroke. The availability of ATP increases the power stroke cycles (energy generation by lysing the ATP).

Meanwhile, sarcoplasmic reticulum actively collect the calcium present in the sarcoplasm. This results in the decrease in sarcoplasmic calcium level. So, the calcium start to migrate from the thin filaments which results in tropomysin remodelling to the native form. The native form of tropomyosin replaces the myosin and bind with the thin filament (Figure 16.2).

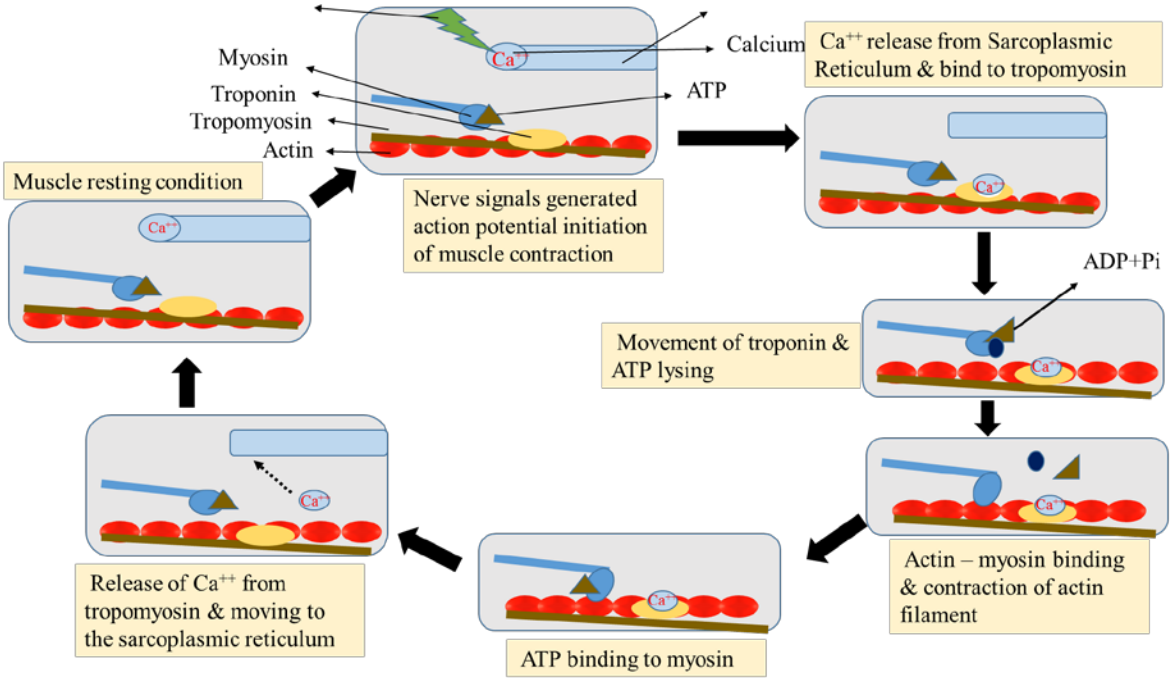


Figure 16.2 Molecular mechanism of Skeletal muscle contraction

In smooth muscles, troponin is replaced by p-light chain protein. In sarcoplasm, calmodulin and myosin-light chain kinase are present. In excited or action potential generated condition, sarcoplasmic calcium level increases calmodulin which immediately bind with four calcium level. Ca^{++}-calmodulin complex immediately binds with the enzyme p-light chain kinase. P-light chain kinase-calmodulin complex actively phosphorylate the p-light chain. Phosphorylated p-light chain readily dismantle from the actin filament. Immediately, myosin bind with actin after ATP lysis and results contraction of actin filament. When ATP binds with myosin, it again disassemble from the actin filament and p-light chain bind back to the actin to lead relaxed condition.

Lecture 18: Reproductive Biology (Part-I)

Introduction: Life of an organism is not infinite and during the life-span every organism needs to produce progeny to maintain existenance. It is essential to maintain a high level of biodiversity and living stock. In the current lectures,we will discuss different modes of reproduction.

Modes of Asexual reproduction:

1. Binary division-binary division is most common mode of cell division in bacteria (Figure 18.1). In this mode of cell division, a single bacteria cells grow transversely with the synthesis of chromosomal DNA. A transverse septum appears in the middle of the cell body and divides the bacterial cell into the two with a distribution of chromosomal DNA, ribosome and other cellular machinery.

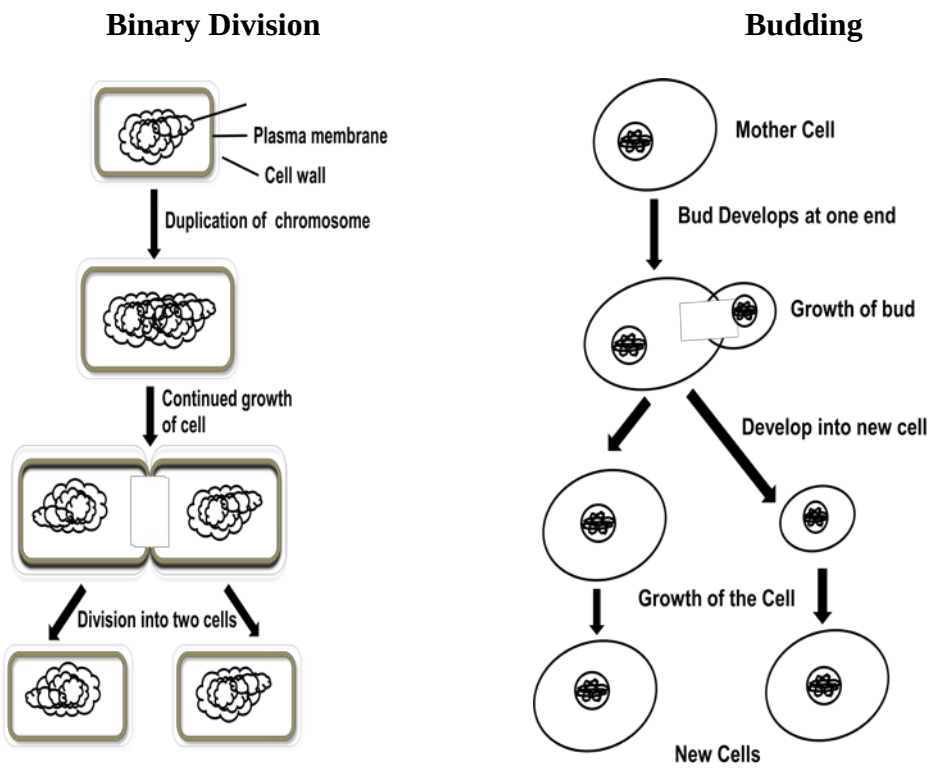


Figure 18.1: Different modes of cell division in bacteria.

Measuring Bacterial growth- A number of methds has been developed to measure bacterial growth in liquid media and in solid support media. A few are discussed below:

Microscopic count-bacterial cells can be counted easily on a "petroff-hausser counting chamber" (Figure 18.2). The chamber has a ruling to make square (1/400 mm^2) of equivalent volume. A glass slide is placed (~1/50mm height) to make a chamber filled with bacterial cell suspension. Volume of each chamber is 1/20,000 mm^3. This chamber can be used to observe bacteria with phase contrast microscope. For example, if each chamber has 8 bacteria then there are 8x20,000,000 or $1.6x10^8$ bacteria/ml. A very high or low concentration of bacterial sample can not be counted accurately.

Plate count method-In this method, a defined amount of bacterial culture suspension is introduced onto solid support media to grow and give colonies. If number of colonies on solid media is too high, then serial dilution of original stock can be plated on solid media and number of colony can be counted with a colony counter. A manual colony counter has lamp at the bottom, a grid to divide the bacterial culture plate and a magnifying glass to visualize and count single colony. A plate with colony count of 30-300 can be used to determine the number of bacteria present in original stock.

Number of bacteria per ml= Number of colonies counted on plate X dilution of sample

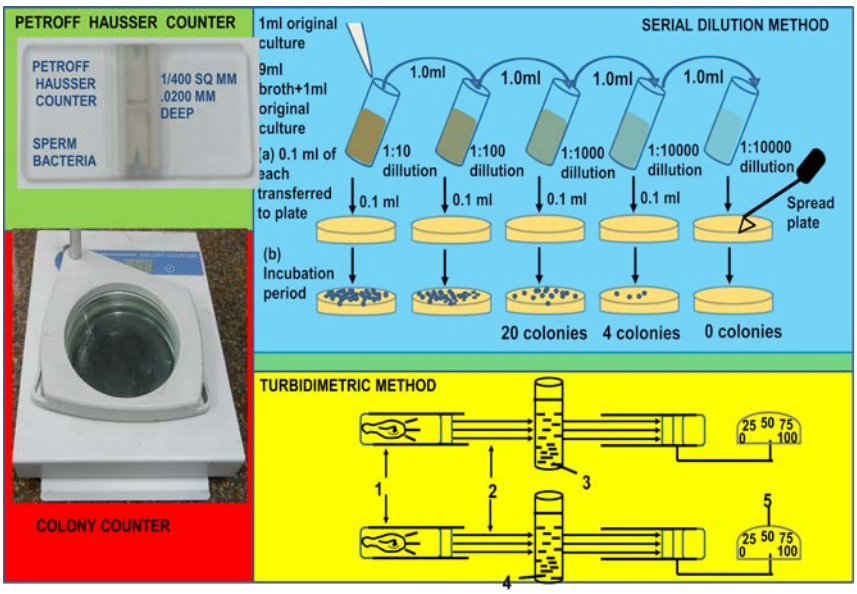


Figure 18.2: Different methods of bacterial counting.

Turbidimetric methods-This method is based on light scattering principles of particulate matter such as bacteria. A bacteria cell suspension is placed in test cuvette and corresponding media in reference cuvette. The optical density or absorbance of the bacterial suspension is used to measure the number of bacteria number. This method can not distinguish between live or dead bacteria as both form contribute to the turbidity.

Nitrogen content and Dry weight- A bacterial cell mass can be measured by direct measuremenof dry weight of culture or nitrogen content.

Growth cycle of bacteria- As discussed earlier, the most common method of bacteria division is binary fission and by this method, one bacteria cell gives two daughter cells. The time a bacteria takes to perform one division is called as generation time and it depends on bacteria species and media properties.

Hence, if we start from one bacteria, it divides after every generation time as follows-

Generation (n)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**n**
No. of bacteria	**1**	**2**	**4**	**8**	**16**	**32**	**64**	
No. of bacteria	**1**	2^1	2^2	2^3	2^4	2^5	2^6	2^n

Hence, After n generations, no of bacteria will be

$N=1 \times 2^n$……. Eq 18.1

But assume if number of bacteria at time 0 is N_o, then

$N=No \times 2^n$……..Eq 18.2

$\text{Log } N=\text{Log } N_o+n \log_{10} 2$……...Eq 18.3

$n= 3.3 (\text{Log}_{10} N-\text{Log}_{10} N_o)$…….Eq 18.4

Eq 18.2 can be used to determine number of bacteria, if initial number of bacteria and number of generation is known where as Eq 9.4 can directly been used to calculate number of generations.

2. Budding-In this mode of cell division, chromosomal DNA divides to form two copies. Sister chromosomal DNA moves to the one side of the cell and this portion of the cells protrude from main body to form bud. Eventually bud grows in size and get separated from main cell to develop a new cell.

3. Fragmentation-This mode of asexual division is more common in filamentous bacteria. In this mode, filament of the growing cell gets fragmented into small bacillary or coccoid cells, these cellular fragments eventually develop into new cell.

4. Spore Formation: Spores are produced and give rise to new individual on germination. There are several kinds of spores (Figure 18.3) and these are as follows:

(A) Zoospores: These are motile and flagellated spores produced inside the zoosporangia. These are without cell wall and they utilizes the flagella to swim in water to disperse distant locations. These spores are found in fungi especially phycomycetes.

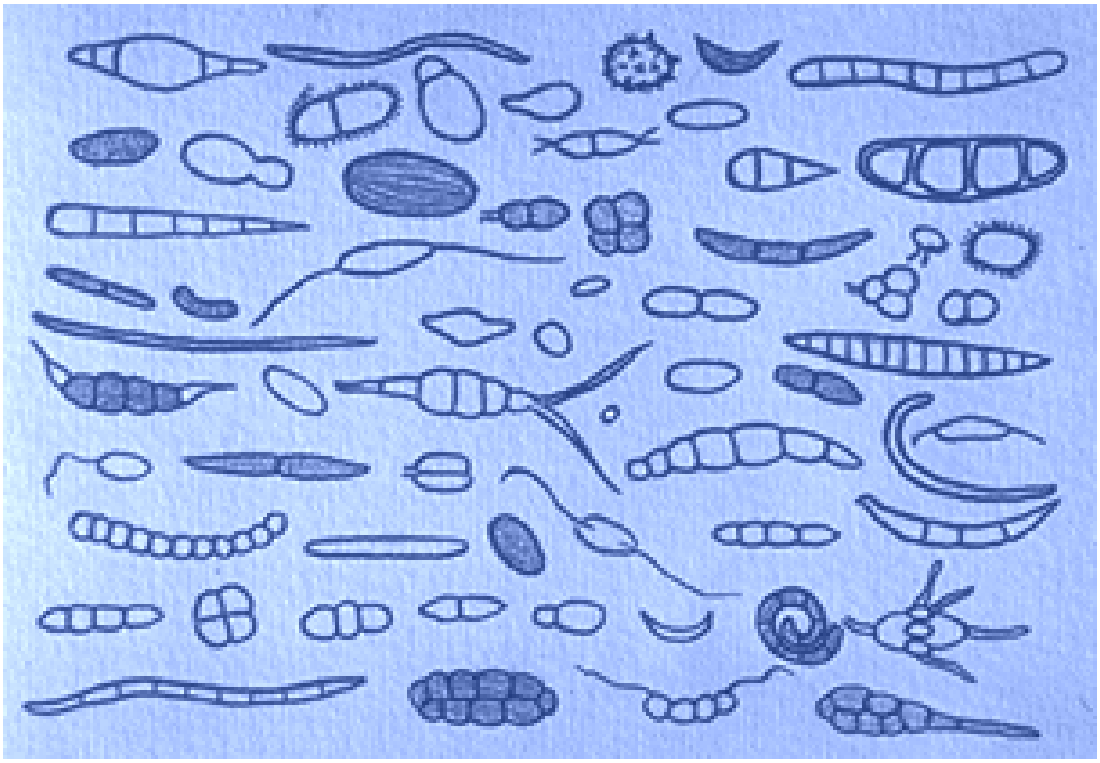


Figure 18.3: Different types of spores

(B) Sporangiospores: These are non-motile spores produced inside the sporangia. These spores are dispersed by wind and they germinate upon suitable conditions. These spores are found in fungi and they grow to give new mycelium.

(C) Chlamydospores: These are thick walled resting spores produced directly from hyphal cells. These spores are capable of storing large quantitity of food material and these spores are capable of storing for long period.

(D) Oidia: In this condition, hyphae of growing fungi break open to form oidium which behaves like spores. These spores are thin walled and do not store large food material. The oidia are produced from fungi when they have excess water, sugar and certain salts. Upon immigrate release of oidia, they germinate to form new fungi otherwise these spore don't survive harsh conditions.

(E) Conidia: These are non-motile spores produced singly or a chains by constriction at the tip or lateral side of special hyphal branches, called conidiospores. They are produced exogenously, dispersed by wind and germinate directly giving out germ tubes.

Lecture 19: Reproductive Biology (Part-II)

5. Vegetative Propogation: This is another mode of asexual reproduction where vegetative part of the organism break and give rise to new organism. This mode of reproduction is common in higher plants where body parts such as root, stem and leaves takes part into vegetative reproduction. Under natural conditions, plant body parts takes part in vegetative reproduction. The different examples in this catagrory are as follows:

(A) Roots: The modified root planted in soil develop shoot from the bud present on root and adventiuos root at the base to give rise new plant (Figure 19.1). Ex. Sweet potatos, Topioca, Yam, Dahila and Tinospora.

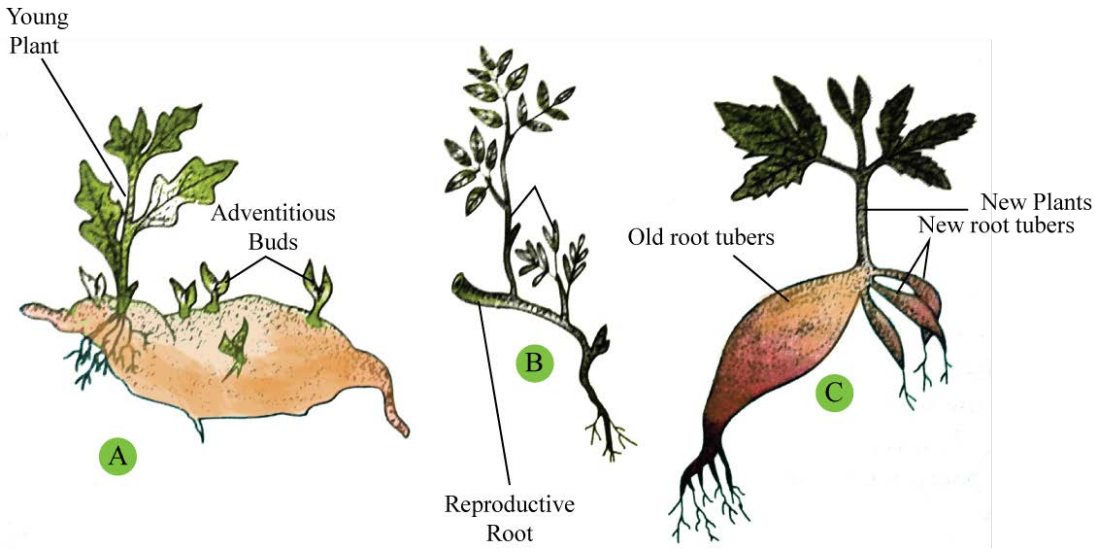


Figure 19.1: Different examples of vegetative reproducing by roots.

(B) Stems: Underground modified stems grow into new plants and help in vegetative reproduction. There are different varients stems, these are as follows:

(i) Suckers: These are shoot grow horizontally in soil and they come out to form new arial shoots. Once it is break from the parent plant, it grows as independent plant. Ex. Mint, Chrysanthemum.

(ii) Rhizomes: These are modified stems with stored material to withstand adverse conditions. Once they are getting favorable condition, they give rise to shoot and root at the base. Ex. Typha, Canna, Ginger, Turmeric, Lotus etc.

(iii) Corms: These are highly condensed and specialized stem with many buds. They can be abe to withstand unfavorable conditions. Ex. Banna, Crocus, Gladiolus etc.

(iv) Bulbs: This gives new plant when sown in soil. Ex. Onion, garlic, Lilies etc.

(v) Tubers: These are underground modified stems with several buds. For ex. Potato has several eyes which grows into new plant when planted with a portion of the swollen tuber. It is a common mode of propogation in the case of potato (Figure 19.2).

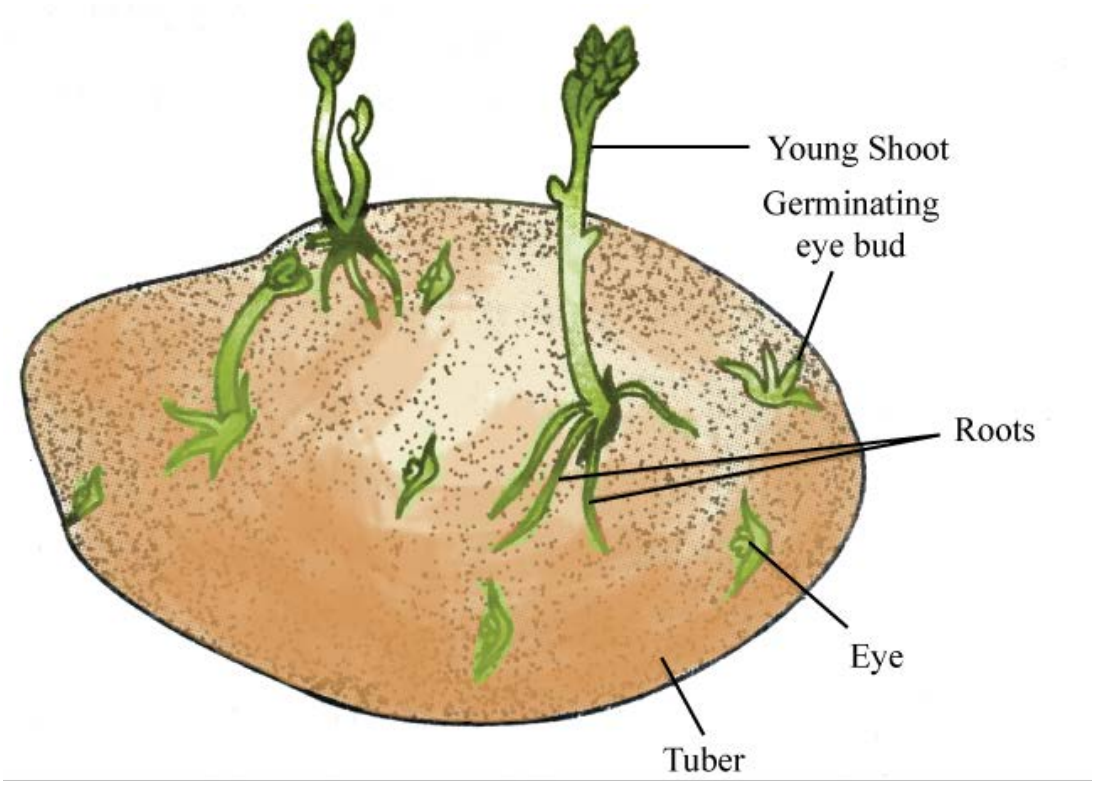


Figure 19.2: Different examples of vegetative reproducing by shoots. Figure need redraw]

(C) Creeping Stems: These are stems runs along the soil and give rise to new plants. It has 3 different variants:

(i) Runners: These are creepers which produces adventious root at each nodes. Each node give rise to aerial shoot which becomes a new plant. Ex. *Cynodon, Oxalis, Centella* etc.

(ii) Stolons: These are arched runner which cross over small obstacles and develop small plantlets at their nodes. Ex. *Fragaria*, *Vallisneria* etc.

(iii) Offsets: These are internode long runners which develop tuft of leaves at the apex. Ex. *Pistia*.

(D) Aerial Stems: The aerial stems develops new plant when they break and segment fall on the soil. Ex. *Cactus*.

(E) Leaves: Some plant develop adventitious buds on their leaves and these leaves buds off and give rise to new plants (Figure 19.3). For ex. Bryophyllum, developes several small planets with root on the margin of leaves (Figure 19.3). In few cases, develops bud when get injured and placed on the moist soil. Ex. *Kalanchoe*, *Begonia*, *Streptocarpus* etc.

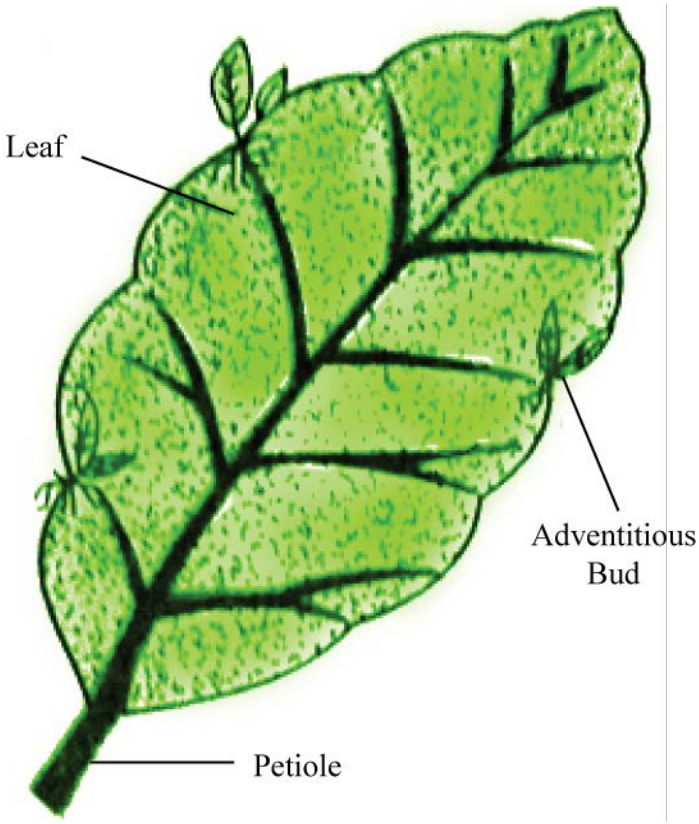


Figure 19.3: Vegetative reproducing by leaves. Figure need redraw

(F) Bulbils: These are fleshy buds produced in the axil of the foliage leaves instead of axillary buds. They have ability to grow and give new plant when shed off and fall on ground (Figure 19.4). Ex. *Oxalis*, *Allium sativum*, *Dioscorea*, Lily, Pineapple. In few plants, flower bud develop into bulbils which give rise to new plant whe shed from the parent plant (Figure 19.4).

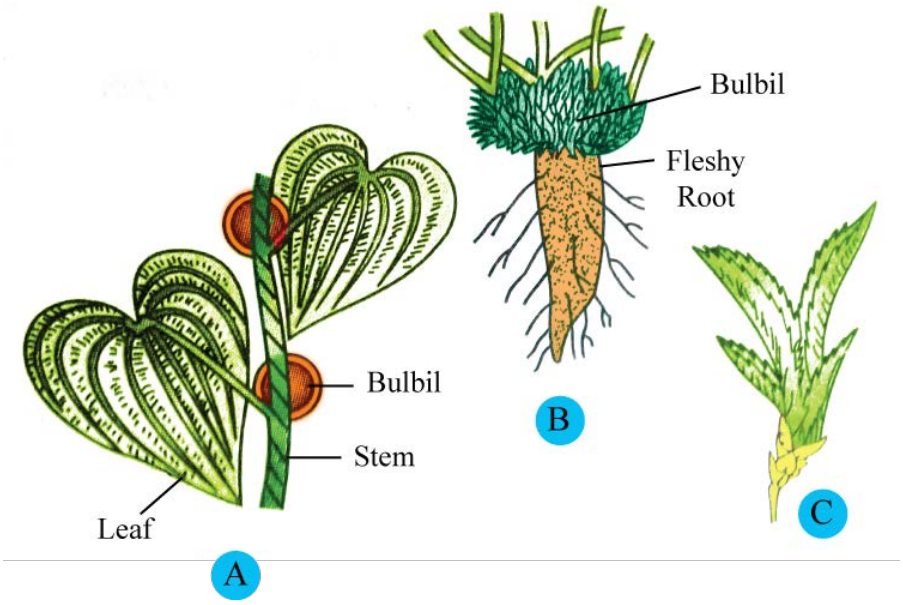


Figure 19.4: Different examples of vegetative reproducing by bulbils.

(G) Turions: These are fleshy buds develop in aquatic plants for vegetative propogations. Ex. *Potamogeton*, *Utricularia* etc.

Lecture 20: Reproductive Biology (Part-III)

Introduction: So afr we have discussed different asexual methods in bacteria, fungi and lower plants. Now in the current lecture, we will discuss different steps of sexual reproduction with suitable examples. The major steps of sexual reproduction is given in the Figure 20.1.

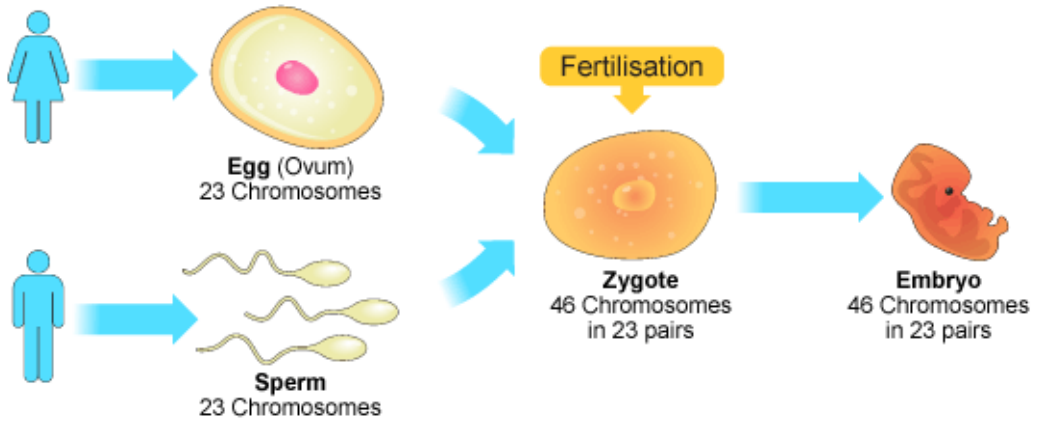


Figure 20.1: An Over-view of different steps in sexual reproduction.

Step 1: Organism produces male and female gametes.

Step 2: These gametes are fused to form zygote.

Step 3: Zygote develop into new organism.

But miute details of these steps are not identical in every organism. In the current lecture, we will focus more on the generalized events rather than any specific organism.

Sexuality is organisms: The male and female parents are separated in many organisms and these are said to be **unisexual** or **dioecious**. The different between human male and female sex character is given in Table 20.1. In few animals both sex organs are present in the same animal. These are considered as bisexual or hermaphrodite For ex. Earthworm, liverfluke, leech. Bisexuality facilitates the efficiency of fertilization and higher yield of eggs. It also facilitates self pollination in plants as well.

TABLE 20.1: DIFFERENCE IN SEX CHARACTER IN HUMAN MALE AND FEMALE.

Character	Male	Female
Body Build	Body is larger, muscular and stronger	Body is small, less muscular and weaker.
Hair	Beard, mustache and chest hair	Absent
Breast	Absent	Very well developed
Skin	Hairy and course	Less hairy and soft
Pelvis	Narrow	Broad
Larynx	Well developed	Less developed
Voice	Low pitched	High pitched
Behaviour	Aggressive	Often mild

A generalized sexual reproduction in organism has 3 events:

1. Pre-fertilization events: A number of preparatory events are required to facilitate the fusion of gametes to give zygote. These preparatory events are as follows:

A. Gametogenesis: The maturation and formation of gamets inside the sex organ is known as gametogenesis. The gamates are of two types; male and female. In most of the organism gamates are haploid (1N) cells with single set of chromosomes. In lower plants such as algae, both gametes are identical in shape, size and activity. These kind of gametes are known as **isogametes** or **homogametes** (Figure 20.2). In sexual reproduction, it is a generalized fact that gametes from male and female are morphologically distinct, these type of gametes are known as **heterogametes**. In these organisms, male gametes are known as **microgametes** or **spermetazoa**, and the female gamete termed **megagametes** or **ova**. Male gametes are small, motile and approach female gametes for fertilization. In contrast, female gametes are large, non-motile and store food material to provide nourishment for developing embryo.

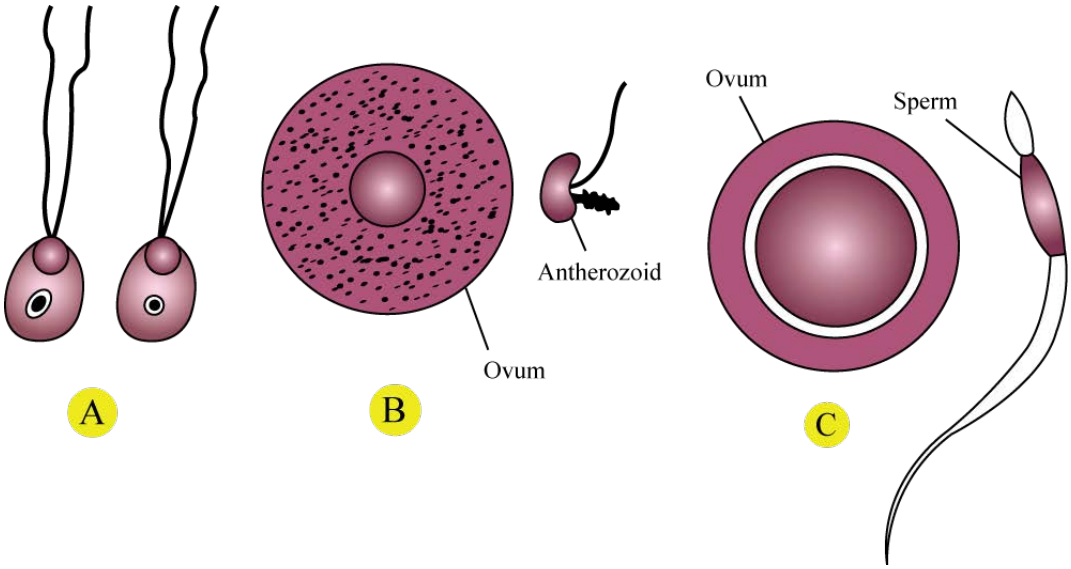


Figure 20.2: Different types of Gametes.

The gametes are formed after meiotic divisions. In this process, diploid (2n) cells will give rise haploid (1n) gametes (Figure 20.3). In the process of sexual reproduction, the gametes fused with each other to form zygote (2n). This process is known as fertilization. The meiosis and fertilization are important event to maintain the number of chromosome constant over several generations (Figure 20.3). In addition, during crossing over, exchange of genetic material between homologous chromosomes results in new combinations of genes. It results generation of genetic diversity and acquire of new phenotype.

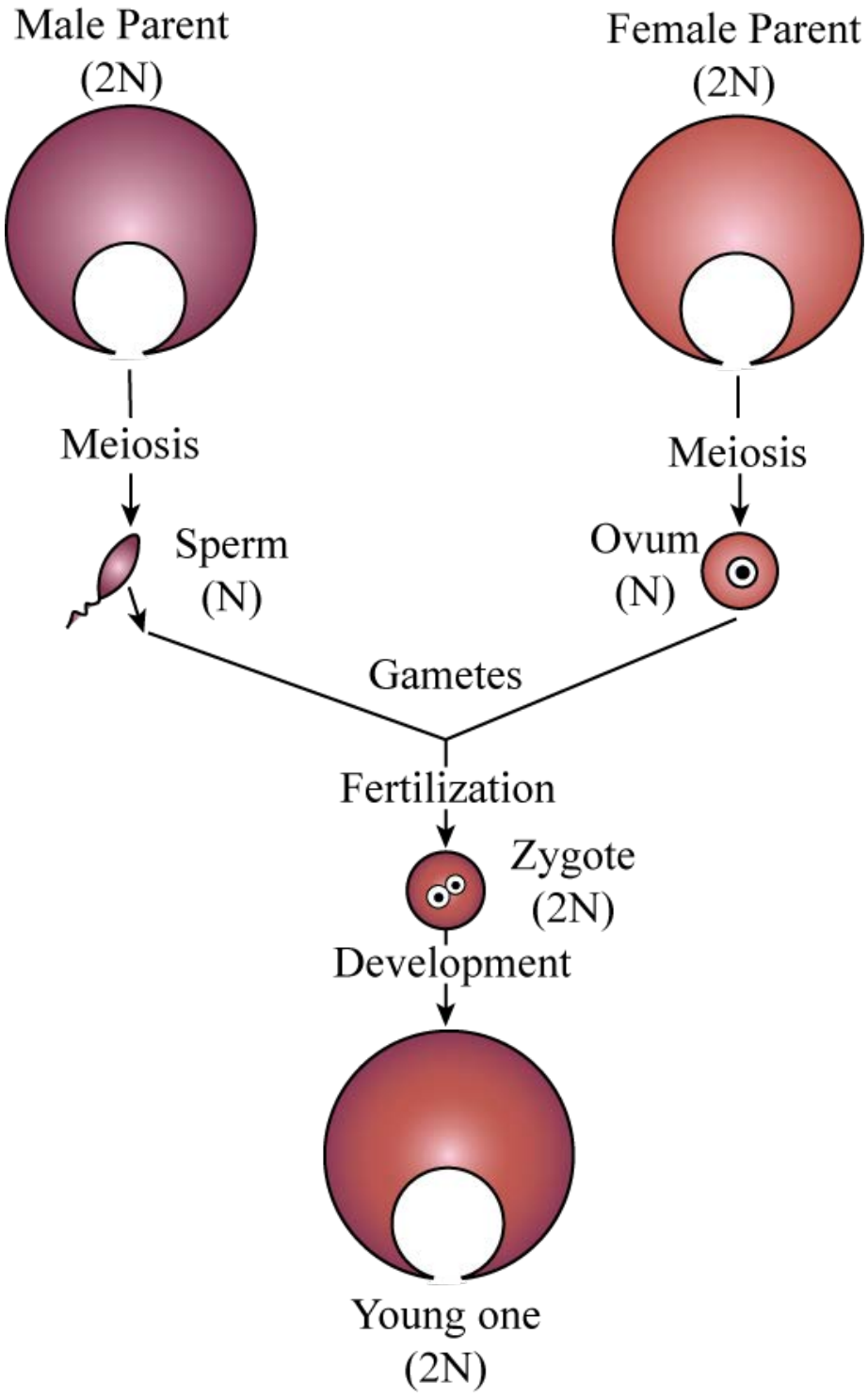


Figure 20.3: Sexual reproduction keeps the chromosome number constant.

B. Gamete Transfer: Once the gametes are formed inside the gametangia, the next step is to bring these gametes closer to facilitate their fusion or fertilization. In lower plants, the flagellated male gametes, produced inside the antheridia are liberated into the external medium of water. They reach to the female sex organ archegonia, to fuse with female gamete egg. A large number of male gametes failed to reach female gamete. In higher plants, the male gametes are produced inside the pollen grains. These pollen grains are transferred to the stigma (female reproductive organ) through a process known as pollination. The mediator used for pollination are air, water, animal and insects (Figure 20.4). Once the pollen reach to the suitable stigma, pollen tube germinate to produce a long tube, called pollen tube. Each pollen tube carries the male gametes to the female gamete (Egg) to complete the sexual fusion.

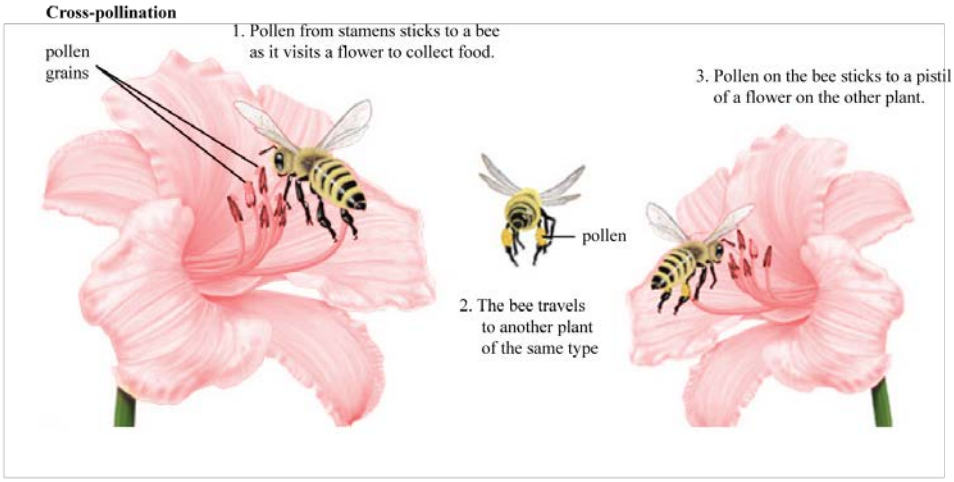


Figure 20.4: Sexual reproduction keeps the chromosome number constant. [need redraw]

2. Fertilization: The fusion or fertilization of male and female gametes takes place in different locations. The different variants are as follows:

A. External Fertilization and External Development: This is more common in aquatic animals such as fishes, frog etc. In this mode, male and female gametes are released into the surrounding water, where fertilization ocuurs and offsprings develops. It is important for the successes of this mode of fertilization and development that both parents should release gametes at the same time.

B. Internal Ferilization and external Development: This mode is common in birds, lizards, reptiles etc where fertilization occurs inside and then development occur outside. In this mode, sperms are inserted into the female body through an appropriate organ. After fertilization, zygote passes outside the female reproductive tract and develop into the offsprings.

C. Internal Ferilization and Internal Development: This mode is common in mammals where sperms are inserted into the female body through an appropriate organ. After fertilization, embryo develop into the offsprings.

3. Post-fertilization events: All events after fertilization are considered as post-fertilization events. These events are as follows:

A. Zygote formation: Fusion of male and female gametes give rise to diploid (2n) zygote. Formation of zygote is the first step towards development of offsprings.

B. Embryogenesis: Zygote develops into the embryo through a series of events collectively known as embryogenesis. In few animals, embryogenesis can occur inside the female reproductive system whereas in few cases it occurs outside the female body. Based on the embryogeneis, animals are classified into two classes:

(i) Oviparous Animals: Animals lay fertilized eggs or infertilized eggs. The animals fall under this category are birds and reptiles. The egg has hard calcareous shell to protect from damage. The eggs are incubated at a particular temperature and ultimately offsprings hatch out from the egg.

(ii) Viviparous Animals: These animals give birth of young ones. The zygote develops inside the body of female.