PERIYAR ARTS COLLEGE, CUDDALORE -1

PG & RESEARCH DEPARTMENT OF ZOOLOGY

AFFILIATED TO THIRUVALLUVAR UNIVERSITY

STUDY MATERIAL

COURSE:	**II M.Sc ZOOLOGY**	**YEAR: 2020 -2021**	**SEMESTER- III**
SUBJECT PAPER	**ANIMAL PHYSIOLOGY – UNIT IV**		**PAPER CODE**
PREPARED BY NAME	**DR.S.ARULJOTHISELVI**		**MZO31**
DESIGNATION	**ASSISTANT PROFESSOR**		

SYLLABUS - UNIT IV

Neuro muscular co -ordination – types of neurons, transmissions of nerve impulse and reflex action. Chemical composition of muscle fiber and physiology of muscle contraction. Myoneural junction. Physiology of mammalian Reproduction – reproductive cycle – hormonal control of reproduction.

I. **Neuro muscular co -ordination**
II. **Neurons and its types**
III. **Transmissions of nerve impulse**
IV. **Reflex action**
V. **Muscle fibre – Structure, types and its Chemical composition**
VI. **Physiology of muscle contraction**
VII. **Myoneural junction**
VIII. **Physiology of Mammalian Reproduction**
IX. **Reproductive cycle - Hormonal control of Reproduction.**

I. Neuro muscular co -ordination

Neuromuscular coordination can be defined as the ability of the central nervous system (CNS) to control the muscles in the execution of multi-limb functional movements.

Neuromuscular Coordination, also known as “motor control” or “muscle memory” is the ability of the nervous system to efficiently recruit a muscle or a group of muscles in order to perform a specific task unconsciously.

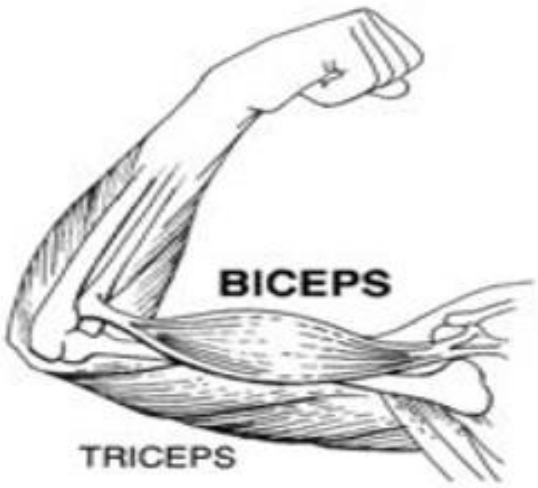
Through a series of interactions between neurological messages, a complex system is formed, connecting different aspects of muscle actions (static, dynamic, reactive), muscle contractions, coordination, joint stability, body alignment and balance.

- Neuromuscular coordination has two components:
- Intra-muscular Coordination and Inter-Muscular Coordination.
- Both of them are important to incorporate in one's training program in order for one to be efficient with his movement and to minimize the risk of injury.
- 'Intra-muscular coordination' is the activation of an individual neuro-muscular unit within a muscle fiber. This has three main elements:
- 1- Rate coding: it is the firing rate of neuro-muscular control units which in return increases the strength of muscular contraction. Resistance training is known to be the ideal method to enhance your code rating.
- 2- Recruitment of neuromuscular motor units: it allows alternation between muscle groups (when a group of muscles are exhausted, others compensate). It could be increased by maximum load training or plyometric exercises.

  3- Motor units synchronization: it improves the ability of recruiting muscle fibers at the exact time required leading to greater force generation and more efficient movement
- 'Inter-muscular coordination' which is the interactions between the agonist, antagonist, and stabilizer muscle groups during specific tasks and activities.
- In each exercise there are four main functions of the associated muscles, Agonists (prime movers), Antagonists, Stabilizers and Assistors.
- The Agonists is generally the muscle we are exercising.
- The Antagonist is the opposing muscle and acts in contrast to the agonist.
- The Stabilizer muscles are those that hold a joint in place so that the exercise may be performed.
- The Assistors help the Agonist muscle doing the work. The stabilizer muscles are not necessarily moving during exercise, but provide stationary support.
- For example, when doing biceps curls, the biceps are the agonists, the triceps are the antagonists and various muscles including the deltoids are the stabilizer muscles.

  However, when doing a triceps push down, now the triceps are the agonists and the biceps are the antagonists

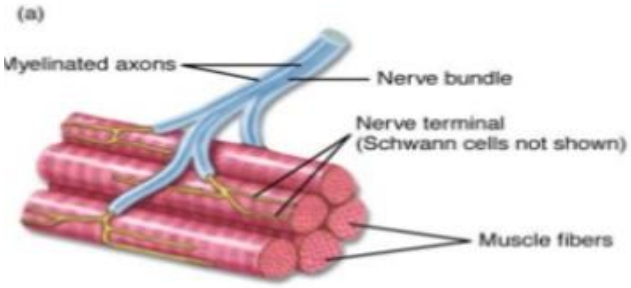
  The biceps and triceps act against one another to bend and straighten the elbow joint. To bend the elbow, the biceps contracts and the triceps relaxes. To straighten the elbow, the triceps contract and the biceps relax
- .

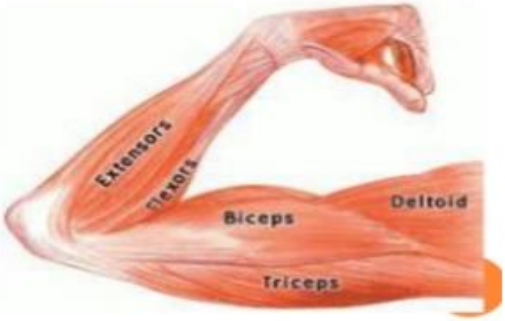


NEUROMUSCULAR COORDINATION WORKS ON TWO LEVELS

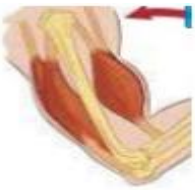
1) Intra-Muscular Coordination

2) Inter-Muscular Coordination

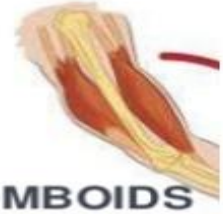




EXAMPLE :
BICEPS CURL



Provide main force **BICEPS** (*agonist*)

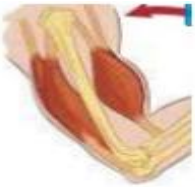


Need co ordination by **TRICEPS** (*antagonist*)

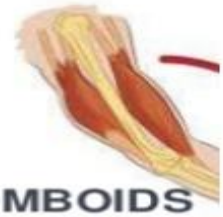
Need co ordination of **TRAPEZIUS** and **RHOMBOIDS** (*fixators*)

Need co-ordination of **PRONATOR TERES** (*synergists*)

EXAMPLE :
BICEPS CURL



Provide main force **BICEPS** (*agonist*)



↓

Need co ordination by **TRICEPS** (*antagonist*)

↓

Need co ordination of **TRAPEZIUS** and **RHOMBOIDS** (*fixators*)

↓

Need co-ordination of **PRONATOR TERES** (*synergists*)

SYNCHRONIZATION OF MOTOR UNITS

- ***Synchronization** means co-ordination of events to operate a system, and maintain each event on time.*
- *It is the simultaneous discharge of action potentials in pairs of motor units with similar recruitment thresholds*
- ***Increased synchronization** of motor units enhances the ability to recruit muscle fibers at the exact time required leading to improvements in both efficiency and the force generated*

II. Neurons and Types of neurons

Nervous System

The neural or nervous system is a complex network of nerve cells or neurons. The nervous system is specialized to carry messages while the endocrine system provides chemical integration through hormones. To better understand the nervous system, one must realize the difference between a neuron and a nerve. Neurons are cells that form the core of the nervous system as they have the ability to receive and transmit signals. They have characteristic elongated shape and consist of three parts:

- There are three types of nerves in the body:
- Autonomic nerves. These nerves control the involuntary or partially voluntary activities of your body, including heart rate, blood pressure, digestion, and temperature regulation.
- Motor nerves. These nerves control your movements and actions by passing information from your brain and spinal cord to your muscles.
- Sensory nerves. These nerves relay information from your skin and muscles back to your spinal cord and brain. The information is then processed to let you feel pain and other sensations.

• Neurons, also known as nerve cells, send and receive signals from our brain While neurons have a lot in common with other types of cells, they're structurally and functionally unique.

• Specialized projections called axons allow neurons to transmit electrical and chemical signals to other cells. Neurons can also receive these signals via rootlike extensions known as dendrites.

Neuron And Nerves

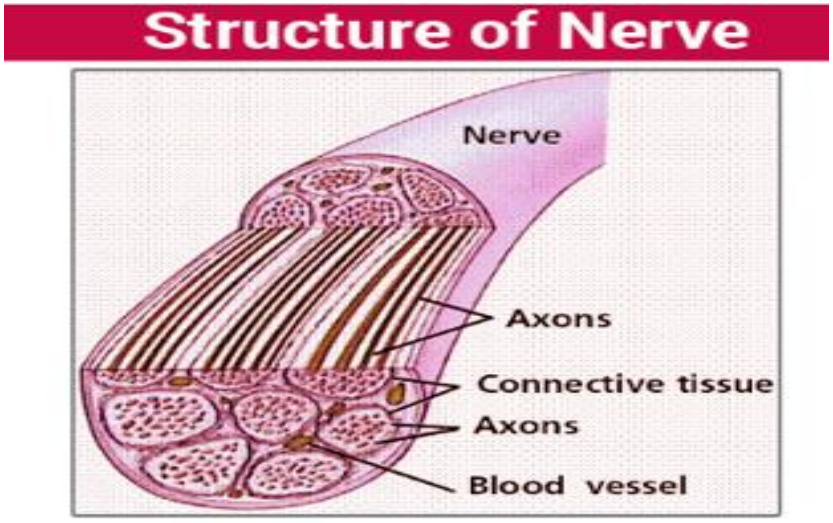
Though nerve and neuron sounds similar but they are two different components of the body and are closely related to each other. Nerves are actual projections of neurons.

Neuron is an individual specialized cell which are primarily involved in transmitting information through electrical and chemical signals. They are found in the brain, spinal cord and the peripheral nerves. Neuron is also known as the nerve cell. There are two types of neurons – sensory neurons and motor neurons. A group of neurons form a nerve. Neurons are the structural and functional units of the nervous system.

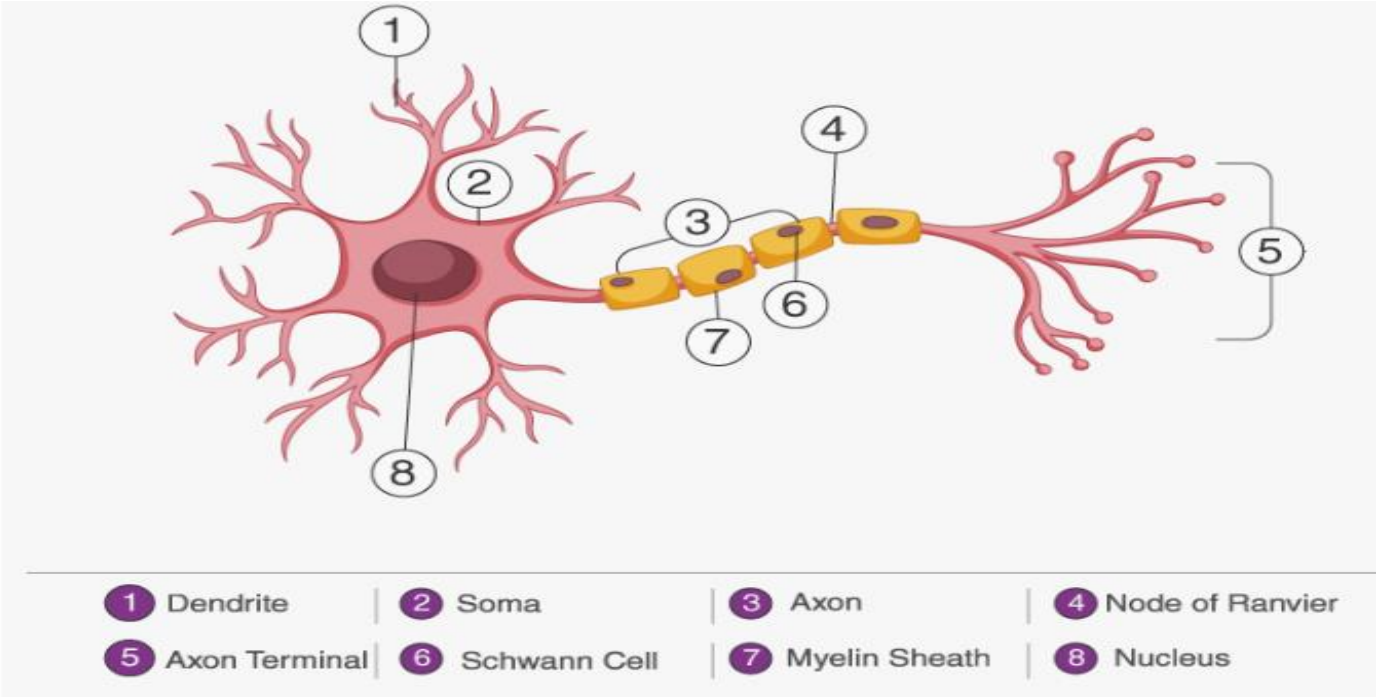
Nerve is an enclosed, cable-like bundle of axons and nerve fibers found in the peripheral nervous system. There are three types of nerves autonomic nerves, motor nerves, and sensory nerves.

- Nerve cell body: It consists of the eukaryotic cell components like the nucleus, endomembrane system, and organelles.
- Dendrites: Tiny projections branching out at the neuron's receiving end, of the nerve cell body. They act like tiny antennas that pick up signals from other cells.
- Axon: A long, thin fiber that extends from the nerve cell body. It branches at its tips to end in synaptic terminals that are marked by swellings called synaptic knobs. Many axons happen to be insulated by a fatty myelin sheath, which is formed by cells called Schwann cells. Between the Schwann cells, one finds small gaps in insulation called the nodes of Ranvier.

A bundle of axons is termed as a nerve. Nerve signals travel rapidly along the axons of myelinated nerves as the electrical signals tend to hop along the axon from gap to gap, rather than having to flow along the whole axon. Scientists have named this type of nerve conduction the saltatory conduction.



Cross-section of a Nerve



- **Parts of a neuron**
- Neurons vary in size, shape, and structure depending on their role and location. However, nearly all neurons have three essential parts: a cell body, an axon, and dendrites.

1. Cell body

- Also known as a soma, the cell body is the neuron's core. The cell body carries genetic information, maintains the neuron's structure, and provides energy to drive activities.
- Like other cell bodies, a neuron's soma contains a nucleus and specialized organelles. It's enclosed by a membrane which both protects it and allows it to interact with its immediate surroundings.

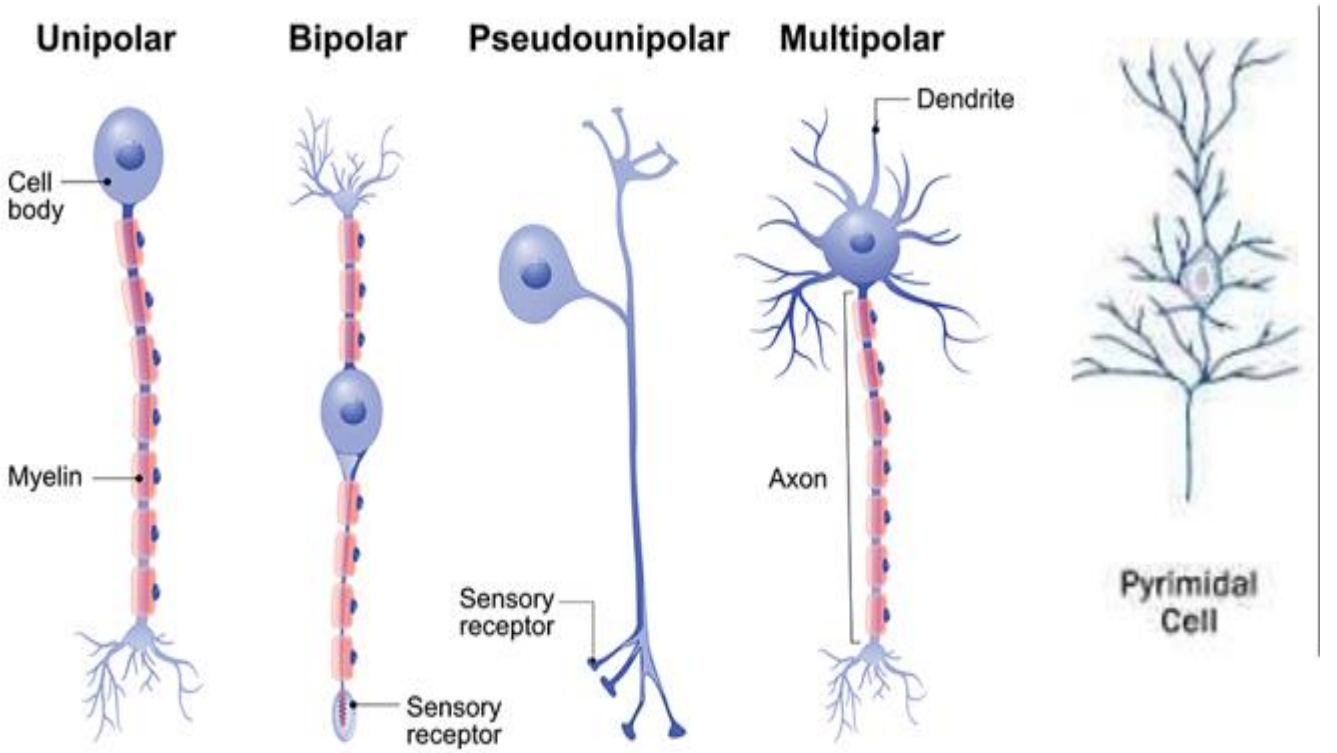
2. Axon

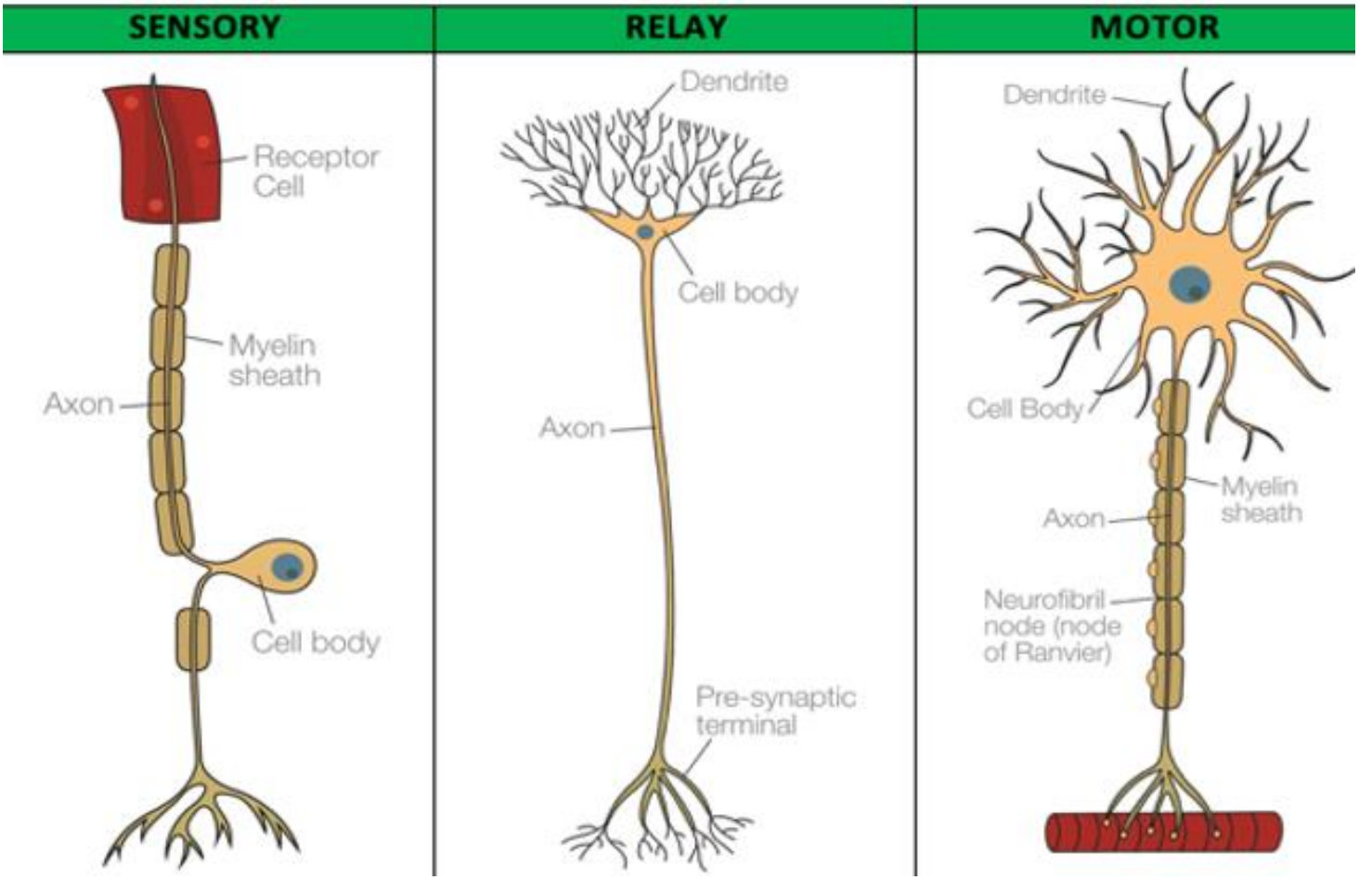
- An axon is a long, tail-like structure which joins the cell body at a specialized junction called the axon hillock. Many axons are insulated with a fatty substance called myelin. Myelin helps axons to conduct an electrical signal. Neurons generally have one main axon.

3. Dendrites

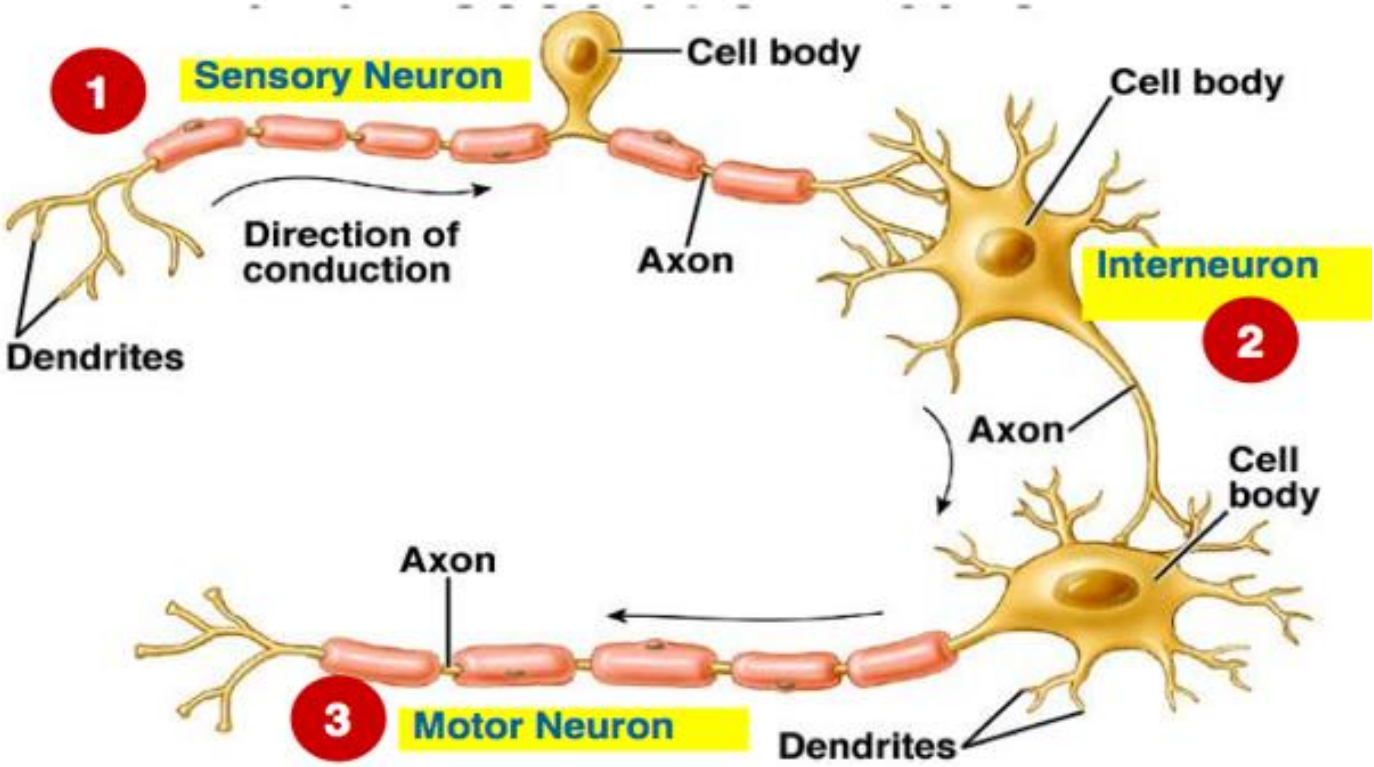
- Dendrites are fibrous roots that branch out from the cell body. Like antennae, dendrites receive and process signals from the axons of other neurons. Neurons can have more than one set of dendrites, known as dendritic trees. How many they have generally depends on their role.
- For instance, Purkinje cells are a special type of neuron found in the cerebellum. These cells have highly developed dendritic trees which allow them to receive thousands of signals.

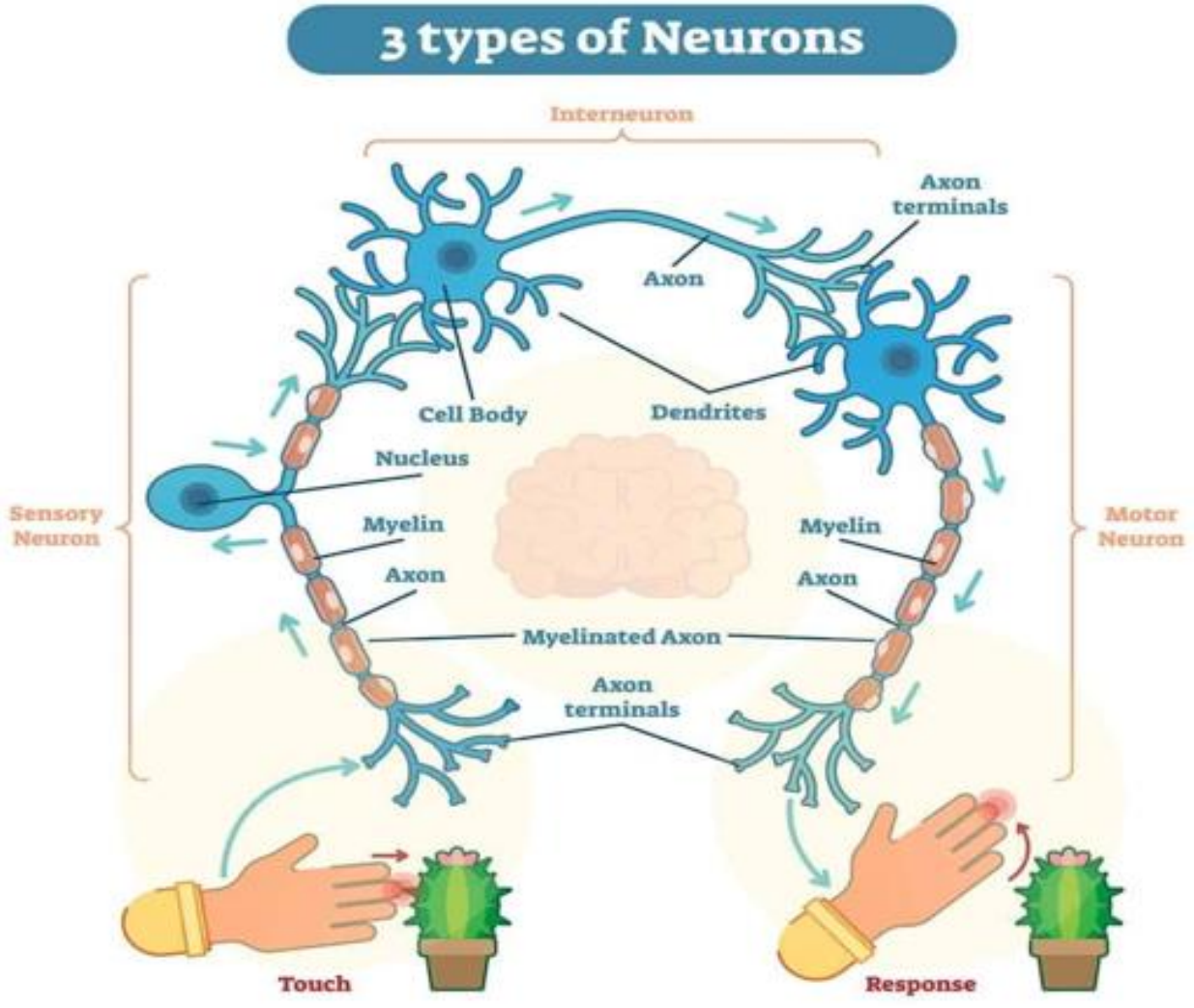
Types of Neurons





Three Types of Neurons





III. Transmissions of nerve impulse

- The transmission of a nerve impulse along a neuron from one end to the other occurs as a result of electrical changes across the membrane of the neuron.
- The membrane of an unstimulated neuron is polarized—that is, there is a difference in electrical charge between the outside and inside of the membrane.
- The inside is negative with respect to the outside.

- Polarization is established by maintaining an excess of sodium ions (Na^+) on the outside and an excess of potassium ions (K^+) on the inside.
- A certain amount of Na^+ and K^+ is always leaking across the membrane through leakage channels, but Na^+/K^+ pumps in the membrane actively restore the ions to the appropriate side.
- The main contribution to the resting membrane potential (a polarized nerve) is the difference in permeability of the resting membrane to potassium ions versus sodium ions.
- The resting membrane is much more permeable to potassium ions than to sodium ions resulting in slightly more net potassium ion diffusion (from the inside of the neuron to the outside) than sodium ion diffusion (from the outside of the neuron to the inside) causing the slight difference in polarity right along the membrane of the axon.
- Other ions, such as large, negatively charged proteins and nucleic acids, reside within the cell. It is these large, negatively charged ions that contribute to the overall negative charge on the inside of the cell membrane as compared to the outside.
- In addition to crossing the membrane through leakage channels, ions may cross through gated channels. Gated channels open in response to neurotransmitters, changes in membrane potential, or other stimuli.
- The following events characterize the transmission of a nerve impulse
- Resting potential. The resting potential describes the unstimulated, polarized state of a neuron (at about –70 millivolts).
- Graded potential. A graded potential is a change in the resting potential of the plasma membrane in the response to a stimulus.
- A graded potential occurs when the stimulus causes Na^+ or K^+ gated channels to open. If Na^+ channels open, positive sodium ions enter, and the membrane depolarizes (becomes more positive).
- If the stimulus opens K^+ channels, then positive potassium ions exit across the membrane and the membrane hyperpolarizes (becomes more negative).
- A graded potential is a local event that does not travel far from its origin. Graded potentials occur in cell bodies and dendrites.
- Light, heat, mechanical pressure, and chemicals, such as neurotransmitters, are examples of stimuli that may generate a graded potential (depending upon the neuron).
- The following four steps describe the initiation of an impulse to the "resetting" of a neuron to prepare for a second stimulation:
- Action potential. Unlike a graded potential, an action potential is capable of traveling long distances.

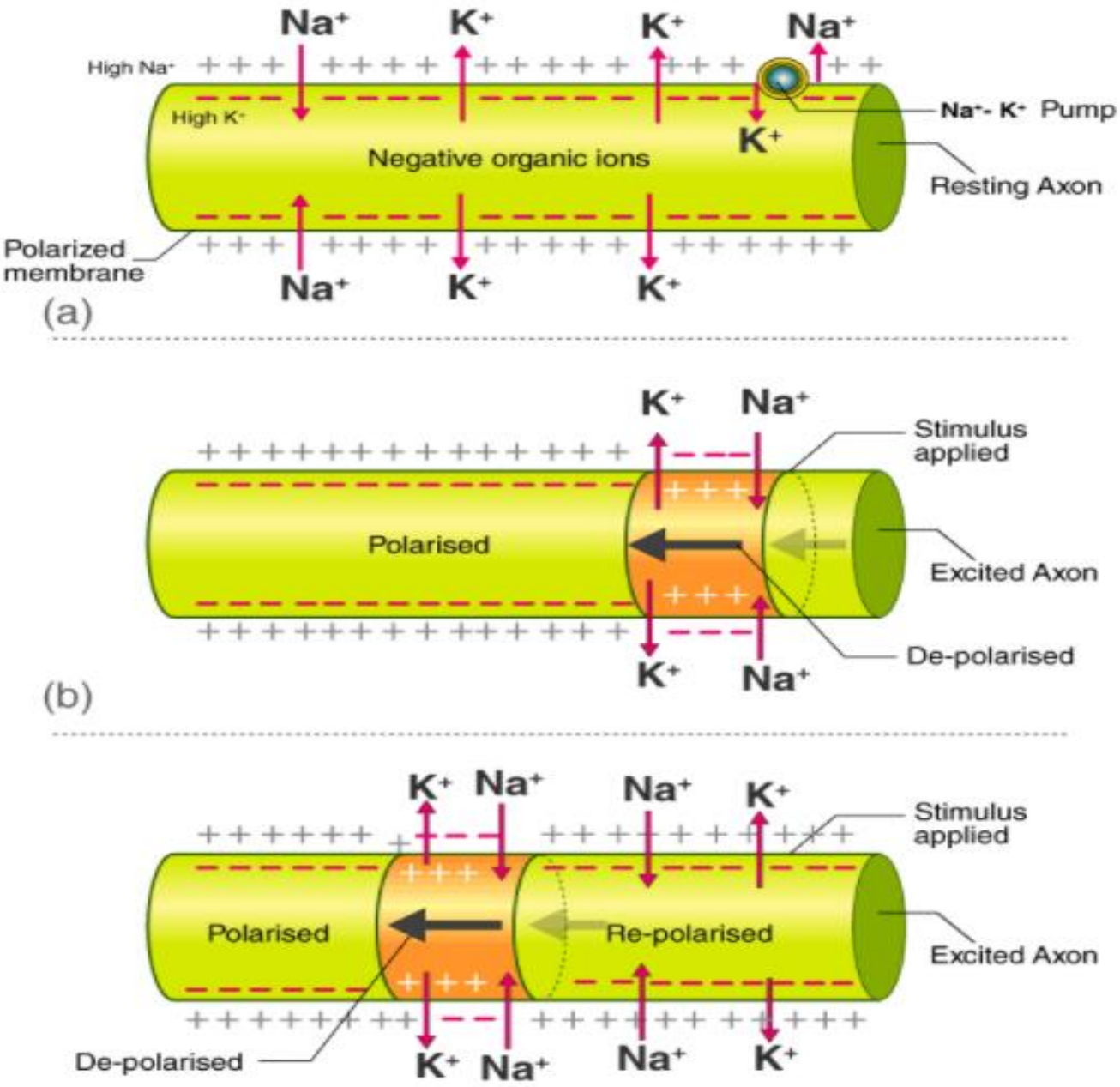
- If a depolarizing graded potential is sufficiently large, Na^+ channels in the trigger zone open.
- In response, Na^+ on the outside of the membrane becomes depolarized (as in a graded potential).
- If the stimulus is strong enough—that is, if it is above a certain threshold level—additional Na^+ gates open, increasing the flow of Na^+ even more, causing an action potential, or complete depolarization (from –70 to about +30 millivolts).

  5. This in turn stimulates neighboring Na^+ gates, farther down the axon, to open.

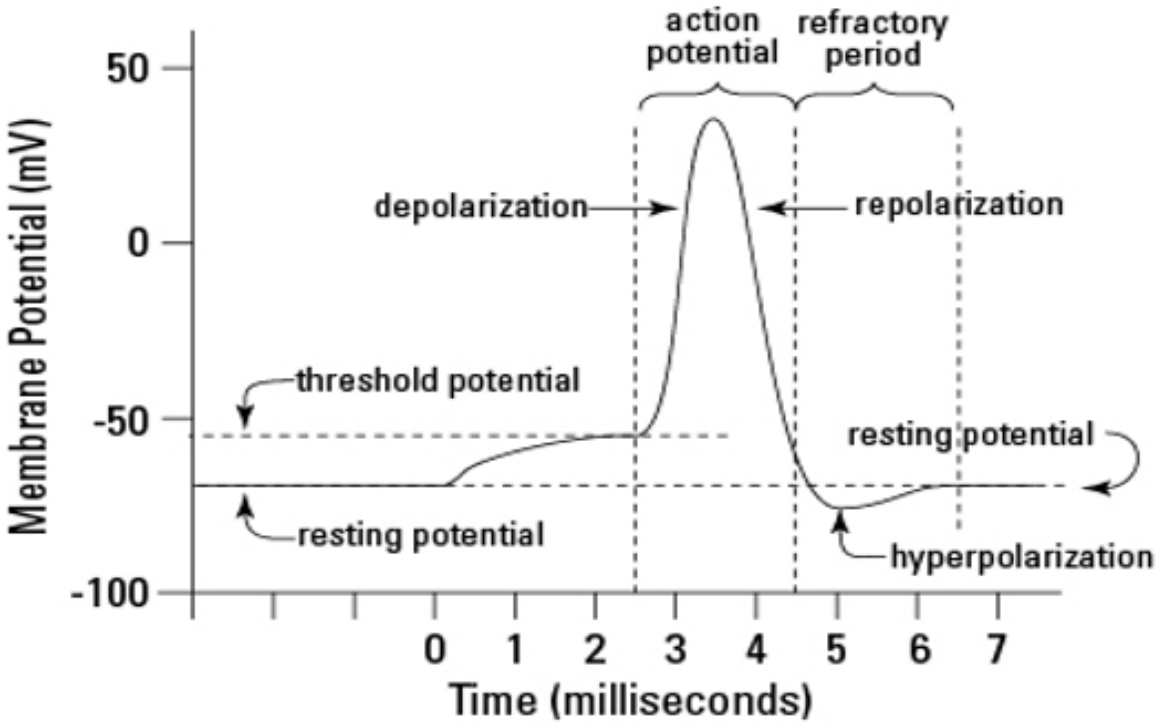
  In this manner, the action potential travels down the length of the axon as opened Na^+ gates stimulate neighboring Na^+ gates to open. The action potential is an all-or-nothing event: When the stimulus fails to produce depolarization that exceeds the threshold value, no action potential results, but when threshold potential is exceeded, complete depolarization occurs.
- Repolarization. In response to the inflow of Na^+, K^+ channels open, this time allowing K^+ on the inside to rush out of the cell.
- The movement of K^+ out of the cell causes repolarization by restoring the original membrane polarization.
- Unlike the resting potential, however, in repolarization the K^+ are on the outside and the Na^+ are on the inside.
- Soon after the K^+ gates open, the Na^+ gates close.
- 3. Hyperpolarization. By the time the K^+ channels close, more K^+ have moved out of the cell than is actually necessary to establish the original polarized potential. Thus, the membrane becomes hyperpolarized (about –80 millivolts).
- 4. Refractory period. With the passage of the action potential, the cell membrane is in an unusual state of affairs.
- The membrane is polarized, but the Na^+ and K^+ are on the wrong sides of the membrane.
- During this refractory period, the axon will not respond to a new stimulus.
- To reestablish the original distribution of these ions, the Na^+ and K^+ are returned to their resting potential location by Na^+/K^+ pumps in the cell membrane.

  Once these ions are completely returned to their resting potential location, the neuron is ready for another stimulus.

TRANSMISSION OF NERVE IMPULSE



. . .Events that characterize the transmission of a nerve impulse.



- A muscle is a group of muscle tissues which contract together to produce a force.
- A muscle consists of fibers of muscle cells surrounded by protective tissue, bundled together many more fibers, all surrounded in a thick protective tissue.
- A muscle uses ATP to contract and shorten, producing a force on the objects it is connected to.
- There are several types of muscle, which act on various parts of the body.

IV. Muscle fibre – Structure , types and its Chemical composition

Structure of Muscle

A muscle consists of many muscle tissues bundled together and surrounded by *epimysium*, a tough connective tissue similar to cartilage.

The epimysium surrounds bundles of nerve cells that run in long fibers, called *fascicles*.

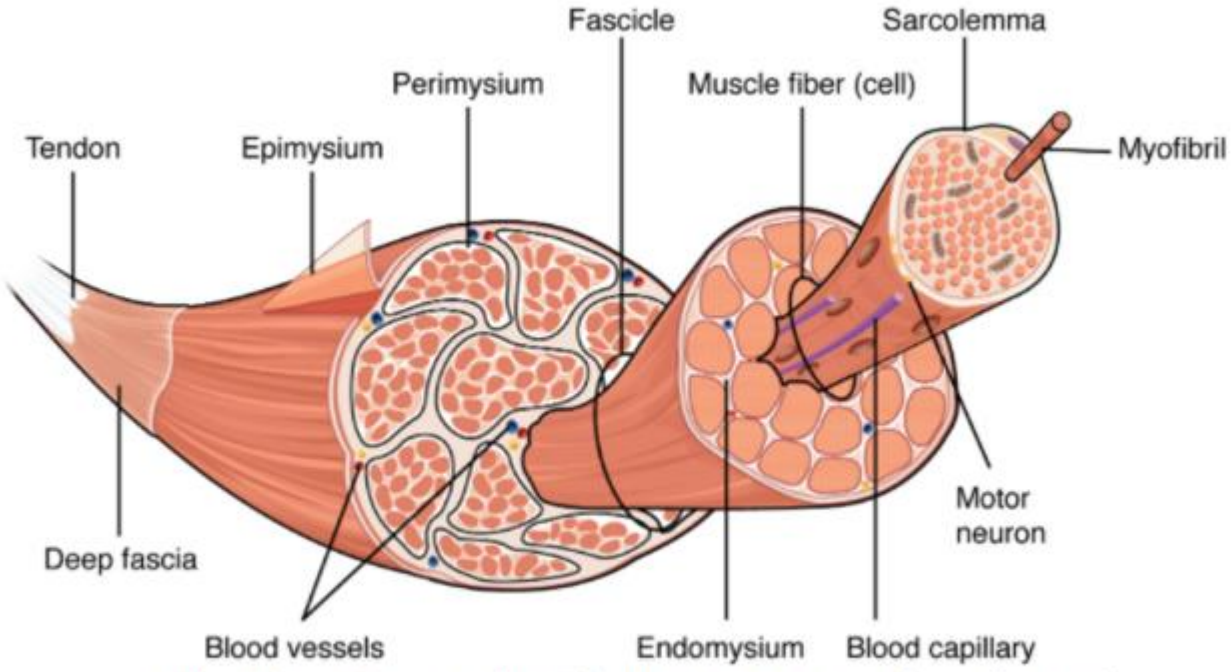
These fascicles are surrounded by their own protective layer, the *perimysium*.

This layer allows nerves and blood to flow to the individual fibers.

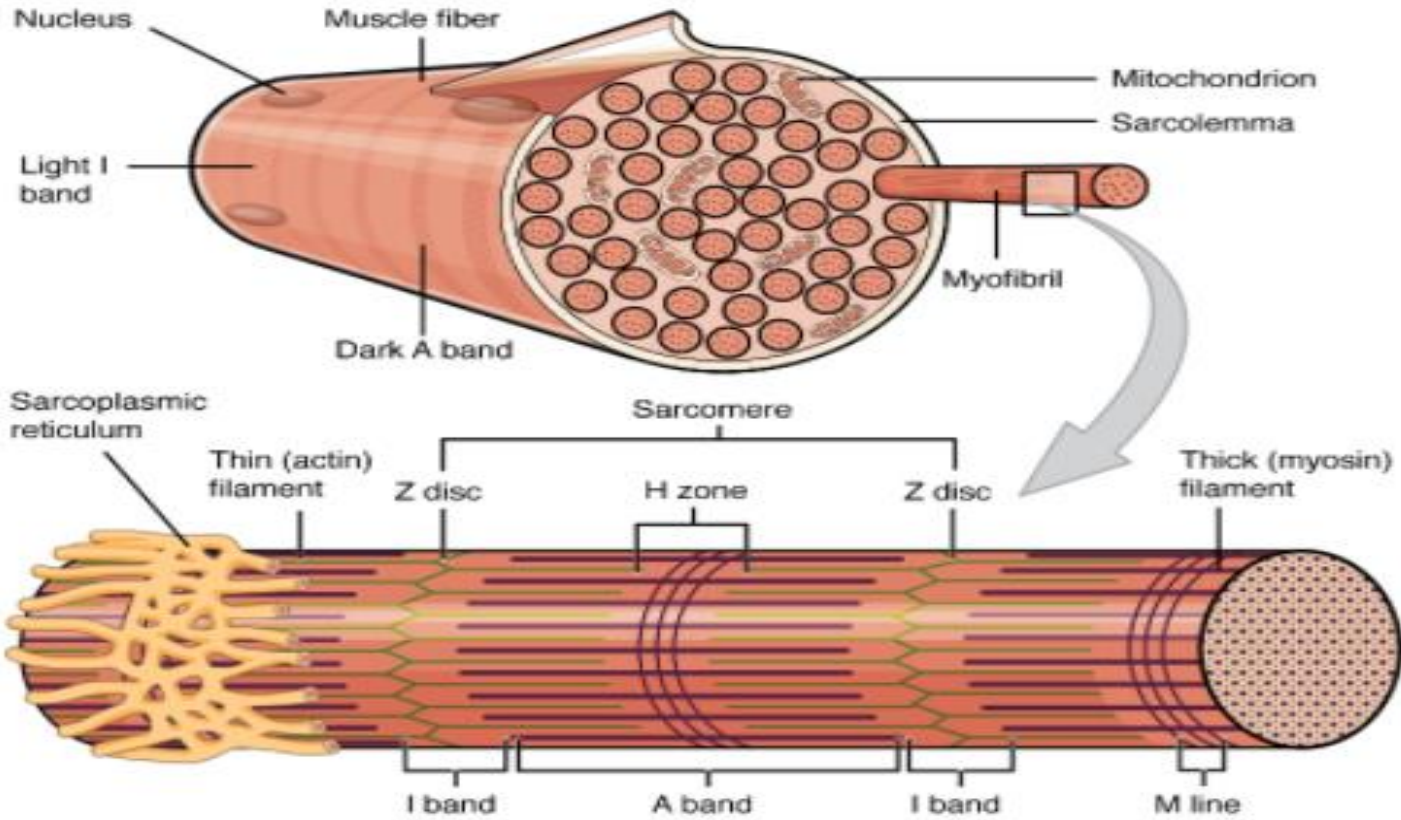
Each fiber is then wrapped in an *endomysium*, another protective layer.

As seen in the image below, a muscle is arranged in a basic pattern of bundled fibers separated by protective layers.

- These layers and bundles allow different parts of a muscle to contract differently.
- The protective layer surrounding each bundle allows the different bundles to slide past one another as they contract.
- The epimysium connects to *tendons*, which attach to the *periosteum* (a dense layer of vascular connective tissue enveloping the bones except at the surfaces of the joints) connective tissue that surrounds bones.
- Being anchored to two bones allows movement of the skeleton when the muscle contracts.
- A different type of muscle surrounds many organs, and the epimysium connects to other connective tissues to produces forces on the organs, controlling everything from circulation to food processing.

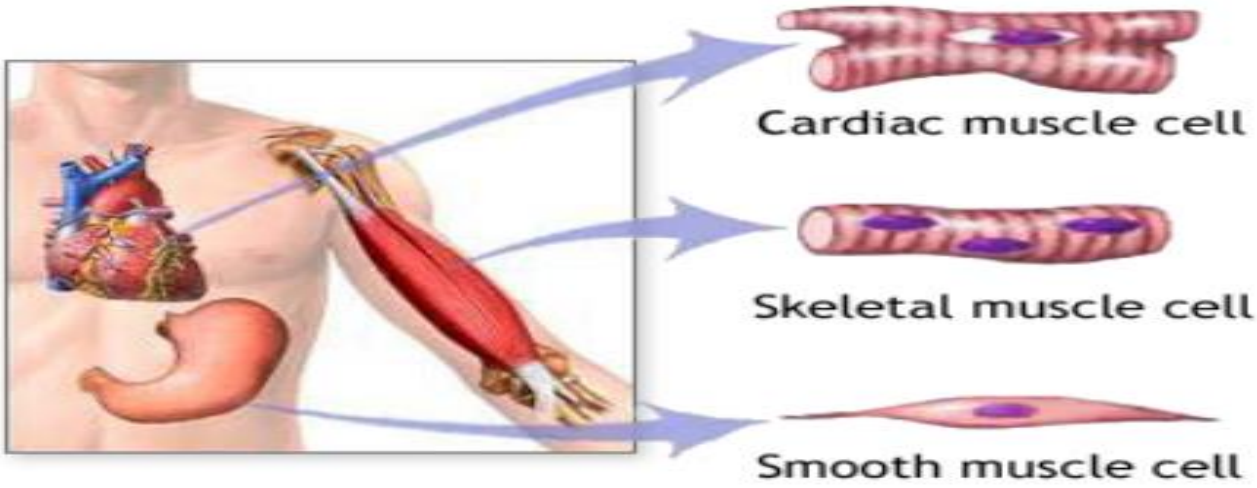


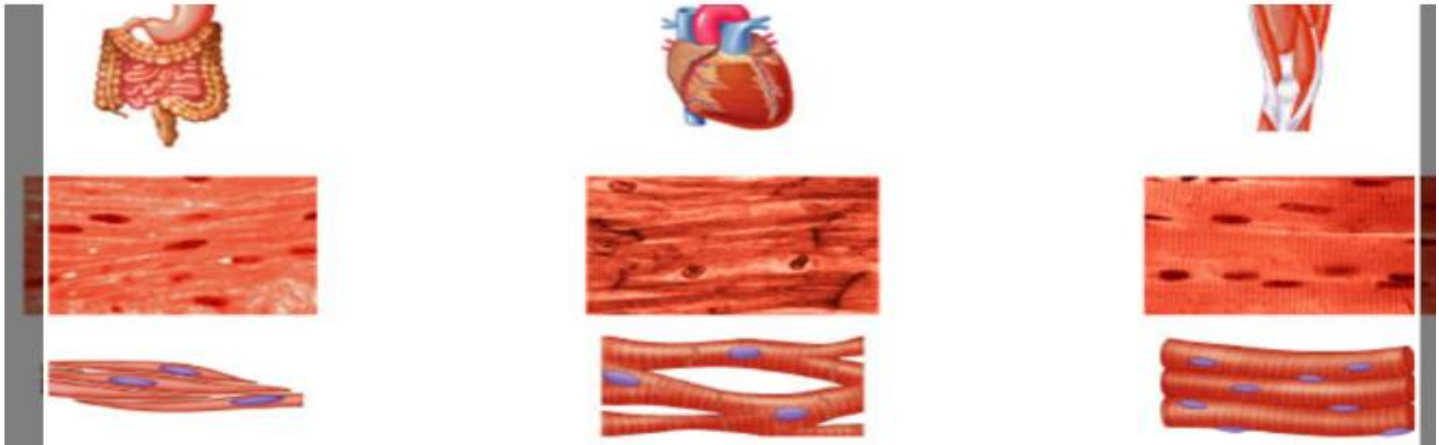
The Three Connective Tissue Layers: *Bundles of muscle fibers, called fascicles, are covered by the perimysium. Muscle fibers are covered by the endomysium.*



- **Muscle Fiber:** *A skeletal muscle fiber is surrounded by a plasma membrane called the sarcolemma, which contains sarcoplasm, the cytoplasm of muscle cells. A muscle fiber is composed of many myofibrils, which contain sarcomeres with light and dark regions that give the cell its striated appearance.*

Types of muscle tissue





Smooth muscle
- has spindle-shaped, nonstriated uninucleated fibers.
- occurs in walls of internal organs.
- is involuntary.

Cardiac muscle
- has striated, branched, uninucleated fibers.
- occurs in walls of heart.
- is involuntary.

Skeletal muscl
- has striated, tubular, multinucleate fibers.
- is usually attached to skeleton.
- is voluntary.

CONTRACTILE PROTEINS

Actin:

Actin consists of three components - F-actin, tropomyosin and troponin.

F- Actin has myosin binding site where myosin head attaches itself during muscle contraction.

In relaxed muscle tropomyosin covers myosin binding sites on actin and thus blocks attachment of myosin heads to actin.

During muscle contraction troponin removes tropomyosin from myosin binding sites on actin.

Myosin:

It consists of a globular head with a short cross arm and a tail.

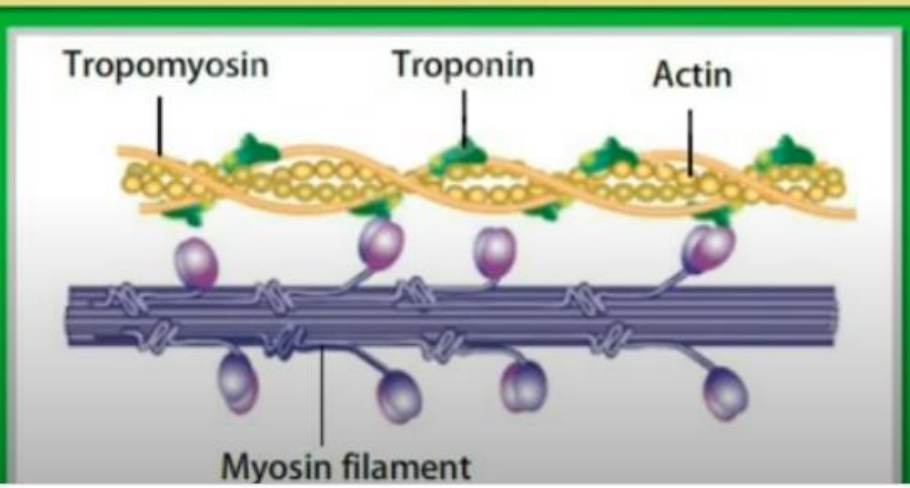
The globular head is an active **ATPase enzyme** that has binding sites for actin and active sites for ATP.

Structure of Contractile Proteins

Actin is a globular protein (G actin) which polymerizes into double helical strands (F actin).

Tropomyosin and the troponin form the other constituents of the thin filaments.

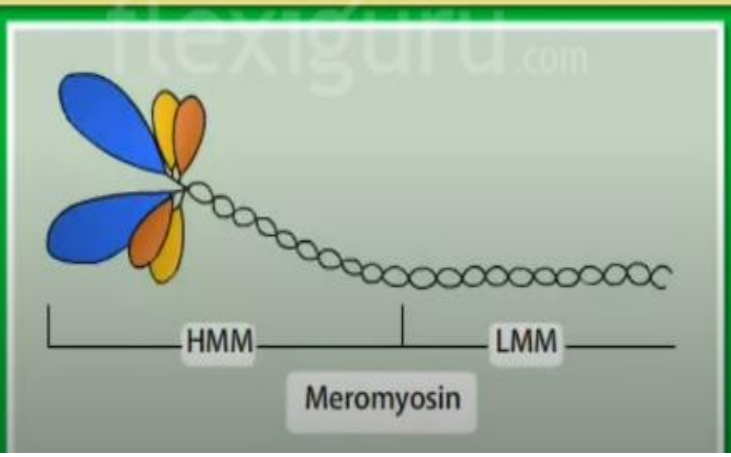
The tropomyosin extends over actin filaments and blocks the myosin binding sites.

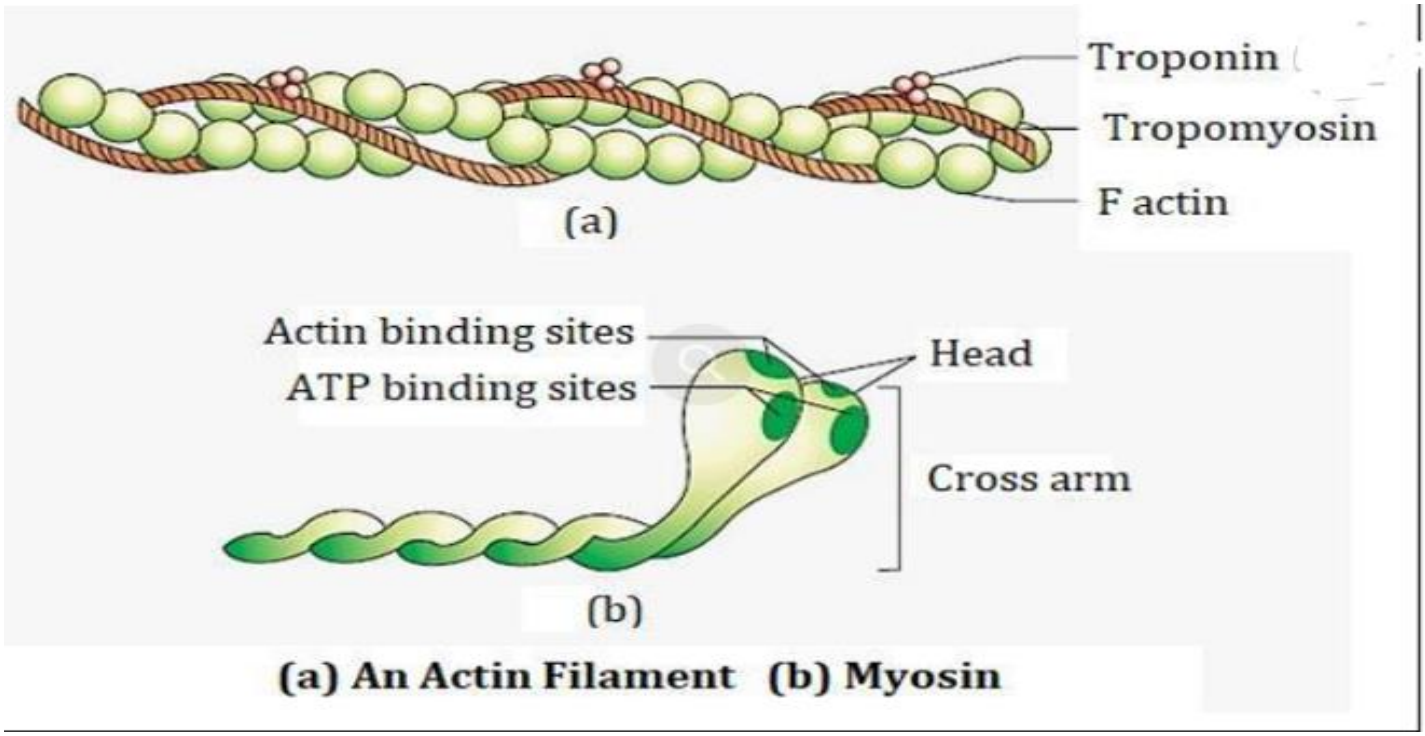


One myosin filament consists of numerous monomeric proteins called meromyosins.

Each meromyosin has two parts, heavy meromyosin (HMM) and light meromyosin (LMM).

Heavy meromyosin has globular head which is the portion that combines with actin filament. The component of heavy meromyosin that is the head and short arm project outwards at regular interval and form cross arm.





(a) An Actin Filament (b) Myosin

Tropomyosin : It is the most recently studied protein component of the myofibrils which is present together with actin in thin filaments and forms a specific complex with F-actin in vitro. Its molecule is rod-like; 400Å long and 20Å diameter with a molecular weight 70,000.

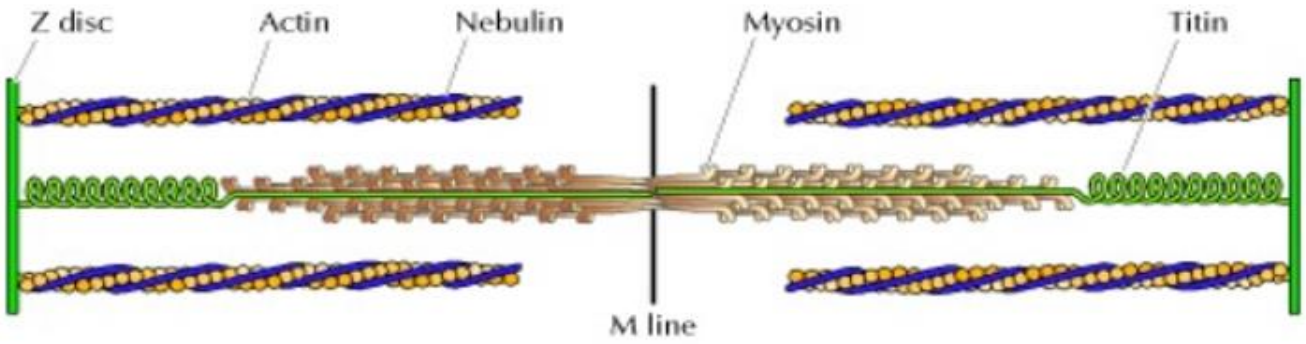
It has two subunits in the form of α-helices in an extended coiled—coil conformation. When added to actomyosin solution tropomyosin inhibits its calcium activated ATPase activity but not its magnesium activated ATPase activity.

Troponin : This protein has globular molecules and is found in the thin filaments together with actin and tropomyosin. It promotes the aggregation of purified tropomyosin. Its biological function is not clear.

In addition to these above proteins there are some other proteins found in the muscles, these are **α-actinin** and **paramyosin**. α-actinin protein has a molecular weight of about 160,000 and interacts strongly with actin, causing cross-linkage of the F-actin filaments and gel formation. It has been established that α-actinin and tropomyosin are contained in the Z-lines.

Paramyosin is the contractile protein of muscle myofibrils of annelids and molluscs. It has a molecular weight of about 151,000.

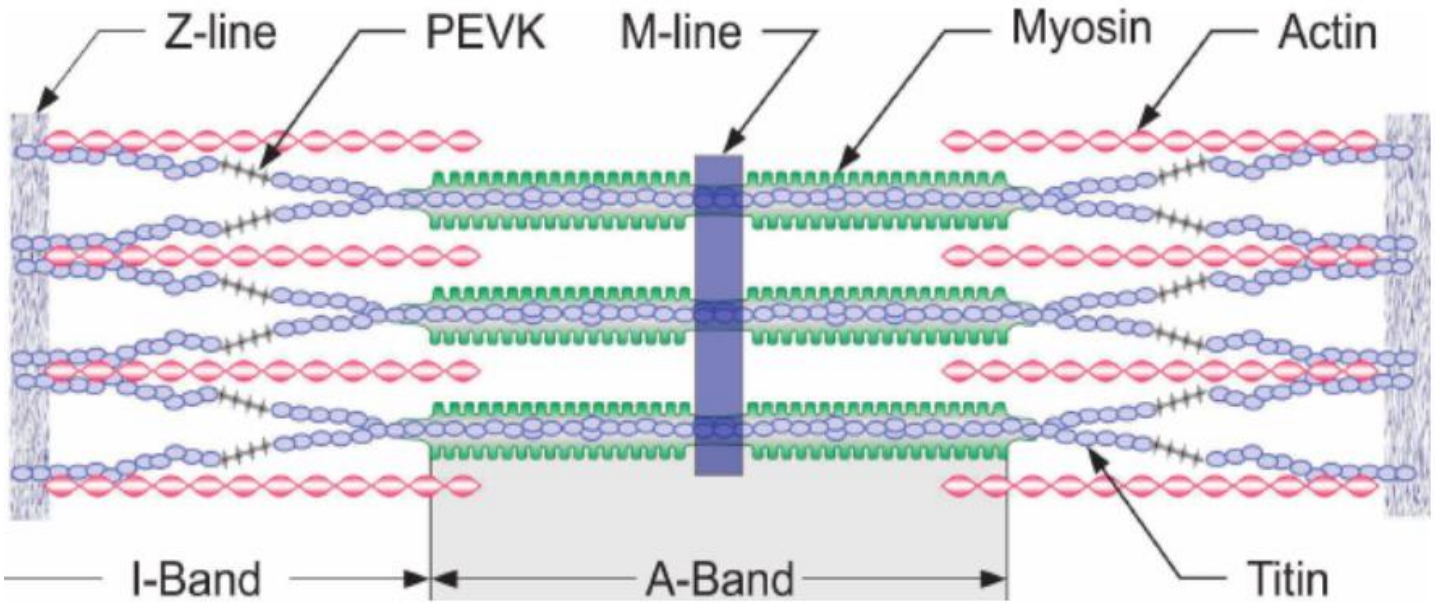
- Two additional proteins **(titin and nebulin)** also contribute to sarcomere structure and stability .
- Titin is an extremely large protein (3000 kd), and single titin molecules extend from the M line to the Z disc.
- These long molecules of titin are thought to act like springs that keep the myosin filaments centered in the sarcomere and maintain the resting tension that allows a muscle to snap back if overextended.
- Nebulin filaments are associated with actin and are thought to regulate the assembly of actin filaments by acting as rulers that determine their length.



Titin and nebulin

Molecules of titin extend from the Z disc to the M line and act as springs to keep myosin filaments centered in the sarcomere.

Molecules of nebulin extend from the Z disc and are thought to determine the length of associated actin filaments.



Schematic Drawing Of A Sarcomere With The Contractile

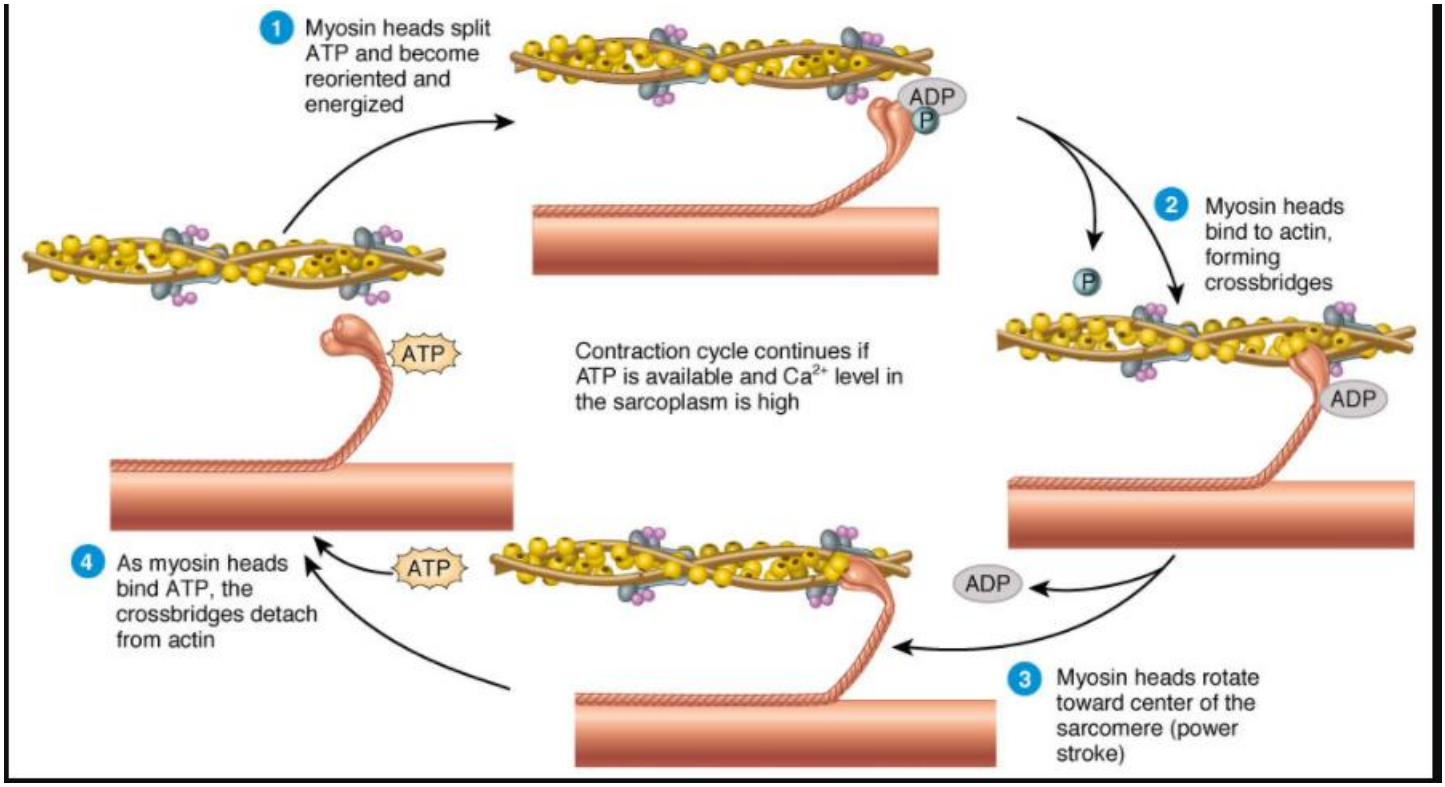
VI. Physiology of muscle contraction

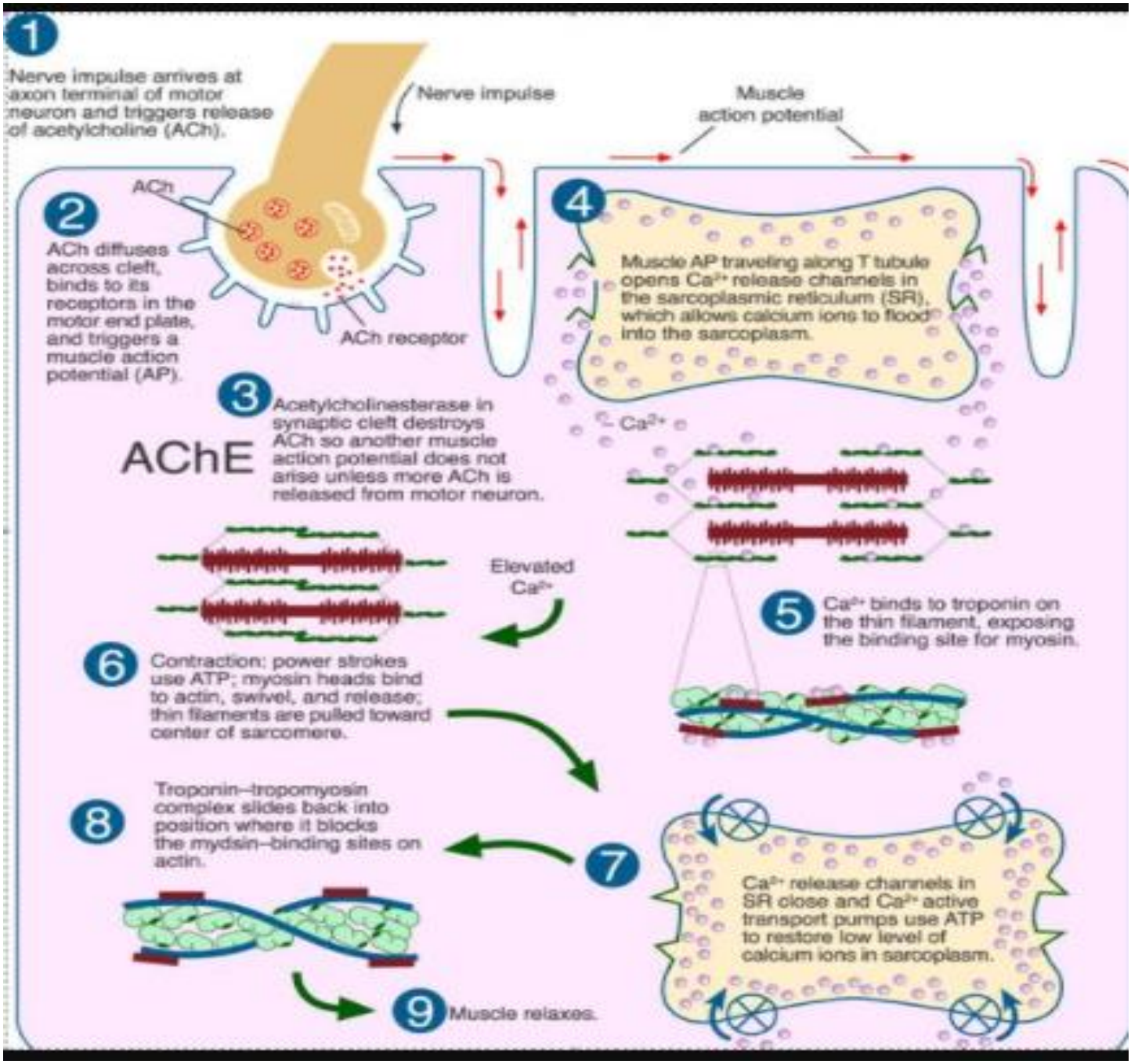
MECHANISM OF MUSCLE CONTRACTION AND RELAXATION

- **Muscle contraction** is the activation of tension-generating sites within muscle fibers.
- In physiology, muscle contraction does not necessarily mean muscle shortening because muscle tension can be produced without changes in muscle length, such as when holding a heavy book or a dumbbell at the same position.
- The termination of muscle contraction is followed by **muscle relaxation**, which is a return of the muscle fibers to their low tension-generating state.

The sliding filament theory : The sliding filament theory was independently formulated by H. E. HUXLEY and J. HANSON and by A. F. HUXLEY and R. NIEDERGERKE. This theory was most strongly supported by the arrangements of myofilaments. This theory states that the contractile units of muscle appear to be composed of thick and thin filaments which normally overlap somewhat in the relaxed muscle. When the muscle contracts on stimulation, these filaments do not change in length but merely slide over one another, *i.e.*, the thin (actin) filaments slide in the spaces between the myosin filaments with the result that I or light bands shorten, while there is no change in the A or dark band. However, disappearance of H zone in dark band may be observed. This is because of closing in of actin filaments. All these changes are associated with closing in of two Z lines of a sarcomere which is in proportion to muscular contraction.

It is thought that the cross bridges on the thick filaments might pull the thin filaments in a kind of ratchet action, while muscle is contracted but during relaxation these cross bridges disappear. This indicates the presence of active sites on the actin filaments into which the cross bridges temporarily hook to pull the filaments a short distance and then release them. It means the contraction and relaxation of muscle are brought about by the repetition formation and breakage of cross bridges respectively between thick filaments of A band and thin filaments of I band.


1 Myosin heads split ATP and become reoriented and energized
ADP
P
2 Myosin heads bind to actin, forming crossbridges
P
ADP
ATP
Contraction cycle continues if ATP is available and Ca^{2+} level in the sarcoplasm is high
4 As myosin heads bind ATP, the crossbridges detach from actin
ATP
ADP
3 Myosin heads rotate toward center of the sarcomere (power stroke)



- Mechanism of Muscle contraction:
- When the nerve impulse from brain and spinal cord are carried along motor neuron to neuromuscular junction, Ca++ ions are released in the terminal axon. Increases calcium ion concentration stimulates the release of neurotransmitter (Acetylcholine) in the synaptic cleft. The neurotransmitter binds to the receptor on the sarcolemma and depolarization and generate action potential across muscle fiber for muscle contraction. The action potential propagates over entire muscle fiber and move to the adjacent fibers along transverse tubules. The action potential in transverse tubules causes the release of calcium ion from sarcoplasmic reticulum, which stimulate for muscle contraction.
- The sequences of muscle contraction explained by sliding filament theory are as follows
- 1. Blocking of myosin head:
- Actin and myosin overlaps each other forming cross bridge. The cross bridge is active only when myosin head attached like hook to the actin filament.

- When muscle is at rest, the overlapping of actin filament to the myosin head is blocked by tropomyosin. The actin myofilament is said to be in OFF position
- 2. Release of calcium ions:
- Nerve impulse causing depolarization and action potential in the sarcolemma trigger the release of calcium ions from sarcoplasmic reticulum.
- The calcium ion then binds with the troponin complex on the actin myofilament causing displacement of troponin complex and tropomyosin from its blocking site exposing myosin binding site.
- As soon as the myosin binding site is exposed, myosin head cross bridge with actin filament. Now, the actin myofilament is said to be in ON position.
- 3. Active Cross-bridge formation:
- When myosin head attached like hooks to the neighboring actin filament, active cross bridge is formed. The cross bridge between actin and myosin filament acts as an enzyme (Myosin ATPase).
- The enzyme Myosin ATpase hydrolyses ATP stored into ADP and inorganic phosphate and release energy. This released energy is used for movement of myosin head toward actin filament. The myosin head tilts and pull actin filament along so that myosin and actin filament slide each other. The opposite end of actin myofilament within a sarcomere move toward each other, resulting in muscle contraction.
- After sliding the cross bridge detached and the actin and myosin filament come back to original position. The active cross bridge form and reform for 50-100 time within a second using ATP in rapid fashion. Therefore, muscle fiber consists of numerous mitochondria.
- In muscle contraction, sarcomere can contracts by 30-60% of its length
- In summary the sliding filament theory of muscle contraction can be broken down into four distinct stages, these are;
- **1. Muscle activation:** The motor nerve stimulates an action potential (impulse) to pass down a neuron to the neuromuscular junction. This stimulates the sarcoplasmic reticulum to release calcium into the muscle cell.

  2. Muscle contraction: Calcium floods into the muscle cell binding with troponin allowing actin and myosin to bind. The actin and myosin cross bridges bind and contract using ATP as energy (ATP is an energy compound that all cells use to fuel their activity – this is discussed in greater detail in the energy system folder here at ptdirect).

  3. Recharging: ATP is re-synthesised (re-manufactured) allowing actin and myosin to maintain their strong binding state

  4. Relaxation: Relaxation occurs when stimulation of the nerve stops. Calcium is then pumped back into the sarcoplasmic reticulum breaking the link between actin and myosin. Actin and myosin return to their unbound state causing the muscle to relax. Alternatively relaxation (failure) will also occur when ATP is no longer available.

The sequence of chemical changes that take place during muscle contraction are as follows :

1. **Conversion of adenosine triphosphate into adenosine diphosphate :** The first and the important chemical change, that takes place during muscle contraction, is the conversion of the adenosine triphosphate into the adenosine diphosphate. This conversion is brought about by the enzyme, **adenosine triphosphatase** (ATPase) present in the muscle. During this conversion one molecule of phosphoric acid is removed from the adenosine triphosphate which supplies the immediate energy to the muscle for contraction. This reaction can occur anaerobically.

2. **Break down of creatine phosphate (phosphocreatine) :** The next step is the break down of creatine phosphate present in the muscle to produce creatine and phosphoric acid. The phosphoric acid molecule combines with adenosine disphosphate (ADP) and forms ATP.

3. **Break down of muscle glycogen :** The glycogen present in the muscle after reacting with phosphoric acid liberated during the break down of ATP into ADP, is converted into glucose phosphate.

Glycogen + Phosphoric acid → Glucose phosphate.

4. **Formation of fructose diphosphate :** The glucose phosphate, after undergoing various chemical reactions, is converted into fructose diphosphate.

$$\text{Glucose phosphate} \xrightarrow[\text{reaction}]{\text{Enzymatic}} \text{Fructose diphosphate.}$$

5. **Formation of lactic acid :** Fructose diphosphate after undergoing various chemical changes is converted into lactic acid. During the formation of lactic acid three molecules of ATP are formed.

Fructose diphosphate → Lactic acid + 3 ATP.

6. **Resynthesis of creatine phosphate :** During periods of inactivity or less intense activity, the creatine is rephosphorylated by ATP (enzymatic reactions are reversible) produced in intermediary

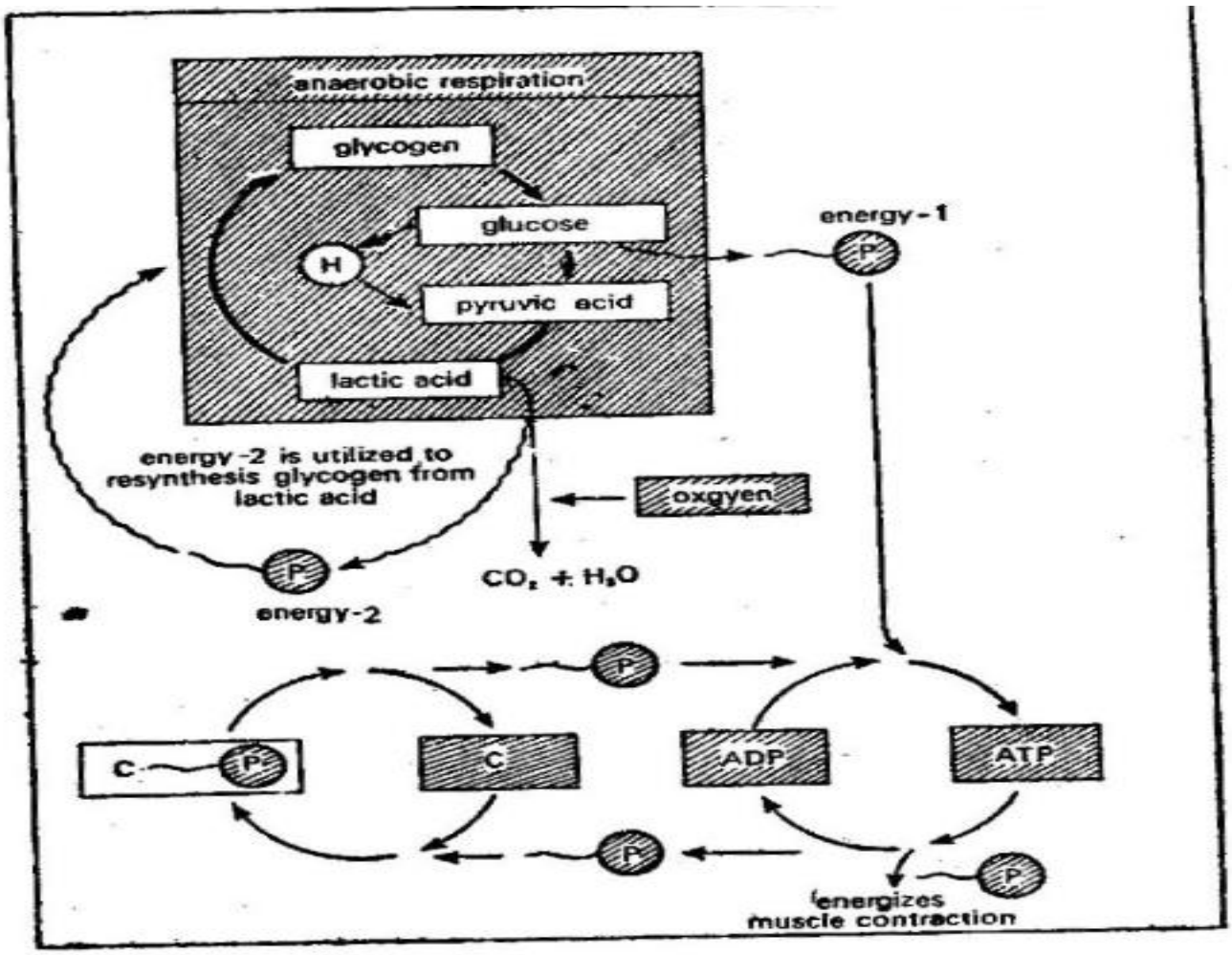


Diagram showing various chemical reactions involved in the liberation of energy for muscle contraction.

Summary of events of muscle contraction : The various events which happen during a brief contraction, or single twitch of a vertebrate striated muscle fibre, are as follows :

1. As soon as muscle fibre or muscle is stimulated, immediately electrical events in the form of action potentials appear over the surface of muscle fibre.
2. These electrical events travel over the sarcolemma and down the numerous transverse tubules to the interior of the muscle.
3. As a result calcium ions are released from the T-sarcotubular system or cisternae of the sarcoplasmic reticulum.
4. Free liberated calcium ions bring about the sliding of the actin filaments in spaces between the myosin filaments, with the result contraction is effected in the muscle. This process requires energy which is derived from the breakdown of the ATP to ADP + inorganic phosphate. The breakdown of ATP takes place in the presence of ATPase enzyme and calcium ions. During this process some heat is also produced.
5. The contraction results from the sliding of the thin actin filaments in spaces between the thick myosin filaments, so that adjacent Z-lines come closer, light band disappears, there is no change in dark or A band but H zone disappears. The development of tension and the sliding is the result of the action of

6. The ADP formed is converted back to ATP by creatine phósphate, and probably by other metabolic processes as well.
7. After contraction the sarcoplasmic reticulum begins to reabsorb the calcium ions which were released, with the result ATPase activiy and contraction cease.
8. When contraction ceases due to reabsorption of calcium ions by the sarcoplasmic reticulum, the mvofibrils are stretched out again through the action of antagonistic muscles. ATP must be present.
9. Creatine formed during the contraction is rephosphorylated in the presence of ATP, some heat is produced.
10. ADP formed during the rephosphorylation of creatine into creatine phosphate, is converted back into ATP by oxidative phosphorylation in the mitochondria. During this conversion more heat is produced.
11. Any lactic acid generated during contraction is reoxidized to pyruvic acid, and the reduced nucleotide formed, is ultimately oxidized by the mitochondria to produce more ATP.

MECHANICAL PHENOMENA

Isotonic and isometric contractions : The muscles of the body some times contract purely isotonically and sometimes isometrically. When the muscle shortens and performs mechanical work, without undergoing any change in its tone, such a contraction of muscle is known as **isotonic contraction** (*iso*, same ; *tonus*, tension). In other words isotonic is that contraction when the resistance offered by the load is less than the tension developed in the muscle. The muscles of legs which propel the body by alternate contraction and relaxation, as in walking, the contractions are isotonic. On the other hand when the length of the muscle does not change but its tone is considerably increased during activity, such a contraction is known as **isometric** contraction

(*iso*, same ; *metric*, length). During isometric contraction, no doubt, tension is developed in the muscle but the muscle fails to perform mechanical work. The muscles of the arm and hands in holding an object and the muscles of the trunk and legs in supporting the body in its erect position against the force of gravity are the examples of muscles which contract isometrically.

Summation : When a muscle is stimulated by a single subliminal stimulus, no contraction occurs. Yet, if two or more of these inadequate stimuli that are just below threshold intensity are given in rapid succession, a muscle contraction is evoked. This is what is known as summation of subliminal stimuli. Similarly the phenomenon where in one contraction is added to a previous one to produce a great shortening of the muscle is called summation.

Tetanus : Tetanus is a type of contraction caused by repeated brief stimuli at a frequency such that each successive stimulus comes after the refractory period of the preceding one or in other words it is a sustained contraction of muscle due to the fusion of many twitches following each other in rapid succession ; the external cause lies in the large number of stimuli presented to the muscle in a unit of time.

Staircase phenomenon or treppe : When a muscle is stimulated with single shock of constant strength at a frequency of about 1/sec, a series of contraction is obtained in which first few twitches of the series increase successively in amplitude. This is known as the **staircase phenomenon** or **treppe.**

Fatigue : If a muscle is stimulated repeatedly at intervals not close enough to produce tetanic contraction, it does not contract. The muscle which does not respond to stimuli at all, is said to be in a state of **fatigue.** This is due to accumulation of lactic acid in the muscle.

VII. Myoneural Junction (Neuromuscular junction)

A neuromuscular junction (NMJ), also called a myoneural junction, is the connection between a motor neurons and a muscle fibers. These neurons are the site at which the neuron transmits a signal from the brain to the muscle fiber, causing it to contract.

Therefore, neuromuscular junctions represent the channel of communication between the nervous system and muscle cells. Their function is to allow the nervous system to control the contraction of muscles, and hence they represent an important structure in the regulation of much of our biological functions.

A neuromuscular junction is a synapse between a motor neuron and skeletal muscle. The space between the motor neuron and the skeletal muscle cell is simply referred to as a synapse. Synaptic transmission includes all the events within the synapse leading to excitation of the muscle. At this site, the nerve loses its myelin sheath and gets expanded. Acetylcholine is stored in some vesicles present in this expanded portion. Motor end plate is the part of the muscle facing the expanded nerve terminal.

The neuron is sending the transmission and is thus referred to as the pre-synaptic cell, while the muscle is receiving the transmission and is referred to as the post-synaptic cell. Neurotransmitters are molecules stored in the pre-synaptic cell that is secreted into the synapse. Neurotransmitters, in turn, bind to receptors on the postsynaptic cell membrane, and these receptors are specific for that neurotransmitter. The structure motor end plates convoluted and it has enzyme acetyl cholinesterase.

Structure of a Neuromuscular Junction

The anatomy of a neuromuscular junction can be divided into three parts:

- the presynaptic terminal (i.e. the motor neuron)
- the synaptic cleft
- the postsynaptic membrane (i.e. the membrane of the muscle cell).

Presynaptic Terminal

A motor neuron has a dendritic end and an axonal end. The dendrites receive the signals from adjacent neurons, whereas the axon is where the signal is passed on to the next neuron or cell.

The presynaptic terminal of a neuromuscular junction refers to the axonal terminal of a motor neuron. Motor neurons are the neurons that directly control effector organs, in this case, muscle cells. This axon terminal end is the presynaptic terminal of a neuromuscular junction.

Importantly, there are synaptic vesicles present in the presynaptic terminal. These vesicles are small pockets that are separated from the rest of the cell. These vesicles contain neurotransmitters, which are chemical messengers that are responsible for the transmission of the message. In the case of the neuromuscular junction, the neurotransmitter is acetylcholine (Ach).

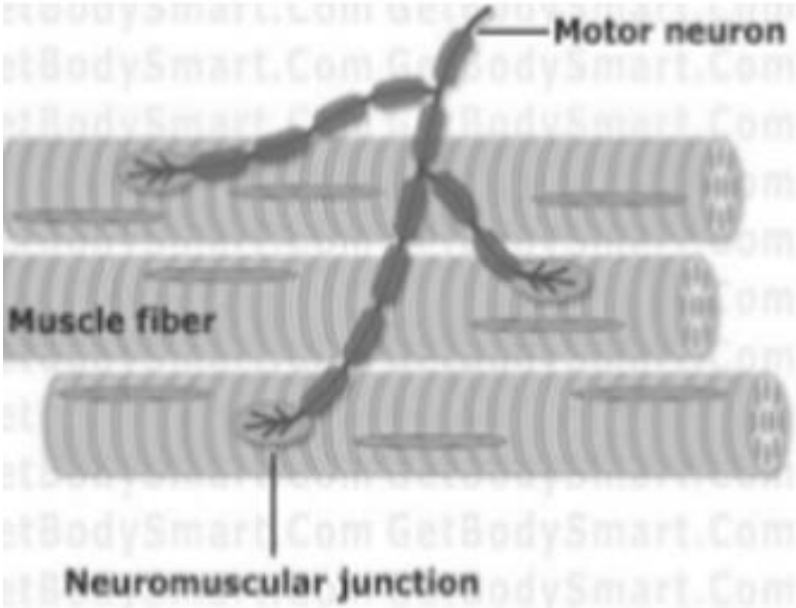
Synaptic Cleft

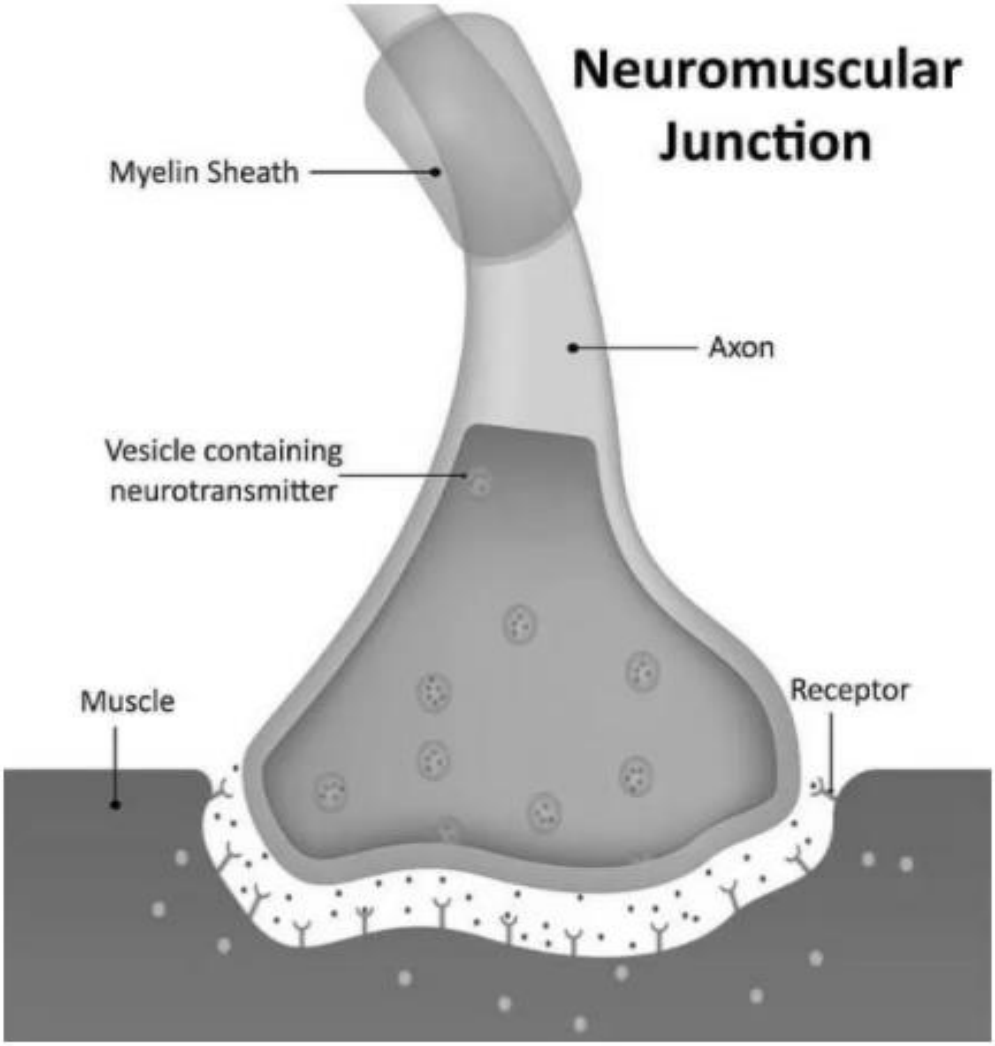
The synaptic cleft, also sometimes referred to as the synaptic gap, is the approximately 20 nm space between the presynaptic terminal (the axonal terminal) and the postsynaptic membrane (the muscle cell that will receive the signal). This gap is important for the control of the concentration of neurotransmitter that communicates the signal to the muscle cell.

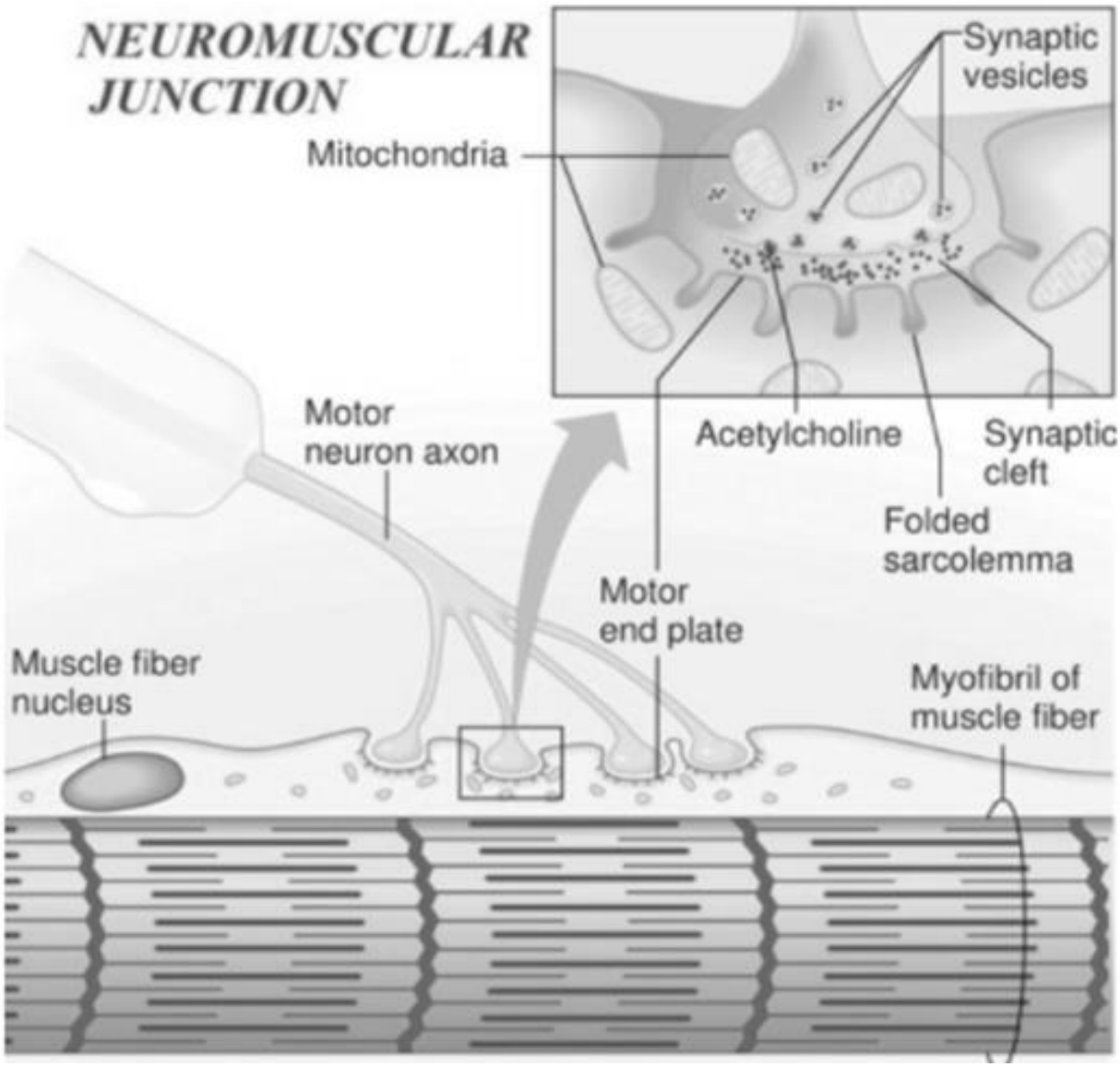
Postsynaptic Membrane

The postsynaptic membrane is the membrane of the muscle fiber cells to which the signal is travelling. This membrane has many indents that increase the surface area of the membrane, which is important for the transmission of the signal from the motor neuron.

Additionally, the muscle cells have a specialized cell membrane, called the sarcolemma, that aids in the transmission of signals throughout the fiber.


Motor neuron
Muscle fiber
Neuromuscular junction


Neuromuscular Junction
Myelin Sheath
Axon
Vesicle containing neurotransmitter
Muscle
Receptor



Steps of Signalling at Neuromuscular Junctions

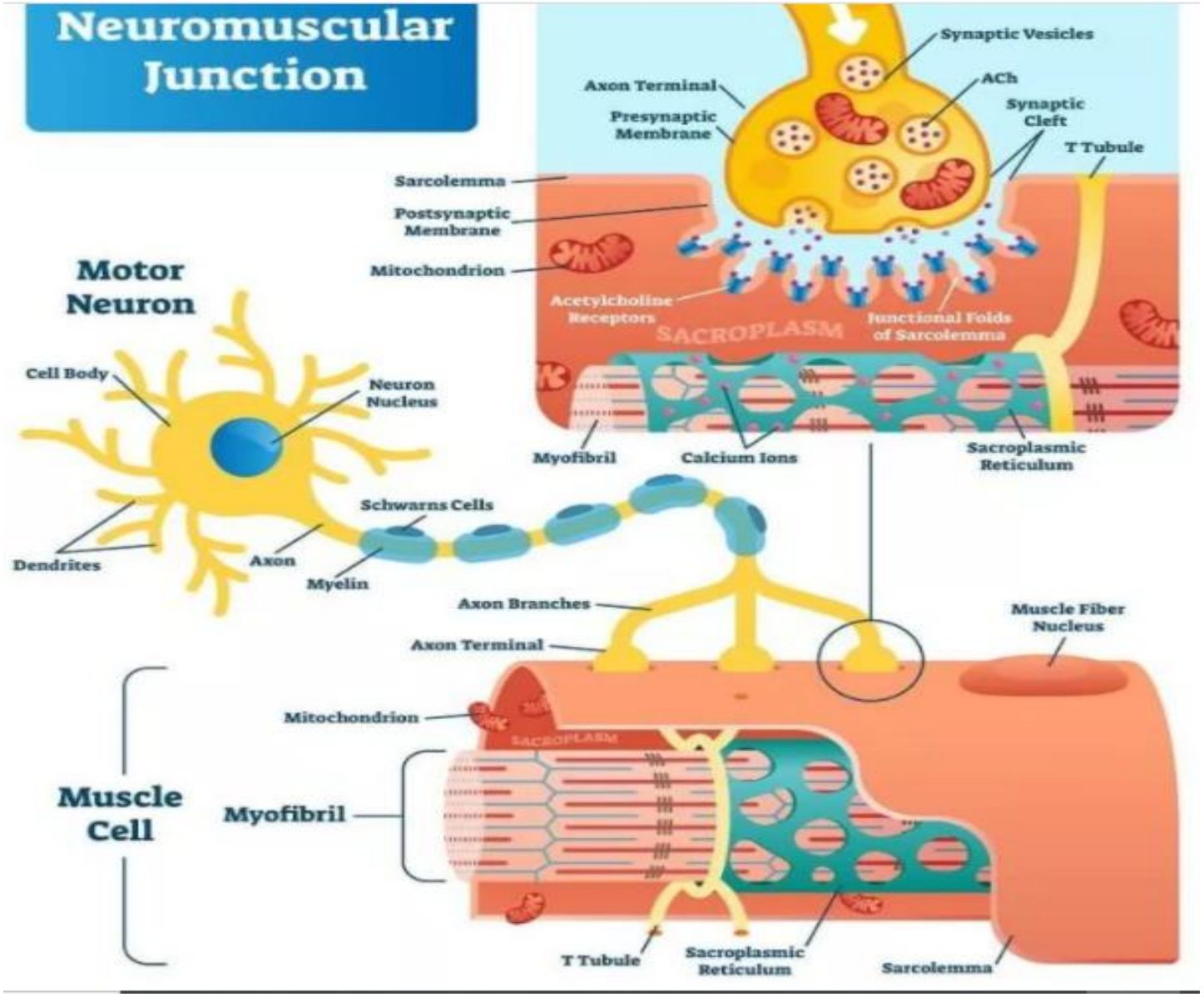
The events involved in the transmission of a signal at a neuromuscular junction are summarized in the six steps below.

1. Firstly, the signal from the axon terminal of the previous neuron travels down the motor neuron to the presynaptic axon terminal. This causes the activation and opening of calcium channels in the membrane, allowing calcium ions to enter the neuron.
2. The axonal terminal contains neurotransmitters (specifically, acetylcholine) that are packaged into vesicles. When calcium floods into the neuron, it binds the proteins on the surface of these vesicles, called SNARE proteins. These SNARE proteins mediate vesicle fusion, prompting the vesicles to fuse with the cell membrane.
3. Once they have fused to the membrane, the vesicles can release their contents (acetylcholine) outside the cell, through the process of exocytosis.

4. As a result, acetylcholine floods the synaptic cleft, where it can reach the postsynaptic membrane by diffusion.
5. Acetylcholine binds to acetylcholine receptors, also called nicotinic acetylcholine receptors. These are present in the many folds of the postsynaptic membrane (the sarcolemma). Thus, the increased surface area that is generated by these folds serves to maximize the number of receptors to which acetylcholine can bind on the membrane.
6. The binding of acetylcholine to its receptors causes ion channels to open, allowing sodium and potassium ions to flood the cell. This causes depolarization, permitting calcium ions to enter the cell. It is the calcium ions that carry out muscle contractions.

   Calcium ions can propagate the signal to contract to other muscle cells by moving between cells through structures called gap junctions, which link the muscle cells, allowing them to behave in sync.

   There is also a reservoir of calcium ions present in the muscle cell, in an organelle called the sarcoplasmic reticulum. The signalling at the neuromuscular junction also causes this organelle to release its calcium ions, contributing to muscle cell contraction.


Neuromuscular Junction
Synaptic Vesicles
Axon Terminal
ACh
Presynaptic Membrane
Synaptic Cleft
T Tubule
Sarcolemma
Postsynaptic Membrane
Mitochondrion
Acetylcholine Receptors
SACROPLASM
Junctional Folds of Sarcolemma
Motor Neuron
Cell Body
Neuron Nucleus
Myofibril
Calcium Ions
Sacroplasmic Reticulum
Schwarns Cells
Dendrites
Axon
Myelin
Axon Branches
Muscle Fiber Nucleus
Axon Terminal
Mitochondrion
SACROPLASM
Muscle Cell
Myofibril
T Tubule
Sacroplasmic Reticulum
Sarcolemma

VIII. Reflex Action

Animals show two types of actions voluntary and involuntary.

The involuntary actions are known as the reflex actions.

Definition of Reflex Action: A reflex action may be defined as a spontaneous, automatic and mechanical response to a stimulus acting on a specific receptor without the will of an animal.

Examples of Reflex Action: examples of reflex actions in man are knee-jerk reflex, movement of diaphragm during respiration, blinking of eyes, coughing, yawning, sneezing etc.

In knee-jerk reflex, a gentle strike below the knee cap, while sitting with freely hanging legs, kicks the leg forward.

MECHANISM OF REFLEX ACTION

A reflex action is brought about in the following way.

When acid is applied to a toe of a decapitated frog.

The stimulus is received by a receptor in the skin, receptor is a general term for any type of sense organ.

On receiving a stimulus, the receptor sets up a sensory impulse.

The latter is carried to the spinal cord through the dorsal sensory root of a spinal nerve, i.e. sciatic nerve, in the above example.

The spinal cord transforms the sensory impulse into a motor impulse.

The latter is transmitted to the leg muscles.

The muscles then contract and the leg is withdrawn to avoid the stimulus.

The muscles are referred to as the effectors, where the impulse ends and response is given.

The path travelled by an impulse in a reflex action is called the reflex arc.

It consists of five parts:

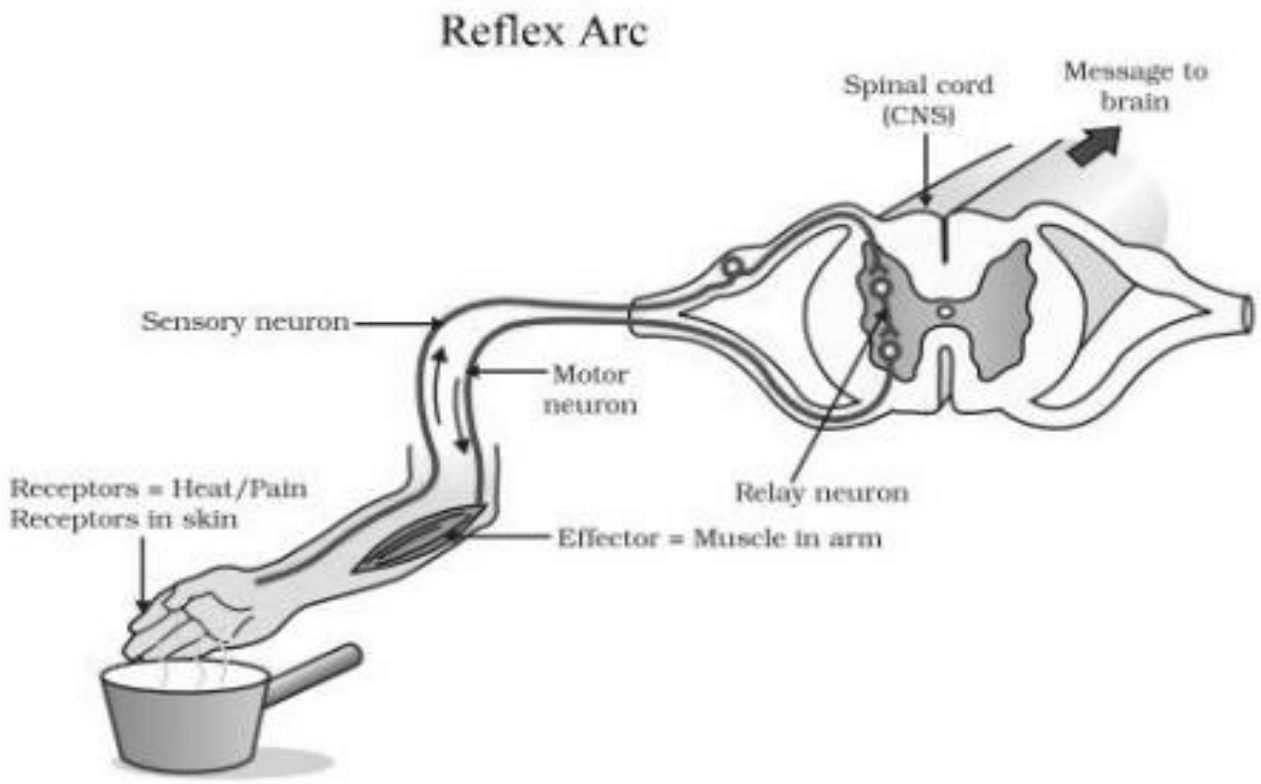
(i) A specific receptor, the neurons of which receive a stimulus and set up a sensory impulse.

(ii) An afferent nerve, which brings the sensory impulse from the receptor to the central nervous system.

(iii) A portion of the central nervous system, brain or spinal cord, the neurons of which analyse and interpret the sensory impulse and set up an appropriate motor impulse. Brain and spinal cord are called modulators.

(iv) An efferent nerve, which carries the motor impulse from the central nervous system to the specific effectors

(v) An effector, where impulse terminates and response is given as per instructions received from the modulators.



IX. Physiology of mammalian Reproduction

Female Reproductive Physiology

Female reproductive system is located in the pelvic region. It consists of - a pair of ovaries, a pair of oviducts, uterus, cervix, vagina and the external genitalia. A pair of mammary glands is also integrated structurally and functionally with the parts of female reproductive system to support the process of ovulation, fertilization, gestation, parturition and care of the baby after birth. A pair of oviducts, uterus, cervix, vagina constitute the female accessory ducts.

Ovaries-

- The primary female sex organs that produce the ovum and several ovarian hormones, steroid in nature.
- Located one on each side of the lower abdomen.
- Each ovary is covered by a thin epithelium which encloses the **ovarian stroma.**
- The ovarian stroma is divided into two zones – **a peripheral cortex** and an **inner medulla**.

Oviduct (fallopian tube)-

- 10-12 cm in length.
- Extends from the periphery of each ovary to the uterus.
- Part closer to the ovary is the funnel shaped
- **Fimbriae** are the finger like projections located on the edges of the infundibulum.
- Fimbriae help in collection of the ovum after ovulation.
- The infundibulum leads to the **ampulla** which is the wider part of the oviduct
- The last part of the oviduct is **isthmus** which has a narrow lumen and it joins the uterus.

Uterus-

- Uterus is also called **womb**.
- The shape of the uterus is like an inverted pear.
- Ligaments attached to the pelvic wall support the uterus.
- The narrow **cervix** opens the uterus into the vagina.
- **Cervical canal** is the cavity of the cervix which forms **birth canal** along with vagina.
- Three layers of tissues are present in the uterus wall- the outer thin membrane bound **perimetrium**, middle thick layer of smooth muscle called **myometrium**, inner glandular layer called **endometrium**.
- Endometrium lines the uterine cavity.
- During menstrual cycle, endometrium undergoes cyclical changes but the myometrium exhibits strong contraction during parturition.

External genitalia

- Vagina is the female external genitalia.
- Vagina includes mons pubis, labia majora (labia majus), labia minora (labia minus), hymen and clitoris.
- Mons pubis is a cushion of fatty tissue covered by skin and pubic hair.
- The labia majora are folds of tissue extend down from the mons pubis and surround the vaginal opening.

- Under the labia majore, there are paired tissue folded to form labia monora.
- Hymen is membrane covering the opening of the vagina.
- A tiny finger-like structure which lies at the upper junction of the two labia minora above the urethral opening is called clitoris
-

Female Reproductive Physiology

I. Function of the female reproductive system
2. Oogenesis
3. Folliculogenesis
4. Ovarian Cycle Regulation
5. Menstrual cycle
6. Cervical mucous during the menstrual cycle
7. Ovum pickup and transport in F tube

II. Function of the female reproductive system 1. Produces, sustains , and allows oocytes to be fertilized by sperm 2. Supports the development of an offspring (gestation) 3. Gives birth to a new individual (parturition

III. Ovary : Produces oocytes in a process called oogenesis
Female sex hormones: estrogens and progesterone
Developed: Near the kidneys during fetal development
Toward the end of pregnancy descend into the pelvic cavity.

IV. The ovary:
Outer cortex: containing multiple tiny ovarian follicles
Each follicle contains an immature oocyte, surrounded by one layers of cells
The cortex is covered by a low columnar epithelium: germinal epithelium
Beneath the germinal epithelium is a dense collagenous layer: tunica albuginea
Inner medulla: where scar tissues and connective tissue are located.

V. Fallopian tube:
Firmbriae: Finger – like appendages that collect the ovum from the ovary during ovulation.
Infundibulum channels the ovum from the firmbriae into the tube
Ampulla: the curvature of the tube where most fertilization occurs
Inner wall of uterine tube is made of ciliated mucosa , where the cilia propel the ovum toward the uterus.

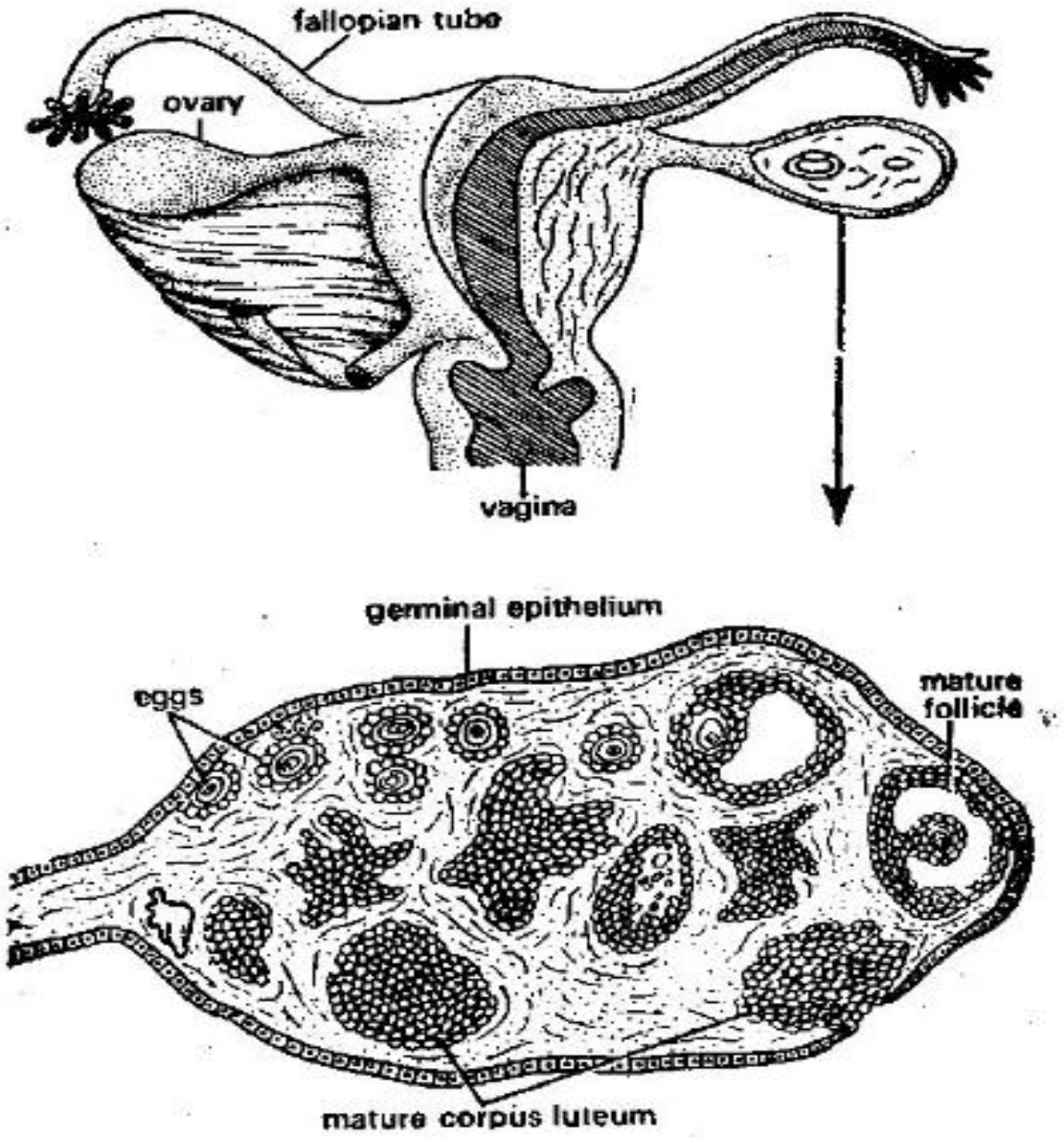
VI. Uterus
3 layers of tissue
Perimetrium (fibrous connective tissue)
Myometrium (smooth muscle)
Endometrium (epithelial and connective tissues) .

Endometrium:
After fertilization: embryo adheres to the endometrial layer for further development: implantation
To prepare for implantation and development , endometrium is stimulated by estrogens to thicken and becomes vascularzed: process called the menstrual cycle
Myometrium: under the stimulation of oxytocin, contracts during labor to expel the fetus into the vagina .
The base of uterus is closed by a narrow passageway called cervix to prevent the entry of foregin substances.

VII. Vagina:
An elastic channel inferior to the cervix
Serves as:
birth canal" during parturition
copulatory receptacle, where it receives the penis during sexual intercourse
coveys
acids secretion from cervix
uterine secretions (i.e. menstrual flow)

VIII. Oogenesis
In the ovarian cortex, a process called oogenesis (formation of egg) occurs to develop a mature
Before birth
million of primordial oocytes exist in the ovaries: most of them spontaneously degenerate At birth only 1
million primordial oocytes are left
By puberty (age 10-11) only 400,000 remain in the ovaries

IX. From puberty to menopause:
Some of these primordial oocytes (containing 46 chromosomes) undergo DNA replication: primary oocytes (with 46 pairs of chromosomes).
Primary oocytes
undergo "crossing - over" to shuffle their genes, and meiosis I will occur to divide the cells into:
secondary oocytes (containing 46 unique chromosomes) and
the first polar bodies (also containing 46 unique chromosomes ; but will be degenerated) .



Female sex organs (upper); T.S. of ovary showing different developing stages of ovum (lower).

Male Reproductive Physiology

Male reproductive system is located in the pelvis region. It Consists of – a pair of testis, glands, accessory ducts, external genitalia.

Testes-

- Smooth organ situated outside the abdominal cavity within a pouch called
- The scrotum helps in maintaining the low temperature of the testis which is 2-2.5^{O} C which is below than the normal internal body temperature.
- Each testisis 4 to 5 cm in length and 2 to 3 cm in width in adults.
- Each testis contains about250 compartments called **testicular lobules.**
- Each testicular lobules contain one to three highly coiled **seminiferous tubules**, in which sperms are produced.
- The wall of each seminiferous tubules lined by two types of cells called **male germ cells (spermatogonia)** and **Sertoli cells.**
- The male germ cells undergo meiosis leading to sperm formation and Sertoli cells provide nutrition to the germ cells.

- The regions outside the seminiferous tubules called **interstitial spaces** contain small blood vessels and **interstitial cells** or **Leydig cells.**
- Leydig cells synthesize and secrete testicular hormones called **androgens**.

Accessory ducts-

- The male accessory ducts include **rete testis**, **vasa efferentia**, **epididymis** and **vas deferens.**
- The seminiferous tubules of the testis open into the vasa efferentia through rete testis.
- The vasa efferentia leave the testis and open into epididymis located along the posterior surface of each testis.
- The epididymis leads to vas deferens that ascends to the abdomen and loops over the urinary bladder.
- Vas deferens receives a duct from seminal vesicle and opens into urethra as the ejaculatory duct.
- The urethra originates from the urinary bladder and extends through the penis to its external opening called **urethral meatus.**

Accessory glands-

- The male accessory glands include paired **seminalvesicles**, prostate gland and paired bulbourethral glands.
- Accessory glands secrete **seminal plasma** which is rich in fructose, calcium and some enzymes
- Secretion of bulbourethral gland also helps in lubricating the penis.

External genitalia-

- The penis is the male external genitalia.
- Some special tissues make up the penis which helps in the erection of the penis.
- The enlarged end of penis called the **glans penis**.
- **Foreskin**, a loose fold of tissue covers the glans penis.

1. Function of male reproductive system
2. Spermatogenesis
3. Spermatozoa
4. Journey of sperm
    1. Ejaculation
    2. Sperm motility.
    3. Sperm ascent

1. Functions of male reproductive system –

Male Reproductive System

• Testes

• Epididymis

• Ductus deferens

• Accessory glands –

Prostate glands

Seminal vesicles –

Bulbourethral glands

The male reproductive system:

1. Produce, maintain & transport viable spermatozoa

2. Hormone production

    1. develops secondary sexual characteristics

    2. Involved in feedback mechanisms relating to spermatogenesis

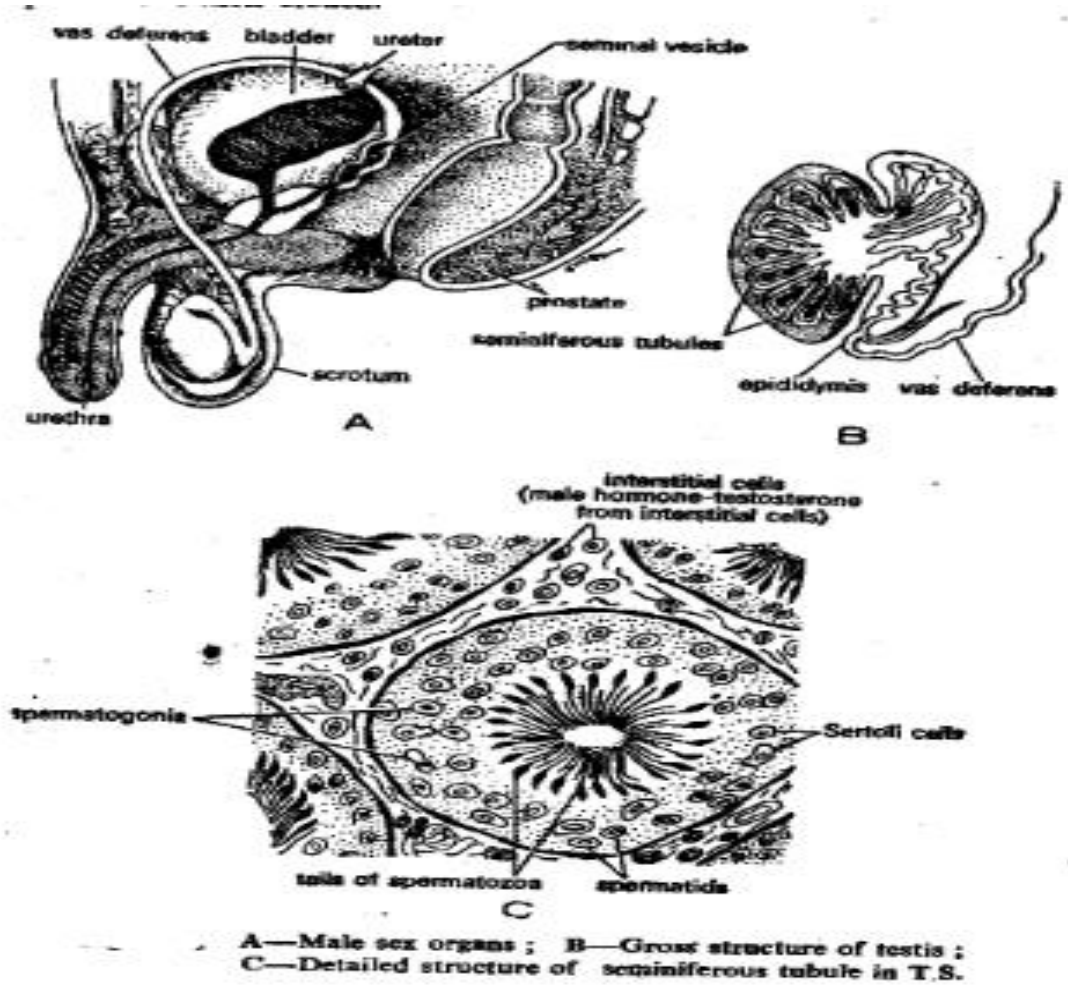
Testis:

Produces sperm in a process called spermatogenesis

Male sex hormones (testosterone)

Developed in: male foetus near the kidneys - descend to the scrotum about 2 months before birth - Enclosed by a layer of fibrous connective tissue called tunica alumina - Contains about 250 functional units called lobules - each lobule contains about 4 seminiferous tubules where spermatogenesis occurs

All somniferous tubules in a testis converge and form a channel called rate testis



A—Male sex organs ; B—Gross structure of testis ;
C—Detailed structure of seminiferous tubule in T.S.

Scrotum:

A pouch – like cutaneous extension that contains the two testes

Located outside of pelvic cavity: prevent overheating of testes [internal temperature of scrotum is always about 3 ˚F below body temperature] .

Epididymis: An expanded tubule from the rate testis where sperm is stored (for about 3 days), matured and become fully functional.

Contains cilia on its columnar epithelium that help move sperm toward vas deferens during ejaculation.

Vas deferens:

A tubule (about 10 inches long) that connects epididymis to the urethra for transporting sperm during ejaculation. Contains smooth muscle that undergoes rapid peristalsis during ejaculation .

Accessory sex glands

Seminal vesicles: secrete an alkaline solution that makes up 60% of the semen volume

Fructose: nutrient for the sperm

Prostaglandins: stimulate uterine contraction during sexual excitation

decrease cervical mucus viscosity

stimulate reverse peristalsis of the uterus.

Coagulating enzyme:

turn semen into a bolus that can be readily propelled into the vagina.

Prostate gland: secretes a slightly acidic, milky white fluid that makes up about 30% of semen volume

neutralize the pH of semen and vaginal secretion. Prostatic fibrinolysin acts to decoagulate" the semen, which helps the sperm begin their journey in female GT.

Bulb urethral gland: secretes a clear lubricating fluid that aids in sexual intercourse.

Composition of Semen 10%: Sperm & testicular fluid 30%: Prostatic secretions 60% Seminal vesicle secretions.

Reproductive organs of the male

Urethra: A tubule located inside the penis for urine excretion and semen ejaculation

Contains smooth muscle that performs rapid peristalsis during ejaculation .

Penis: A copulatory organ that is responsible for delivering the sperm to the female reproductive tract.

Seminiferous Tubules

About 1,000 seminiferous tubules in each testis

conduct spermatogenesis.

Between the tubules: specialized glandular cells called interstitial cells (or leydig's cells): produce testosterone.

Inside the tubules: specialized cells called sertoli's cells: support and nourish the sperm.

Function of Seminiferous tubule

1. Maintain environment for spermatogonia by the basal lamina and the Sertoli cells
2. • Sertoli cells separate the lumen from the basal lamina and create a blood-testis barrier
3. • Creates 3 compartments – Lumen: low glucose, high K+ & steroid hormones – Basal compartment: the baso-lateral side of the sertoli cells & containing the developing spermatogonia – Interstitial fluid space: below the basal lamina and contains the Leydig cells 2. Produce hormones/paracrines
4. • From Sertoli cells
5. • From Leydig cells

Function of Sertoli cells

Produce hormones & paracrines involved with control of hypothalamus-pituitary-gonad axis and the testes directly

1. AMH Secreted during embryogenesis Prevents development of the Müllerian ducts

2. Inhibin & activin Regulate FSH release from anterior pituitary

Inhibin: decreases FSH release

Activin: increases LH function & increases FSH release

Function of Leydig cells

1. Produce androgens
2. • testosterone, androstenedione and DHEA –Increase spermatogenesis –Influence secondary sexual characteristics Stimulated to produce androgens by LH
   • FSH increases the response to LH by Leydig cells

X. Reproductive cycle and Hormones involved in Reproductive cycle

The reproductive cycle starting from the one menstruation till the next one in the female primates is called menstrual cycle. The first menstruation which begins at puberty and is called menarche . The cycle is repeated at an interval of 28-29 days. Menstrual cycle involve three phases- menstrual phase, follicular phase and luteal phase.

Menstrual phase-

Menstrual flow occurs and lasts for about 3-5 days.
The endometrial lining of the uterus breaks along with the blood vessels which forms a red fluid and results in menstrual flow.
If the ovum is fertilized by a sperm menstrual flow does not occur and hence indicates pregnancy.

The menstrual cycle is the process of discharge of blood and other things from the vagina of a woman every month from puberty to menopause excluding pregnancy. It is a natural periodical process that brings changes in the female reproductive system which is responsible for the pregnancy.

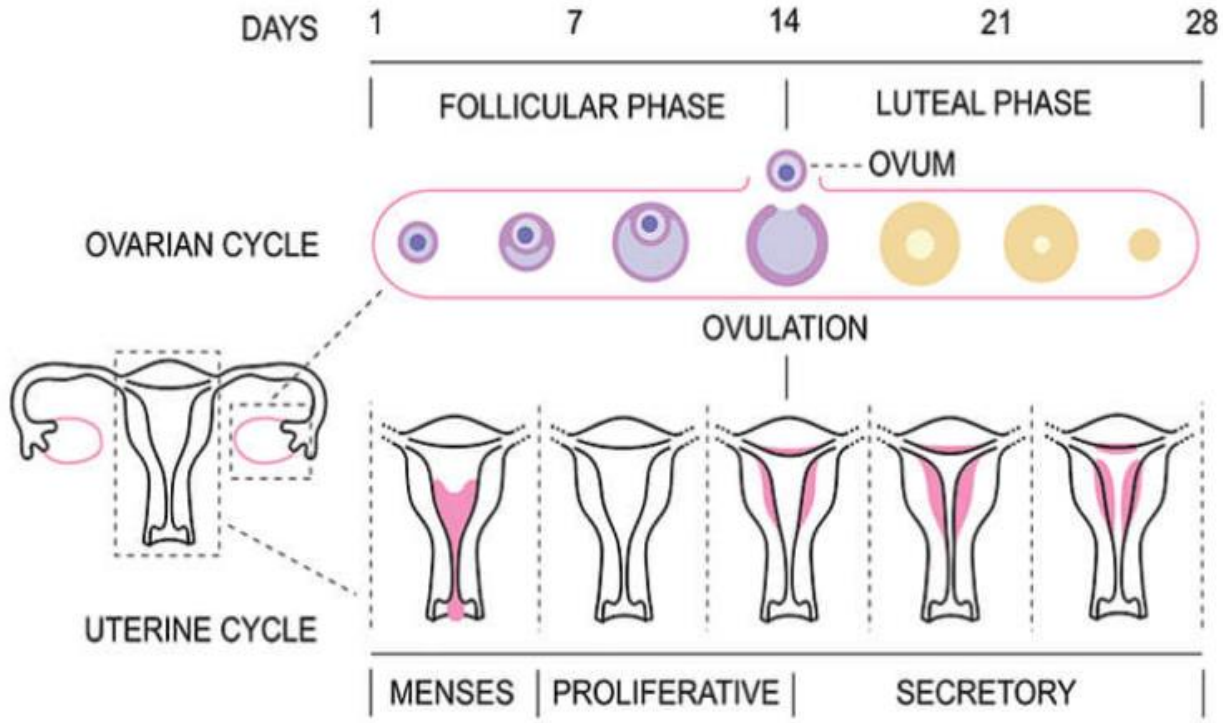
- It includes changes that occur in the ovary and the uterine walls simultaneously as a result of changes in the level of hormones in the blood.
- Two significant events occur within the female reproductive organs:
- First is the release of single ovum from one of the ovaries and,
- the second is that the uterine endothelium is prepared for the plantation of a fertilized ovum.
- If the ovum is not fertilized, the lining is released which results in menstruation.
- The duration of the cycles averages about 28 days. However, the period that might differ in different women can range from 20 days to 45 days. The difference in the duration is associated with decreased fertility.

Hormones involved in the menstrual cycle.

- The hypothalamus secretes a luteinizing hormone-secreting hormone which stimulates the anterior part of the pituitary to secrete:

1. Follicle Stimulating Hormone (FSH) causes the maturation of ovarian follicles and stimulates the release of Oestrogen which is responsible for ovulation.
2. Luteinizing Hormone (LH) which triggers ovulation and formation of corpus luteum and release of progesterone.

- Hormones released in the cycle are stimulated by a negative feedback mechanism. The hypothalamus is stimulated when the level of estrogen and progesterone is low in blood and is switched off when their concentration is high.
- The menstrual cycle is described by ovarian and uterine cycles. The ovarian cycle involves the formation and maturation of follicular cells in the ovary, whereas the uterine cycle describes the changes in the endothelial layer of the uterus.



Ovarian Cycle

The ovarian cycle involves the formation and maturation of follicular cells in the ovary. This cycle is divided into three phases:

Follicular phase-

In this phase, the primary follicles in the ovary grow to become a fully matured graafian follicle.

Endometrium regenerates through proliferation.

Changes in Pituitary hormone and ovarian hormones induce the formation of graafian follicle and regeneration of endometrium.

The secretion of gonadotropins like luteinizing hormone and follicular stimulating hormone increases gradually during this phase and stimulates follicular development as well as secretion of oestrogens by the growing follicles.

Both LH and FSH attain a peak level in the middle of cycle about 14th day.

Rapid secretion of LH leading to its maximum level during the mid-cycle called LH surge induces rupture of Graafian follicle and thereby the release of ovum known as ovulation.

- After puberty, as a result of the release of a large amount of FSH and LH by the pituitary, the ovaries with the follicles start to grow.
- During the first stage, the targeted follicular cells enlarge up to two-fold to three-fold in diameter. These enlarged follicular cells are termed primordial follicles.
- After a few days, the level of FSH surpasses LH which accelerates the growth of 6-10 primary follicles that compete for dominance. Under the influence of FSH, these cells develop layers of granulosa cells as well as express the LH receptors on the granulosa cells.
- The second layer of cells called theca develops around these follicles which can produce other sex hormones like oestrogen and progesterone.

- LH from the pituitary and the oestrogen within the follicles cause accelerated growth of the primary follicles into vesicular follicles.
- The ovum present inside the follicles develops aggressively increasing in size another threefold to four-fold. After a week or more of growth, one of the follicles starts outgrowing other follicles (a process called atresia). The reason behind the process of atresia is not yet known; however, it is imperative as it prevents more than one child during pregnancy.
- The single follicle further increases in size and forms the mature follicle.

Ovulation Phase

- Ovulation in women with regular 28 days of sexual cycles occurs 14 days after the onset of menstruation. Few days before ovulation the follicle starts to swell with a protruding centre called the stigma.
- The in-surge of the LH hormone and the release of oestrogen from the follicle degrades the cells at the stigma and results in a hole. The secondary oocyte leaves the follicle through the hole and reaches the peritoneal cavity. The secondary oocyte then reaches the fallopian tube through the fimbriae. If there is left-right coordination between the ovaries is not yet known. However, occasionally, both the ovaries release an ovum, which results in the formation of fraternal twins.
- If a sperm fertilizes the oocyte, it develops into a mature ovum. If fertilization doesn't occur, the secondary oocyte degenerates within the fallopian tube.

Luteal phase-

In this phase, the ruptured part of Graafian follicle transforms into yellow body called Corpus luteum.

The corpus luteum secretes large amounts of progesterone hormone which maintains the endometrium for implantation of the fertilized ovum.

During pregnancy all events of the menstrual cycle stop and there is no menstruation.

In the absence of fertilization, the corpus luteum degenerates hence causes disintegration of the endometrium leading to menstruation and a new cycle begins.

In human beings, menstrual cycles ceases around 50 years of age and known as menopause.

- The luteal phase is the last phase of the ovarian cycle and it corresponds with the secretory phase of the uterine cycles.
- During the first few hours of ovulation, the remaining follicular cell, including the granulosa and theca develops into lutein cells. This cell then becomes filled with lipid components that give them a yellow appearance. The total mass of the cell is called corpus luteum.
- Corpus luteum produces progesterone that inhibits the release of FSH and LH by the pituitary. Consequently, the concentration of FSH and LH falls over time and the corpus luteum degenerates.
- The falling levels of progesterone then trigger menstruation. The process from the start of ovulation to the withdrawn of progesterone takes around two weeks. Even though the sexual cycle in all women is not the same; the duration of the luteal phase remains more or less the same in all women.
- In the case of a successful pregnancy, the degeneration of corpus luteum is prevented by the release of human chorionic gonadotropin (HCG) from the placenta. Corpus luteum is essential to produce progesterone which maintains the new pregnancy.

Uterine cycle

The uterine cycle includes the changes in the endothelial layer of the uterus. It is divided into three phases.

Menstruation

- Menstruation, also called menses, menstrual bleeding, or a period, is the first phase of the uterine cycle. This occurs as a result of the degeneration of corpus luteum which inhibits the release of FSH and LH from the pituitary and thus prevents the proliferation of other follicular cells.
- The menstrual flow often serves as a sign to indicate the women is not pregnant; however, bleeding might also occur during pregnancy due to several reasons.
- The menstrual flow consists of blood from broken capillaries, secretions from endometrial glands, endometrial cells as well as an unfertilized ovum.
- This phase usually lasts about 3-5 days but might range from 2-7 days in some women. On average, 35 milli litres of blood is lost during menstruation, but 10ml to 80ml is considered normal.
- A protein called plasmin is responsible for the prevention of clotting during menstruation.
- Pain in the back, stomach, and upper thigh is common during the first few days of menstruation and severe pain is commonly observed in adolescent girls (67% of women observe severe cramping).

Proliferative Phase

- This is the second phase of uterine cycles where the oestrogen causes the proliferation of the endometrial layer in the uterus.
- After the maturation of follicles in the ovary, they cause the release of oestrogen which causes the growth of a new layer of endometrium called proliferative endometrium. The endometrium becomes thick with the rapid cell multiplication and increases the mucus-producing cells as well as blood capillaries.
- The oestrogen also causes the formation of crypts in the cervix that facilitate the secretion of vaginal discharge.
- This phase ends when ovulation occurs and the level of oestrogen declines.

Secretive Phase

- The final phase of the uterine cycle corresponds with the luteal phase of the ovarian cycle, which occurs after ovulation.
- The corpus luteum releases progesterone hormone, which is particularly essential to make the uterus receptive for the implantation of the fertilized ovum. The endometrium becomes oedematous and the secretory glands produce a large amount of watery liquid to assist the passage of spermatozoa.
- If fertilization occurs, the fertilized ovum travels to the uterus through the uterine tube and become embedded.
- However, if fertilization doesn’t occur, menstruation occurs and a new cycle is initiated.

SOURCES

- Hall JE and Guyton AC. (2011) Textbook of Medical Physiology. Twelfth Edition. Elsevier Saunders.
- Waugh A and Grant A. (2004) Anatomy and Physiology. Ninth Edition. Churchill Livingstone.
- Marieb EN and Hoehn K. (2013) Human Anatomy and Physiology. Ninth Edition. Pearson Education, Inc.