

Physiology of Skeletal Muscle

The material contained in these slides corresponds to your assigned readings found in Chapter 10 of our text.

Introduction to Skeletal Muscle

- **Learning Objectives:**

1. Be familiar and understand the five general functions of skeletal muscle.
2. Know the five characteristics of skeletal muscle tissue.

Functions of Skeletal Muscle

- Movement (body)
 - Move bones, speak, breathe, swallow
- Maintenance of posture
 - Stabilize joints, allows us to maintain body position
- Protection and support
 - Package internal organs and hold them in place
- Regulating elimination of materials
 - Circular **sphincters** control passage of material at orifices (digestive system)
- Heat production
 - Help maintain body temperature (e.g. shivering thermogenesis)



Characteristics of Skeletal Muscle Tissue

- **Excitability:** can respond stimuli (neurotransmitters) by changing electrical membrane potential (and producing action potentials)
- **Conductivity:** transmit/propagate action potentials along the sarcolemma (similar to AP propagation along an axon)
- **Contractility:** allows for muscle fibers/cells (and whole muscles) to shorten (exhibited when filaments slide past each other)
- **Elasticity:** ability to return to original length following a lengthening or shortening
- **Extensible:** ability to be stretched

Anatomy of Skeletal Muscle

• Learning Objectives:

1. Identify and describe the three CT layers associated with a muscle.
2. Describe the structure and function of a tendon and an aponeurosis.
3. Explain the function of blood vessels and nerves serving a muscle.
4. Explain how a skeletal muscle fiber becomes multinucleated.
5. Describe the sarcolemma, T-tubules, and sarcoplasmic reticulum of a skeletal muscle fiber.
6. Distinguish between thick and thin filaments.

Anatomy of Skeletal Muscle con't

• Learning Objectives:

7. Understand the structural organization of myofibrils, myofilaments, and sarcomeres.
8. List and describe the structures associated with energy production within skeletal muscle fibers.
9. Define and know the components of a motor unit. Describe its distribution in a muscle, why it varies in size and how that affects muscle tension.
10. Be familiar with the three components of a neuromuscular junction.
11. Describe a skeletal muscle fiber at rest.

Gross Anatomy of Skeletal Muscle

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- What is the hierarchy of structures in a muscle?
 - A whole muscle contains many fascicles
 - A fascicle consists of many muscle fibers
 - A muscle fiber is a muscle cell
- In addition to the muscle cells, a skeletal muscle contains nerves, blood vessels, and connective tissue

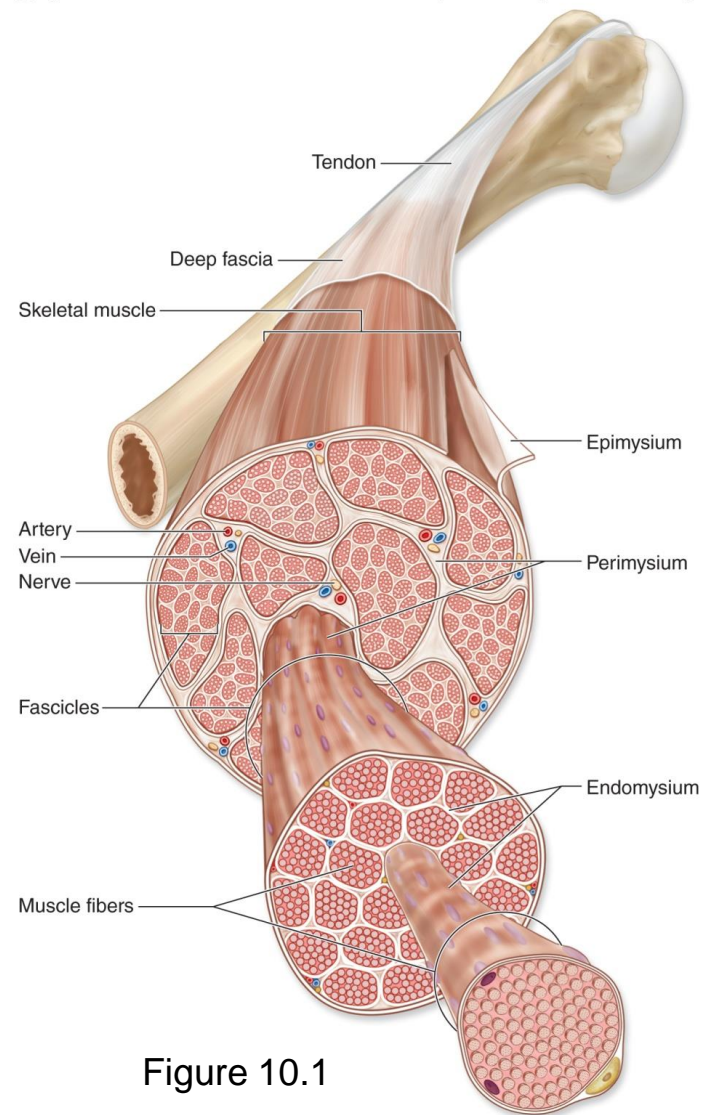


Figure 10.1



Gross Anatomy of Skeletal Muscle

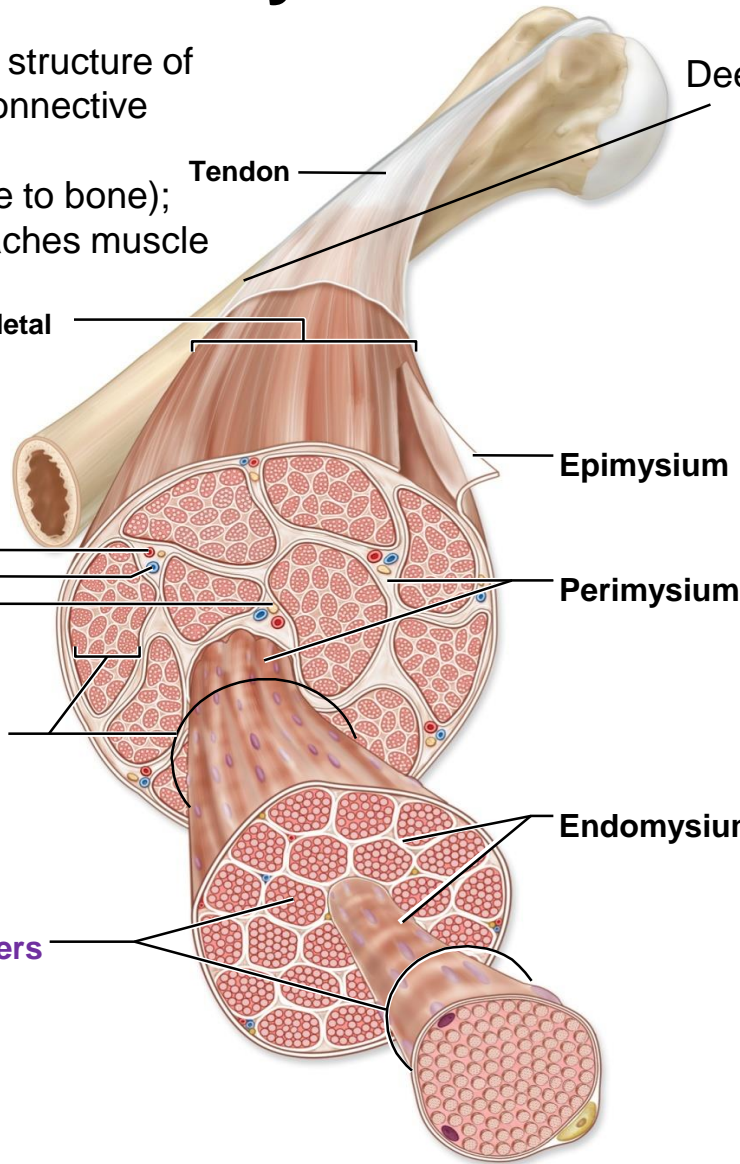
Tendon: cordlike structure of dense regular connective tissue (attaches muscle to bone); aponeurosis attaches muscle to muscle

Whole Skeletal muscle

Artery
Vein
Nerve

Fascicles

Muscle fibers



Deep fascia

Dense irregular connective tissue external to epimysium
Separates different muscles while binding them together; contains nerves, blood vessels, and lymph vessels

Epimysium – dense *irregular* CT (covers entire muscle)

Perimysium – dense *irregular* CT (covers *fascicles*); contains nerves and blood vessels (*arteries* & *veins*)

Endomysium – areolar CT (covers individual *muscle fibers*); provides capillary support to muscle fiber cells

Microscopic Anatomy of Skeletal Muscle

Development of Skeletal Muscle

Skeletal muscles are unique in that they are one of the few types of cells in our body which is *multinucleated*

Single muscle fibers are formed from the fusion of embryonic myoblasts cells. Each myoblast retains its nucleus during fusion leading to mature muscle fibers with multiple nuclei.

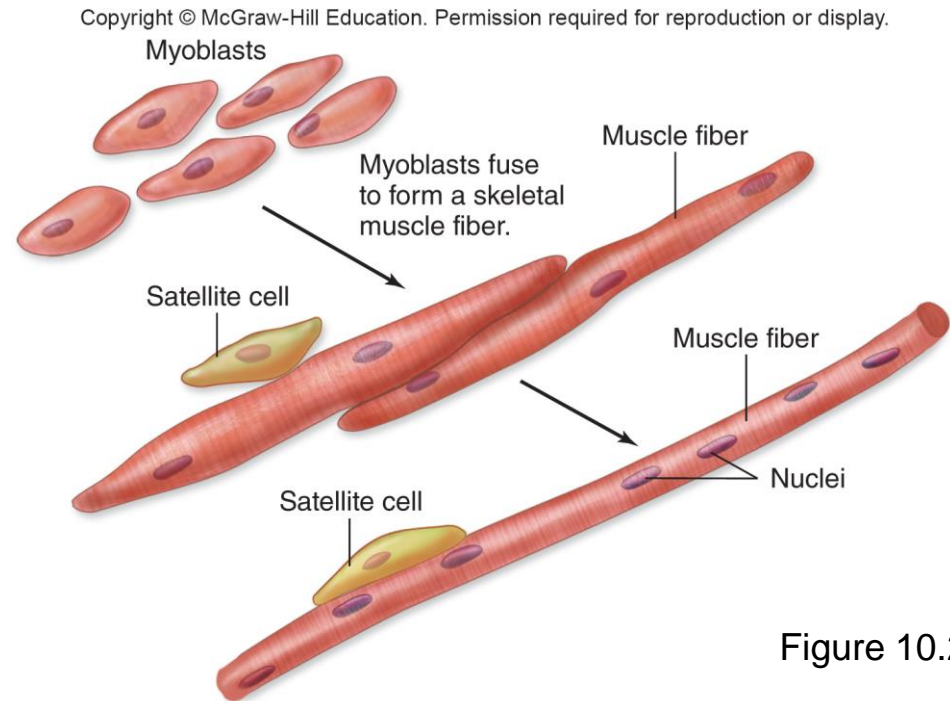
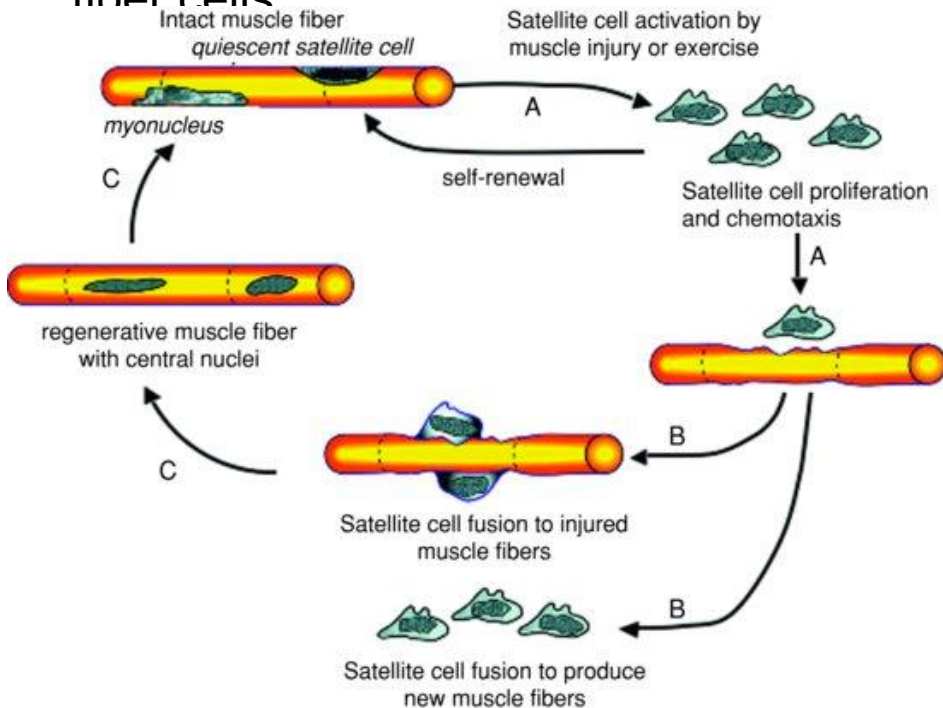


Figure 10.2

Microscopic Anatomy of Skeletal Muscle

Development of Skeletal Muscle

When muscle cells are injured, unfused embryonic cells 'satellite' (myosatellite) cells will fuse and attempt to repair damaged muscle fiber cells



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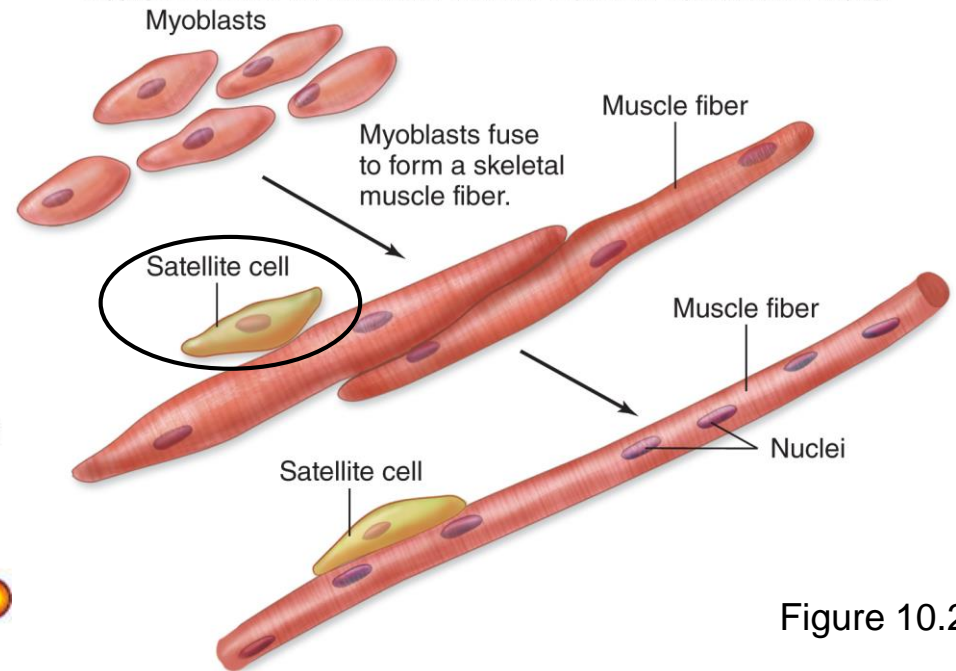
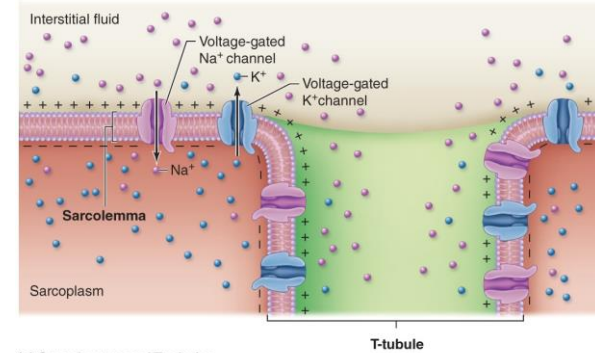


Figure 10.2

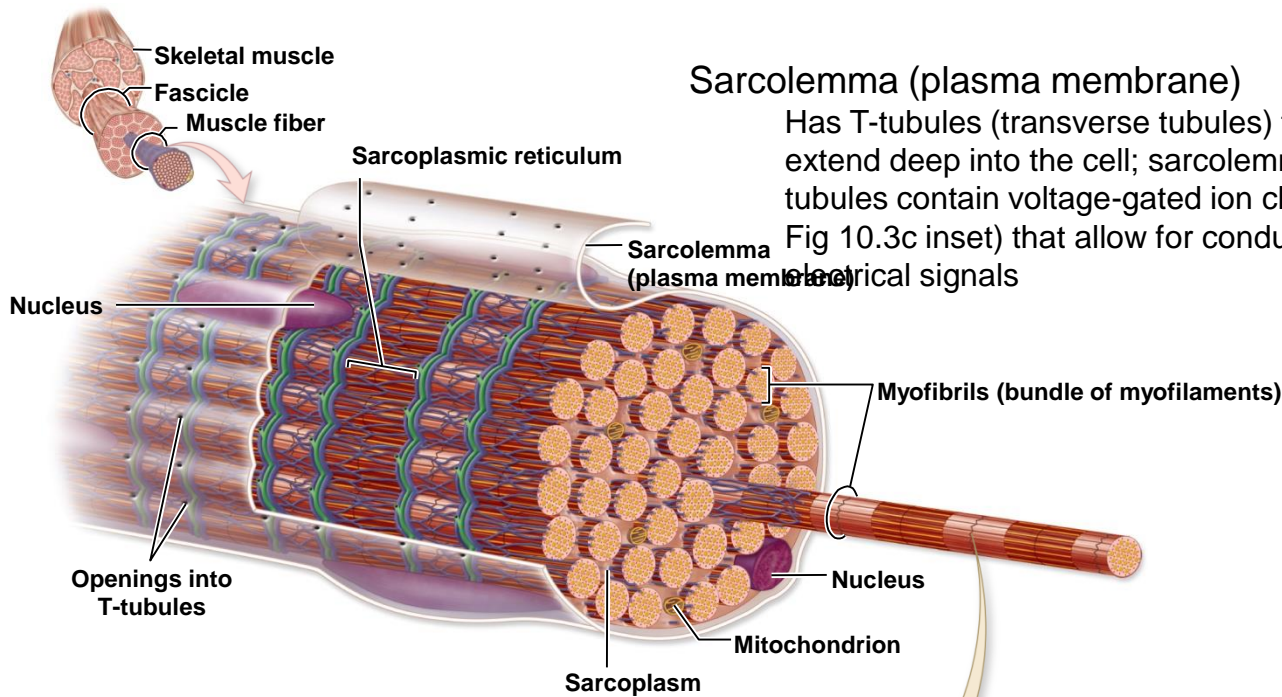
Microscopic Anatomy of Skeletal Muscle



(c) Sarcolemma and T-tubules

T-tubule

Figure 10.3c



Sarcolemma (plasma membrane)

Has T-tubules (transverse tubules) that extend deep into the cell; sarcolemma and its T-tubules contain voltage-gated ion channels (see Fig 10.3c inset) that allow for conduction of electrical signals

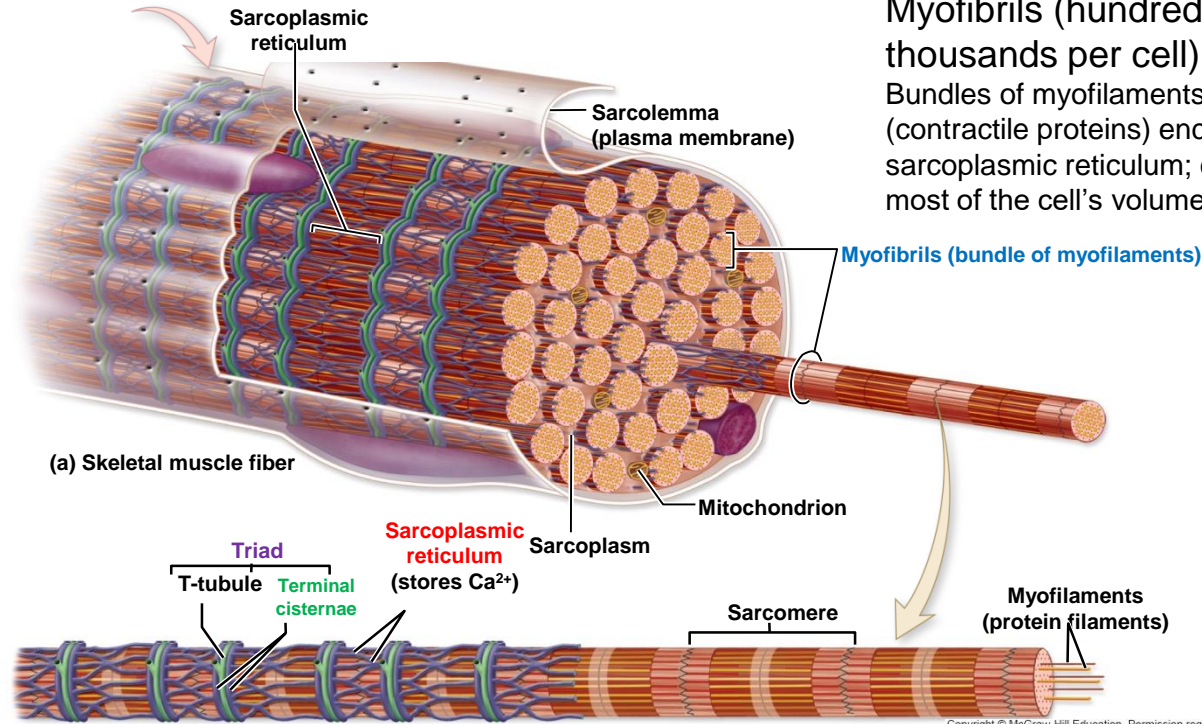
Sarcoplasm (cytoplasm)

Has typical organelles (e.g. mitochondria) plus contractile proteins

From Figure 10.3

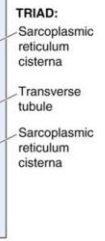
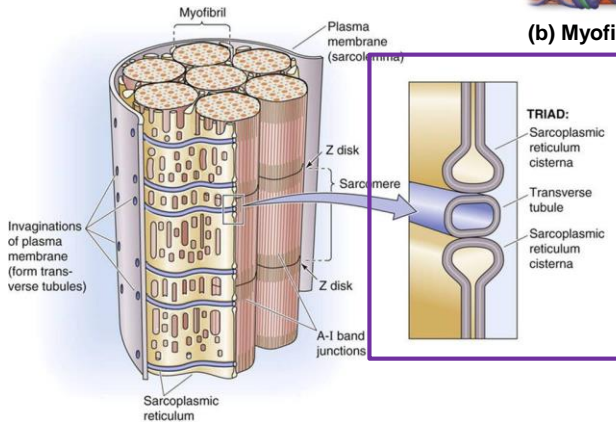
Microscopic Anatomy of Skeletal Muscle

Myofibrils (hundreds to thousands per cell)
 Bundles of myofilaments (contractile proteins) enclosed in sarcoplasmic reticulum; comprise most of the cell's volume



From Figure 10.3

(b) Myofibril

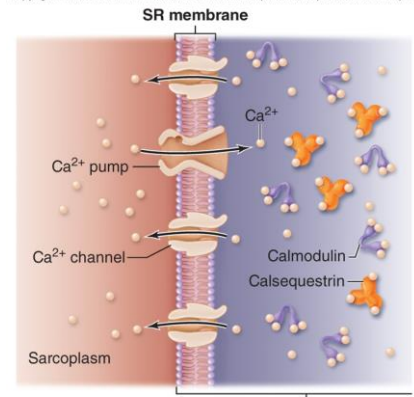


Sarcoplasmic reticulum (SR)

Internal membrane complex similar to smooth endoplasmic reticulum; contains

Terminal cisternae: blind sacs of sarcoplasmic reticulum
 Stores calcium ions until muscle fiber cells is stimulated; arranged in groups of two which border a T-tubule to form a **Triad**

SR also contains channels which allow for calcium diffusion when a muscle fiber is stimulated and calcium pumps (SR Ca²⁺ ATPase) which actively transport calcium from the sarcoplasm to the SR.



(d) Sarcoplasmic reticulum

Microscopic Anatomy of Skeletal Muscle

- **Myofibrils** contain thick and thin filaments

- **Thick filaments**

(myosin – contractile protein)

- Consist of bundles of many myosin protein molecules
 - Each myosin molecule has two heads and two intertwined tails
 - Heads have binding site for actin of thin filaments and ATPase site
 - Heads point toward ends of the filament

- **Thin filaments**

(actin – contractile protein)

- Consist fibrous actin (F-actin)
- Each strand (of F-actin composed of actin globules (G-actin))
- Each G-actin has a myosin binding site to which myosin heads attach during contraction

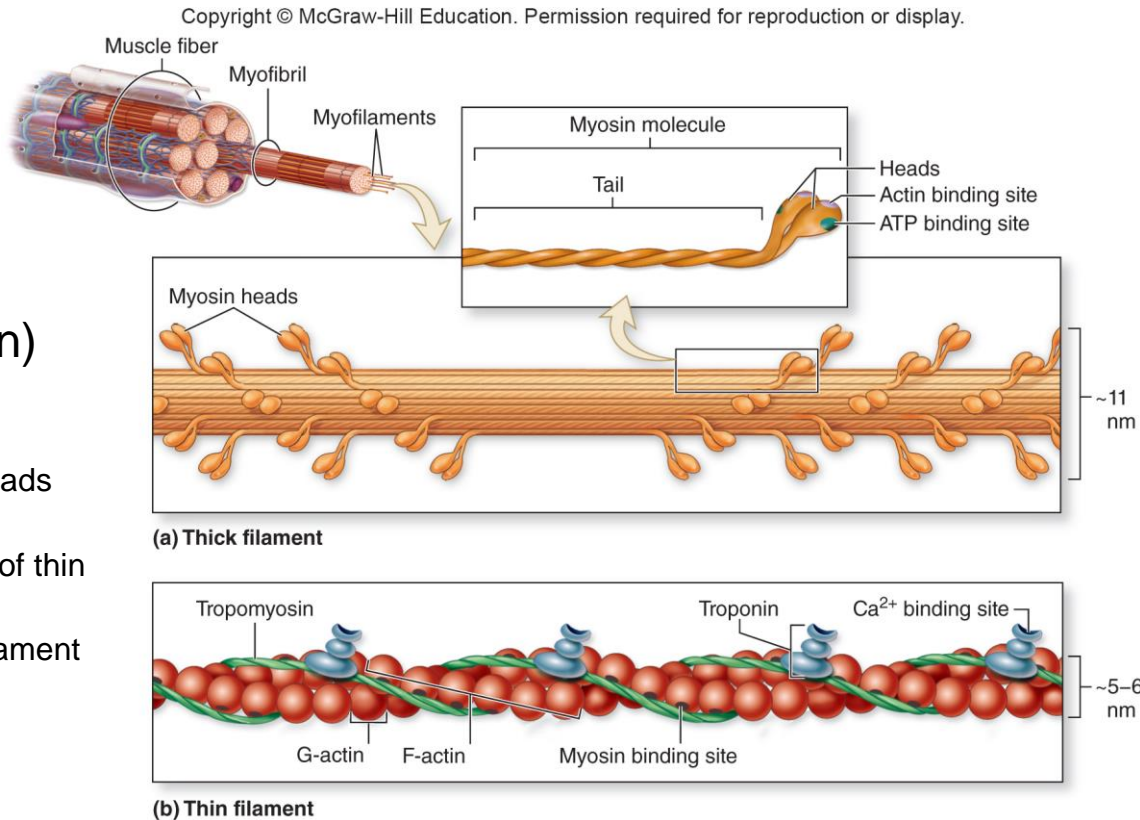
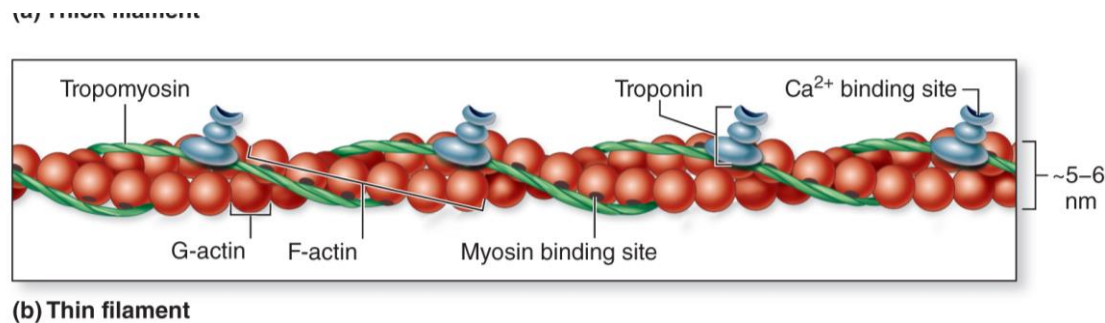


Figure 10.4

Microscopic Anatomy of Skeletal Muscle



From Figure 10.4

- **Myofibrils** also contain regulatory proteins
 - Troponin and Tropomyosin (regulatory proteins)
 - Tropomyosin: twisted stringlike protein covering actin in a noncontracting muscle
 - Troponin: globular protein attached to tropomyosin
 - When Ca²⁺ binds to troponin it pulls tropomyosin off actin allowing contraction

Microscopic Anatomy of Skeletal Muscle

- Organization of a sarcomere
 - Myofilaments arranged in repeating units, **sarcomeres** ‘functional units’
 - Composed of overlapping thick and thin filaments
 - Separated at both ends by **Z discs** which anchor thin filaments
 - Specialized proteins perpendicular to myofilaments
 - Anchors for thin filaments
 - The positions of thin and thick filaments give rise to alternating I-bands and A-bands

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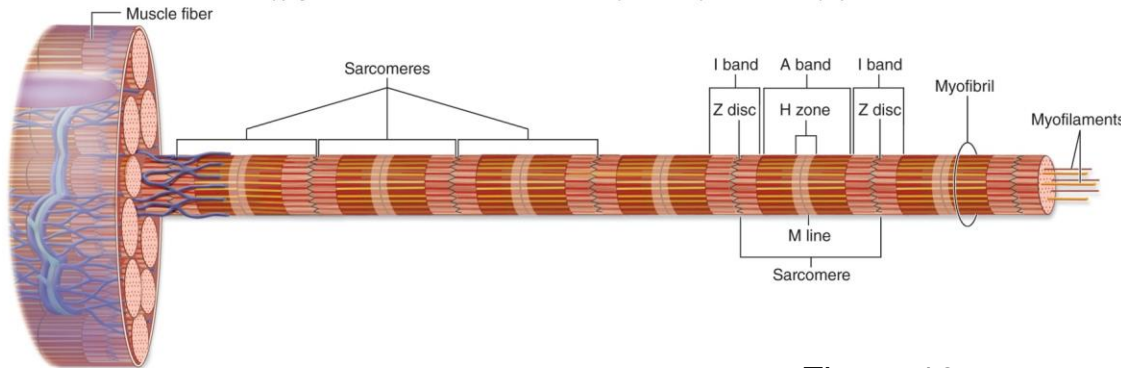
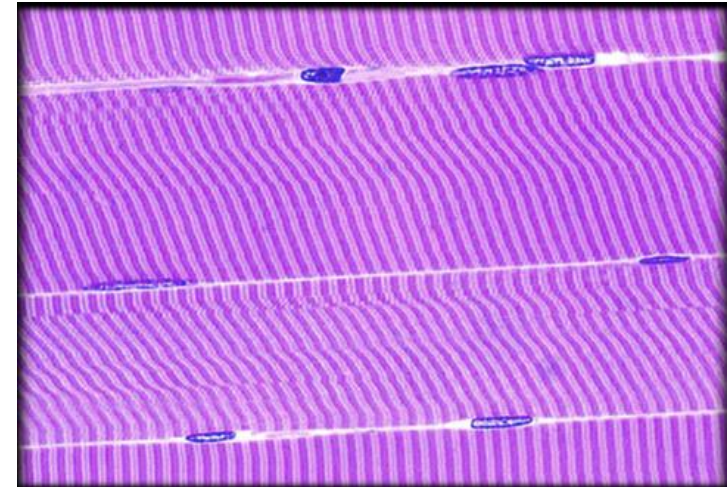


Figure 10.5a



(a)



Microscopic Anatomy of Skeletal Muscle

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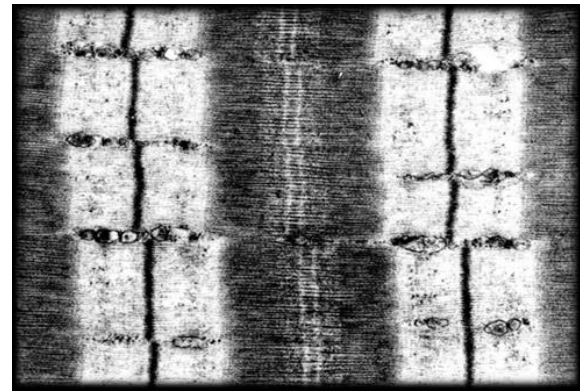
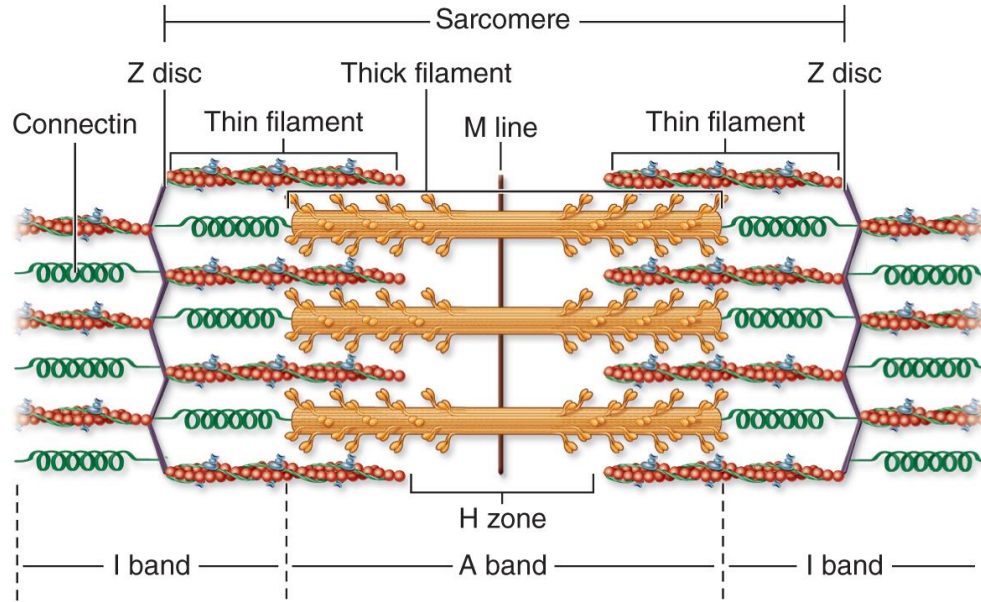


Figure 10.5 b



(b) I bands

Light-appearing regions that contain only thin filaments
 Bisected by Z disc
 Get smaller when muscle contracts (can disappear with maximal contraction)

A band

Dark-appearing region that contains thick filaments and overlapping thin filaments
 Contains H zone and M line
 Makes up central region of sarcomere

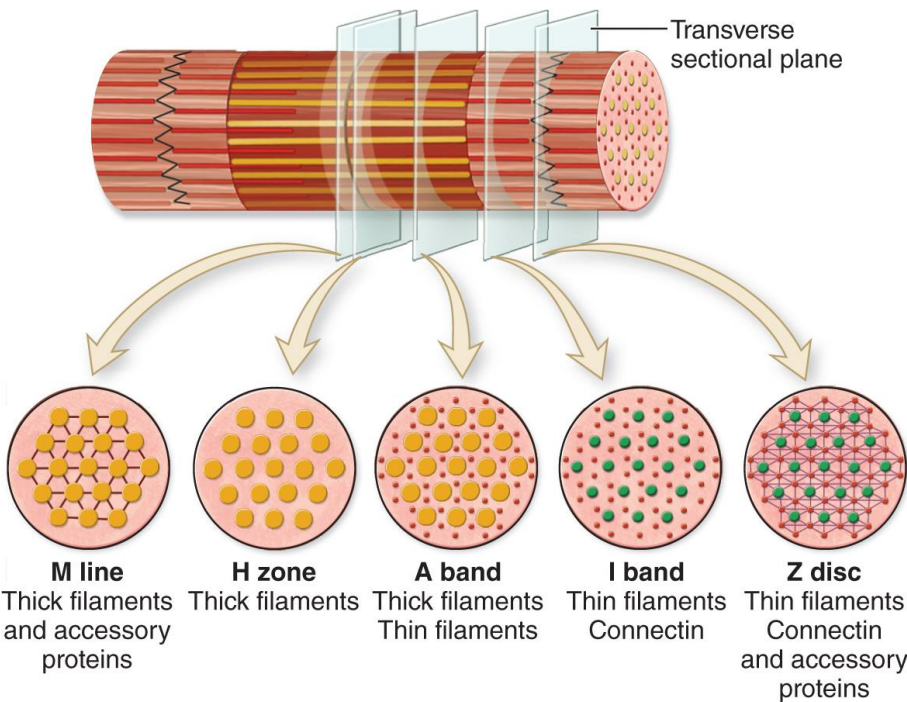
- **H zone:** central portion of A band
 Only thick filaments present; no thin filament overlap
 Disappears with maximal muscle contraction
- **M line:** middle of H zone
 Protein meshwork structure
 Attachment site for thick filaments



Microscopic Anatomy of Skeletal Muscle

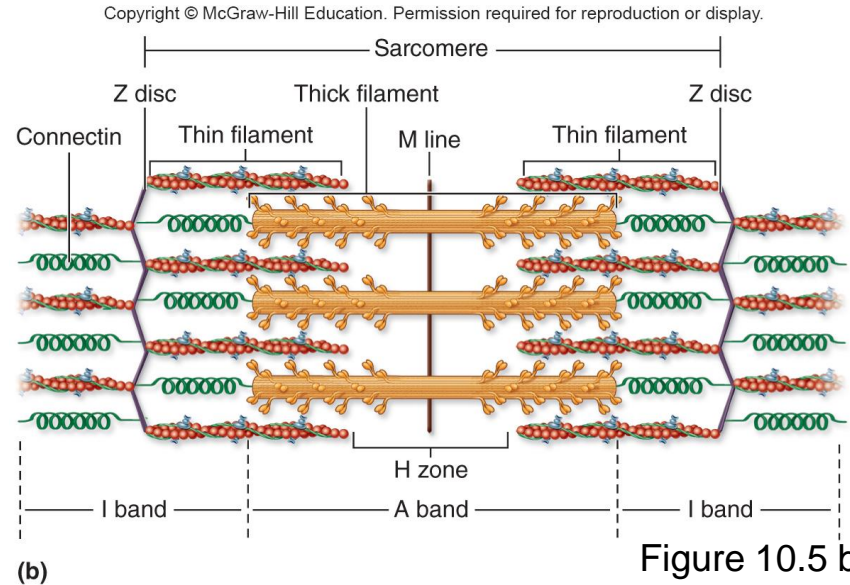
The interactions of the contractile overlap in a hexagonal pattern. Depending on the location one views the sarcomere, the presence of contractile and regulatory proteins will vary.

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(c)

Figure 10.5 c



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Microscopic Anatomy of Skeletal Muscle

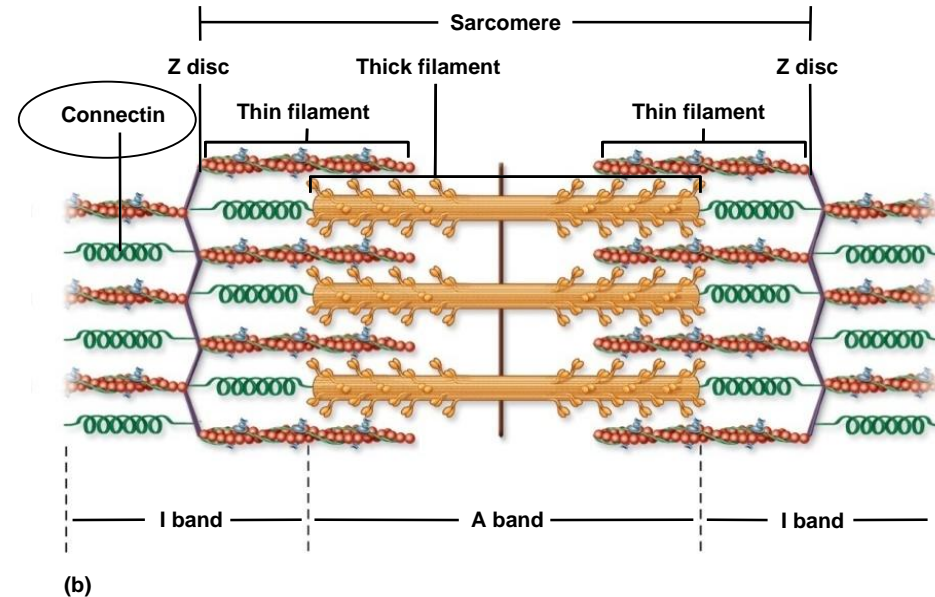
- Other structural and functional proteins

- **Connectin (Titin)**

- Stabilizes thick filaments and has “springlike” properties (passive tension)

- **Dystrophin**

- Anchors some myofibrils to sarcolemma proteins
- Abnormalities of this protein cause muscular dystrophy



Jerry Lewis ★

MDA TELETHON

Helping Jerry's Kids

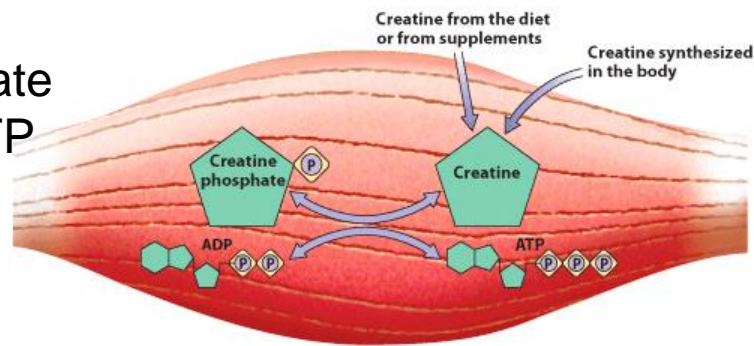
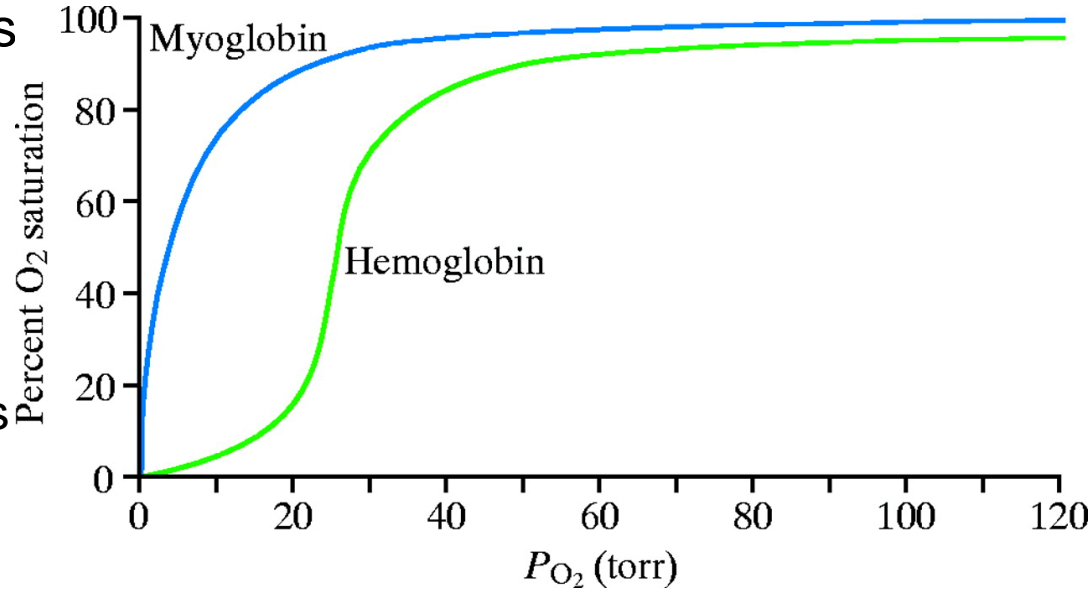


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Microscopic Anatomy of Skeletal Muscle

- Mitochondria and other structures associated with energy production

- Muscle fibers have abundant mitochondria for aerobic ATP production
- **Myoglobin** within cells allows storage of oxygen used for aerobic ATP production
- Glycogen is stored for when fuel is needed quickly
- Creatinine phosphate can quickly give up its phosphate group to help replenish ATP supply



Innervation of Skeletal Muscle Fibers

- **Motor unit:** a motor neuron and all the muscle fibers it controls

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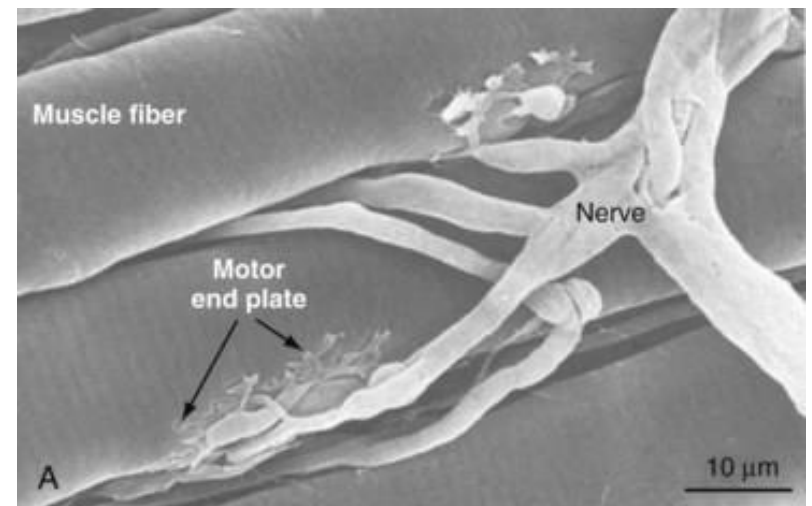
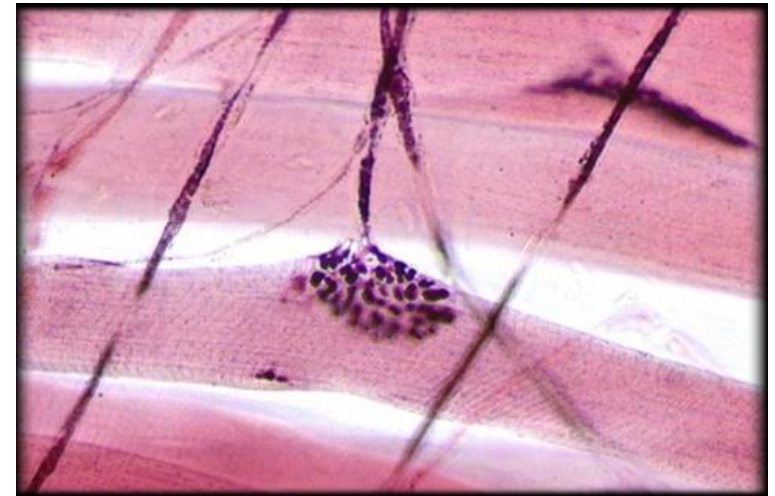
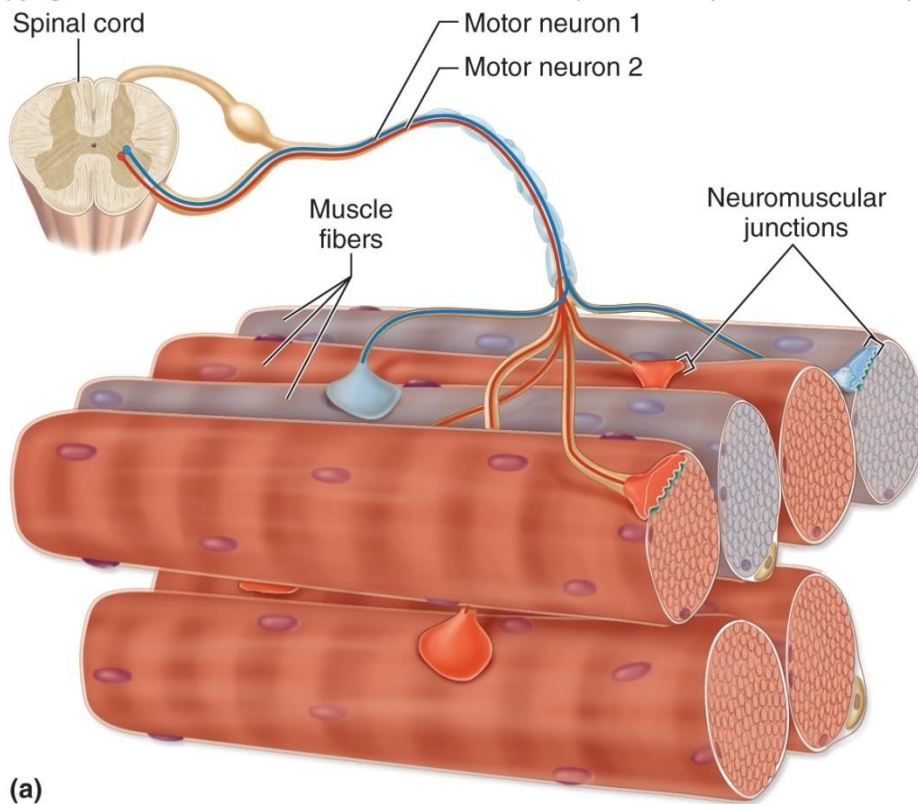
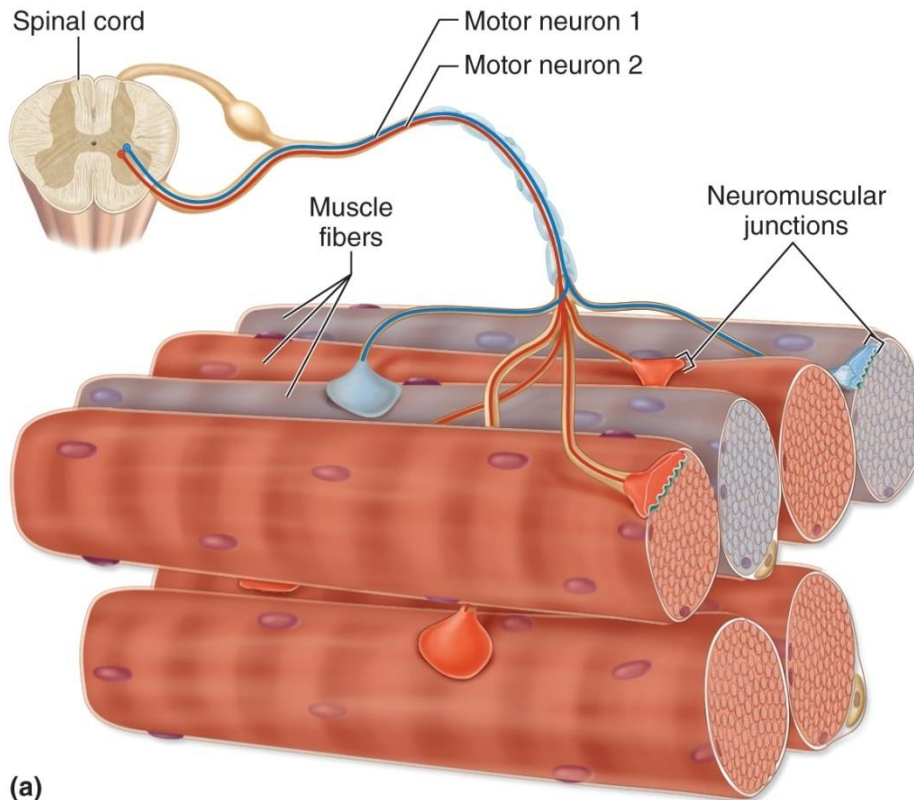


Figure 10.6a

Innervation of Skeletal Muscle Fibers

- **Motor unit:** a motor neuron and all the muscle fibers it controls

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- Motor unit

- Axons of motor neurons from spinal cord (or brain) innervate numerous muscle fibers
- The number of fibers a neuron innervates varies
 - Small motor units have less than five muscle fibers (allows for precise control)
 - Large motor units have thousands of muscle fibers (allows for large forces but not precise control)
- Fibers of a motor unit are dispersed throughout the muscle (not just in one clustered compartment)

Figure 10.6a

Innervation of Skeletal Muscle Fibers

• Neuromuscular junction

- Location where motor neuron innervates muscle
- Usually mid-region of muscle fiber
- Has synaptic knob, synaptic cleft, motor end plate

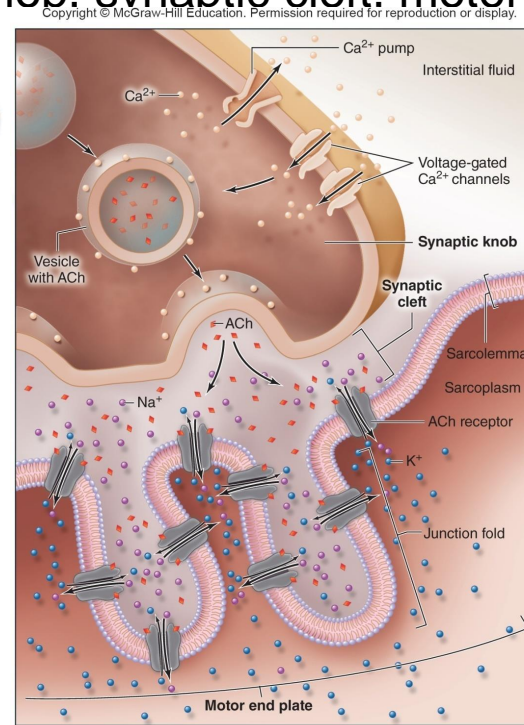
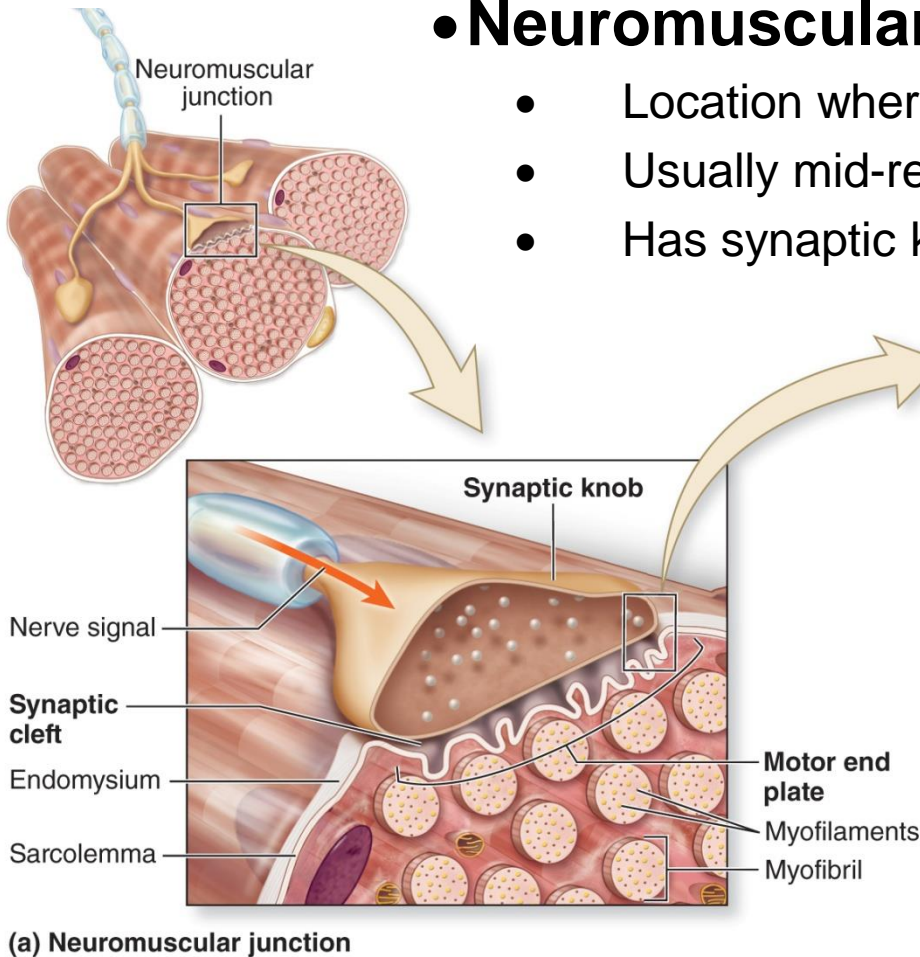


Figure 2.7a

Innervation of Skeletal Muscle Fibers

Synaptic knob

Expanded tip of the motor neuron axon that contains:

- synaptic vesicles containing acetylcholine (ACh)
- Ca^{2+} pumps in plasma membrane (establishes Ca^{2+} gradient)
- voltage-gated Ca^{2+} channels in membrane

Synaptic cleft

Narrow fluid-filled space

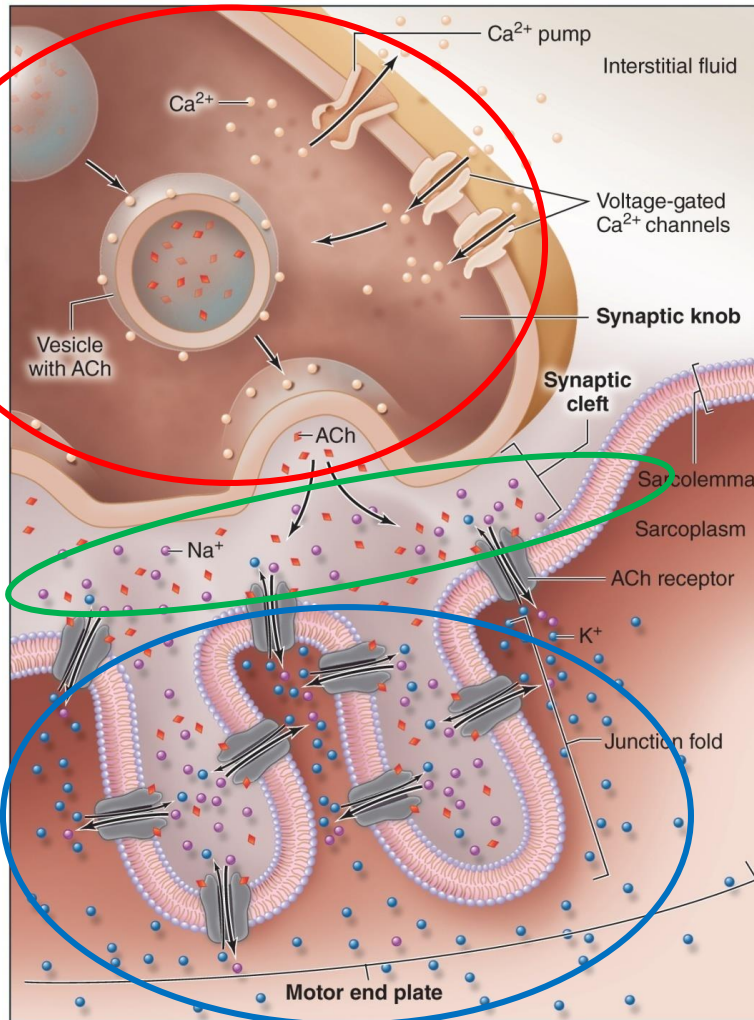
Separates synaptic knob from motor end plate

Acetylcholinesterase resides here

Enzyme that breaks down ACh molecules

Motor end plate

Specialized region of sarcolemma with numerous folds containing ACh receptors



(b) Close-up of neuromuscular junction

Figure 2.7b



Skeletal Muscle Fibers at Rest

- Muscle fibers exhibit **resting membrane potential (RMP)**
 - Fluid inside cell is negative compared to fluid outside cell
 - RMP of muscle cell is about -90 mV
 - RMP set by leak channels and Na^+/K^+ pumps (not shown). Also present are voltage-gated channels which play a role in action potential propagation.

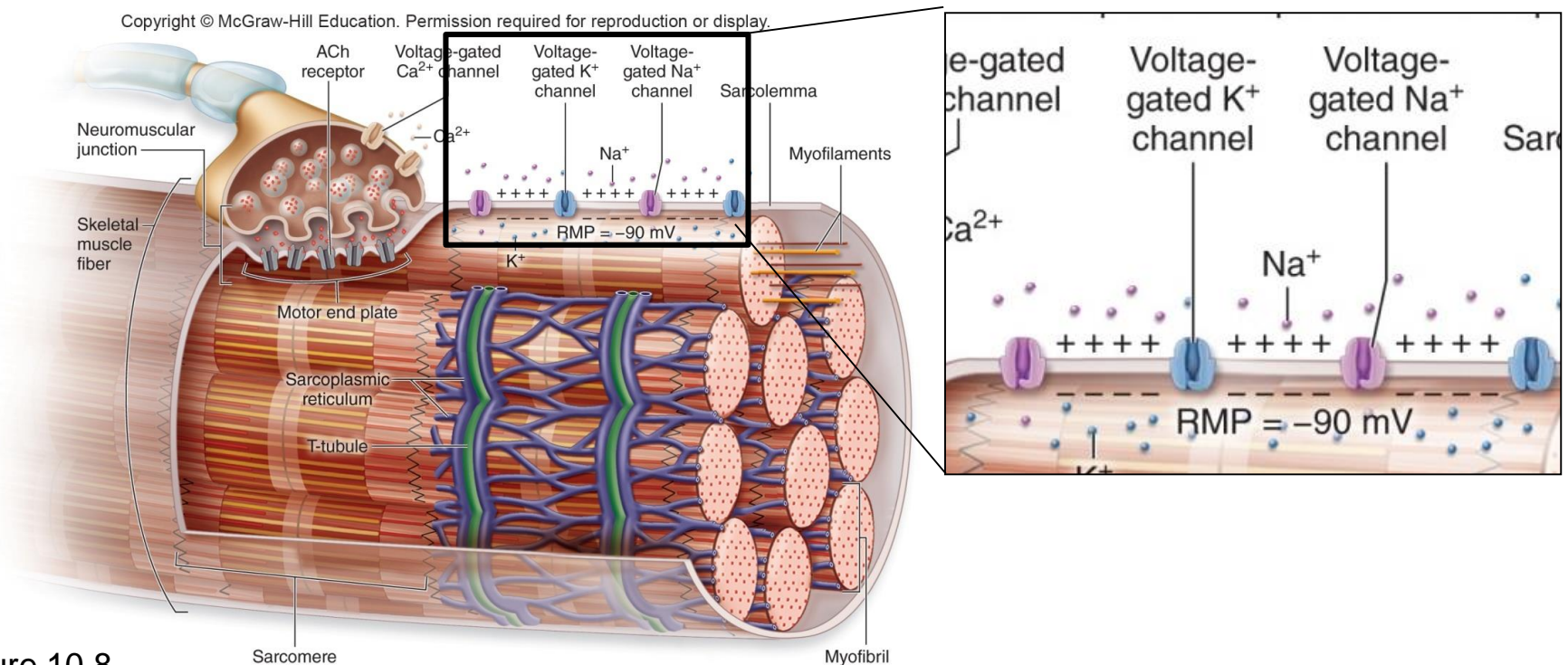


Figure 10.8