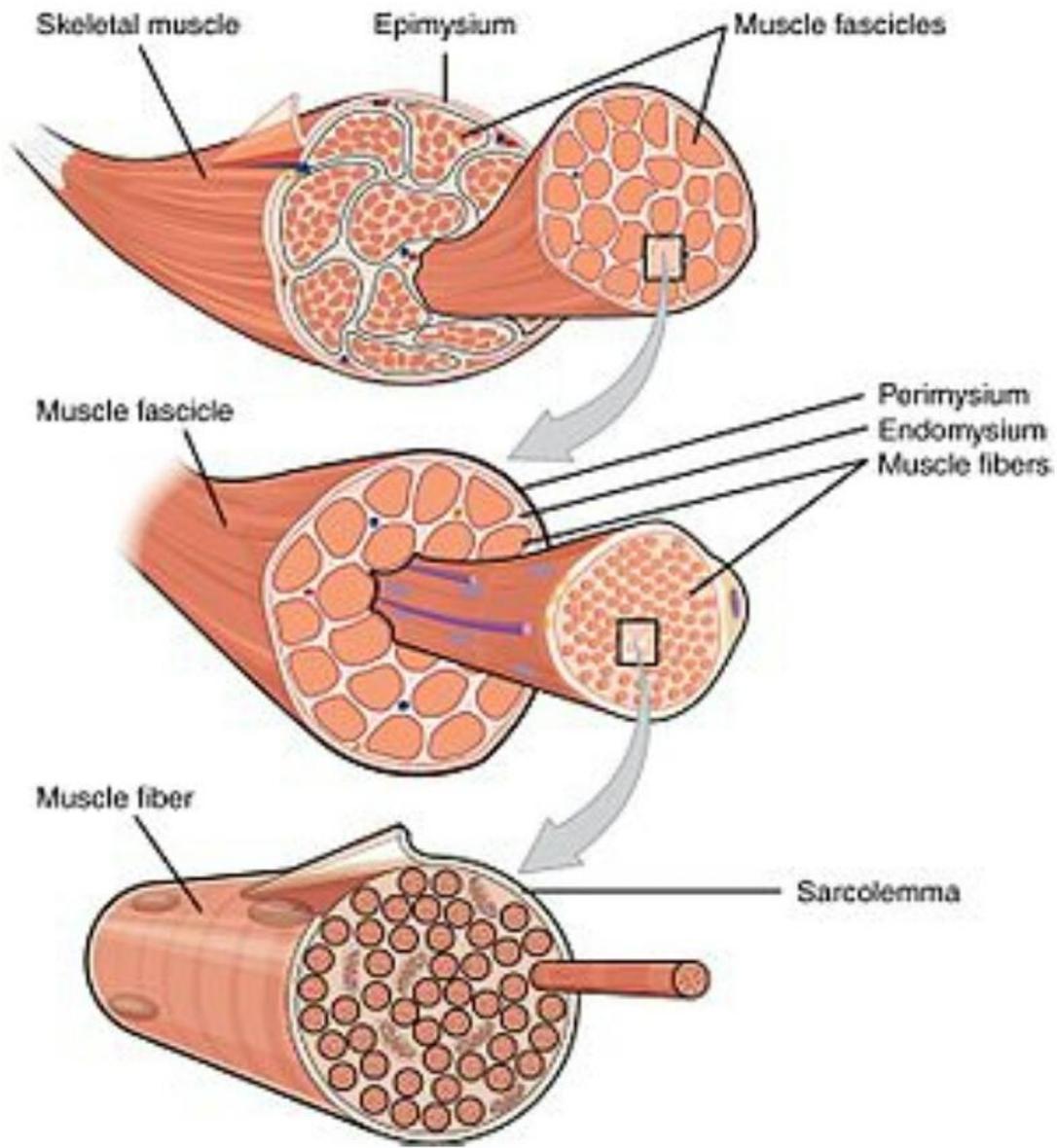


STRUCTURE OF MUSCLE



- Skeletal muscle – 35-65% of carcass weight of meat animals
- Epimysium- CT sheath covering the entire muscle
- Perimysium- CT sheath surrounding bundles of MF
- Endomysium- surrounds individual muscle fibres



Muscle fiber/ Myofiber/ Muscle cell

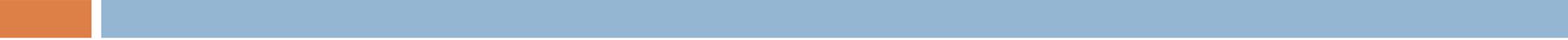
- Structural unit of muscle fiber
- 75-92% of total muscle volume
- Long, unbranched, multinucleated, thread like cells
- 10-100 μm diameter

Sarcolemma

- Muscle cell membrane (elastic in nature)
- Motor nerve fiber endings terminate on sarcolemma at myoneural junction
- Motor end plate- structures at myoneural junction form a raised mound on the muscle surface

Myofibril

- Organelle unique to muscle
- Long thin rods (1-2 μm diameter) with their long axis parallel to the long axis of the fiber
- Muscle fiber of 50 μm diameter has 1000-2000 myofibrils
- Cross striated myofibrils remain embedded in the cytoplasm of muscle fiber



Myofibrillar cross section- highly organized array of dots of two distinct sizes that comprises of

- a. Thick filaments – arranged parallel to each other, in exact alignment across entire surface of myofibril
- b. Thin – aligned across myofibril, parallel to each other and the thick filaments

Thick and thin filaments overlap at certain regions – hence banded/ striated appearance (alternate light and dark areas)

- Light band- singly refractive , isotropic, I band
- Dark band- doubly refractive, anisotropic, A band, denser
- Z disk- dark thin band that bisects I band
- **Sarcomere**- Repeating structural unit of myofibril, basic unit where muscle contraction and relaxation occurs. It is unit of myofibril between two Z disks ($\frac{1}{2}$ I Band + A band + $\frac{1}{2}$ I band)
- Sarcomere length – 2.5 μm (resting stage)
- **H zone**- region A band where only thick filaments are present
- **Pseudo H zone**- region of A band containing only rod portion of myosin molecules, no heads present
- **M line**-

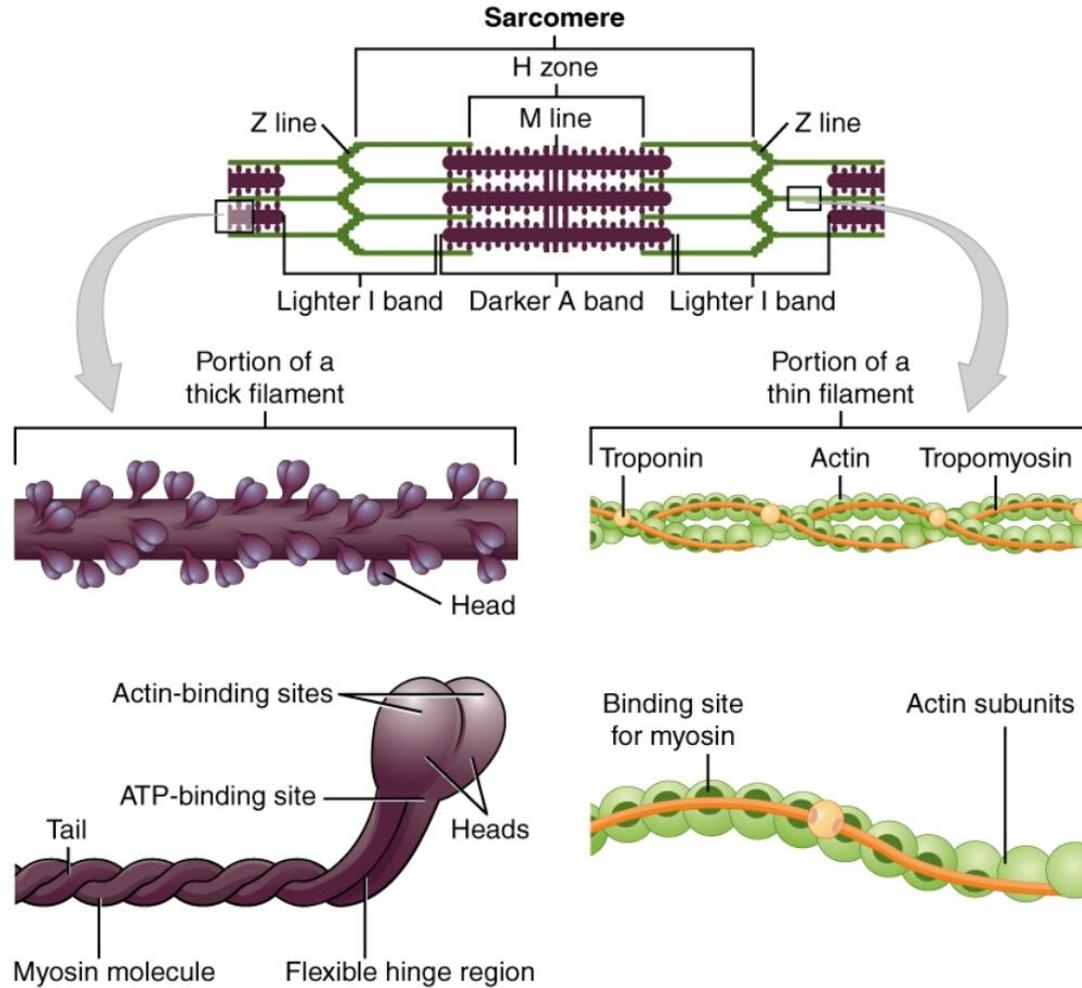


Figure 3. The Sarcomere. The sarcomere, the region from one Z-line to the next Z-line, is the functional unit of a skeletal muscle fiber.

Myofilaments

Thick filaments- constitute A band

- 14- 16 nm in diameter, 1.5 μm in length
- Predominant protein- myosin

Thin filaments-

- 6-8 nm in diameter, 1 μm on either side of Z disk
- constitute I band and extend beyond I band into A band
- Predominant protein- actin

Z disk ultrastructure

- An actin filament on one side of the Z disk lies between two actin filaments on opposite side of Z disk
- Actin filaments do not pass through the Z disk
- Z disk is made of Z filaments, connect with actin filaments on either side of Z disk.
- 1 actin filament connects to 4 Z filaments that pass through Z disk and then connects with an actin filament in the adjacent sarcomere

Proteins of myofibril

- More than 20 proteins where 6 constitute app 90% of total myofibrillar proteins (MP)
- Myosin, actin, titin, tropomyosin, troponin and nebulin
- On basis of function-
 - Contractile- actin , myosin
 - Regulatory- tropomyosin, troponin
 - Cytoskeletal- titin , nebulin (integral to structure of Z disk)

Contractile proteins

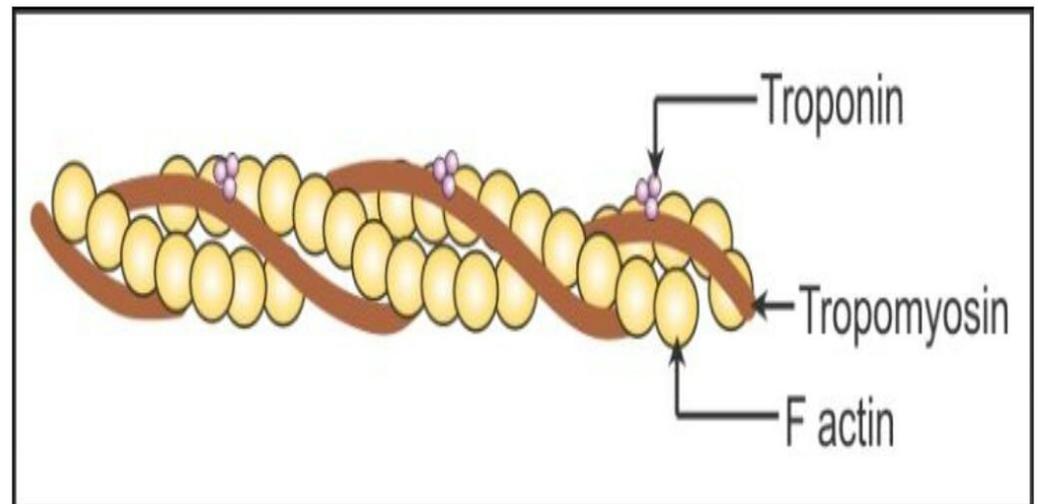
1. Actin- 20% of MP

Globular shaped app 5.5 nm in diameter

G shaped actin- monomeric form

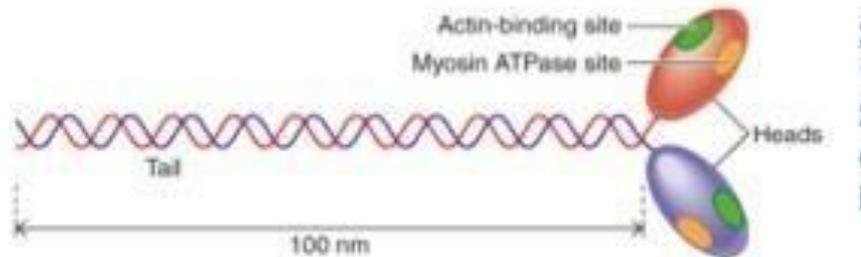
G actin monomers polymerize to form F actin

2 strands of F actin are spirally coiled around one another to form “super helix”

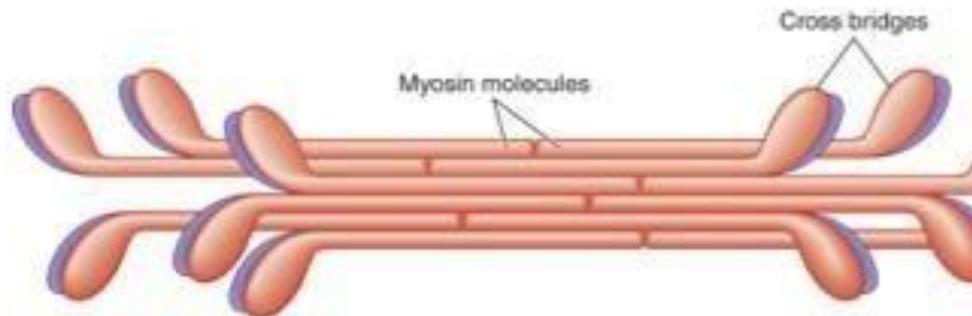


2. Myosin- Fibrous protein , 45% of MP

- Elongated rod shaped with a thickened portion at one end (head)
- Head region is double headed and projects laterally from the long axis of the filament



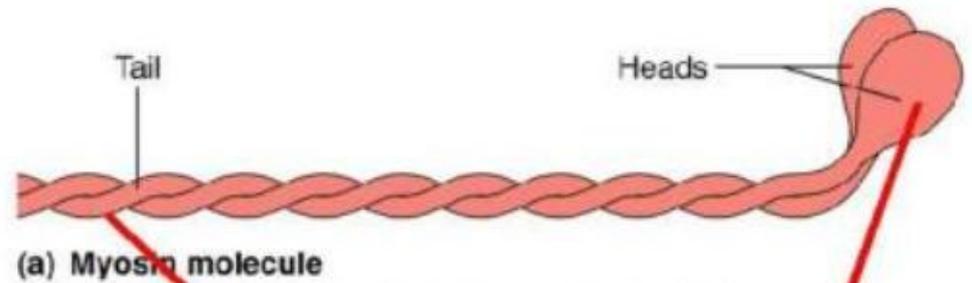
(a) Myosin molecule



(b) Thick filament

- Portion between head and tail is known as neck
- Myosin filaments are arranged in opposite directions on either side of M line.
- Myosin heads- active site which forms cross bridges with actin filaments during contraction
- Myosin when subjected to proteolytic digestion splits into two fractions ie. Light meromyosin and heavy meromyosin
- Pseudo H zone- centre of the A band myosin filaments contain only rod portion of myosin molecules, no heads present

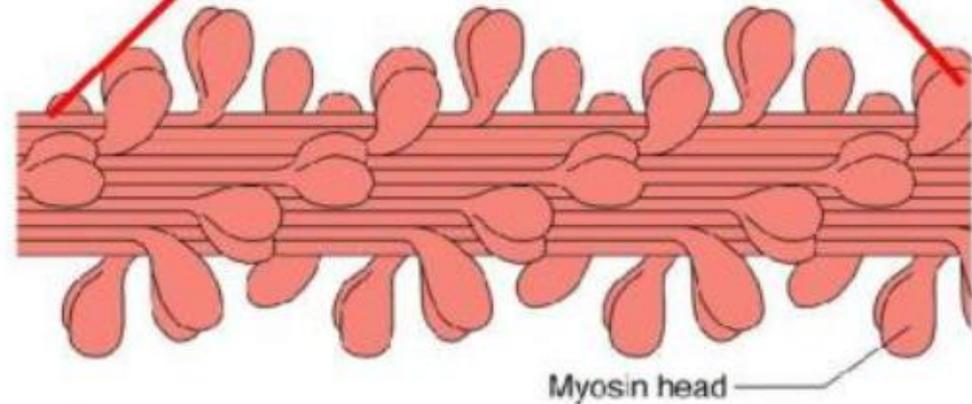
Thick Filament: Myosin



(a) Myosin molecule

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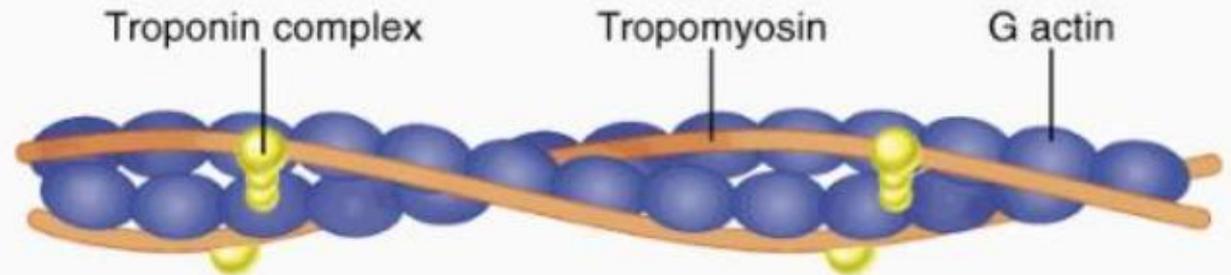
Myosin tails are arranged to point toward the center of the sarcomere, and the heads point to the sides of the myofilament band.



(b) Portion of a thick filament

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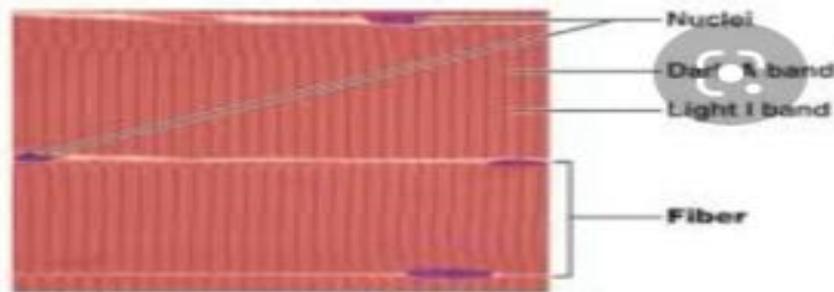
Thin Filament: Actin



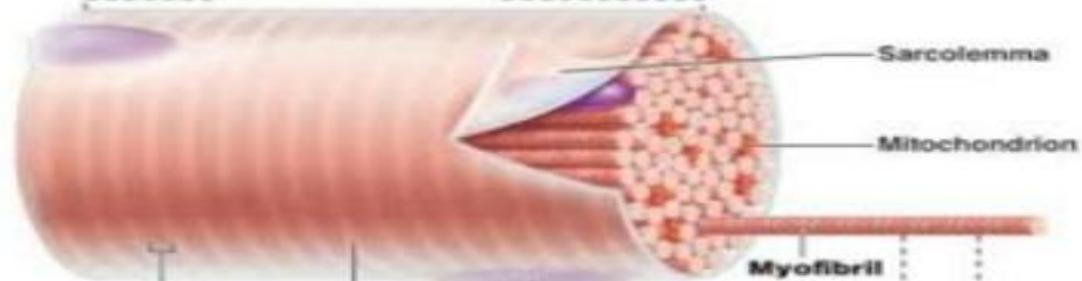
(c) Portion of a thin filament

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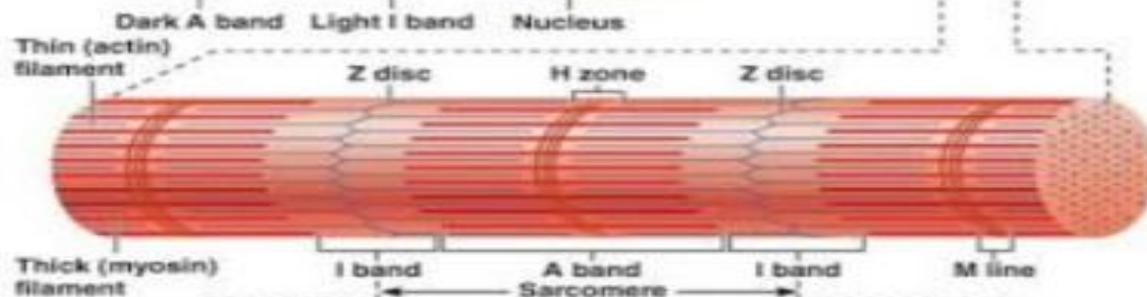
(a) Photomicrograph of portions of two isolated muscle fibers (700x). Notice the obvious striations (alternating dark and light bands).



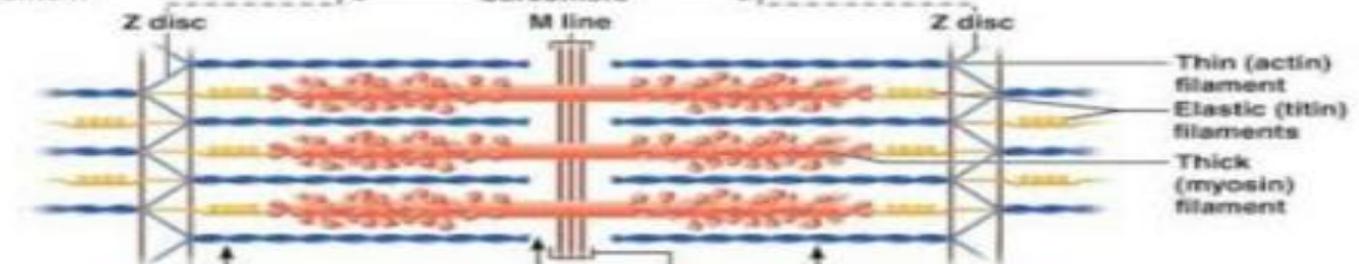
(b) Diagram of part of a muscle fiber showing the myofibrils. One myofibril extends from the cut end of the fiber.



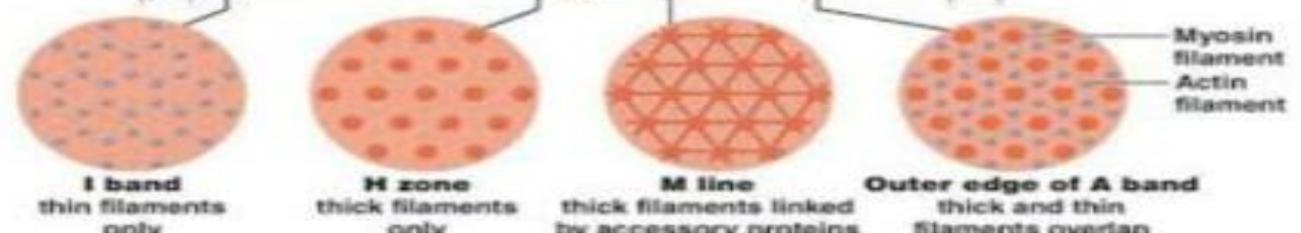
(c) Small part of one myofibril enlarged to show the myofilaments responsible for the banding pattern. Each sarcomere extends from one Z disc to the next.



(d) Enlargement of one sarcomere (sectioned lengthwise). Notice the myosin heads on the thick filaments.



(e) Cross-sectional view of a sarcomere cut through in different locations.



Regulatory proteins

Tropomyosin- 5 % of MP, Lies in close contact with actin filament

Each strand lies alongside, within each groove of actin super helix

Single molecule extends length of 7 G-actin mol .

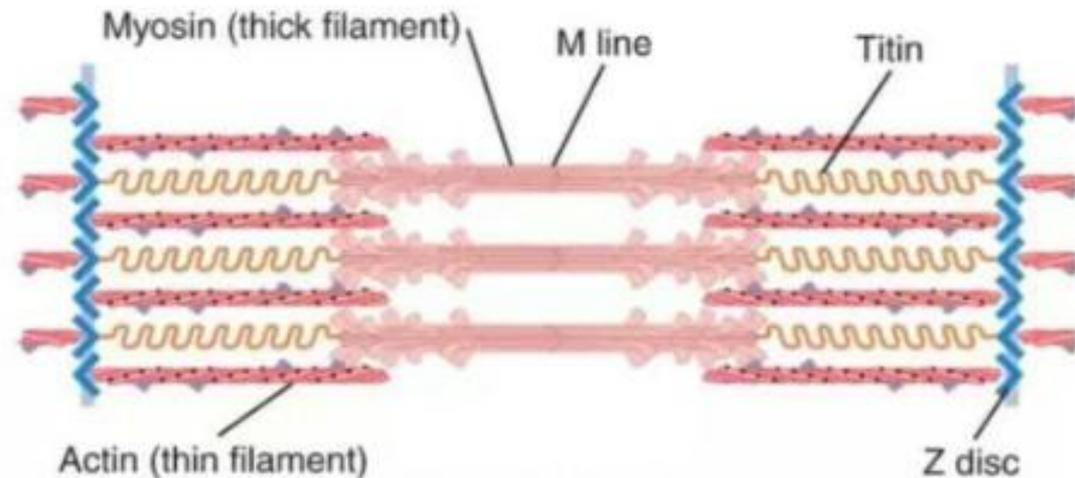
Troponin- 5% of MP

- Present at well defined intervals in grooves of actin filament
- Lies along the tropomyosin strands
- 1 mol of troponin for every 7-8 G actin molecules

* refer previous slide for representation

Cytoskeletal proteins

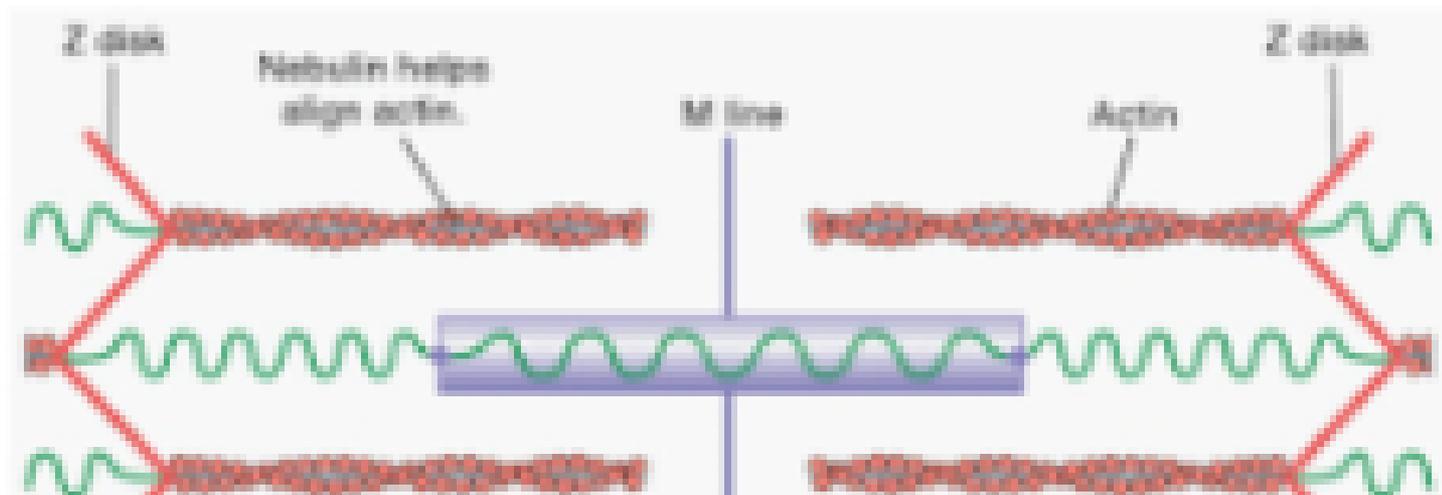
- **Titin**- most abundant, 10% of MP.
- 3rd filament
- Largest polypeptide known (25000 aa)
- Extend longitudinally in each half sarcomere from M line to Z disk
- Portion of titin in A band is inelastic and that in I band is elastic



Hall: Guyton and Hall Textbook of Medical Physiology, 12th Edition
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- Binds to the outside shaft of the thick filament and C protein that encircles and stabilizes the thick filament
- Provides scaffold for alignment of filaments during myofibril and sarcomere formation
- Mature myofibrils- maintains structure and integrity of myofibrils

- **Nebulin** – 4% of MP
- Located close and parallel to actin filament
- Extends along the length of the thin filament from A band to Z disk
- Developing muscle- organization of thin filaments
- Mature muscle- serves as scaffold for stability of thin filaments, anchors thin filaments to Z disk



- C protein- 2% , H protein- 1% , Myomesin-2% , Mprotein-1% , skelemin-1%- stabilize the rod portion of myosin molecules
- Alpha actinin (2%), Cap z (1%)- integral components of Z disk

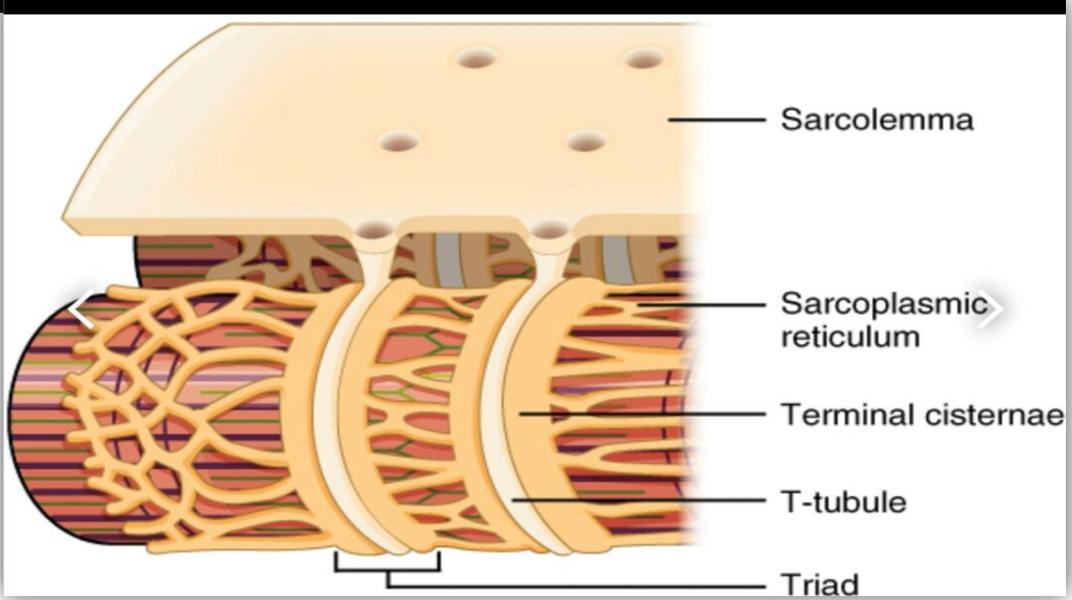
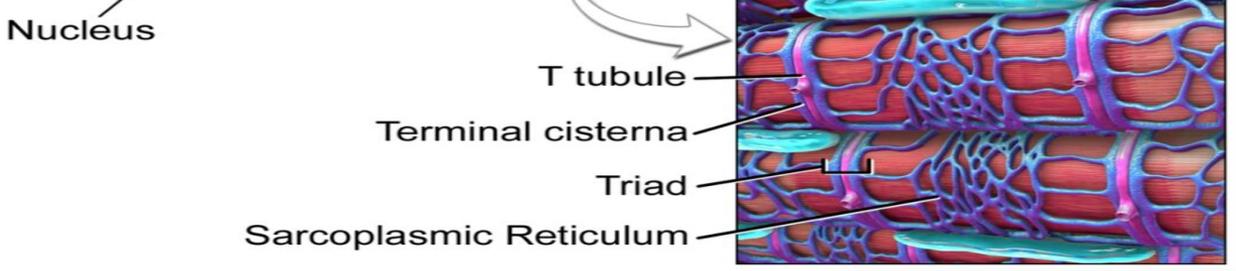
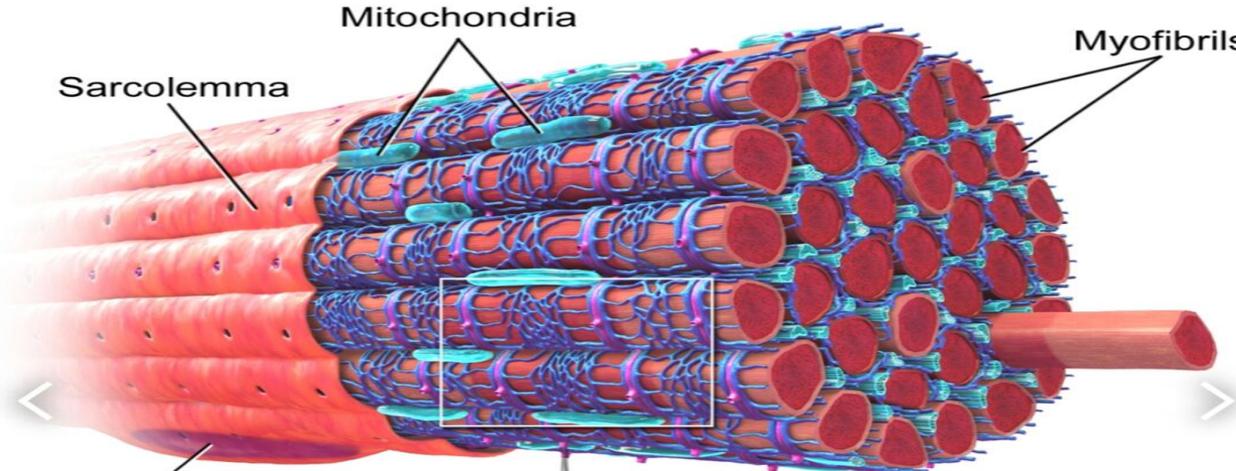
Sarcoplasmic reticulum and T tubules

- SR is a membranous system of tubules and cisternae that forms closely meshed network around each myofibril
- T tubules- associated with sarcolemma

Elements of SR

- Longitudinal tubules- thin tubules oriented in the direction of myofibrillar axis
- Fenestrated collar- In the H zone region the longitudinal tubules converge forming a perforated sheet
- Terminal cisternae- At junction of A and I band the longitudinal tubules converge and join with a pair of larger, transversly oriented tubular elements

- Longitudinal tubules extend from fenestrated collar to terminal cisternae in both directions
- T tubule runs transversely across the sarcomere at A-I band junction and lies between two tubular elements of the terminal cisternae pair
- Triad- structure formed by a T-tubule and terminal cisternae on either sides. This is located at A-I junction. It is responsible for regulation of excitation-contraction coupling, whereby a stimulus excites the muscle and causes it to contract.



- Mitochondria- located in sarcoplasm, power house of the cell
- Lysosomes- small vesicles located in the sarcoplasm. Contain enzymes capable of digesting cell. Cathepsins (proteolytic enzyme) is of major importance
- Golgi complex- secretory cells

- **Smooth muscle-** only a small proportion of meat, has single nucleus, centrally located. SR is less developed, myofilaments less ordered. Actin and myosin are present in same proportion as in skeletal muscle but no striations.
- **Cardiac muscle-** unique property of rhythmic contractability, centrally placed nucleus, less branched fibers, striated appearance. T-tubules are larger in diameter, occur at Z disk. Terminal cisternae is absent. Intercalated disk are present across the entire fiber

Connective tissue

- CT surrounding muscles, muscle bundles and muscle fibers is fibrous, k/a **connective tissue proper**
- Bone, cartilage- supportive CT

CT proper  ground substance plus embedded cells
extracellular fibers

Ground substance

- Viscous solution containing soluble glycoproteins referred to as proteoglycans (core protein attached to glycosaminoglycans)
- Contains substrates and end products of CT metabolism such as tropocollagen and tropoelastin
- Glycosaminoglycans – hyaluronic acid and chondroitin sulphate

Extracellular fibers

- Collagen and elastin
- Collagen- most abundant protein in animal body , significantly influences meat tenderness
- 20-25% of total body protein
- Principal structural protein of CT
- Glycoprotein that contain small amounts of glucose and galactose
- Glycine- most abundant aa , 1/3 rd of total aa
- Hydroxyproline and proline – another 1/3rd , hydroxyproline is constant (13-14%) component of collagen, does not occur in other animal proteins

- Tropocollagen – structural unit of collagen fibril
- Tropocollagen molecules are composed of three α chains to form a triple helix
- Accordingly 12 types of collagen out of which type I, III, IV, V and VII are associated with CT of skeletal muscle.
- Insolubility and high tensile strength of collagen fibers is due to intermolecular cross linkages which increases and becomes more stable with age. Hence meat from aged animals is tougher.

Elastin

- Less abundant CT, rubbery protein present in arterial walls and ligaments, framework of diff organs
- Glycine- most abundant aa
- Desmosine and isodesomine are 2 unique aa present in elastin
- Insolubility – presence of high content of non polar aa.

Connective tissue cells

- Fibroblasts- synthesize precursors of extracellular components of CT ie. Tropocollagen, tropoelastin and ground substance
- Mesenchymal cells- precursors of fibroblasts and adipoblasts
- Adipose cells- deposition of fat