Muscle physiology

Classification of Muscles

There are more than 600 muscles in our body. Muscles perform many useful functions and help us in doing everything in day to day life. Muscles are classified by three different methods based on different factors:

I. Depending upon the presence or absence of striations

II. Depending upon the control

III. Depending upon the function.

DEPENDING UPON CONTROL Depending upon control, the muscles are classified into two types: 1. Voluntary muscle 2. Involuntary muscle.

Voluntary Muscle: Voluntary muscle is the muscle that is controlled by the will. Skeletal muscles are the voluntary muscles. These muscles are innervated by somatic nerves.

Involuntary Muscle: The muscle that cannot be controlled by the will is called involuntary muscle. Cardiac muscle and smooth muscle are involuntary muscles. These muscles are innervated by autonomic nerves.

DEPENDING UPON SITUATION: the muscles are classified into three types depending upon the situation:

1. Skeletal muscle
2. Cardiac muscle
3. Smooth muscle.

Skeletal Muscle: is situated in association with bones forming the skeletal system. The skeletal muscles form 40 to 50% of body mass and are voluntary and striated. These muscles are supplied by somatic nerves. The fibers of the skeletal muscles are arranged in parallel.

Cardiac muscle: forms the musculature of the heart. These muscles are striated and involuntary. Cardiac muscles are supplied by autonomic nerve fibers.

Smooth Muscle: Smooth muscle or visceral muscle is situated in association with viscera. Smooth muscle is nonstriated and involuntary. Because of the absence of cross striations it is called smooth or plain muscle. It is supplied by autonomic nerve fibers.

Structure of Skeletal Muscle

The muscle mass (or tissue) is made up of a large number of individual muscle cells or **myocytes.** The muscle cells are commonly called muscle fibers because these cells are long and slender in appearance. The skeletal muscle fibers are multinucleated and arranged parallel to one another with some connective tissue in between. The muscle mass is separated from the neighboring tissues by the thick fibrous tissue layer known as **fascia.** Beneath the fascia, the muscle is covered by a connective tissue sheath called **epimysium**. In the muscle, the muscle fibers are arranged in various groups called the bundles or fasciculi. The connective tissue sheath that covers each fasciculus is called perimysium. Each muscle fiber is covered by the connective tissue layer called the **endomysium**

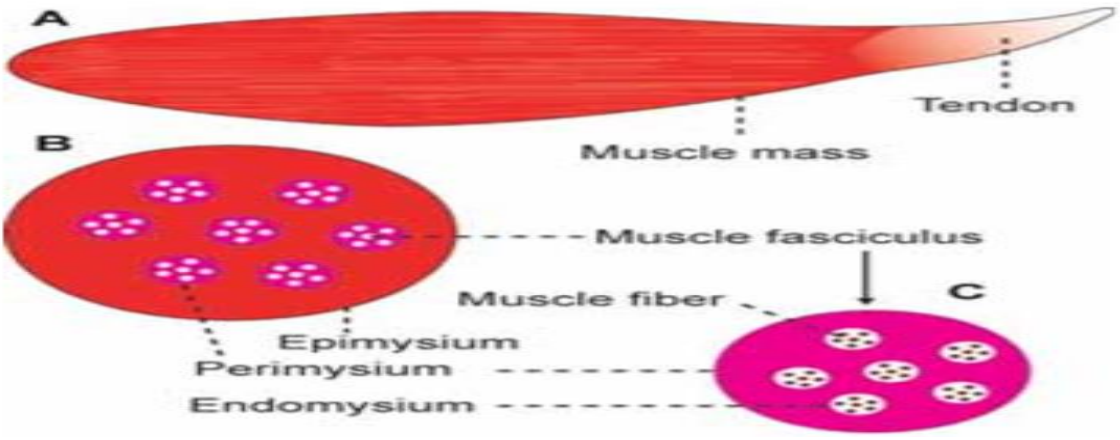


Diagram showing A = Skeletal muscle mass B = Cross-section of muscle C = One muscle fasciculus Diagram showing A = Skeletal muscle mass B = Cross-section of muscle C = One muscle fasciculus

Each muscle cell or muscle fiber is cylindrical in shape. The length of the fiber is between 1 and 4 cm depending upon the length of the muscle. The diameter of the muscle fiber varies from 10 to 100 μ. The muscle fibers are attached to bone by a tough cord of connective tissue called tendon. Each muscle fiber is enclosed by a cell membrane called plasma membrane that lies beneath the endomysium. It is also called **MYOFIBRIL.** Myofibrils or myofibrillae are the special structures present only in muscle fibers. These are the fine parallel filaments present in **sarcoplasm** of the muscle cell. The myofibrils run through the entire length of the muscle fiber.

MICROSCOPIC STRUCTURE OF A MYOFIBRIL

Light microscopic studies show that, each myofibril consists of a number of two alternating bands. The two bands are:

1. Light band or 'I' band **2.** Dark band or 'A' band.

In an intact muscle fiber, 'I' band and 'A' band of the adjacent myofibrils are placed side by side. It gives the appearance of characteristic cross striations in the muscle fiber. I band is divided into two portions by a narrow dark line called 'Z' line or 'Z' disk. The 'Z' line is formed by a protein disk which does not permit passage of light. The portion of myofibril in between two 'Z' lines is called **sarcomere**.

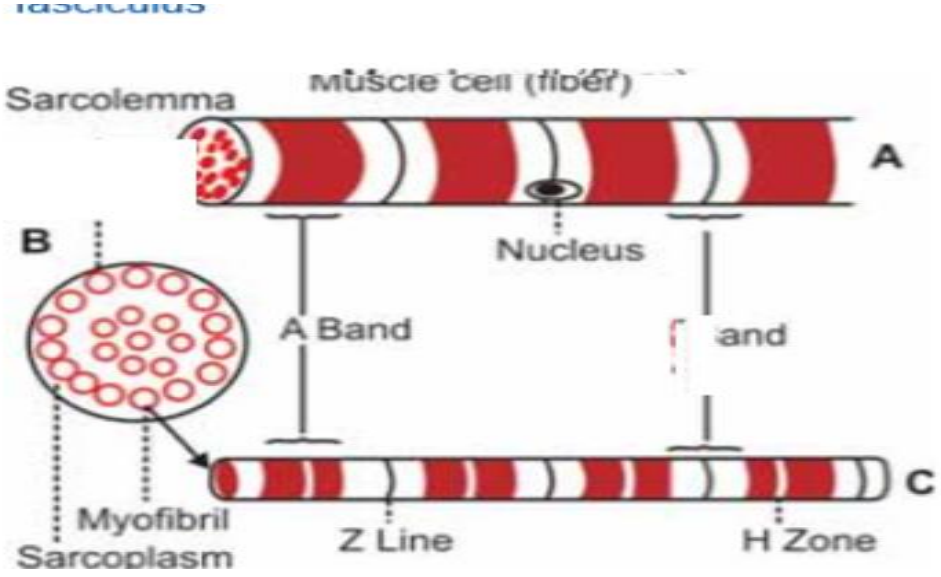
Sarcomere is the structural and functional unit of the skeletal muscle.

The sarcomere consists of many thread like structures called myofilaments. Myofilaments are of two types: **1.** Actin filaments **2.** Myosin filaments.

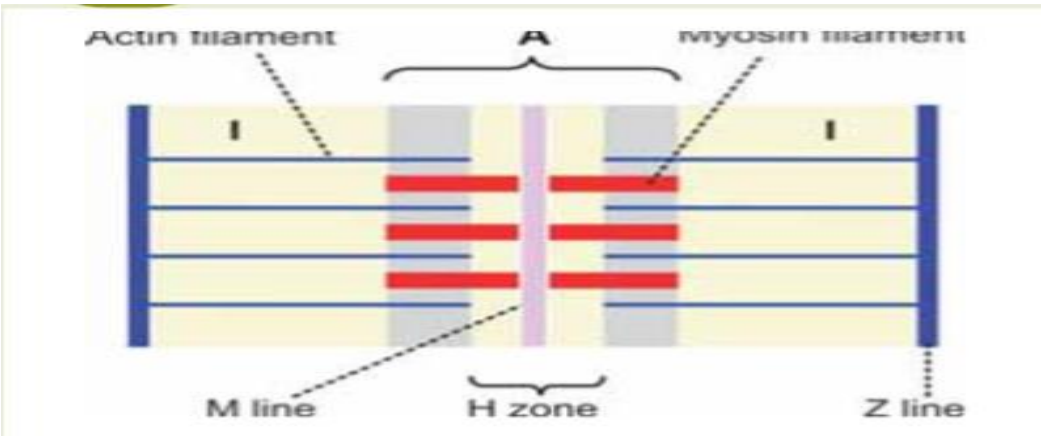
Actin Filaments Actin filaments are the thin filaments that extend from either side of the 'Z' lines, run across 'I' band and enter into 'A' band up to 'H' zone.

Myosin Filaments Myosin filaments are thick filaments and are situated in 'A' band. Some lateral processes (projections) or cross bridges arise from myosin filaments. These bridges have enlarged structures called myosin heads at their tips.

The myosin heads attach themselves to actin filaments. These heads pull the actin filaments during contraction of the muscle by means of a mechanism called sliding mechanism or ratchet mechanism.



A = One muscle cell B = Cross section of one muscle cell C = One myofibril



Sarcomere. A = A band, I = I band

CONTRACTILE ELEMENTS (PROTEINS) OF MUSCLE the myosin filaments are formed by protein molecules called myosin molecules. The actin filaments are formed by three types of proteins called actin, tropomyosin and troponin. These four proteins together constitute the muscle proteins or the contractile elements of the muscle. In addition to the contractile proteins, the sarcomere contains some more proteins.

MYOSIN MOLECULE Each myosin filament consists of about 200 myosin molecules. Myosin is a globulin which is made up of 6 polypeptide chains. Out of these, two are heavy chains and four are light chains. The two heavy chains twist around each other to form a double helix. At one end, the two chains remain twisted around one another and form the tail portion. At the other end, both the chains turn away in opposite directions.

ACTIN MOLECULE

Actin molecules are the major constituents of the thin actin filaments. Each actin molecule is called F actin and it is derived from G actin. There are about 300-400 actin molecules in each actin filament. The actin molecules in the actin filament are also arranged in the form of a double helix. Each F actin molecule has an active site to which the myosin head is attached

TROPOMYOSIN

There are about 40-60 tropomyosin molecules situated along the double helix strand of actin filament. In relaxed condition of the muscle, the tropomyosin molecules cover all the active sites of F actin molecules.

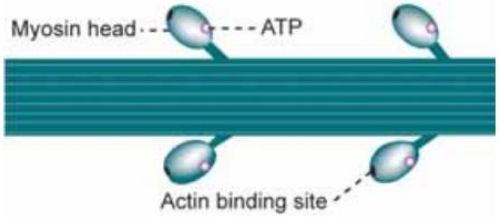
TROPONIN

It is formed by three subunits:

1. Troponin I – attached to F actin

2. Troponin T – attached to tropomyosin

3. Troponin C – attached to calcium ions.



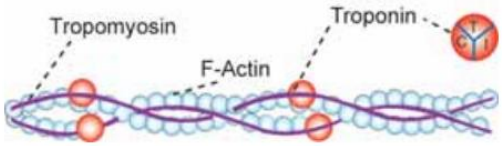


FIGURE 21-6: Part of actin filament. Troponin has three subunits, T, C and I

SARCOTUBULAR SYSTEM

Sarcotubular system is a system of membranous structures in the form of vesicles and tubules in the sarcoplasm of the muscle fiber. It surrounds the myofibrils embedded in the sarcoplasm.

The sarcotubular system is formed mainly by two types of structures:

1. 'T' tubules 2.
2. 'L' tubules or sarcoplasmic reticulum.

'T' Tubules 'T' tubules or transverse tubules are narrow tubules formed by invagination of the sarcolemma. These tubules penetrate all the way from one side of the muscle fiber to other side.

Because of their origin from sarcolemma, the 'T' tubules open to the exterior of the muscle cell. Therefore, the ECF runs through their lumen.

Function of 'T' Tubules

The 'T' tubules are responsible for rapid transmission of impulse in the form of action potential from sarcolemma to the myofibrils.

'L' Tubules or Sarcoplasmic Reticulum

The 'L' tubules or longitudinal tubules are the closed tubules that run in long axis of the muscle fiber forming sarcoplasmic reticulum. These tubules form a closed tubular system around each myofibril and do not open to exterior like 'T' tubules. The 'L' tubules correspond to the endoplasmic reticulum of other cells. At regular intervals, throughout the length of the myofibrils, the 'L' tubules dilate to form a

pair of lateral sacs called terminal cisternae. Each pair of terminal cisternae The 'T' tubule along with the cisternae on either side is called the triad of skeletal muscle.

Calcium ions are stored in 'L' tubule and the amount of calcium ions is more in cisternae.

Functions of 'L' tubules

The 'L' tubules store a large quantity of calcium ions. When the action potential reaches the cisternae of 'L' tubule, the calcium ions are released into the sarcoplasm. The calcium ions trigger the processes involved in contraction of the muscle. The process by which the calcium ions cause contraction of muscle is called excitation contraction coupling.

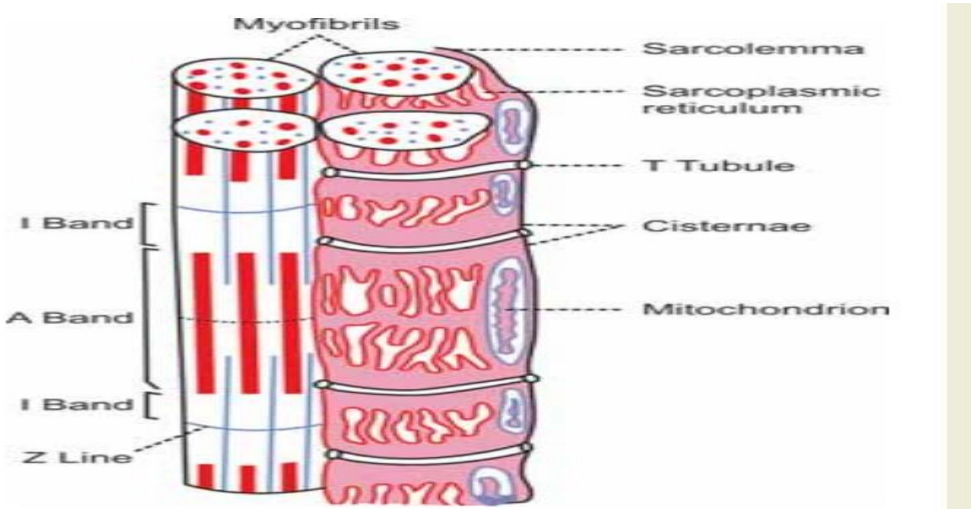


Diagram showing the relation between sarcotubular system and parts of sarcomere. Only few myofilaments are shown in the myofibril drawn on the right side of the diagram

Properties of Skeletal Muscle

EXCITABILITY

Excitability is defined as the reaction or response of a tissue to irritation or stimulation. It is a physicochemical change.

STIMULUS

Stimulus is the change in environment. It is defined as an agent or influence or act, which brings about the response in an excitable tissue.

There are four types of stimuli, which can excite a living tissue:

1. Mechanical stimulus (Pinching)

2. Electrical stimulus (Electric shock)

3. Thermal stimulus (By applying heated glass rod or icepiece)

4. Chemical stimulus (By applying chemical substances like acids). Electrical stimulus is commonly used for experimental purposes.

CONTRACTILITY: is the response of the skeletal muscle to a stimulus by change in either the length or tension of the muscle fibers.

TYPES OF CONTRACTION: Muscular contraction is classified into two types based on change in the length of muscle fibers or tension of the muscle:

1. Isotonic contraction 2. Isometric contraction.

Isotonic Contraction is the type of muscular contraction in which the tension remains the same and the length of the muscle fiber is altered (Iso = same: Tonic = tension). Example is the simple flexion of arm, where shortening of muscle fibers occurs but the tension does not change.

Isometric Contraction is the type of muscular contraction in which the length of muscle fibers remains the same and the tension is increased. Example is pulling any heavy object when muscles become stiff and strained with increased tension but the length does not change.

RED MUSCLE AND PALE MUSCLE Based on the contraction time, the skeletal muscles are classified into two types, the red (slow) muscles and pale

(fast) muscles. Similarly, the muscle fibers are also divided into two types, type I and type II fibers. Type I fibers (slow fibers or slow twitch fibers) have small diameter. Type II fibers (fast fibers or fast twitch fibers) have large diameter. Most of the skeletal muscles in human beings contain both the types of fibers.

Red Muscles The muscles which contain large number of type I fibers are called red muscles. These muscles are also called slow muscles or slow twitch muscles.

The red muscles have longer contraction time. Back muscles and gastrocnemius muscles are red muscles.

Pale Muscles The muscles which have large number of type II fibers are called pale muscles. These muscles are also called white muscles, fast muscles or fast twitch muscles. The pale muscles have shorter contraction time. Hand muscles and ocular muscles are pale muscles.

The force of contraction of the skeletal muscle is affected by the following factors:

A. Strength of stimulus B. Number of stimulus C. Temperature D. Load.

A. Effect of Strength of Stimulus Force of contraction is directly proportional to strength of stimulus.

B. Effect of Number of Stimulus The response of the muscle in the form of contraction differs depending upon the number of stimuli. If a single stimulus is given, the muscle gives response only once. If two stimuli are given with sufficient time interval it gives response twice. When a muscle is stimulated by multiple stimuli, two types of effects are obtained depending upon the frequency of stimuli: 1. Fatigue 2. Tetanus.

1. Fatigue

Fatigue is defined as the decrease in muscular activity due to repeated stimuli with low frequency. When the stimuli are applied continuously, after some time, the muscle does not show any response to the stimulus. This condition is called fatigue.

2- Tetanus is defined as the sustained contraction of muscle due to repeated stimuli with high frequency. When the multiple stimuli are applied at a higher frequency in such a way that the successive stimuli fall during contraction period of previous twitch, the muscle remains in state of tetanus, i.e. all the contractions are fused. The muscle relaxes only after the stoppage of stimulus or when the muscle is fatigued.