ARULMIGU PALANIANDAVAR ARTS COLLEGE FOR WOMEN

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PG DEPARTMENT OF ZOOLOGY

LEARNING RESOURCES

ANIMAL PHYSIOLOGY

NUTRITION

Introduction

Nutrition in animals is as important as it is for plants. Plants prepare their own food by the process of photosynthesis but animals cannot prepare their own food, hence they need to depend on plants or other animals for their food.

Animals derive their nutrition either by eating plants directly (herbivores), or indirectly by eating animals which have consumed plants (carnivores). Some animals feed on both plants and animals; these animals are termed omnivores. All organisms require food for their survival and growth.

Food has different components, called nutrients, like carbohydrates, fats, minerals, proteins, and vitamins, which are required for the maintenance of the body. These components are complex and cannot be used directly, so they are broken down into simpler components by the process of digestion.

Nutrition in Animals

Nutrition in animals depends upon the feeding habits of the animals. The process of taking in food is called ingestion. The method of ingestion is different in different animals. For example-Bees and hummingbirds suck nectar from plants, a python swallows its prey and cattle feed on grass.

Different feeding habits of animals are the result of evolution. Among the terrestrial animals, the earliest forms were large amphibians that ate fish. While amphibians like frogs fed on small fish and insects, the reptiles began feeding on other animals and plants.

The specialization of organisms towards specific food sources and of course specific ways of eating is one of the major causes of the evolution of form and function. For example, the differences in the parts of the mouth and shape of the teeth in whales, mosquitos, tigers and sharks or distinct forms of beaks in birds, such as in hawks, woodpeckers, pelicans, hummingbirds, and parrots are the results of adaptation to different types of eating by these animals.

Animals can be divided into the following groups depending upon their food habits:

Herbivores: Herbivores are animals that depend upon plants and fruits for their nutrition. Cows, goats, sheep, buffaloes, etc. are herbivores.

Carnivores: Carnivores are animals that depend upon other animals for food. Lion, tigers, wolfs are some examples of carnivores.

Omnivores: These include organisms that eat both plants and animals. Humans, bears, dogs, crows are omnivores.

Types of Nutrition in Animals

The different types of nutrition in animals include:

1. **Filter Feeding:** obtaining nutrients from particles suspended in water. Commonly used by fish.
2. **Deposit feeding:** obtaining nutrients from particles suspended in the soil. Earthworms use this mode of ingestion.
3. **Fluid feeding:** obtaining nutrients by consuming other organisms' fluids. Honey bees, and mosquitos exhibit this mode of food intake.
4. **Bulk feeding:** obtaining nutrients by eating the whole of an organism. Example: Python.
5. **Ram feeding and suction feeding:** ingesting prey via the surrounding fluids. This mode of ingestion is usually exhibited by aquatic predators such as bony fish.

Process of Nutrition in Animals

The process of nutrition in animals involves the following steps:

Ingestion

Ingestion is the process of taking in food.

Digestion

In this process, the larger food particles are broken down into smaller, water-soluble particles. There are physical or chemical processes for digesting food.

Absorption

The digested food is absorbed into the bloodstream through the intestinal wall.

Assimilation

The absorbed food is used for energy, growth and repair of the cells of the body.

Egestion

The undigested food is removed from the body in the form of faeces. This process is known as egestion.

NUTRITION IN HUMAN BEINGS [DIGESTION IN HUMANS]

The body cells cannot use the food in the form it is eaten by us. It is converted into a simpler form by the process of **digestion.**

The process of digestion starts in the **mouth.** From the mouth, the food passes through a **food canal** (called **alimentary canal).**

Alimentary canal is a long, muscular and coiled tube. It starts from the **mouth** and ends at **anus.**

All animals need food to survive, grow and function properly. Often the food eaten is solid. Solid food cannot be absorbed by the body cells as it is. Our digestive system has two basic jobs to do with the food we take in. The first job is to break down large food particles so that they can be carried through the body.

The second job of the digestive system is to transform the molecules of food into simple molecules. We take in foods of all kinds—milk, meat, tea, potato, fish, and so on. These molecules must be broken down into simpler molecules, so that they can finally be built into human protoplasm. Digestive system ensures that the digested material is absorbed into the blood vessels. In this way nourishment reaches all the body cells.

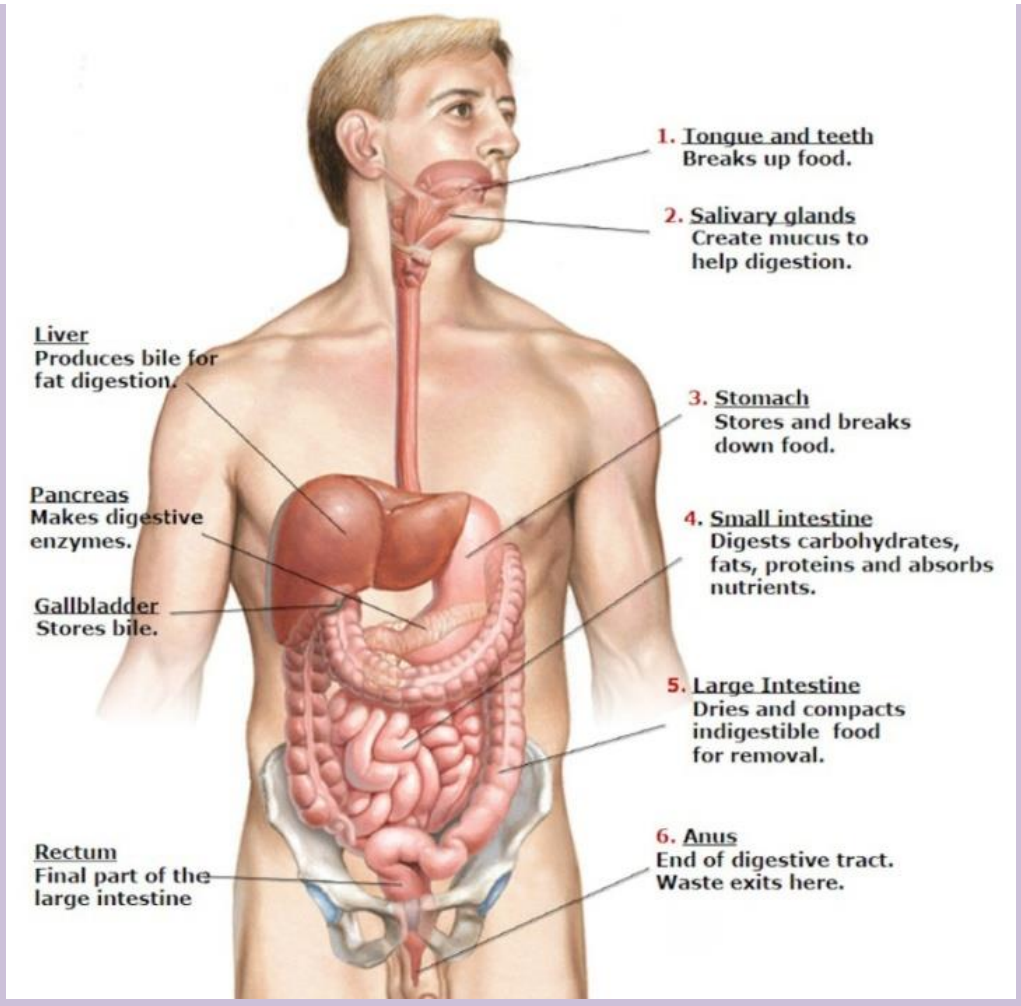
The different organs of the alimentary canal are as follows:

1. Mouth and mouth cavity
2. Oesophagus (gullet)
3. Stomach
4. Small Intestine
5. Large Intestine
6. Anus

Associated with the alimentary canal are some glands. These are:

1. Salivary glands
2. Liver
3. Pancreas.

The alimentary canal along with the associated glands is called the **digestive system** (Figure).



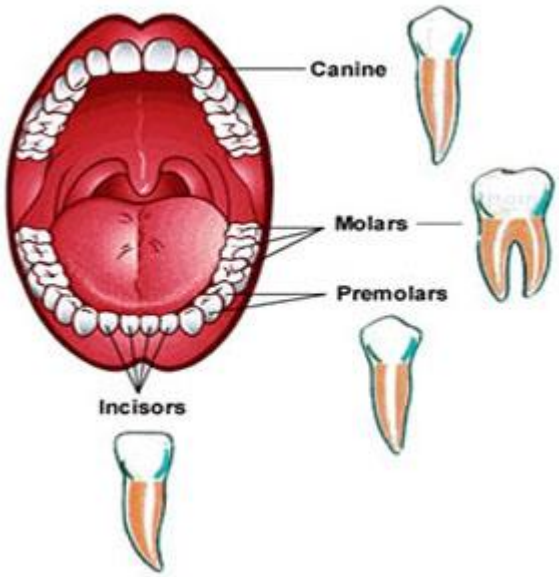
Digestive system

- **I. Mouth**
  The mouth contains the **tongue, teeth and salivary glands.** Process of digestion starts in the mouth itself. Food is bitten off and chewed (masticated) by the teeth. The chewed food gets mixed with the **saliva** secreted by the salivary glands. The tongue helps in mixing the food with saliva and its swallowing down the digestive system.
  Teeth: There are four main kinds of teeth in man **– incisors, canines, premolars and molars** (Figure and Table).
  The front four teeth in each jaw are the **incisors.** They are flat and help in biting the food. On either side of the incisors are the **canines.** These are sharp and two in number in each jaw. They are meant for tearing the food.

TYPES OF TEETH IN HUMANS		
Type of teeth	Number in each jaw	Function
Incisors	4	Biting food
Canines	2	Tearing food

Premolars	4	Grinding and crushing food
Molars	6	Grinding and crushing food

Different types of teeth

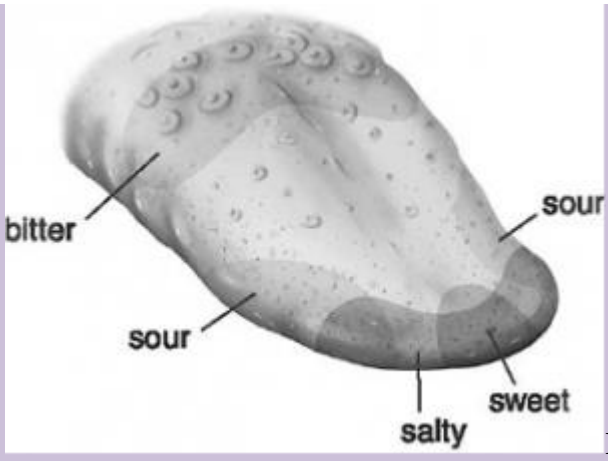


- **The premolars and molars** are meant for grinding and crushing the food. Premolars are behind the canines, two in number on either side in each jaw. Molars are behind the premolars. In an adult, they are six in number in each jaw, three each on either side of the premolars.

  In young people, there are 8 molars in all. The second set of 4 molars appears at the age of eighteen or even later. These are called the **wisdom teeth.**

  Each jaw in an adult has 16 teeth, or 32 teeth in all.

  Man has two sets of teeth – – **milk teeth and permanent teeth.** The first set of teeth in a baby are called milk teeth. These are replaced by permanent teeth when one is a child.
- • At birth, a human infant has no teeth. After six months or so, the first teeth appear in the centre of the lower jaw.
- •Milk teeth are twenty in number.

- 

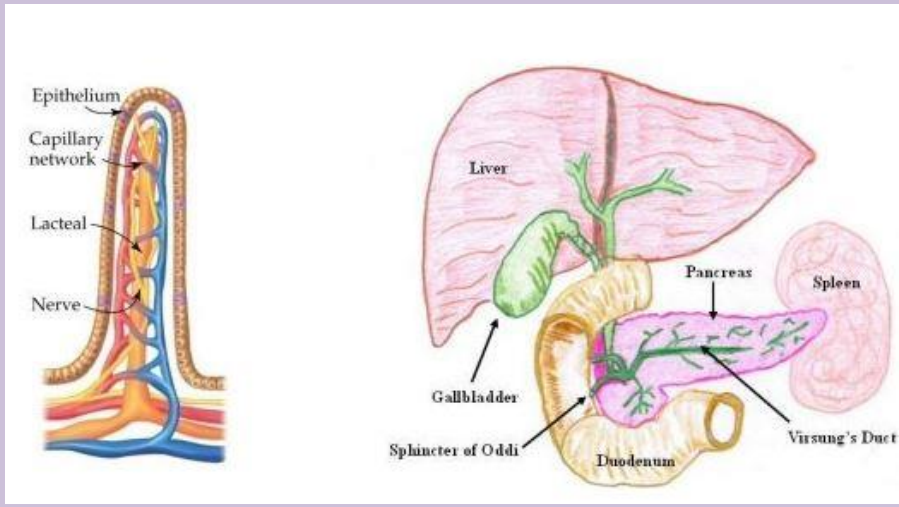
Location of taste buds on the tongue
- **Tongue:** Tongue is-: also important for eating. It helps in Bitter mixing the chewed food with saliva and swallowing the food. Further, the tongue **tastes,** as it has sense organs called the **taste buds.** These buds distinguish four basic tastes – salty, sour, sweet and bitter (Figure). In addition, tongue helps us to speak. **Salivary glands:** There are three pairs of salivary glands in our mouth. A watery material called **saliva** is secreted by these glands. Saliva helps in the digestion of food. Saliva contains an enzyme called **amylase** (also called **ptyalin).** Amylase acts on starch and changes it into a sugar (called maltose). This sugar is sweet and soluble in water.
Note: Liver is the largest gland in the body.
II. Oesophagus (Gullet)
Oesophagus connects the mouth cavity with the stomach, and is also called the **food pipe.** No digestion takes place here. It only helps in pushing the food into stomach.
III. Stomach
The stomach is a muscular bag lying in the upper abdomen. Here the food is churned and converted into a semi-solid paste. The stomach secretes a juice called **gastric juice** and an acid. Proteins present in the food are digested by the gastric juice partly. The partly digested food from here goes to the small intestine.
IV. Small Intestine
Small intestine is a long coiled tube. It also secretes a juice and **digestion of all types of food is carried out here.** As a result of digestion, food is converted into simple form, and glucose, amino acids and fatty acids, etc., are formed. These end products are ready for absorption. The inner surface of the small intestine has a number of finger-like projections called **villi** (Figure). These villi increase the area for absorption of digested food.

Saliva contains an enzyme called **amylase** {also called **ptyalin).** Amylase acts on starch and changes it into a sugar (called maltose). This sugar is sweet and soluble in water. **Small intestine also absorbs the digested food** and passes it on to the blood system. Thus, the nutrients are carried to all parts of the body. Note: Small intestine is larger in length (about 6 metres) than the large intestine (about 1.5 metres). It is the main organ for the absorption of digested food.

V. Large Intestine

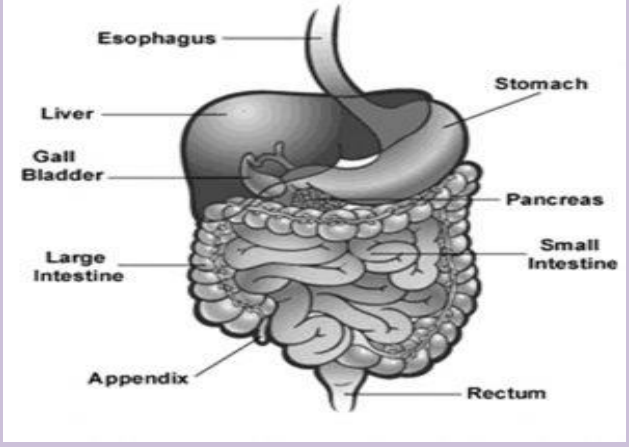
Large intestine has no digestive function to carry out. It helps in absorbing water and in removing the undigested solid wastes through the **anus.**

Liver and Pancreas: These are special organs connected with the digestive system. The liver secretes juices which help in digestion and are stored in a small bag called the **gall bladder** (Figure). The pancreas secretes a substance called **insulin** and also a juice. Insulin is important for regulating sugar level in the body.



- *Villi in the small intestine Associated glands – liver and pancreas – with the alimentary canal*
- **5. Digestion In Humans**

We have already studied the digestive system of humans. The process of digestion is brought about with the help of digestive juices called **enzymes**.

- 

  i) The process of digestion starts in the mouth itself where the food is mixed with saliva. Saliva, secreted by the salivary glands, contains digestive juices which help in the breakdown of starch into sugar. The saliva also makes the food slimy so that it can be easily swallowed.

  ii) The food passes from the mouth into a long tube called the oesophagus (also called food pipe).

  iii) The walls of the oesophagus contracts and relaxes to produce wave-like movements (called peristaltic movements). This movement helps to move the food down into a large sac-like muscular organ called the stomach.

  iv) Further digestion of food takes place in the stomach. The inner wall of the stomach secretes digestive juices, hydrochloric acid, and mucus.

  v) The digestive juices help in the breakdown of proteins into simpler forms.

  vi) The hydrochloric acid kills microorganisms and provides an acidic medium for effective digestion.

  vii) After digestion in the stomach, the semi-digested food called the chyme passes into the small intestine.

  viii) Further digestion of food takes place in the small intestine where the secretions of the liver and pancreas are released.

  ix) The liver secretes bile which plays an important role in the digestion of fats. Bile is stored in an organ called gall bladder before being released in the small intestine.

  x) The secretions of the pancreas called pancreatic juice help in the breakdown of carbohydrates into sugars, proteins into amino acids, and fats into fatty acids and glycerol. Thus, the digestion of various components of food is completed in the small intestine.

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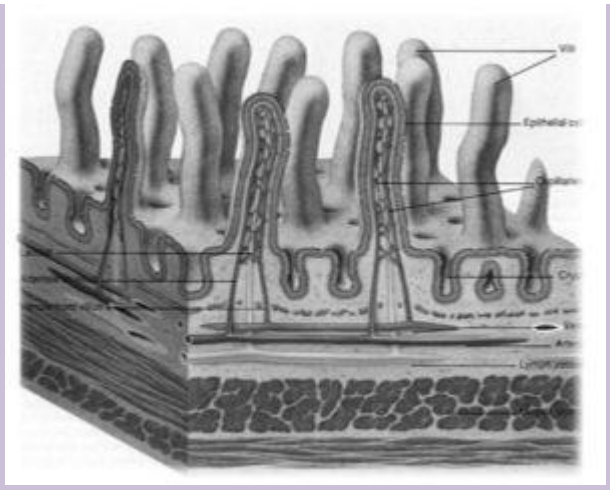
Absorption

- 

i) Even though digestion continues in the small intestine, the main job of the small intestine is to absorb the nutrients.

ii) The lining of the small intestine has finger-like projections called villi (singular: villus) that increase the surface area of the lining.

iii) This makes absorption more efficient. Each villus has a network of fine blood vessels.

iv) Nutrients are absorbed into the blood present in these fine blood vessels.

v) The chyme now passes into the large intestine where only water and minerals remain to be absorbed.

Assimilation

The nutrients that are absorbed in the blood are transported to the rest of the body. The final product of carbohydrate digestion, namely glucose, is broken down in the cells with the help of oxygen into carbon dioxide and water to release energy. Amino acids are used for repairing worn out cells and tissues. Fatty acids and glycerol act as energy reserve and are stored for further use.

Egestion

After absorption of water in the large intestine, the undigested food becomes semi-solid. It is then stored in the rectum until it is excreted via the anus.

Diarrhoea

Sometimes, consumption of infected food or unclean water can result in a condition

called diarrhoea. It is an infection of the intestine and involves passing of watery stools very frequently. This leads to the loss of useful salts from the body and can cause dehydration. Dehydration is a condition that results due to loss of water from the body and can be serious. It can be avoided by giving Oral Rehydrating Solution (ORS) to the patient suffering from diarrhoea. The World Health Organization (WHO) has recommended a simple ORS remedy that can be made at home by simply adding salt and sugar in water.ORS sachets are also easily available in all chemist stores.

RESPIRATION

Respiration:

It is a metabolic process that occurs within the cells of organisms.

Types of respiration in animals:

1. Simple diffusion: Occurs via the cell membrane in simple unicellular creatures like *Amoeba*.
2. Skin: Earthworms and other soil animals use their skin to absorb oxygen from the air and expel carbon dioxide.
3. Gills: They are found in aquatic creatures such as fish, prawns, and mussels. They extract oxygen from water and remove carbon dioxide from the body.
4. Spiracles: This is the respiratory organ of insects such as grasshoppers, cockroaches, houseflies, and mosquitos as tiny pores on their bodies and air tubes called tracheae.
5. Lungs: These are the respiratory organs of land creatures such as humans, birds, lizards, dogs, and frogs. Frogs can breathe through both their lungs and their skin.
6. Anaerobic respiration: It is the process of respiration performed in low levels of oxygen. In this process, glucose is broken down into carbon dioxide, ethyl alcohol, and energy.
7. Aerobic respiration: It is the process of respiration performed in the presence of oxygen. In this process, glucose is broken down into carbon dioxide and water.
8. The three stages of aerobic respiration are -

i. Glycolysis: It is the metabolic process of producing energy by breaking down glucose into pyruvic acid.
ii. Citric acid cycle: It is the series of biochemical reactions taking place in the mitochondria in which acetyl CoA is oxidized and ADP is converted to ATP.
iii. Oxidative phosphorylation: It is the process of synthesis of ATP brought about by the movement of electrons through the electron transport chain of the mitochondria.

MECHANISM OF RESPIRATION IN MAN

The process in which air moves in and out of the lungs is known as breathing. This is carried out through various respiratory organs. In other words, breathing is a simple give and take process.

When we breathe, we take in air rich in oxygen from the atmosphere, in return of which, we give out carbon dioxide-rich in the atmosphere which is utilized by the plants for **photosynthesis**.

This is a continuous process and goes on throughout the life of an organism.

The process of taking in oxygen-rich air is called inhalation. On the contrary, the process of giving out air that is rich in carbon dioxide is known as exhalation.

In a day, a person breathes several times. One breath comprises one inhalation and one exhalation. In a minute, the number of times a person breathes is termed as his/her breathing rate. By calculating the breathing rate, we can know the number of times we breathed in a day.

However, the breathing rate varies which is dependent upon a person's activity. It raises when a person is brisk walking, running or after a heavy exercise; similarly, decreases when a person is calm.

The breathing rate of an adult is 15-18 times per minute. However, during heavy exercise, the breathing rate exceeds 25 times per minute.

he air that we breathe in and out of the lungs varies in its pressure. So basically when there is a fall in air pressure the alveolar spaces fall and the air enters the lungs (inspiration) and as the pressure of the alveoli within exceeds the atmospheric pressure, the air is blown from the lungs (expiration). The flow rate of air is in proportion to the magnitude of the pressure difference.

The breathing mechanism involves two processes:

- Inspiration
- Expiration

Inspiration

In the process of inspiration, there would be a contraction of muscles attached to the ribs on the outer side which pulls out the ribs and results in the expansion of the chest cavity.

Later, the diaphragm, contracts, moves downwards and expands the chest cavity resulting in the contraction of the abdominal muscles.

The expansion of the chest cavity produces a partial vacuum which sucks air into the lungs and fills the expanded alveoli.

Mechanism Of Inspiration

- The process of intake of atmospheric air is known as inspiration. It is an active process.
- When the volume of the thoracic cavity increases and the air pressure decreases, inspiration takes place.
- Contraction of external intercostal muscles increases the volume of the thoracic cavity.
- Contraction of the diaphragm further increases the size of the thoracic activity. Simultaneously, the lungs expand.
- With the expansion of the lungs, the air pressure inside the lungs decreases.

- The pressure equalizes and the atmospheric air rushes inside the lungs.

Expiration

The expiration process is considered once after the gaseous exchange occurs in the lungs and the air is expelled. This expulsion of air is called expiration.

During this process, muscles attached to the ribs contract, the muscles of the diaphragm and the abdomen relax which leads to a decrease in the volume of the chest cavity and increases the pressure of the lungs, causing the air in the lungs to be pushed out through the nose.

Mechanism Of Expiration

- The process of exhaling carbon dioxide is called expiration. It is a passive process.
- It occurs when the size of the thoracic activity decreases and the air pressure outside increases.
- Now the external intercostal muscles relax and the internal intercostal muscles contract.
- As a result, the ribs are pulled inwards and the size of the thoracic cavity is reduced.
- The diaphragm is relaxed and the lungs get compressed.
- Consequently, the pressure increases and the air is forced outside.

Mechanism of Respiration

Mechanism of respiration involves the breathing mechanism and exchange of gases.

The gaseous exchange occurs by diffusion in the alveoli. It depends upon the pressure differences between blood and tissues, or atmospheric air and blood. The exchange of gases takes place at the surface of the alveolus.

The mechanism of breathing has already been explained above. Let us have a look at the steps involved in the exchange of gases.

Exchange of Gases

The exchange of gases takes place in the following manner:

Transport Of Oxygen

- Oxygen in the blood is carried to the tissue in two forms- Oxyhaemoglobin- chemical composition of oxygen with haemoglobin, and solution of oxygen in the blood plasma.
- The oxygen in the blood combines with haemoglobin when the concentration of oxygen is high in the blood.
- Oxyhemoglobin, being unstable, dissociates to release oxygen. Low oxygen, low pH and high temperatures stimulate the dissociation process.

Internal Respiration

The gaseous exchange taking place in the tissues is called internal respiration. Here, the oxygen carried in the form of oxyhemoglobin gets dissociated to release oxygen.

This oxygen breaks down glucose to release carbon dioxide, water, and energy. The energy is utilized by the body, while the carbon dioxide is diffused from the tissues.

Transport Of Carbon dioxide From Tissues To Lungs

Carbon dioxide is transported by three mechanisms:

- Some carbon dioxide dissolves in the water of plasma to form carbonic acid.
- Carbonic acid ionizes to form bicarbonate ions. The hydrogen ions are catalyzed by the enzyme carbonic anhydrase. Bicarbonate ions combine with sodium and potassium to form sodium bicarbonate and potassium bicarbonate.
- Some carbon dioxide combines with haemoglobin for the formation of carbaminohemoglobin.
- It is finally carried to the lungs and released out of the body through expiration.

Intrapleural Breathing

Intrapleural breathing is used to refer to the pressure that is present in the space between the pleura and the lungs. This space is referred to as the pleural cavity. The pressure in this region is normally less than the atmospheric pressure. This is the reason why pleural pressure is termed as negative pressure.

The lung movement is governed by the pressure gradient, the transpulmonary pressure, which exists between the pleura and the lungs. The difference in the pressures between intrapulmonary and intrapleural pressures is known as transpulmonary pressure.

The pressure in the pleural cavity while breathing turns negative while there is an increase in the transpulmonary pressure causing the lungs to expand. While expiration, the lungs recoil as a result of an increase in the pleural pressure.

The competing forces inside the thorax results in the formation of negative intrapleural pressure, one of these forces is associated with the lung's elasticity. The lungs have elastic tissues which cause it to be pulled inwards off the thoracic wall. An inward pull of the lung tissue is also generated by the surface tension of the alveolar fluid. The inward tension generated from the lungs is opposed by forces from the thoracic wall and the pleural fluid.

Respiratory Gas Transport

After the gases have scattered in the lungs, causing the blood to become oxygenated, leaving carbon dioxide, the next phase of transportation of oxygen-rich blood to the tissues takes place. Meanwhile, the next round of deoxygenated blood needs to be brought to the lungs for the cycle to continue.

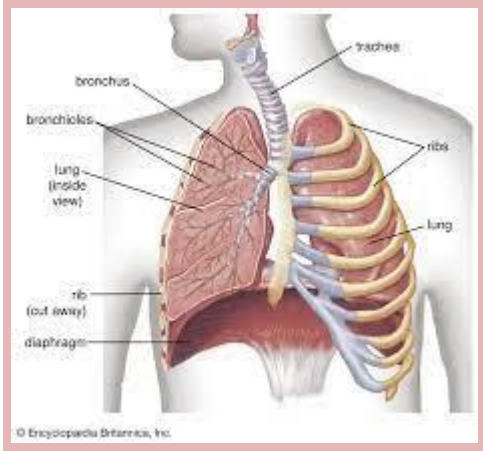
In the bloodstream, the transportation of gases occurs all through the body which is contributed to the cardiovascular system comprising the blood vessels and the heart. The

blood carrying oxygen leaves the lungs to flow into the heart through the pulmonary veins, which are pumped to the rest of the body from the left ventricle through the aorta and its corresponding branches.

This was an overview of the mechanism of breathing and the mechanism of respiration in the human body.

Key Points on Mechanism of Breathing

- Breathing is the physical process of inhaling oxygen and exhaling carbon dioxide.
- The mechanism of breathing involves two main processes: inspiration and expiration.
- Inspiration occurs when the diaphragm and the external intercostal muscles contract.
- Expiration occurs when the diaphragm and the intercostal muscles relax.
- The contraction or relaxation of muscles around the lungs changes the entire volume of air inside the lungs, and so does the pressure.
- If the pressure inside the lungs is more than the outside, the air rushes out. If the opposite happens, the air rushes in.
- Due to the high elasticity of the lung tissue and low surface tension of moisture in the lungs, the lungs have higher compliance.



NEURON STRUCTURE AND CLASSIFICATION

Introduction

Neurons have four specialized structures that allow for the sending and receiving of information: the cell body (soma), dendrites, axon and axon terminals

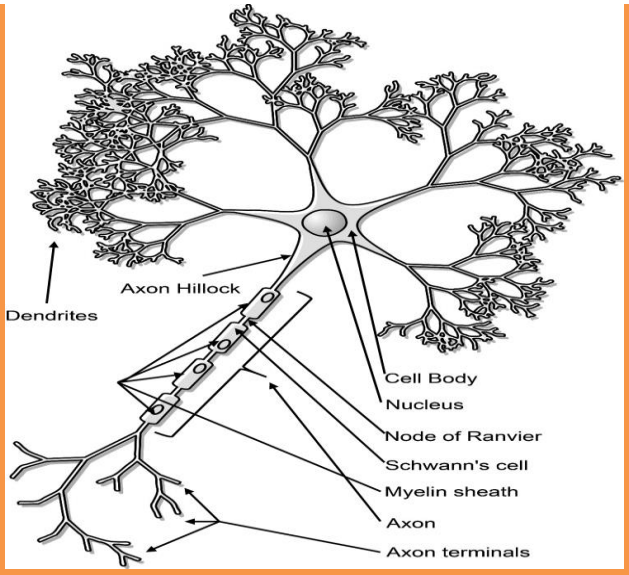
Cell body or soma: The cell body is the portion of the cell that surrounds the nucleus and plays a major role in synthesizing proteins.

Dendrites: Dendrites are short, branched processes that extend from the cell body. Dendrites function to receive information, and do so through numerous receptors located in their membranes that bind to chemicals, called neurotransmitters.

Axon: An axon is a large process that extends from the cell body at a point of origin-called the axon hillock-and functions to send information. In contrast to the shorter dendrites, the axon can extend for more than a meter. Because of this length, the axon contains microtubules and is surrounded by myelin. Microtubules are arranged inside the axon as parallel arrays of long strands that act as highways for the movement of materials to and from the soma. Specialized motor proteins "walk" along the microtubules, carrying material away from the soma (anterograde transport) or back to the soma . This system can move materials down the axon at rates of 400mm/day (see lowest figure). Myelin consists of totally separate cells that coil and wrap their membranes around the outside of the axon. These are essential for electrical insulation and to speed up action potential propagation.

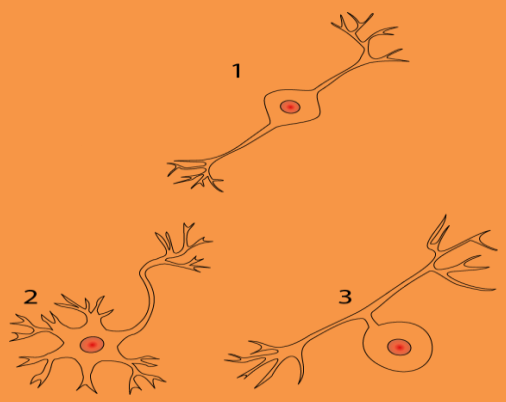
Axon terminals: Once an axon reaches a target, it terminates into multiple endings, called axon terminals. The axon terminal is designed to convert the electrical signal into a chemical signal in a process called synaptic transmission (further explained in the section "Physiology of the Neuron").

Most neurons are amitotic or lose their ability to divide. Exceptions to this rule are found in olfactory neurons (those associated with smell) and hippocampal regions of the brain. Fortunately, lifespans of amitotic neurons is near 100 years. Still, if a neuron is damaged or lost, it is not easily replaced. For this reason, there is usually limited recovery from serious brain or spinal cord injuries. Perhaps the slow recovery rate or lack of regeneration is to ensure that learned behavior and memories are preserved throughout life. Neurons also have exceptionally high metabolic rates and subsequently require high levels of glucose and oxygen.



Classification of Neurons

Structural classification of neurons is based upon the number of processes that extend out from the cell body. Three major groups arise from this classification: **multipolar**, **bipolar,** and **unipolar** neurons.



Multipolar neurons are defined as having three or more processes that extend out from the cell body. They comprise of more than 99% of the neurons in humans, and are the major neuron type found in the CNS and the efferent division of the PNS.

Bipolar neurons have only two processes that extend in opposite directions from the cell body. One process is called a dendrite, and another process is called the axon. Although rare, these are found in the retina of the eye and the olfactory system.

Unipolar neurons have a single, short process that extends from the cell body and then branches into two more processes that extend in opposite directions. The process that extends peripherally is known as the peripheral process and is associated with sensory reception. The

process that extends toward the CNS is the central process. Unipolar neurons are found primarily in the afferent division of the PNS.

Functional Classification of Neurons

Neurons are classified functionally according to the direction in which the signal travels, in relation to the CNS. This classification also results in three different types of neurons: **sensory** neurons, **motor** neurons, and **interneurons**. Sensory neurons, or afferent neurons transmit information from sensory receptors in the skin, or the internal organs toward the CNS for processing. Almost all sensory neurons are unipolar. Motor, or efferent neurons transmit information away from the CNS toward some type of effector. Motor neurons are typically multipolar.

Interneurons are located between motor and sensory pathways and are highly involved in signal integration. The vast majority of interneurons are confined within the CNS.

PHYSIOLOGY OF THE NEURON

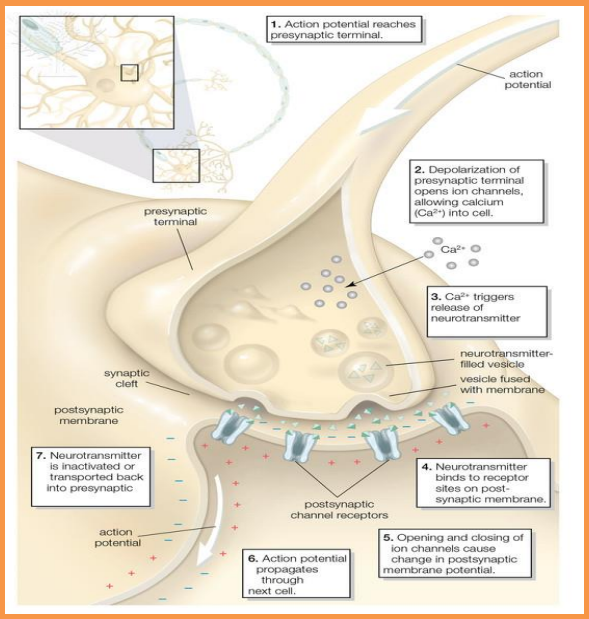
Typically, voltage changes in neurons flow from dendrites, to the soma, to the axon. In sensory neurons, however, environmental stimuli (light, chemicals, pain) activate ion channels which produce action potentials that flow from the axon to the soma. In either case, neurons propagate signals along their axons in the form of action potentials, which is how neurons communicate with other neurons or cells. The communication that occurs between these cells is called synaptic transmission.

The synapse

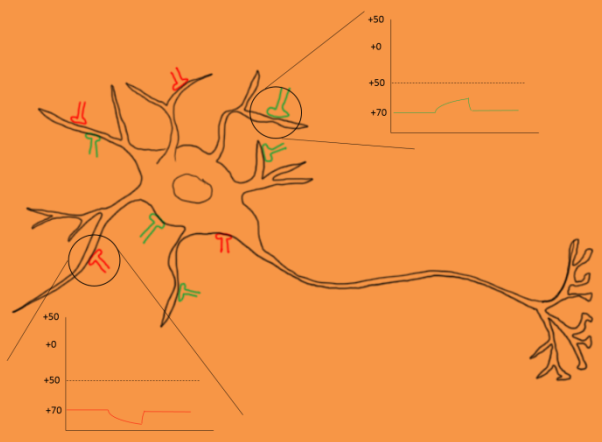
Structurally, two types of synapses are found in neurons: chemical and electrical. **Chemical synapses** occur when neural membranes abut very close together, but remain distinct, leaving a space. **Electrical synapses** occur when membranes are linked together (gap junctions) via specialized proteins that allow the flow of ions from one cell to another. Electrical synapses are found in heart muscle. Because electrical synapses are rare in the nervous system, the remaining discussion will address the chemical synapse.

Chemical synapses use chemicals called neurotransmitters to communicate the messages between cells. The part of the synapse that releases the neurotransmitter into the synapse is called the presynaptic terminal, and the part of the synapse that receives the neurotransmitter is called the postsynaptic terminal. The narrow space between the two regions is called the synaptic cleft. Both the presynaptic and postsynaptic terminals contain the molecular machinery needed to carry out the signaling process. The presynaptic terminal contains large numbers of vesicles that are packed with neurotransmitters. When an action potential arrives at the presynaptic terminal, voltage gated Ca^{++}channels open, which allows for the influx of Ca^{++} which then activates an array of molecules in the neuronal membrane and the vesicular membrane to become activated. These newly activated molecules then induce exocytosis of the vesicles, which results in release of the neurotransmitter. The neurotransmitter then binds to receptors located in the postsynaptic membrane and induces a conformational change. This

conformation change causes the receptor to act as a pore in the membrane for ions to move through. Depending on the type of ion, the effect on the postsynaptic cell may be depolarizing (excitatory) or hyperpolarizing (inhibitory).

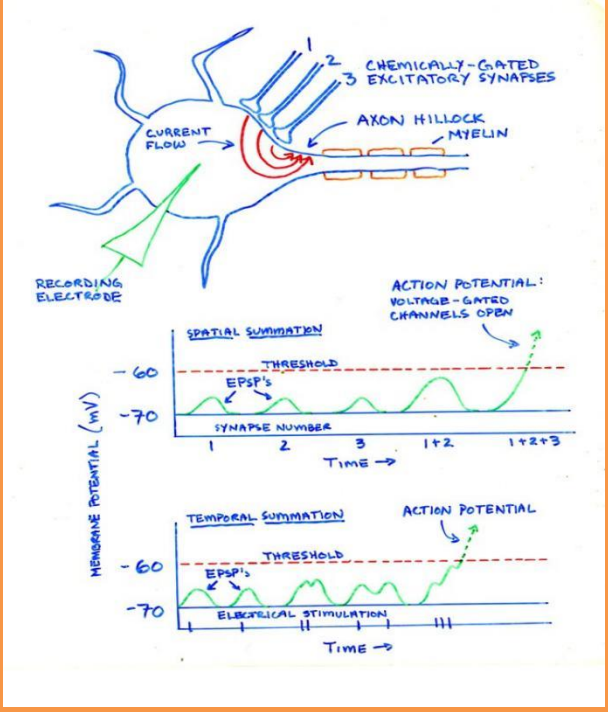


An excitatory response is called an **EPSP** which is the abbreviation for an "excitatory post synaptic potential," whereas an inhibitory response is called an **IPSP** or "inhibitory post synaptic potential." As the name suggests, an EPSP elicits an excitatory response, or membrane depolarization, whereas an IPSP results in an inhibitory response, or membrane hyperpolarization.



EPSP and IPSP. A cell body will have many synapses on it and on its surrounding dendrites. Some of the synapses will result in the cell body membrane potential moving closer to threshold. Other synapses result in the cell body membrane potential moving farther from threshold (hyperpolarization). Any synapse that moves the potential closer to threshold is called an Excitatory Post Synaptic Potential, and any synapse that moves the potential farther from threshold is called an inhibitory Post Synaptic Potential. The net effect of all the EPSPs and IPSPs is experienced at the axon hillock. If threshold is reached, then an action potential will continue down the axon.

The ultimate goal of an EPSP is to cause enough change in the membrane to initiate an action potential. The goal of the IPSP is to cause a change in the membrane to prevent an action potential. Each EPSP or IPSP lasts a few milliseconds and then the membrane returns to the original resting membrane potentials. In many cases, a single EPSP is not sufficient to cause an action potential. Therefore, many EPSPs from multiple synapses can combine at the soma, which results in a much larger voltage change that can exceed threshold and cause and action potential. This phenomenon is called spatial summation. EPSPs from the same synapse can also combine if they arrive in rapid succession; this phenomenon is called temporal summation. Requiring multiple EPSPs to fire an action potential are ways that neurons increase sensitivity and accuracy.



Summation

A response as an EPSP or an IPSP will depend on the type of neurotransmitter/receptor combination present in the synapse. There are over a hundred known neurotransmitters, and

many of them have unique receptors. Receptors can be divided into two broad groups: chemically gated ion channels and second messenger systems. When chemically gated ion channels are activated, certain ions are allowed to flow across the membrane. The ion type will determine on whether the result is an EPSP or an IPSP. When a second messenger system is activated, it results in a cascade of molecular interactions within the target or postsynaptic cell. The type of cascade that is elicited will result in the response being either excitatory or inhibitory.

Excitatory Synapses

Most excitatory synapses in the brain use glutamate or aspartate as the neurotransmitter. These neurotransmitters bind to non-selective cationic channels that allow for Na+ and K+ to pass. As mentioned earlier, it takes many EPSPs from these kinds of synapses to depolarize a postsynaptic neuron enough to reach threshold and trigger an action potential.

A very important subset of synapses in the brain includes a group capable of forming memories by increasing the activity and the strength of the synapse. This process is called **long-term potentiation.** Long-term potentiation operates at the synapse, using the neurotransmitter glutamate and the receptor known as the NMDA receptor. The NMDA receptor is unique in that it is both ligand and voltage regulated. When activated by ligands, it becomes permeable to Na+, but if the charge difference is sufficient, the channel becomes permeable to Ca^{++} as well. Ca^{++} can initiate a second messenger cascade that results in an increase in the number of glutamate receptors, thereby increasing the strength of the synapse. The change in strength can last for weeks, months, or even years depending on whether or not the synapse is continually used.

Inhibitory Synapses

It may seem somewhat of a paradox to have inhibitory synapses, but the excitability of neurons is essentially governed by a balance between excitation and inhibition. The main inhibitory neurotransmitters are GABA and glycine. Both neurotransmitters bind to receptors that result in an increase conductance of Cl-. Because of the negative charge of Cl- and the fact that it usually moves into the cell, the effect is to oppose depolarization and cause the membrane to move away from threshold.

Modulatory synapses

Modulatory synapses are those that can be "primed" by neuromodulators so that they are able to respond more powerfully to other inputs. An example of a priming neuromodulator is norepinephrine. By itself, norepinephrine has little effect on synaptic transmission, but when a cell is exposed to norepinephrine first, it will react more powerfully to glutamate.

GLIAL CELLS

Unlike neurons, the glial cells can be replaced if they are damaged. Glial cells compose half of the volume of the brain and are more numerous than neurons. There are four major types

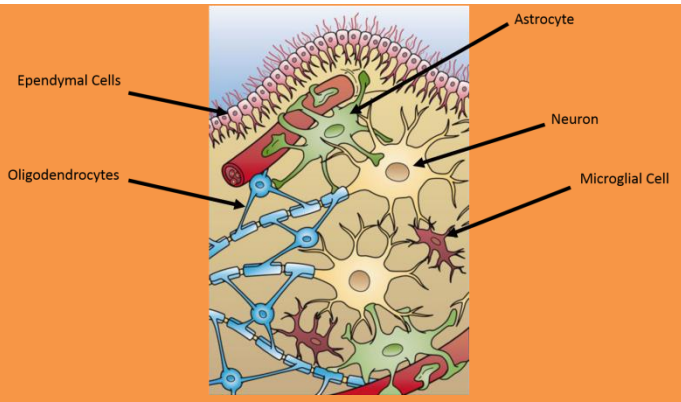
of glial cells in the CNS: the astrocyte, the oligodendrocyte, the ependymal, and the microglial cell.

The astrocyte: Astrocytes have an enormous amount of processes that wrap around blood vessels and neurons. Because of this arrangement, astrocytes are ideally positioned to control and modify the extracellular environment around neurons. Most of the functions of the astrocyte are attributed to controlling this environment.

The Oligodendroctye: The primary function of the oligodendorcyte is to provide and maintain the myelin sheaths around axons. Myelin is the insulating component of the nervous system. It allows for electrical signals to be propagated along one axon without being spread to other axons. Oligodendrocytes send out long 15 to 30 processes, which wrap many times around a section of an axon. Between each "wrapping," there is a small area of exposed axon called the **node of Ranvier**. The wrapping creates many layers of tightly compressed membranes that is called **myelin**. Myelination speeds up the conduction of the action potential down the axon by allowing the action potentials to occur only at the nodes, a process called saltatory conduction. Myelination also induces the clustering of voltage-gated Na+ channels at the nodes. In addition to myelination, oligodendrocytes also play key roles in pH regulation of the CNS. There are many diseases that selectively damage or destroy myelin; the most common demyelinating disease in the CNS is **multiple sclerosis**. Multiple sclerosis (MS) is an autoimmune disease that results in the selective destruction of oligodendrocytes, resulting in a reduction of myelin. The reduction in myelin severely decreases the conduction velocity and duration of action potentials in the affected neuron. This can result in loss of sensory perception and motor control. The cause of MS is currently unknown, but the disease is twice as common in women as in men.

The Ependymal Cell: Ependymal cells line the cavities of the CNS. Ependymal cells are responsible for the production of Cerebral Spinal Fluid (CSF) and are important barriers between the cerebral spinal fluid and the brain extracellular space. These cells beat their cilia to help circulate the cerebral spinal fluid.

The Microglial Cell: Microglial cells are rapidly activated in the CNS in response to injury. Injury causes these cells to proliferate, change shape, and become phagocytic. These cells are also very important in presenting antigens to lymphocytes in response to infection. Although these cells are an important component of the CNS, it is believed that their activity is also toxic to neurons and can result in long term damage. For this reason, medical intervention in response to brain injury often involves factors that inhibit microglial activity.



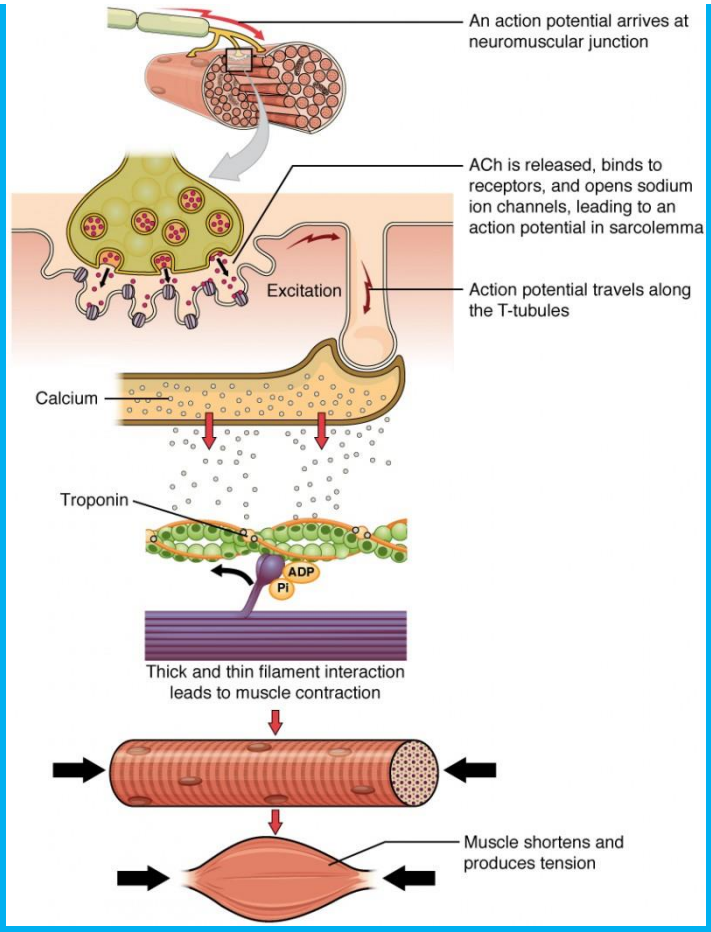
The Schwann Cell: The schwann cell is the mylenating cell of the PNS. In contrast to the oligodendrocyte of the CNS, which uses multiple processes to mylenate multiple segments of axons, a schwann cell provides myelin for a single segment of an axon. Still, the appearance and function of myelin in the PNS is exactly the same as the CNS.

The Satellite Cell: Satellite glial cells help regulate the external chemical environment around neurons of the PNS. In this way they are very similar to the astrocyte of the CNS, but in addition are highly sensitive to injury and inflammation.

Mechanism of muscle contraction

INTRODUCTION

The sequence of events that result in the contraction of an individual muscle fiber begins with a signal—the neurotransmitter, ACh—from the motor neuron innervating that fiber. The local membrane of the fiber will depolarize as positively charged sodium ions (Na^{+}) enter, triggering an action potential that spreads to the rest of the membrane will depolarize, including the T-tubules. This triggers the release of calcium ions (Ca^{++}) from storage in the sarcoplasmic reticulum (SR). The Ca^{++} then initiates contraction, which is sustained by ATP . As long as Ca^{++} ions remain in the sarcoplasm to bind to troponin, which keeps the actin-binding sites “unshielded,” and as long as ATP is available to drive the cross-bridge cycling and the pulling of actin strands by myosin, the muscle fiber will continue to shorten to an anatomical limit.



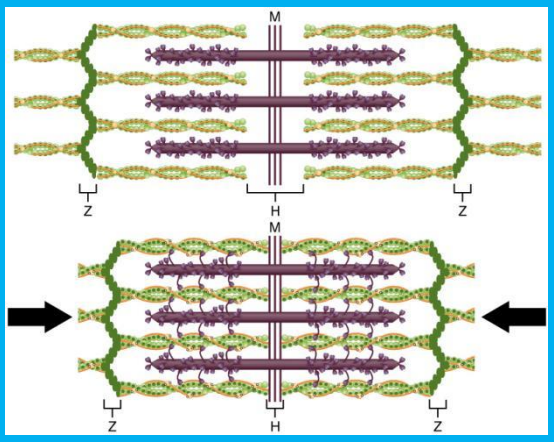
The molecular events of muscle fiber shortening occur within the fiber's sarcomeres . The contraction of a striated muscle fiber occurs as the sarcomeres, linearly arranged within myofibrils, shorten as myosin heads pull on the actin filaments.

The region where thick and thin filaments overlap has a dense appearance, as there is little space between the filaments. This zone where thin and thick filaments overlap is very important to muscle contraction, as it is the site where filament movement starts. Thin filaments, anchored at their ends by the Z-discs, do not extend completely into the central region that only contains thick filaments, anchored at their bases at a spot called the M-line. A myofibril is composed of many sarcomeres running along its length; thus, myofibrils and muscle cells contract as the sarcomeres contract.

The Sliding Filament Model of Contraction

When signaled by a motor neuron, a skeletal muscle fiber contracts as the thin filaments are pulled and then slide past the thick filaments within the fiber's sarcomeres. This process is known as the sliding filament model of muscle contraction.The sliding can only occur when

myosin-binding sites on the actin filaments are exposed by a series of steps that begins with Ca^{++} entry into the sarcoplasm



Tropomyosin is a protein that winds around the chains of the actin filament and covers the myosin-binding sites to prevent actin from binding to myosin. Tropomyosin binds to troponin to form a troponin-tropomyosin complex. The troponin-tropomyosin complex prevents the myosin "heads" from binding to the active sites on the actin microfilaments. Troponin also has a binding site for Ca^{++} ions.

To initiate muscle contraction, tropomyosin has to expose the myosin-binding site on an actin filament to allow cross-bridge formation between the actin and myosin microfilaments. The first step in the process of contraction is for Ca^{++} to bind to troponin so that tropomyosin can slide away from the binding sites on the actin strands. This allows the myosin heads to bind to these exposed binding sites and form cross-bridges. The thin filaments are then pulled by the myosin heads to slide past the thick filaments toward the center of the sarcomere. But each head can only pull a very short distance before it has reached its limit and must be "re-cocked" before it can pull again, a step that requires ATP.

Excitation-Contraction Coupling

All living cells have membrane potentials, or electrical gradients across their membranes based on the distribution of positively and negatively charged ions. The inside of the membrane is usually around -60 to -90 mV, relative to the outside. Neurons and muscle cells can use their membrane potentials to generate and conduct electrical signals by controlling the movement of charged ions across their membranes to create electrical currents. This

movement is controlled by selective opening and closing of specialized proteins in the membrane called ion channels. Although the currents generated by ions moving through these channel proteins are very small, they form the basis of both neural signaling and muscle contraction.

Both neurons and skeletal muscle cells are electrically excitable, meaning that they are able to generate **action potentials**. An action potential is a special type of electrical signal that can travel along a cell membrane as a wave. This allows a signal to be transmitted quickly over long distances.

In skeletal muscle, cross-bridge formation and contraction requires the presence of calcium (Ca++) inside the muscle cell. Excitation signalling of action potentials from the motor neuron are coupled with calcium release. Thus, the **excitation-contraction coupling** process begins with signaling from the nervous system at the neuromuscular junction and ends with calcium release for muscle contraction.Most motor neurons that tell the skeletal muscle fibers to contract originate in the spinal cord. A smaller number of motor neurons are located in the brainstem for activation of skeletal muscles of the face, head, and neck. These neurons have long processes, called axons, which are specialized to transmit action potentials long distances— in this case, all the way from the spinal cord to the muscle itself (which may be up to three feet away). The axons of multiple neurons bundle together to form nerves, like wires bundled together in a cable.

Signaling begins when a neuronal **action potential** travels along the axon of a motor neuron to the axon terminals at the NMJ. The ACh molecules diffuse across a minute space called the **synaptic cleft** and bind to ACh receptors on **chemically-gated** or **ligand-gated channels** located within the **motor end-plate** of the sarcolemma on the other side of the synapse. Once ACh binds, the chemically gated channel opens and positively charged ions can pass through into the muscle fiber, causing it to **depolarize**, meaning that the membrane potential of the muscle fiber becomes less negative (closer to zero.)

The membrane depolarization at the synaptic cleft triggers nearby **voltage-gated sodium channels** to open. Sodium ions enter the muscle fiber further depolarizing the membrane, and an action potential rapidly spreads (or “fires”) along the entire membrane to initiate excitation-contraction coupling.

Things happen very quickly in the world of excitable membranes (just think about how quickly you can snap your fingers as soon as you decide to do it). Immediately following depolarization of the membrane, **repolarization** occurs. Depolarization causes voltage-gated potassium channels open and allow potassium to leave the cell which returns the cell membrane to a negative membrane potential. The concentration gradients of sodium and potassium are then re-established by the sodium-potassium pump. Meanwhile, the ACh in the synaptic cleft is degraded by the enzyme acetylcholinesterase (AChE) so that the ACh cannot rebind to a receptor and reopen its channel, which would cause unwanted extended muscle excitation and contraction.

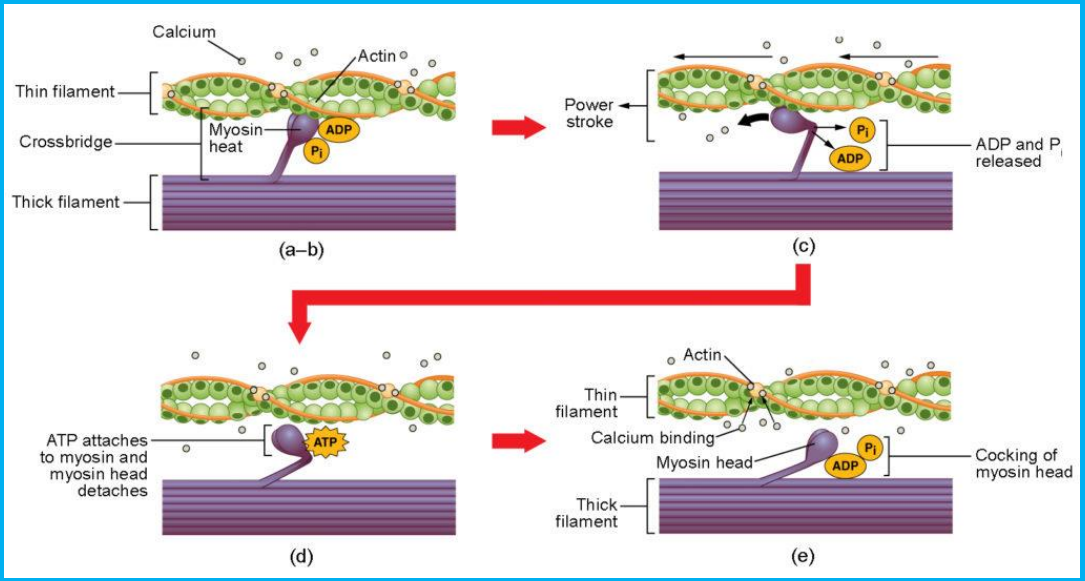
Propagation of an action potential along the sarcolemma is the excitation portion of excitation-contraction coupling and must be coupled to the release of calcium ions for contraction. High concentrations of calcium in skeletal muscle are stored in a specialized type of smooth endoplasmic reticulum organelle called the **sarcoplasmic reticulum (SR)**. The SR structure surrounds the myofibrils, allowing storage and release of calcium directly at sites of actin and myosin overlap. The excitation of the muscle membrane is coupled to the SR release of calcium through invaginations in the sarcolemma called T-Tubules ("T" stands for "transverse"). Because the diameter of a muscle fiber can be up to 100 μm, the T-tubules ensure that the action potential on the membrane can get to the interior of the cell and close to the SR throughout the sarcoplasm. The arrangement of a T-tubule with the membranes of SR on either side is called a **triad**

Voltage-sensitive dihydropyridine receptors (DHPR) on the sarcolemma are mechanically linked to calcium channels in the adjacent SR membrane called ryanadine receptors (RyR). Through the DHPR, the action potential in the sarcolemma triggers the opening of RyR, allowing Ca++ to diffuse out of the SR and into the sarcoplasm. It is the arrival of Ca++ in the sarcoplasm that allows for the binding of actin and myosin and thus initiates contraction and shortening of sarcomeres.

ATP and Muscle Contraction

For thin filaments to continue to slide past thick filaments during muscle contraction, myosin heads must pull the actin at the binding sites, detach, re-cock, attach to more binding sites,

pull, detach, re-cock, etc. This repeated movement is known as the cross-bridge cycle. This motion of the myosin heads is similar to the oars when an individual rows a boat: The paddle of the oars (the myosin heads) pull, are lifted from the water (detach), repositioned (re-cocked) and then immersed again to pull. Each cycle requires energy, and the action of the myosin heads in the sarcomeres repetitively pulling on the thin filaments also requires energy, which is provided by ATP.



Cross-bridge formation occurs when the myosin head attaches to the actin while adenosine diphosphate (ADP) and inorganic phosphate (P_i) are still bound to myosin. P_i is then released, causing myosin to form a stronger attachment to the actin, after which the myosin head moves toward the M-line, pulling the actin along with it. As actin is pulled, the filaments move approximately 10 nm toward the M-line. This movement is called the **power stroke**, as movement of the thin filament occurs at this step. In the absence of ATP, the myosin head will not detach from actin.

One part of the myosin head attaches to the binding site on the actin, but the head has another binding site for ATP. ATP binding causes the myosin head to detach from the actin . After this occurs, ATP is converted to ADP and P_i by the intrinsic **ATPase** activity of myosin. The energy released during ATP hydrolysis changes the angle of the myosin head into a cocked position. The myosin head is now in position for further movement.

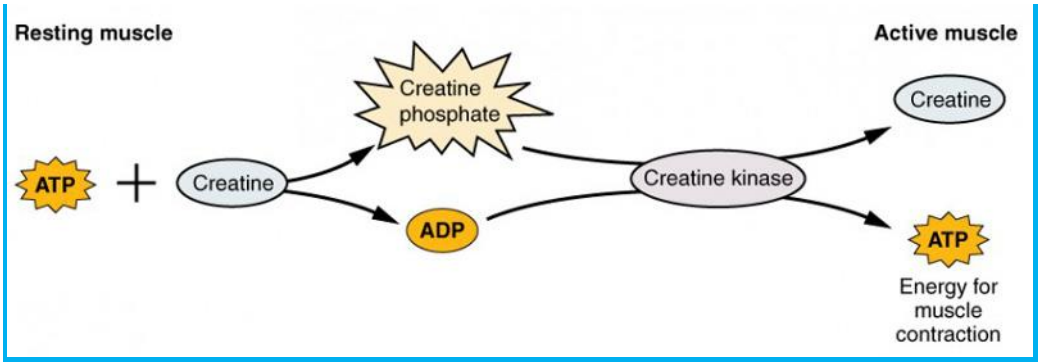
When the myosin head is cocked, myosin is in a high-energy configuration. This energy is expended as the myosin head moves through the power stroke, and at the end of the power stroke, the myosin head is in a low-energy position. After the power stroke, ADP is released; however, the formed cross-bridge is still in place, and actin and myosin are bound together. As long as ATP is available, it readily attaches to myosin, the cross-bridge cycle can recur, and muscle contraction can continue.

Note that each thick filament of roughly 300 myosin molecules has multiple myosin heads, and many cross-bridges form and break continuously during muscle contraction. Multiply this by all of the sarcomeres in one myofibril, all the myofibrils in one muscle fiber, and all of the muscle fibers in one skeletal muscle, and you can understand why so much energy (ATP) is needed to keep skeletal muscles working. In fact, it is the loss of ATP that results in the rigor mortis observed soon after someone dies. With no further ATP production possible, there is no ATP available for myosin heads to detach from the actin-binding sites, so the cross-bridges stay in place, causing the rigidity in the skeletal muscles.

Sources of ATP

ATP supplies the energy for muscle contraction to take place. In addition to its direct role in the cross-bridge cycle, ATP also provides the energy for the active-transport Ca^{++} pumps in the SR. Muscle contraction does not occur without sufficient amounts of ATP. The amount of ATP stored in muscle is very low, only sufficient to power a few seconds worth of contractions. As it is broken down, ATP must therefore be regenerated and replaced quickly to allow for sustained contraction. There are three mechanisms by which ATP can be regenerated: creatine phosphate metabolism, anaerobic glycolysis, fermentation and aerobic respiration.

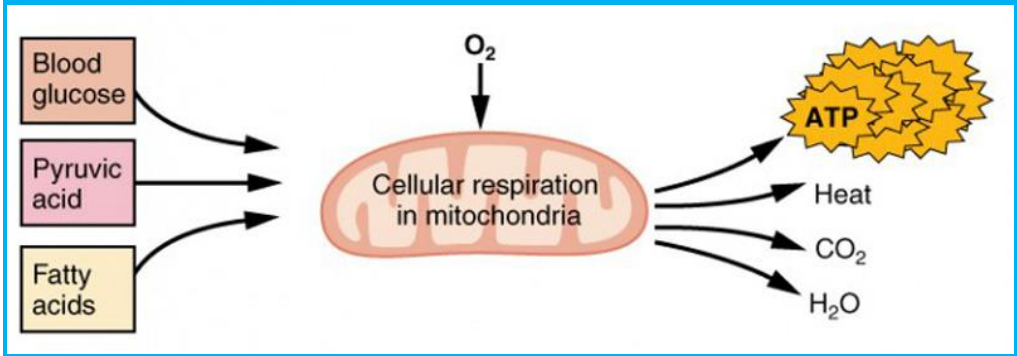
Creatine phosphate is a molecule that can store energy in its phosphate bonds. In a resting muscle, excess ATP transfers its energy to creatine, producing ADP and creatine phosphate. This acts as an energy reserve that can be used to quickly create more ATP. When the muscle starts to contract and needs energy, creatine phosphate transfers its phosphate back to ADP to form ATP and creatine. This reaction is catalyzed by the enzyme creatine kinase and occurs very quickly; thus, creatine phosphate-derived ATP powers the first few seconds of muscle contraction. However, creatine phosphate can only provide approximately 15 seconds worth of energy, at which point another energy source has to be used.



As the ATP produced by creatine phosphate is depleted, muscles turn to glycolysis as an ATP source. **Glycolysis** is an anaerobic (non-oxygen-dependent) process that breaks down glucose (sugar) to produce ATP; however, glycolysis cannot generate ATP as quickly as creatine phosphate. Thus, the switch to glycolysis results in a slower rate of ATP availability to the muscle. The sugar used in glycolysis can be provided by blood glucose or by metabolizing glycogen that is stored in the muscle. The breakdown of one glucose molecule produces two ATP and two molecules of **pyruvic acid**, which can be used in aerobic respiration or when oxygen levels are low, converted to lactic acid.If oxygen is available, pyruvic acid is used in aerobic respiration. However, if oxygen is not available, pyruvic acid is converted to **lactic acid**, which may contribute to muscle fatigue. This conversion allows the recycling of the enzyme NAD^+ from NADH, which is needed for glycolysis to continue. This occurs during strenuous exercise when high amounts of energy are needed but oxygen cannot be sufficiently delivered to muscle. Glycolysis itself cannot be sustained for very long (approximately 1 minute of muscle activity), but it is useful in facilitating short bursts of high-intensity output. This is because glycolysis does not utilize glucose very efficiently, producing a net gain of two ATPs per molecule of glucose, and the end product of lactic acid, which may contribute to muscle fatigue as it accumulates.

Aerobic respiration is the breakdown of glucose or other nutrients in the presence of oxygen (O_2) to produce carbon dioxide, water, and ATP. Approximately 95 percent of the ATP required for resting or moderately active muscles is provided by aerobic respiration, which takes place in mitochondria. The inputs for aerobic respiration include glucose circulating in the bloodstream, pyruvic acid, and fatty acids. Aerobic respiration is much more efficient than anaerobic glycolysis, producing approximately 36 ATPs per molecule of glucose versus four from glycolysis. However, aerobic respiration cannot be sustained without a steady supply of O_2 to the skeletal muscle and is much slower. To compensate, muscles store small

amount of excess oxygen in proteins call myoglobin, allowing for more efficient muscle contractions and less fatigue. Aerobic training also increases the efficiency of the circulatory system so that O_2 can be supplied to the muscles for longer periods of time.



Muscle fatigue occurs when a muscle can no longer contract in response to signals from the nervous system. The exact causes of muscle fatigue are not fully known, although certain factors have been correlated with the decreased muscle contraction that occurs during fatigue. ATP is needed for normal muscle contraction, and as ATP reserves are reduced, muscle function may decline. This may be more of a factor in brief, intense muscle output rather than sustained, lower intensity efforts. Lactic acid buildup may lower intracellular pH, affecting enzyme and protein activity. Imbalances in Na^+ and K^+ levels as a result of membrane depolarization may disrupt Ca^{++} flow out of the SR. Long periods of sustained exercise may damage the SR and the sarcolemma, resulting in impaired Ca^{++} regulation.

Intense muscle activity results in an **oxygen debt**, which is the amount of oxygen needed to compensate for ATP produced without oxygen during muscle contraction. Oxygen is required to restore ATP and creatine phosphate levels, convert lactic acid to pyruvic acid, and, in the liver, to convert lactic acid into glucose or glycogen. Other systems used during exercise also require oxygen, and all of these combined processes result in the increased breathing rate that

occurs after exercise. Until the oxygen debt has been met, oxygen intake is elevated, even after exercise has stopped.

Relaxation of a Skeletal Muscle

Relaxing skeletal muscle fibers, and ultimately, the skeletal muscle, begins with the motor neuron, which stops releasing its chemical signal, ACh, into the synapse at the NMJ. The muscle fiber will repolarize, which closes the gates in the SR where Ca^{++} was being released. ATP-driven pumps will move Ca^{++} out of the sarcoplasm back into the SR. This results in the "reshielding" of the actin-binding sites on the thin filaments. Without the ability to form cross-bridges between the thin and thick filaments, the muscle fiber loses its tension and relaxes.

Muscle Strength

The number of skeletal muscle fibers in a given muscle is genetically determined and does not change. Muscle strength is directly related to the amount of myofibrils and sarcomeres within each fiber. Factors, such as hormones and stress (and artificial anabolic steroids), acting on the muscle can increase the production of sarcomeres and myofibrils within the muscle fibers, a change called hypertrophy, which results in the increased mass and bulk in a skeletal muscle. Likewise, decreased use of a skeletal muscle results in atrophy, where the number of sarcomeres and myofibrils disappear (but not the number of muscle fibers). It is common for a limb in a cast to show atrophied muscles when the cast is removed, and certain diseases, such as polio, show atrophied muscles.