Back-to-Basics: The Intricacies of Muscle Contraction

MIOTA CONFERENCE

OCTOBER 11, 2019

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OBJECTIVES:

1. Review the anatomical structure of a skeletal muscle.
2. Review and understand the process and relationship between skeletal muscle contraction with the vital components of the nervous system, endocrine system, and skeletal system.
3. Review the basic similarities and differences between skeletal muscle tissue, smooth muscle tissue, and cardiac muscle tissue.
4. Review the names, locations, origins, and insertions of the skeletal muscles found in the human body.
5. Apply the information learned to enhance clinical practice and understanding of the intricacies and complexity of the skeletal muscle system.
6. Apply the information learned to further educate clients on the importance of skeletal muscle movement, posture, and coordination in the process of rehabilitation, healing, and functional return.

Four Basic Tissue Categories

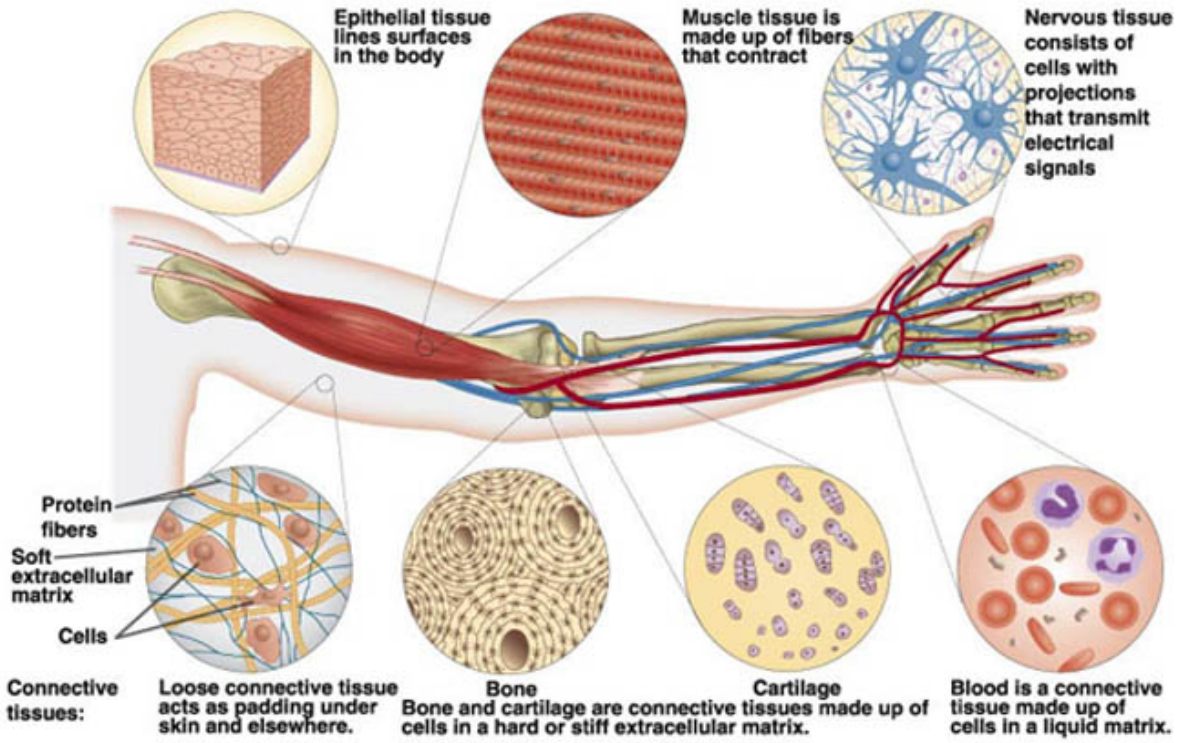
1. *Epithelial*
2. *Muscle*
3. *Nervous*
4. *Connective*

A. Loose Connective

B. Bone

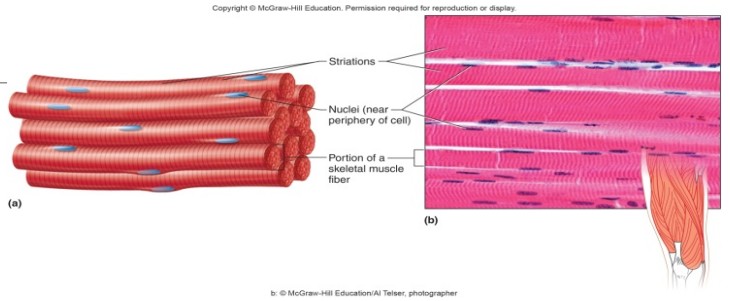
C. Cartilage

D. Blood

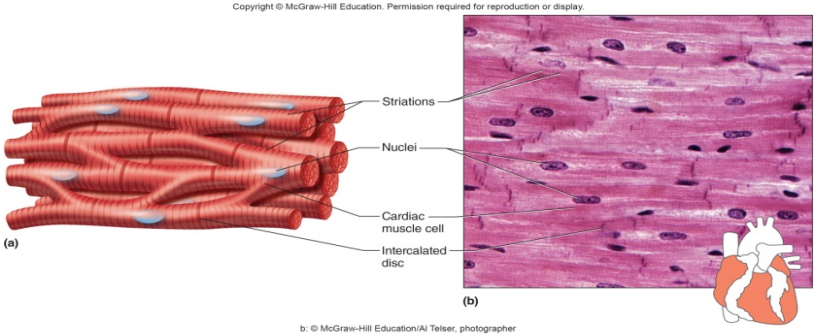


Introduction

There are 3 types of muscle tissue in the muscular system: .



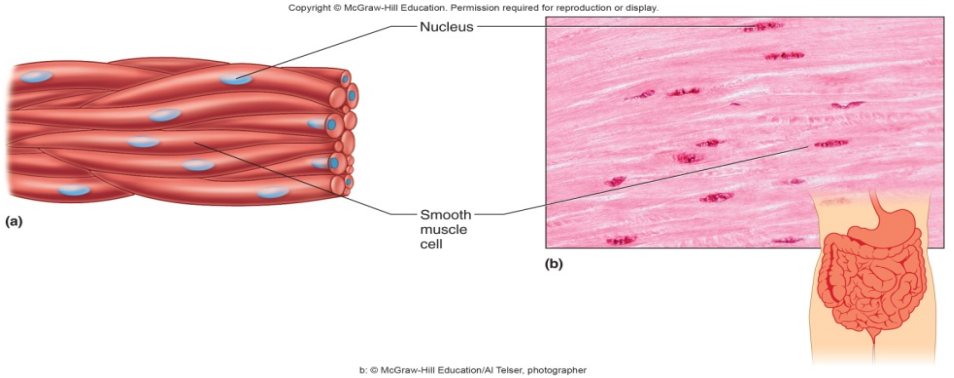
Skeletal muscle: Attached to bones of skeleton. Voluntary. Striated. Tubular shape.



Cardiac muscle: Makes up most of the wall of the heart. Involuntary. Striated with intercalated discs. Branched shape.

Smooth muscle: Found in walls of internal organs and walls of vascular system. Involuntary.

Non-striated. Spindle shape.



Structure of a Skeletal Muscle

Skeletal Muscles:

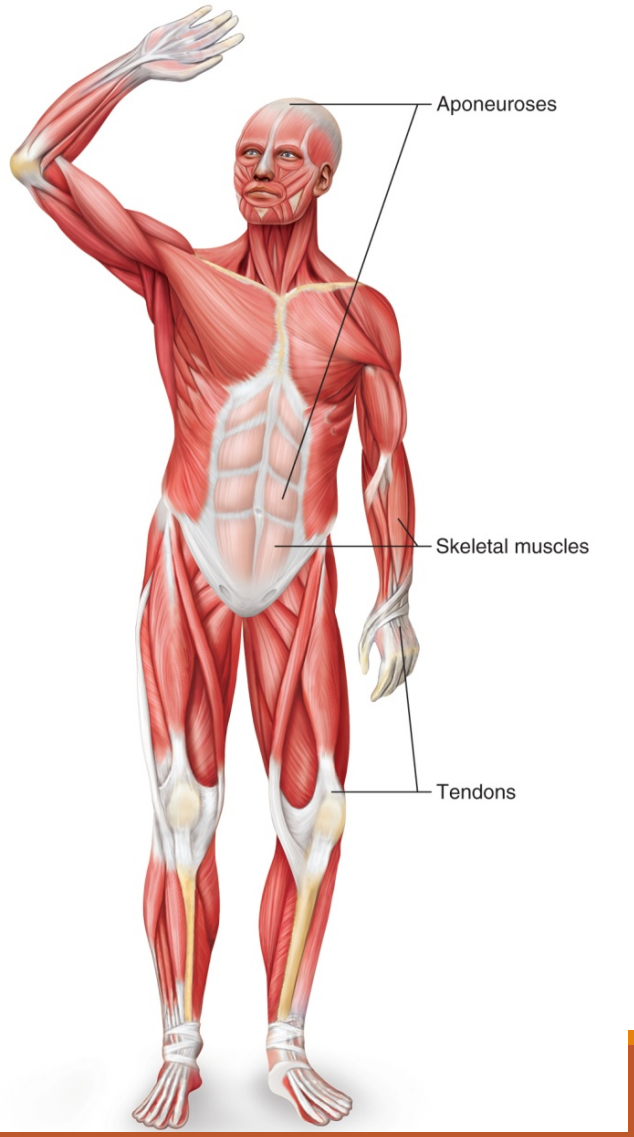
Skeletal muscles are composed of:

- Skeletal muscle tissue
- Nervous tissue
- Blood
- Connective tissues

Connective Tissue Coverings

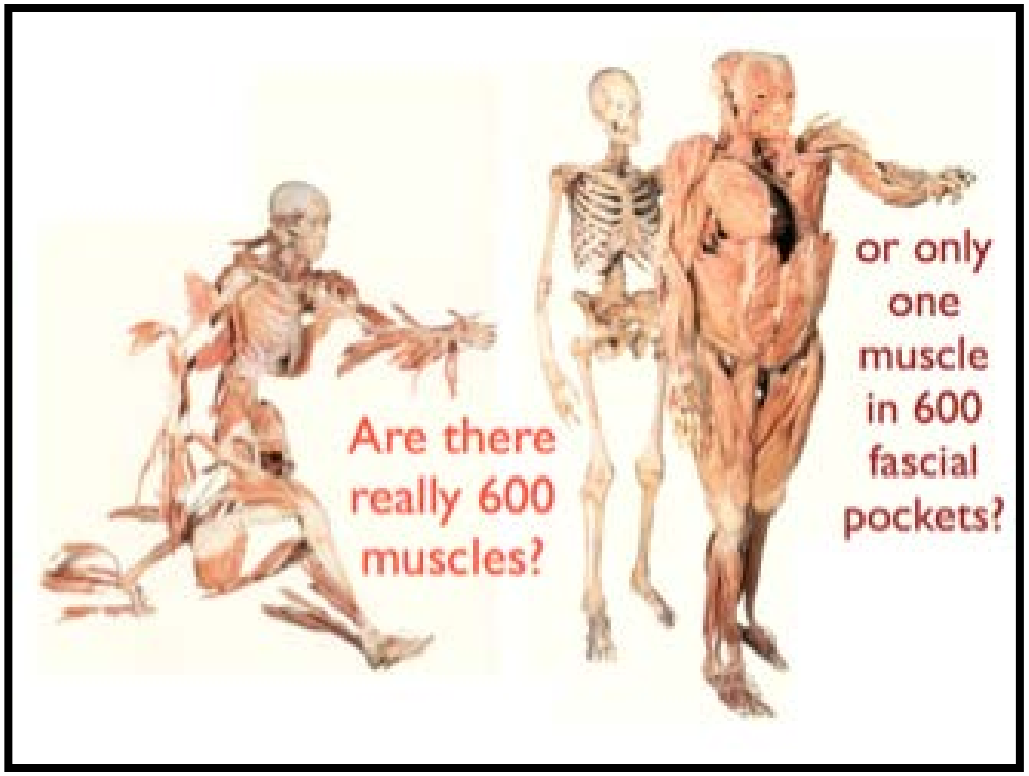
Connective tissue coverings over skeletal muscles:

- Fascia
- Tendons
- Aponeuroses



Fascia:

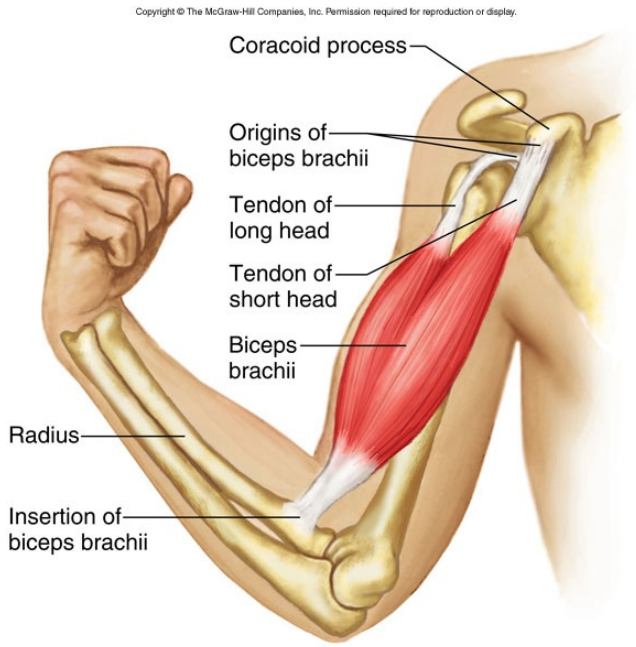
Definition: Layers of dense connective tissue that separates muscle from adjacent muscles, by surrounding each muscle belly.



* Deep fascia helps to form the **subcutaneous layer** of the integumentary system.

Tendons:

1. Muscles are connected to bones by **tendons**. Tendons are made up of **fibrous [dense regular] connective tissue.**



2. **Tendons** hold muscle to bone. Its fibers intertwine with those of the periosteum, which allows movement of a muscle over a joint.

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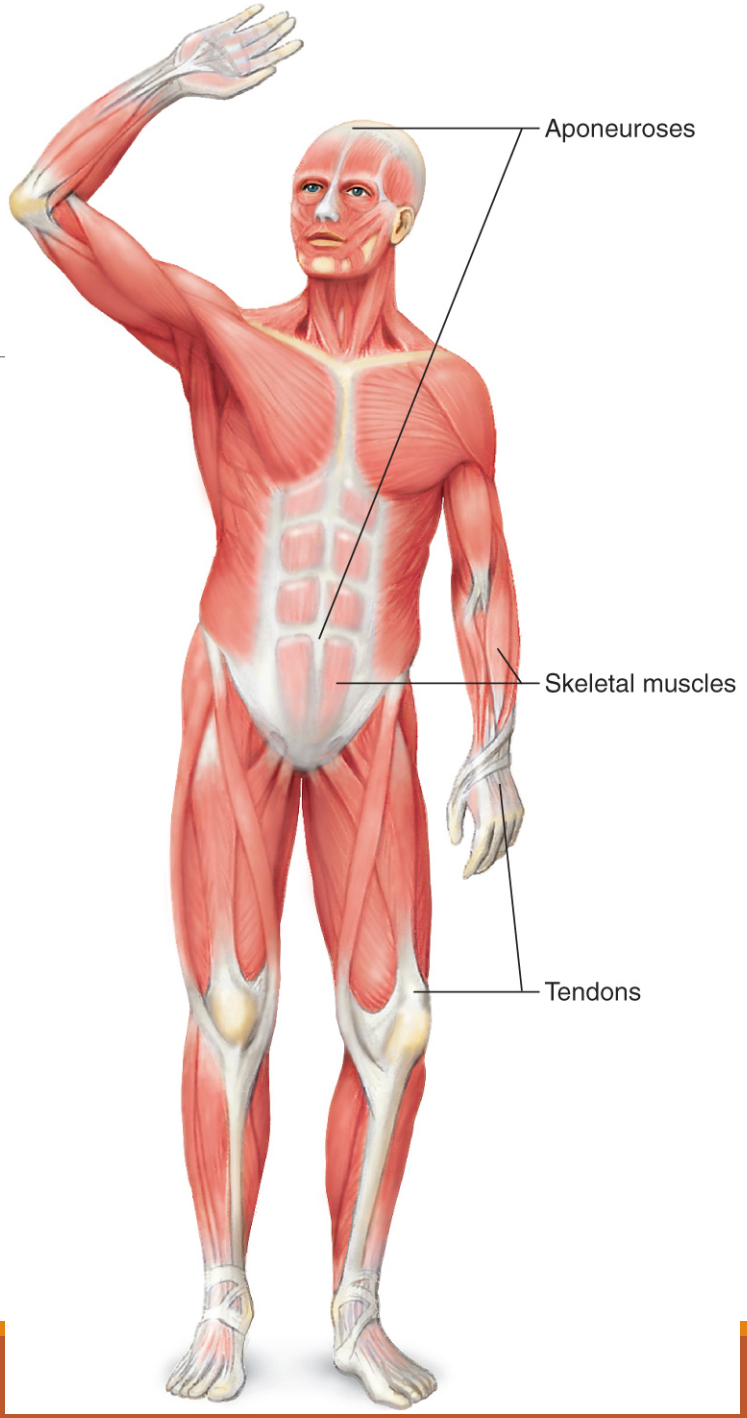
Aponeuroses =

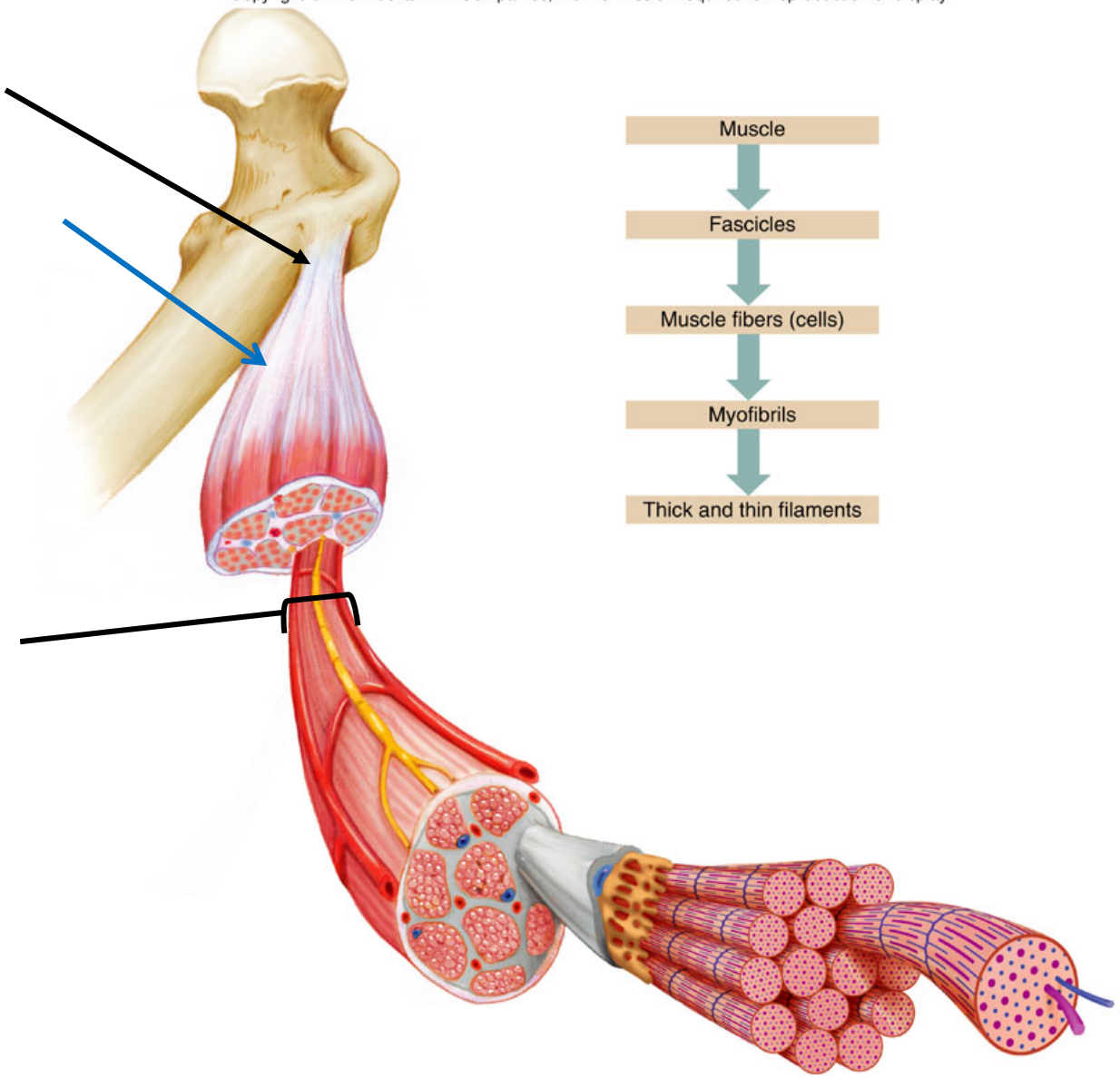
connective tissue of a muscle that forms broad, fibrous sheets to connect <u>muscle to muscle</u>



Tendon

Fascia

Fascicle: a bundle of muscle fibers



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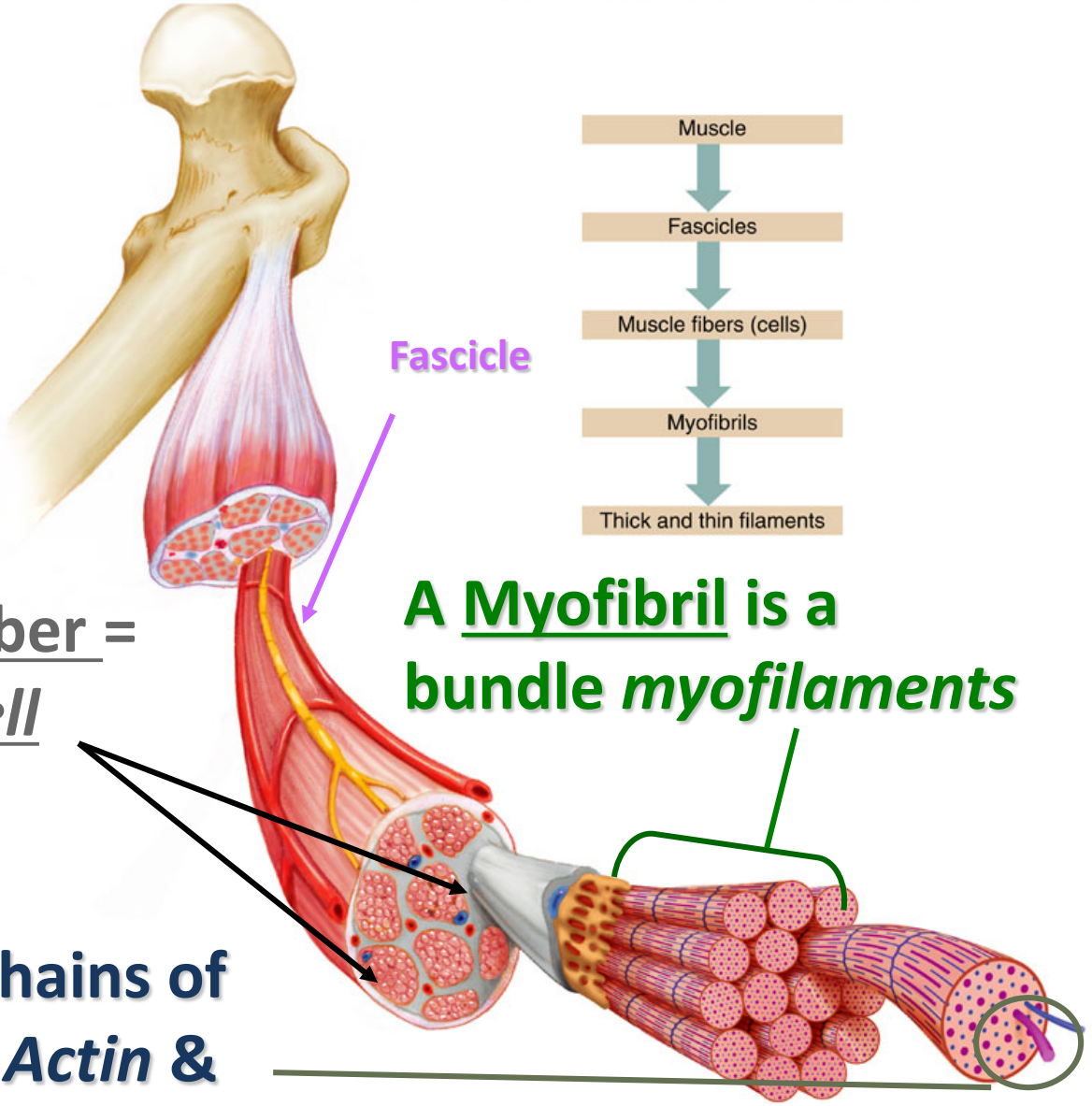

Muscle fiber = *muscle cell*

A Myofibril is a bundle *myofilaments*

Myofilaments are chains of contractile proteins *Actin* & *Myosin*

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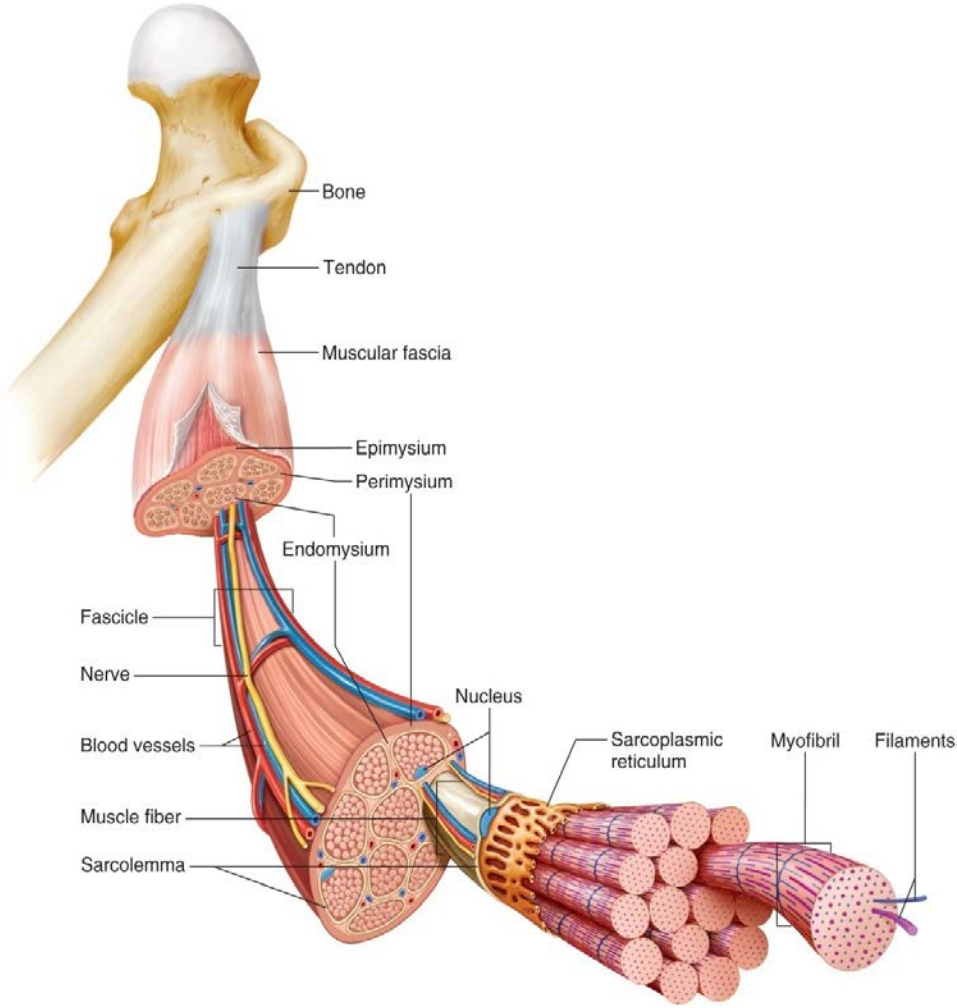
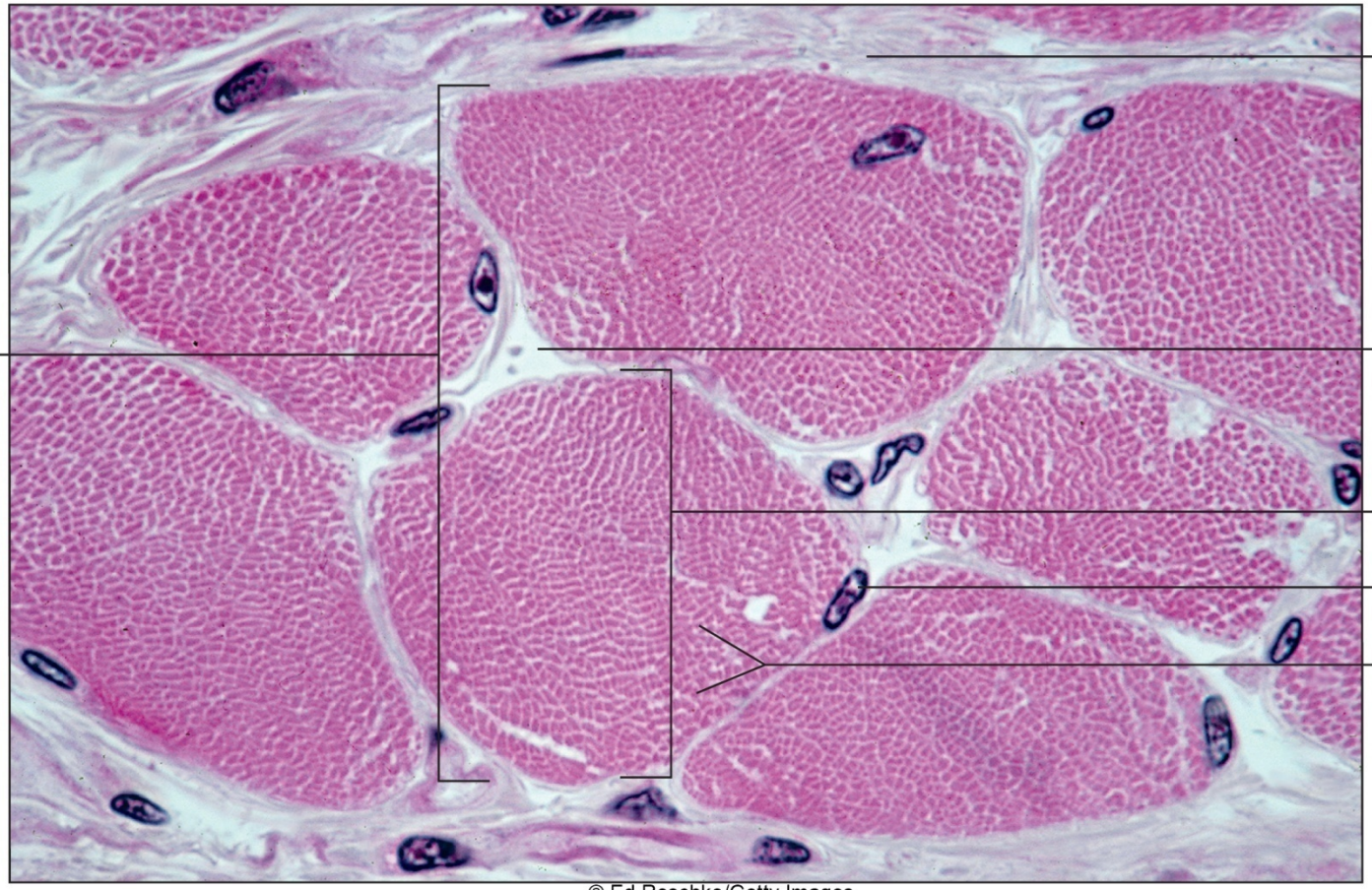
Connective Tissue Coverings

Inside a skeletal muscle:

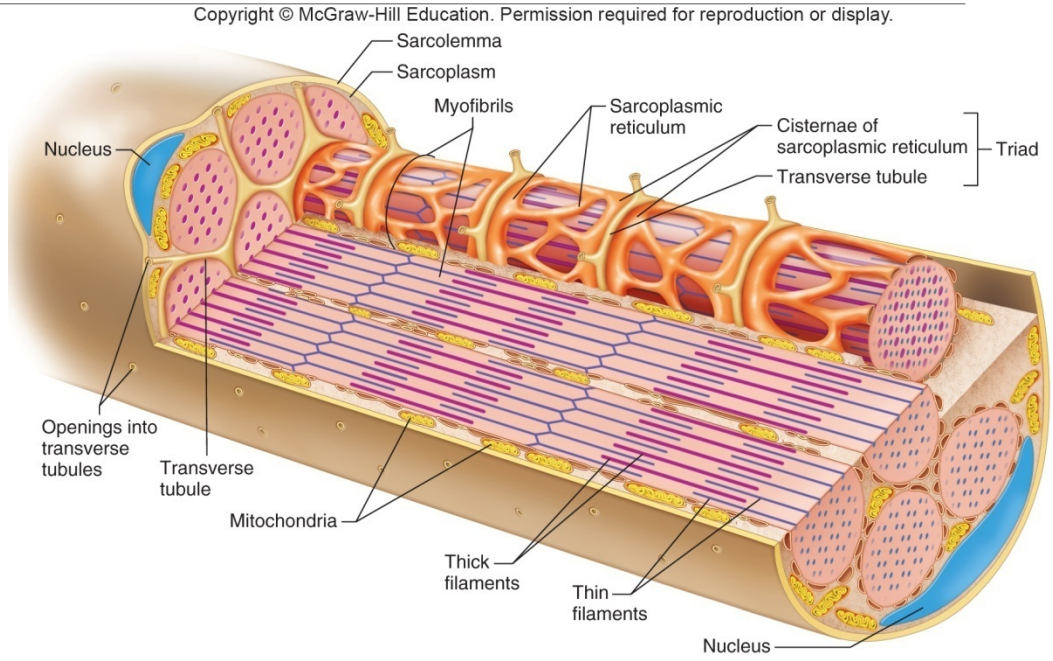
- **Epimysium:** surrounds whole muscle
- **Perimysium:** surrounds fascicles within a muscle
- **Endomysium:** surrounds muscle fibers (cells) within a fascicle

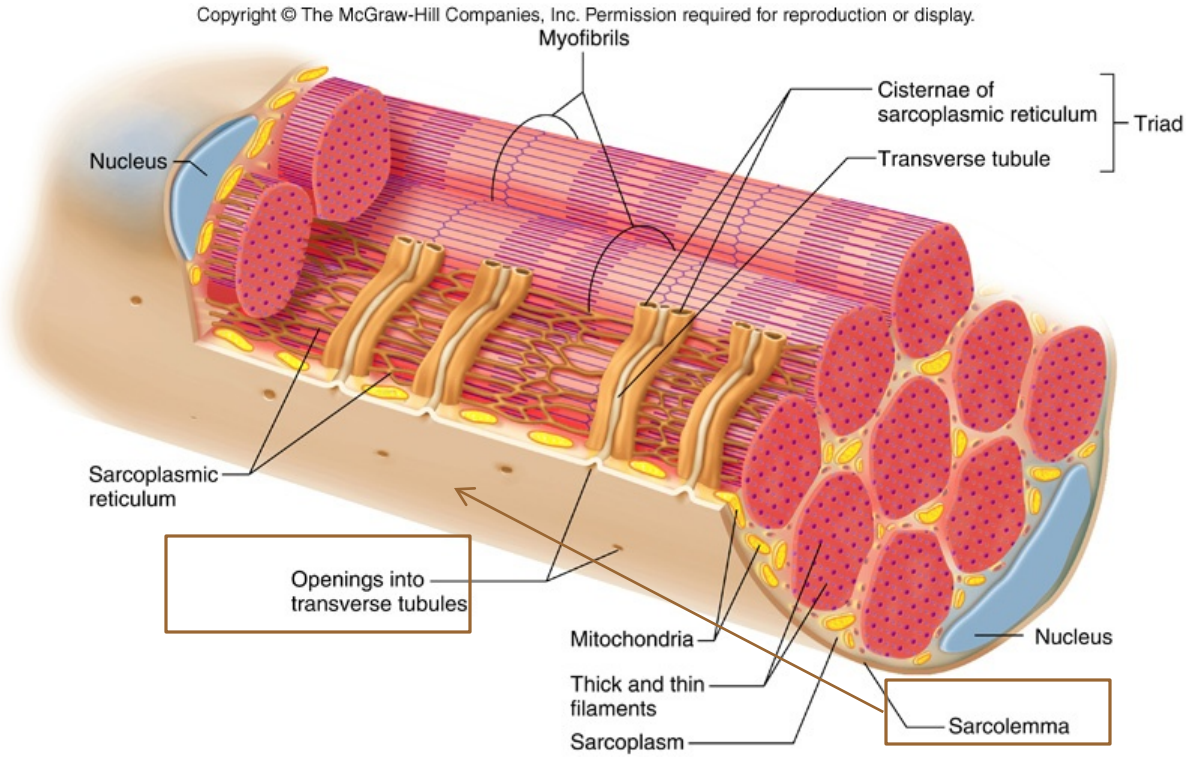




Skeletal Muscle Fibers

- Skeletal muscle fiber = muscle cell
- Multinucleated
- Sarcolemma
- Sarcoplasm
- Many myofibrils
- Myofibrils consist of:
  - thin actin filaments
  - thick myosin filaments
- Sarcomeres
- Sarcoplasmic reticulum (SR)
- Transverse ('T') tubule
- Triad: 1 T tubule and 2 SR cisternae





1. **Sarcolemma**: Is the muscle fiber membrane
2. This membrane folds inward to form the **Transverse Tubules** which conduct electrical impulses

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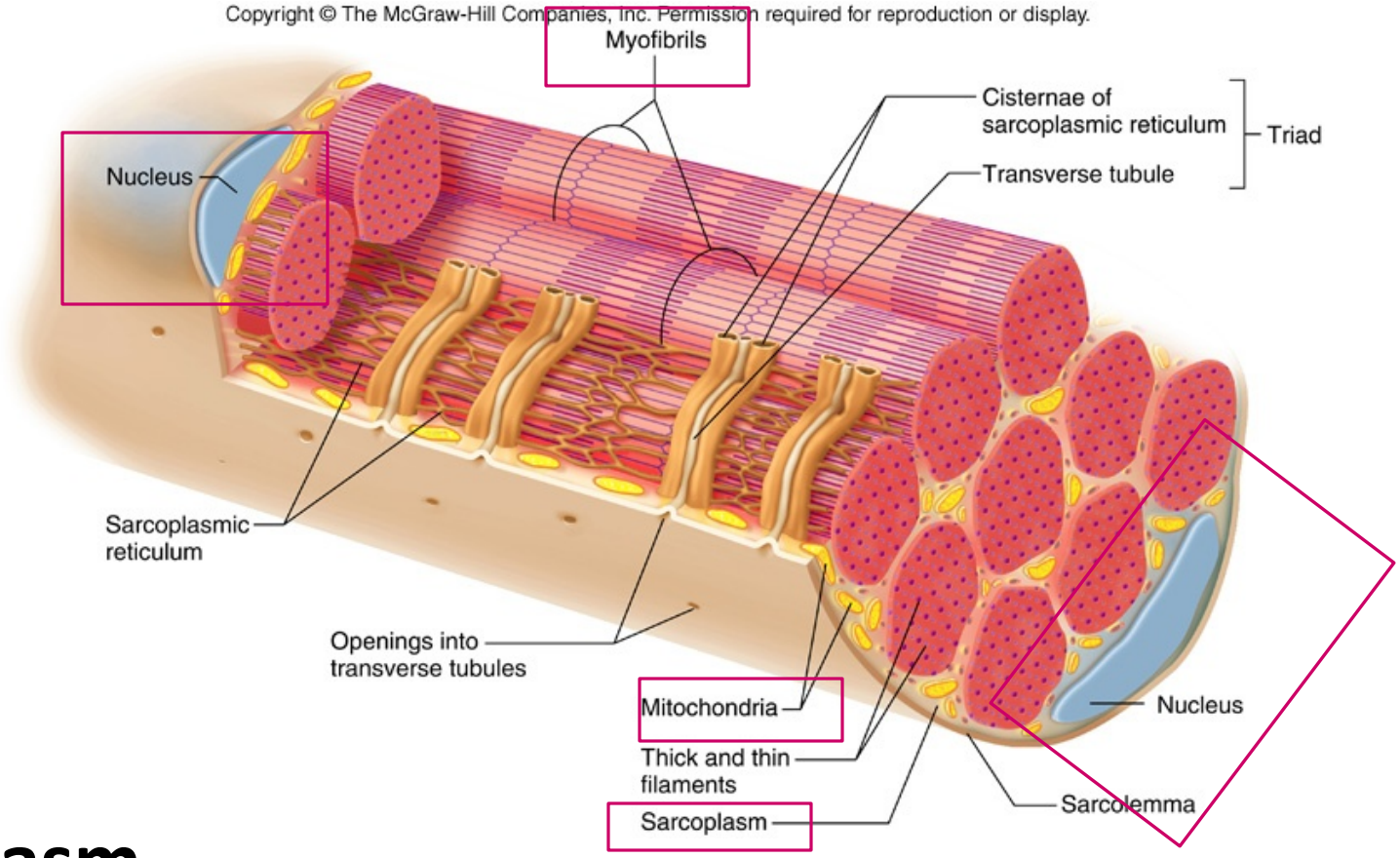

Sarcoplasm:

1. Contains many mitochondria & nuclei
2. Considered the "Cytoplasm" of the muscle cell / fiber
3. Contains the sarcoplasmic reticulum

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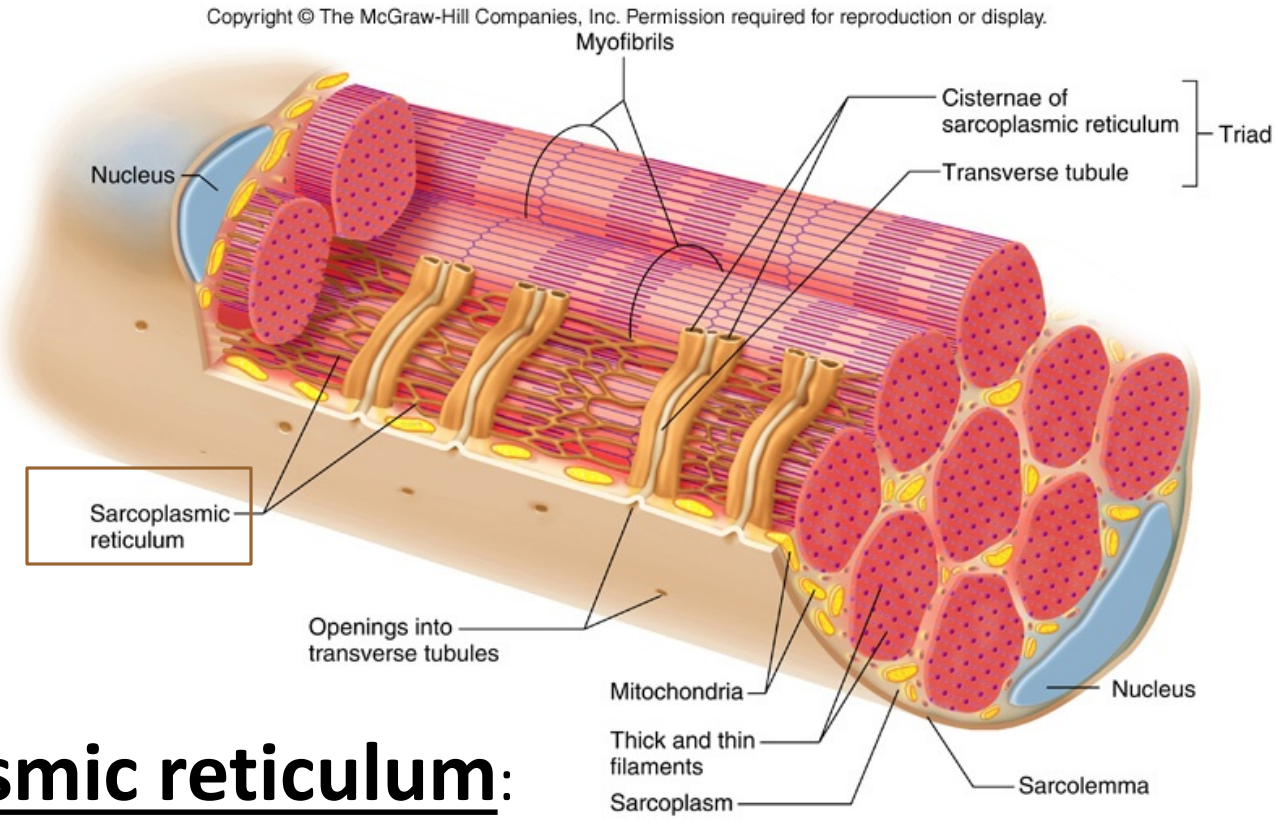

Sarcoplasmic reticulum:

1. Network of membranous channels around each myofibril
2. Stores **calcium** and is continuously pumping calcium in and out

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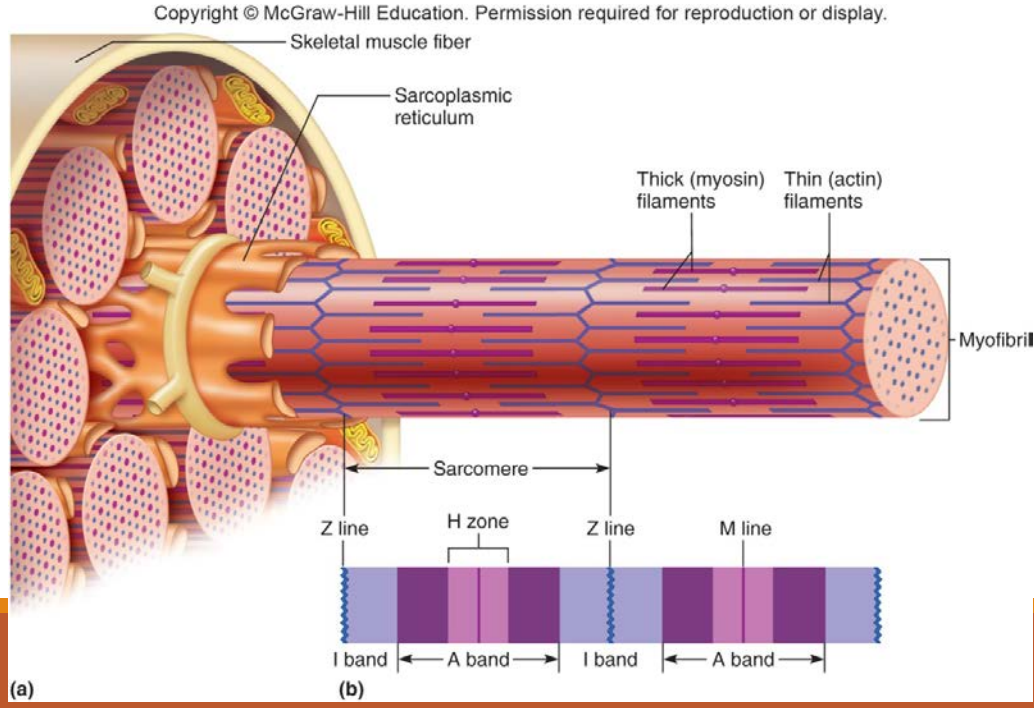
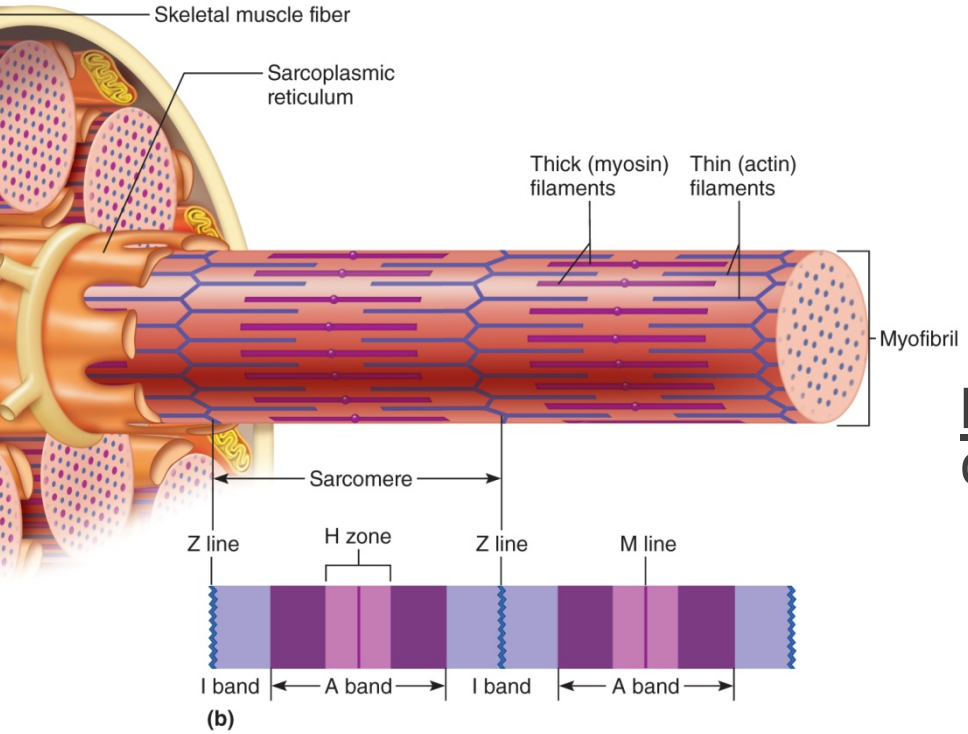
Skeletal Muscle Fibers

Myofibrils consist of sarcomeres connected end-to-end.

Striation pattern is made by arrangement of myofilaments.



Skeletal Muscle Fibers



I Band: Light band, composed of thin actin filaments

A Band: Dark band, composed of thick myosin filaments overlapping with thin actin filaments

H Zone: Center of A band; composed of thick myosin filaments

Z Line: Anchors filaments in place; sarcomere boundary; center of I band

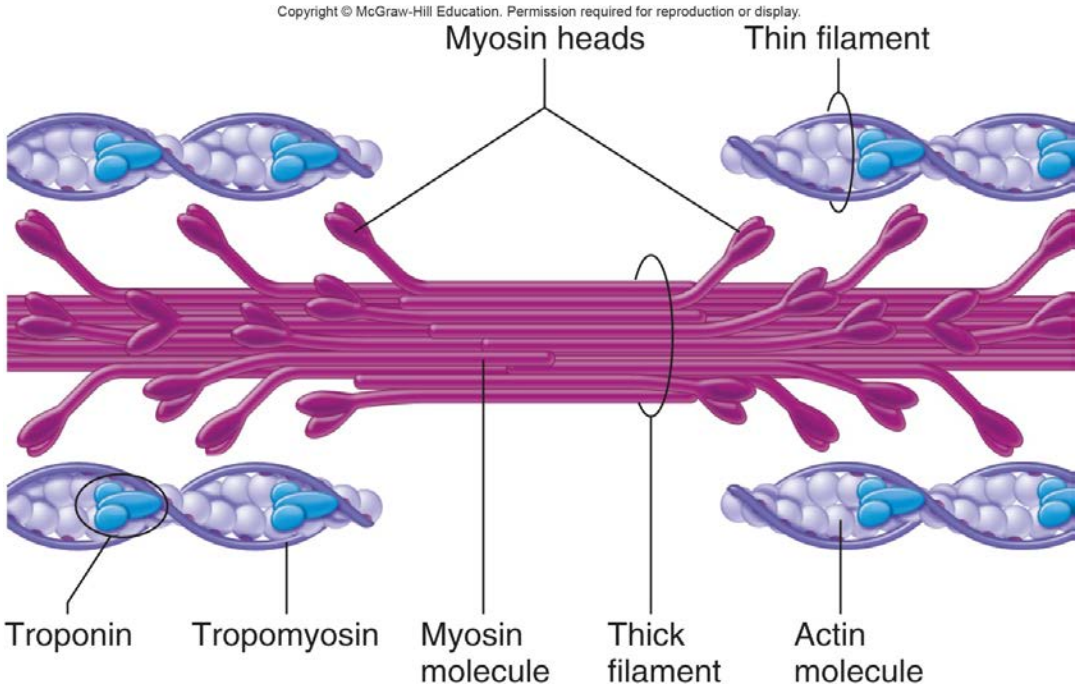
M Line: Anchors thick filaments; center of A band

Skeletal Muscle Fibers

Thick filaments:
Composed of **myosin** protein

Thin filaments:

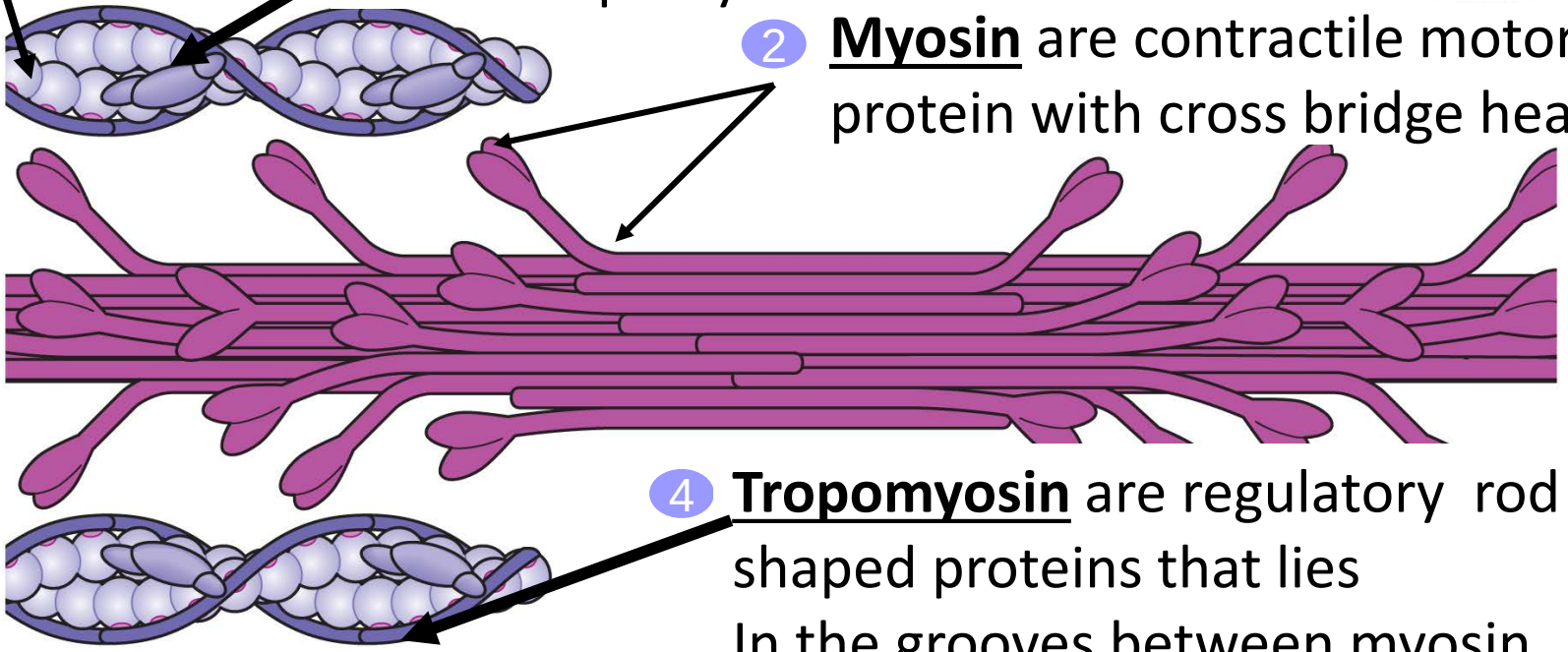
Composed of **actin** protein



1 **Actin** are contractile globular proteins. Each actin protein has a binding site that the head of the Myosin attaches to during muscle contraction.

3 **Troponin** consists of 3 regulatory proteins that attach to the Tropomyosin

2 **Myosin** are contractile motor protein with cross bridge heads



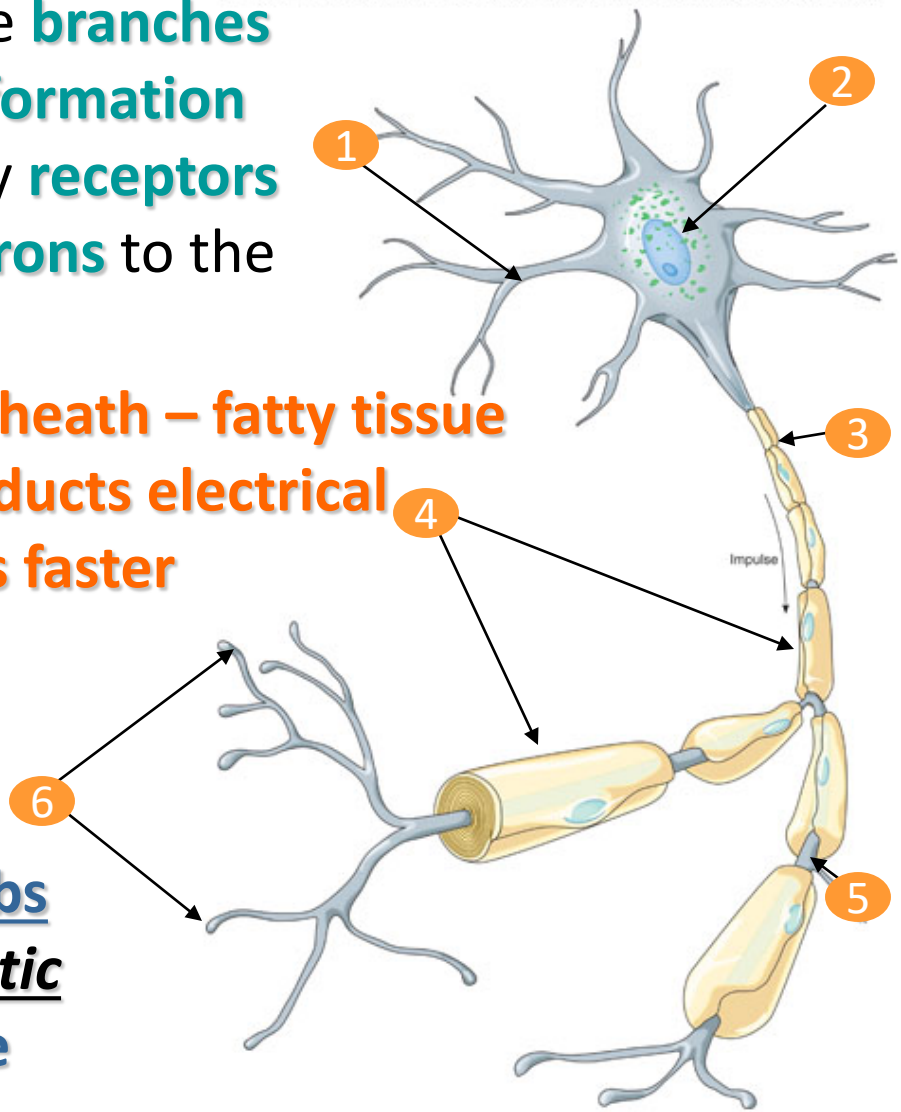
4 **Tropomyosin** are regulatory rod shaped proteins that lies In the grooves between myosin and the actin filaments

Structure of the Neuron

Dendrites are **branches** that **bring information** from sensory **receptors** or **other neurons** to the **cell body**

Cell body interprets information, sends out impulses, and **produces neurotransmitters**

Myelin sheath – fatty tissue that **conducts electrical impulses faster**

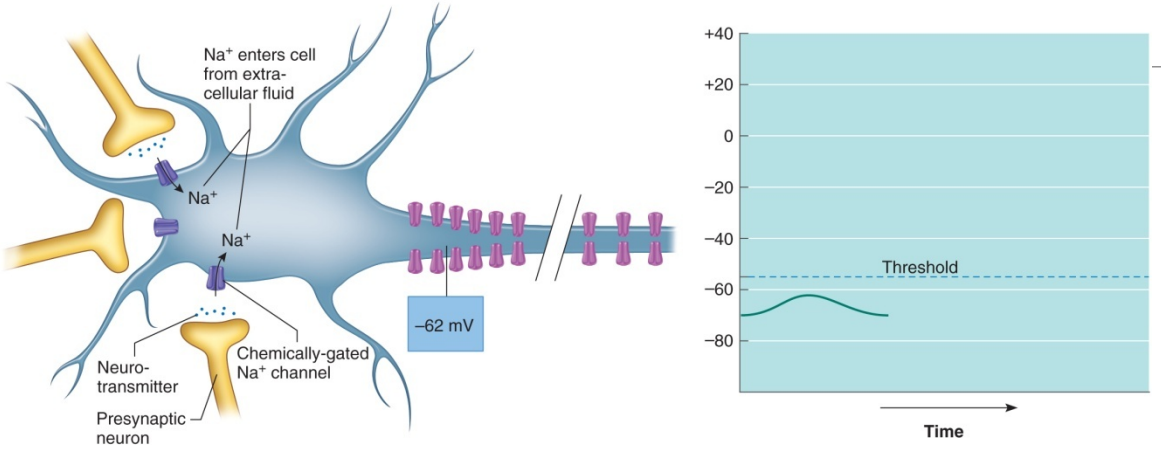


Axon conducts electrical impulse away from **cell body** to its **terminal synaptic bulbs**

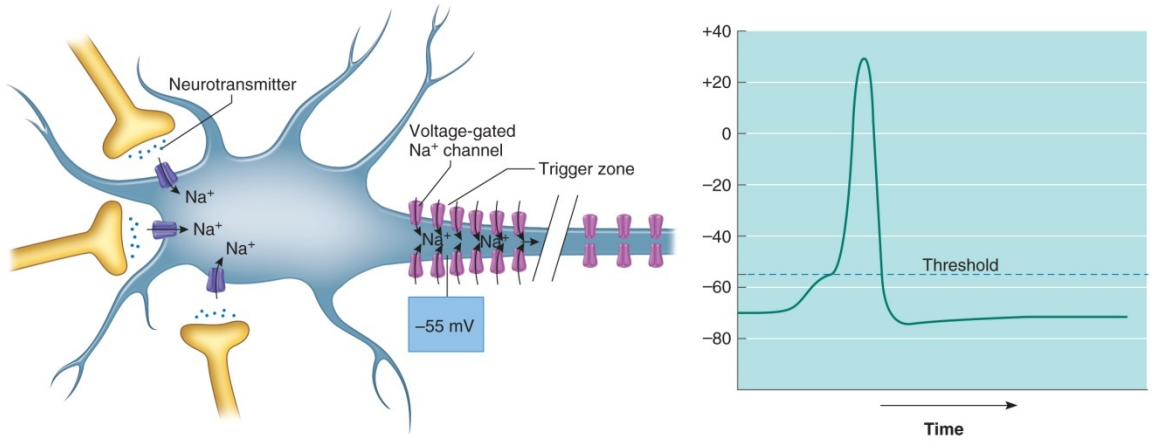
Nodes of Ranvier – breaks in the myelin sheath

Terminal Bulbs (a.k.a. *Synaptic Knobs*) of the Axon

Local Potential Changes



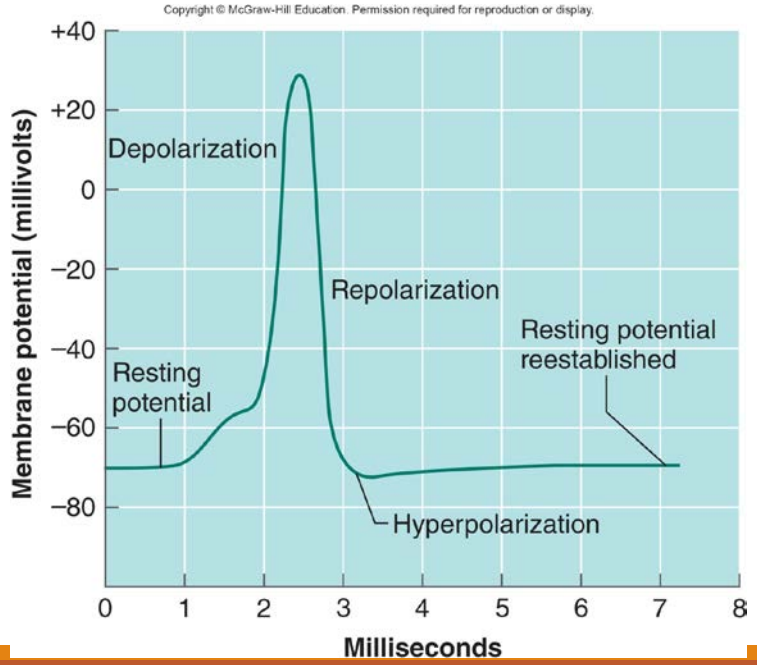
(a) If sodium or potassium channels open, more of that particular ion will cross the cell membrane, altering the resting membrane potential. This illustration depicts the effect of sodium channels opening in response to a neurotransmitter. As sodium ions enter the cell, the membrane potential becomes more positive (or less negative), changing from –70 millivolts to –62 millivolts in this example. This change in a positive direction is called depolarization. Here the depolarization is subthreshold, and does not generate an action potential.

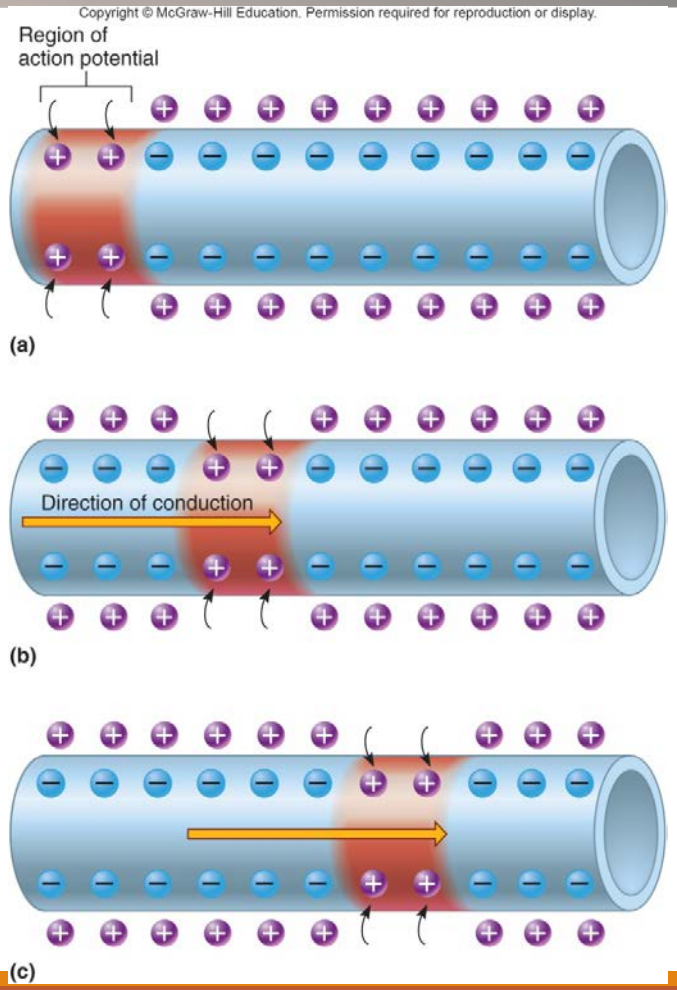


(b) If sufficient sodium ions enter the cell and the membrane potential depolarizes to threshold (here –55 millivolts), another type of sodium channel opens. These channels are found along the axon, especially near the origin in an area called the "trigger zone." Opening of these channels triggers the action potential.

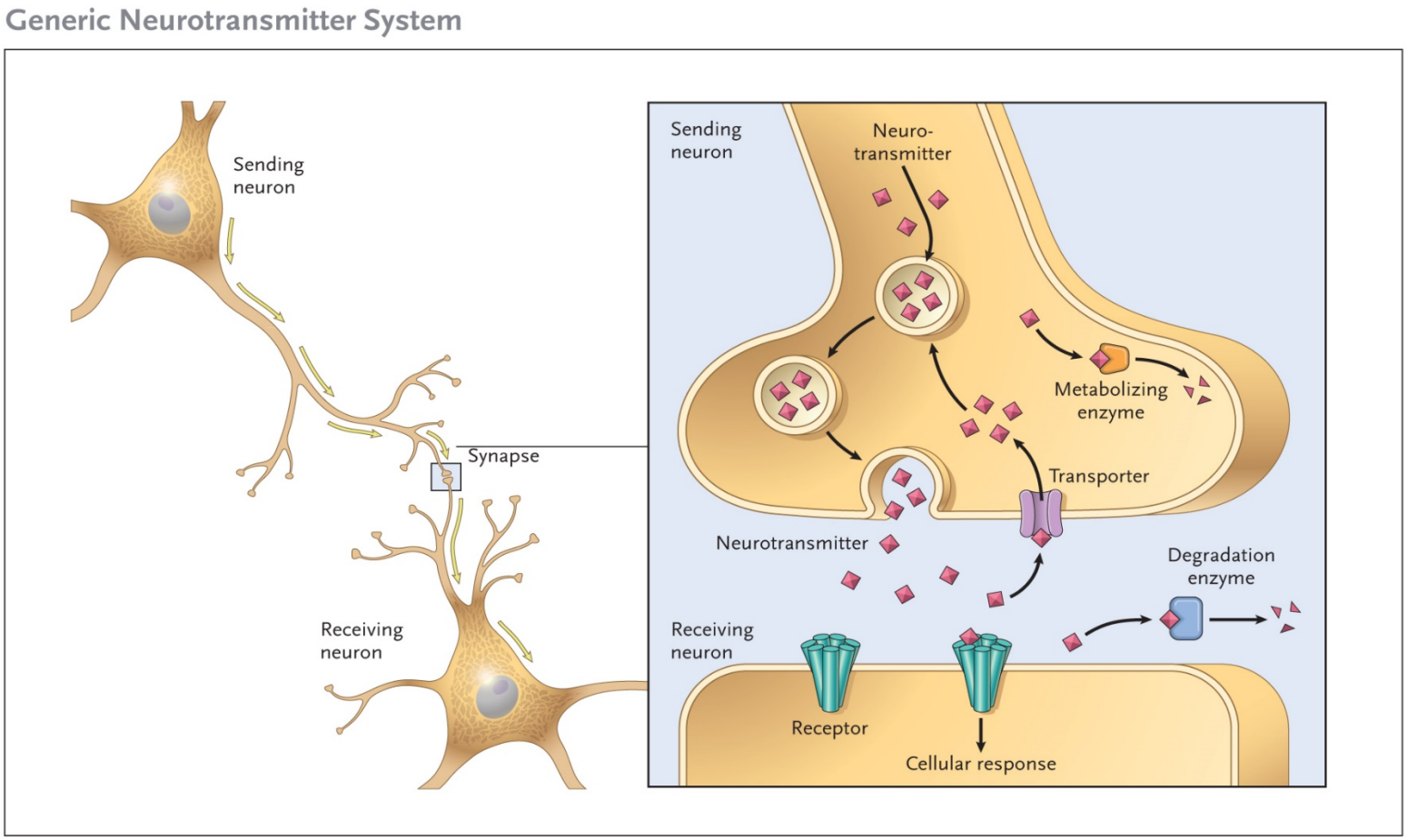
Action Potentials

Action potentials are propagated down the length of the axon as **nerve impulses**:





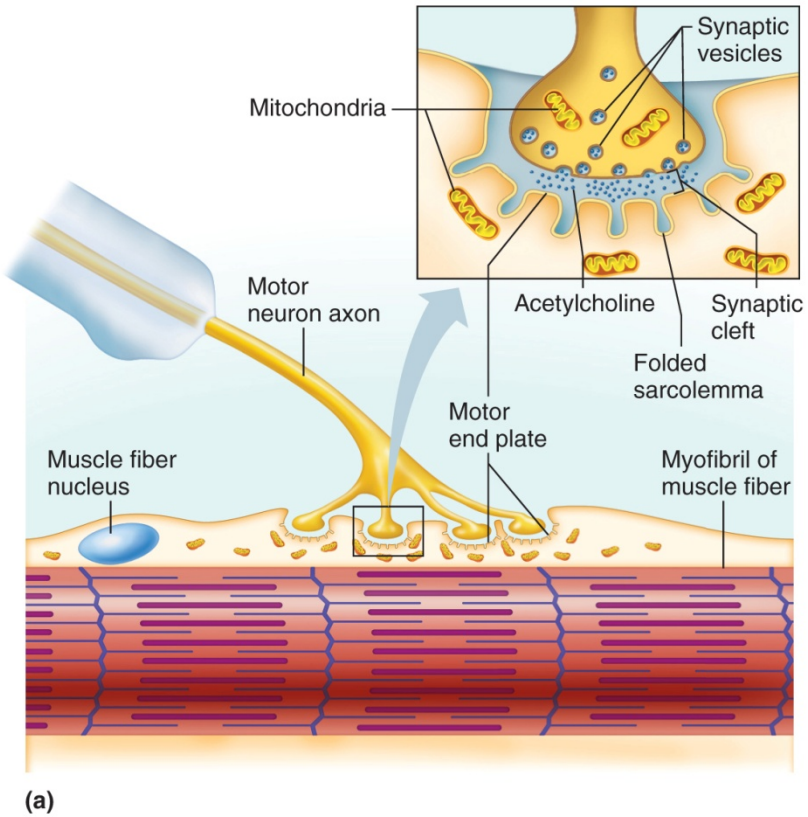
Neurotransmitters: the biological messenger molecules

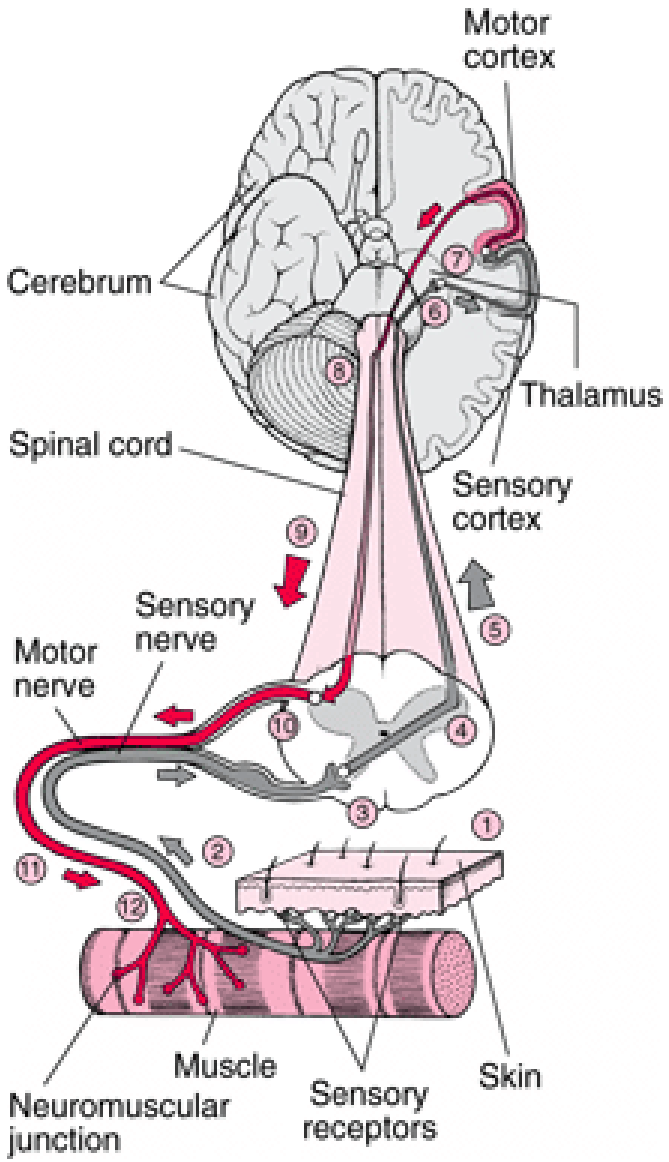


Neuromuscular Junction

Neuromuscular Junction:

- Also called a myoneural junction
- Site where an axon of motor neuron and skeletal muscle fiber interact
- Skeletal muscle fibers contract only when stimulated by a motor neuron
- Parts of a NMJ:
  - Motor neuron
  - Motor end plate
  - Synaptic cleft
  - Synaptic vesicles
  - Neurotransmitters

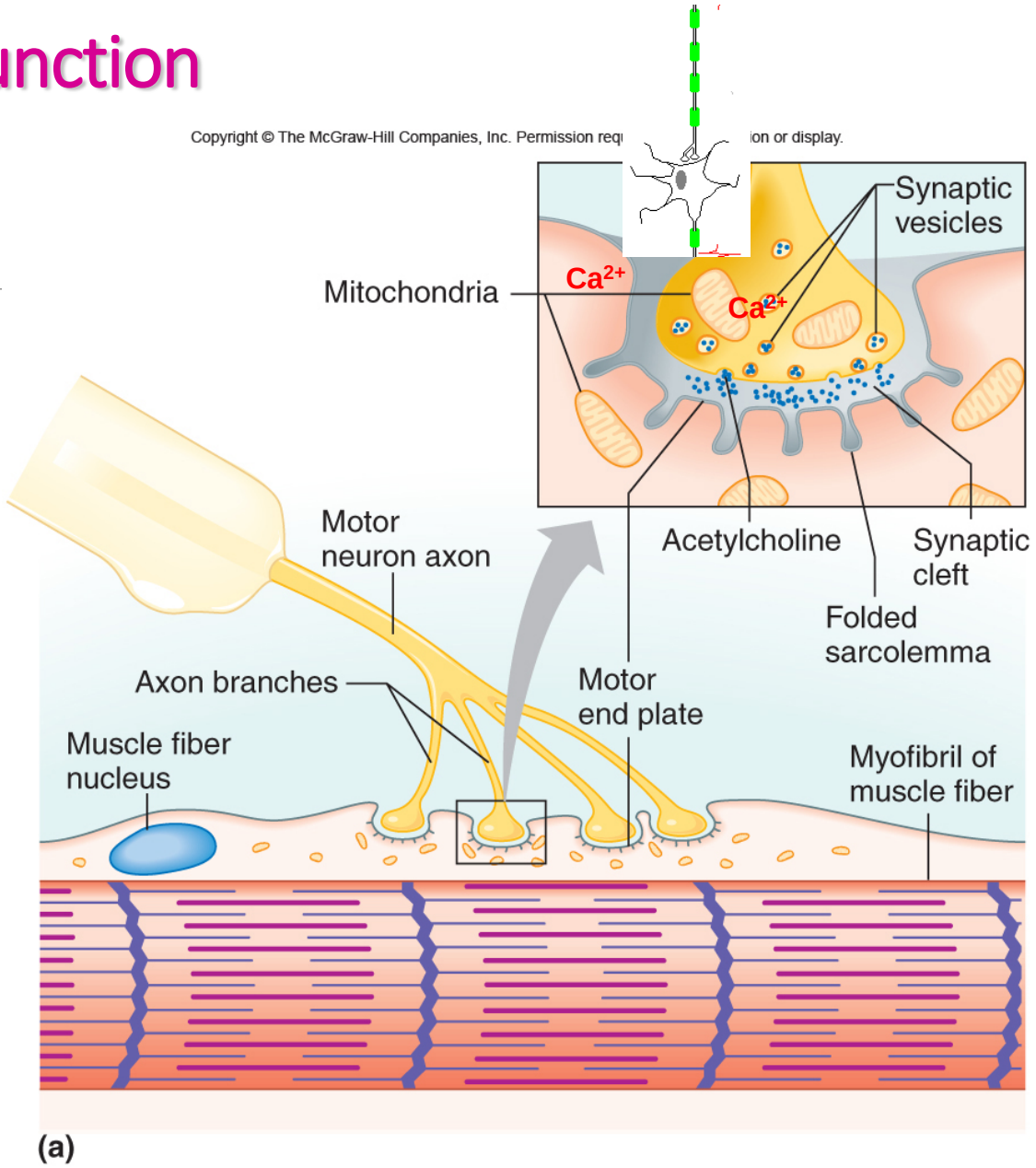




- Since a motor neuron can bring impulses to several fibers, the **neuromuscular junction** is where the motor neuron brings electrical impulses to all the muscle fibers it innervates.

Neuromuscular Junction

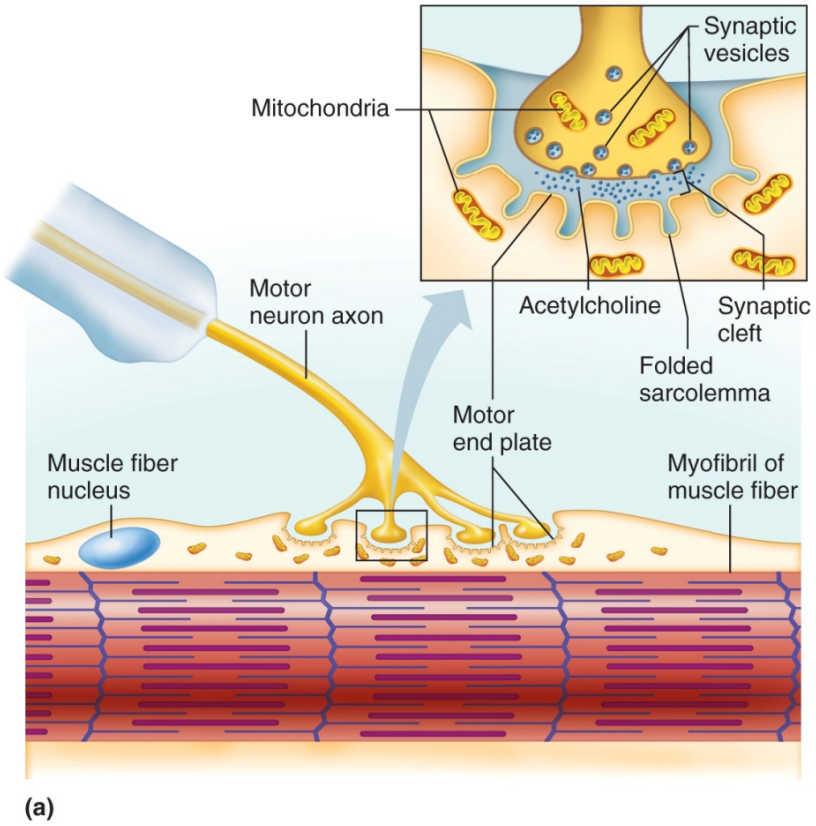
When an electrical impulse reaches the end of the neuron, **Ca^{2+}** diffuses into the synaptic bulbs of the motor neuron; Vesicles of **acetylcholine [Ach]** are released into the synaptic cleft.

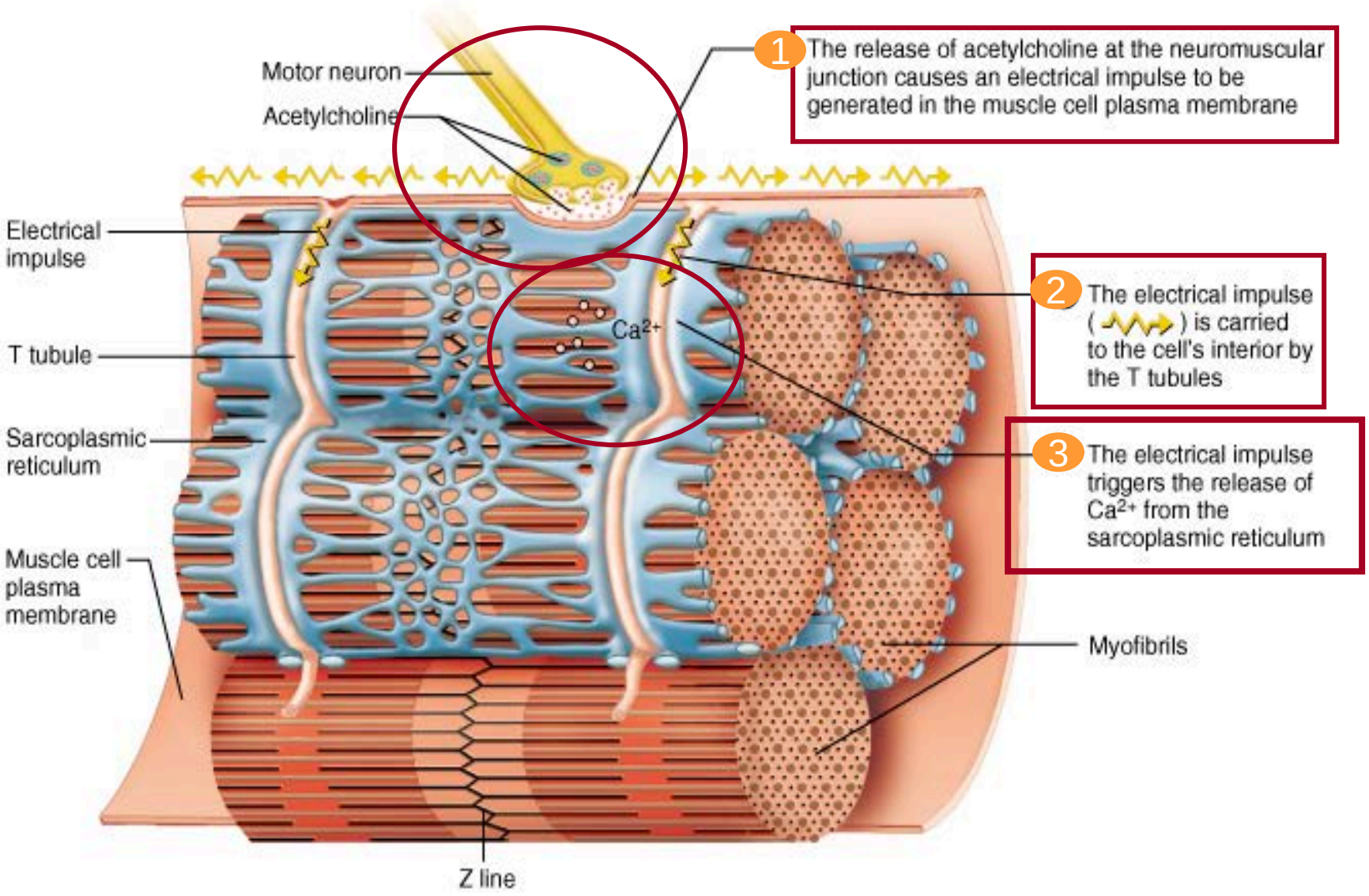


Stimulus for Contraction

- **Acetylcholine** (ACh) neurotransmitter
- Nerve impulse causes release of ACh from synaptic vesicles

ACh causes changes in membrane permeability to Na^+ and K^+ ions, which generates a muscle impulse (action potential)




Motor neuron
Acetylcholine
Electrical impulse
T tubule
Sarcoplasmic reticulum
Muscle cell plasma membrane
Z line
Ca2+
1 The release of acetylcholine at the neuromuscular junction causes an electrical impulse to be generated in the muscle cell plasma membrane
2 The electrical impulse ( ) is carried to the cell's interior by the T tubules
3 The electrical impulse triggers the release of Ca2+ from the sarcoplasmic reticulum
Myofibrils

Relaxation

When neural stimulation of muscle fiber stops:

- **Acetylcholinesterase** (enzyme) rapidly decomposes ACh remaining in the synapse
- Muscle impulse stops when ACh is decomposed
- Stimulus to sarcolemma and muscle fiber membrane ceases
- **Calcium pump** moves Ca^{+2} back into sarcoplasmic reticulum (SR)
- **Troponin-tropomyosin complex** again covers binding sites on actin
- Myosin and actin binding is now prevented
- Muscle fiber relaxes

Muscle contraction can be observed by removing a single skeletal muscle fiber and connecting it to a device that senses and records changes in the overall length of the muscle fiber.

Muscular Responses

Threshold Stimulus

…the minimum strength of stimulation of a muscle fiber required to cause contraction

When strength of stimulus reaches threshold, an action potential is generated

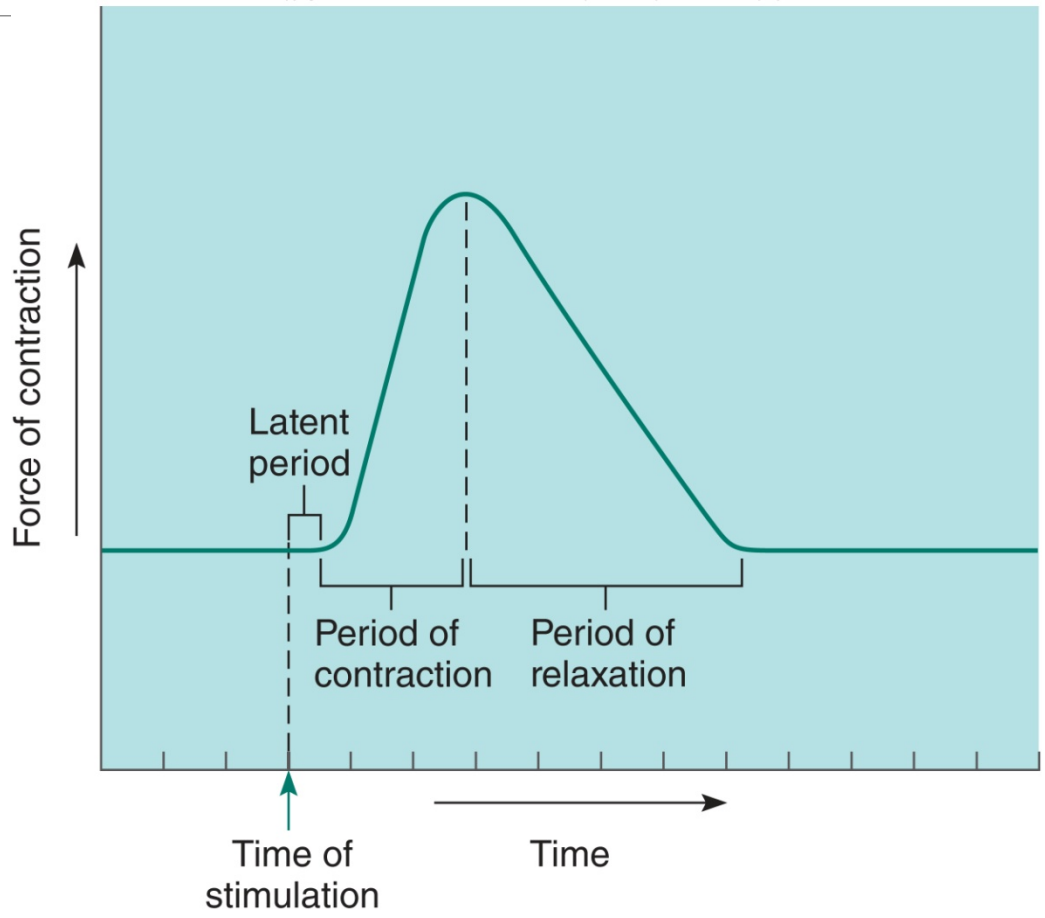
One action potential from a motor neuron releases enough ACh to produce threshold stimulus in muscle fiber, causing a muscle impulse

Recording of a Muscle Contraction

Twitch:

Contractile response of a single muscle fiber to a single impulse

- Latent period
- Period of contraction
- Period of relaxation



Fast- and Slow-Twitch Muscle Fibers

Slow-twitch fibers (Type I):

- Always oxidative
- Resistant to fatigue
- Red fibers
- Abundant myoglobin
- Good blood supply
- Many mitochondria
- Slow to contract

Fast-twitch glycolytic fibers (Type IIb):

- Anaerobic respiration (glycolysis)
- White fibers (less myoglobin)
- Poorer blood supply
- Fewer mitochondria
- More SR than fast-twitch
- Susceptible to fatigue
- Contract rapidly

Use and Disuse of Skeletal Muscles

Hypertrophy: Enlargement of skeletal muscle that is exercised

1. Aerobic exercise stimulates slow-twitch fibers. In response, fibers increase their capillaries and mitochondria.

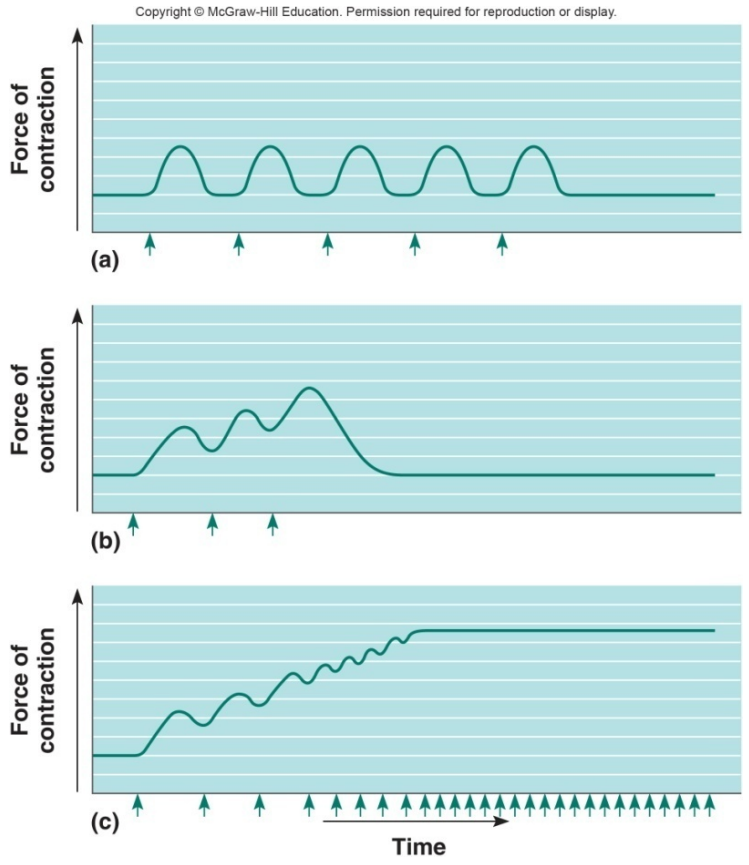
2.Forceful exercise stimulates mainly fast-twitch fibers. In response, fibers produce new actin & myosin filaments, and the muscle enlarges.

Atrophy: Decrease in size and strength of skeletal muscle that is unused

Summation

Summation: Process by which the force of individual muscle fiber twitches combine

- **Produces sustained contractions (needed for strength)**



Recruitment of Motor Units

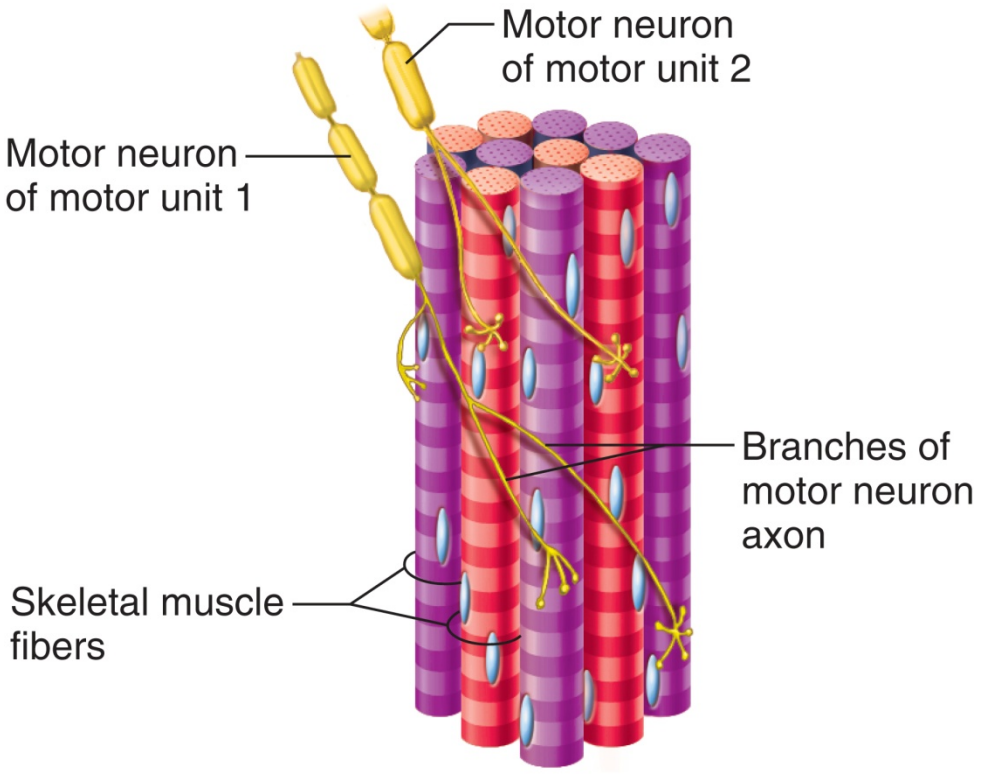
Motor Unit:

A motor neuron + all of the muscle fibers it controls

A whole muscle consists of many motor units

Gross motor movements are produced with large numbers of fibers in a motor unit

Fine motor movements are produced with fewer muscle fibers in a motor unit



Recruitment of Motor Units

Recruitment:

Increase the number of motor units activated, to **produce more force**

As intensity of stimulation increases, recruitment of motor units continues until all motor units are activated

Sustained Contractions

- Smaller motor units (smaller diameter axons) - recruited first
- Larger motor units (larger diameter axons) - recruited later
- Summation and recruitment can produce sustained contractions of increasing strength
- Whole muscle contractions are smooth movements
- **Muscle tone (tonus):** Continuous state of partial contraction in resting muscles

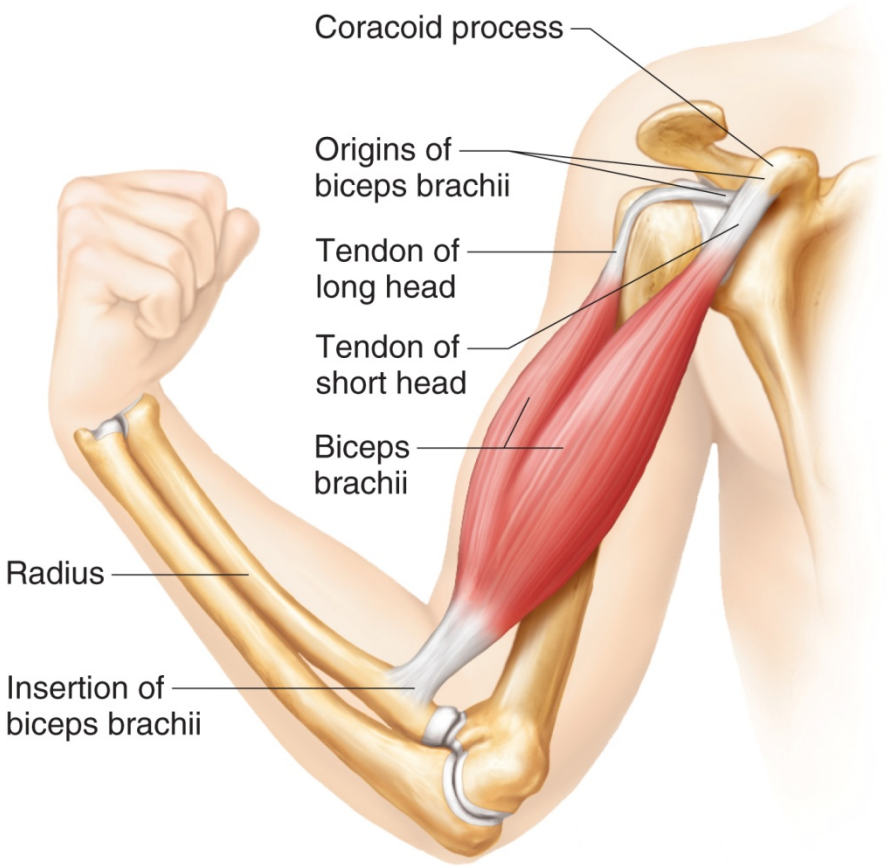
Origin and Insertion

One end of a skeletal muscle is more fixed, and the other end is more movable:

Origin: less movable end

Insertion: more movable end

When a muscle contracts, insertion is pulled toward origin



Interaction of Skeletal Muscles

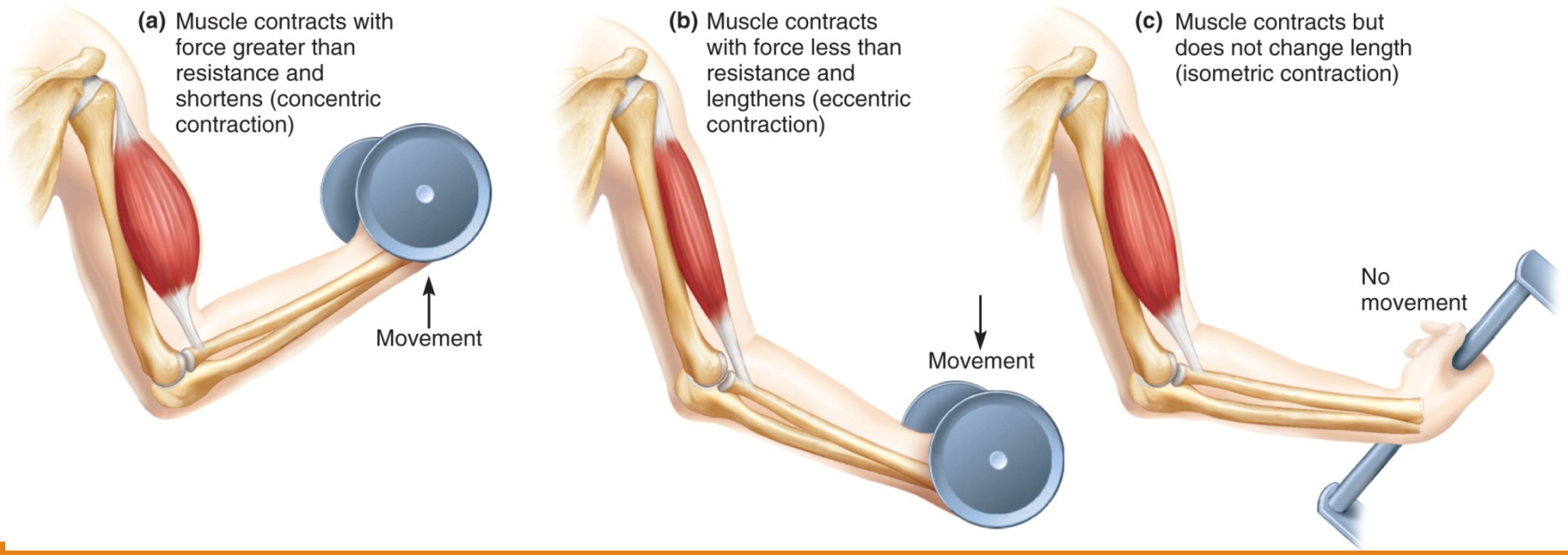
- **Agonist:** muscle that causes an action
- **Prime mover:** agonist primarily responsible for movement
- **Synergists:** muscles that assist agonist / prime mover
- **Antagonist:** muscles whose contraction causes movement in the opposite direction of the prime mover

Types of Contractions

Isotonic: muscle contracts and changes length; equal force

- Concentric: shortening contraction
- Eccentric: lengthening contraction

Isometric: muscle contracts but does not change length; change in force



Length-Tension Relationship

- Length of muscle fiber before stimulation determines amount of force it can develop
- Optimum starting length is resting length of the muscle fiber; this allows the greatest force to develop
- Stretched muscle fibers develop less force, since some myosin heads cannot reach binding sites on actin
- Shortened muscle fibers also develop less force, since compressed sarcomeres cannot shorten further

Energy Sources for Contraction

1. **ATP reserves**: small amount / can provide on a brief contraction

2. **Creatine phosphate**: initial source of energy to regenerate ATP from ADP and P; only last about 10 seconds

3. **Cellular respiration** produces up to 38 ATP per glucose molecule

Oxygen Supply & Cellular Respiration

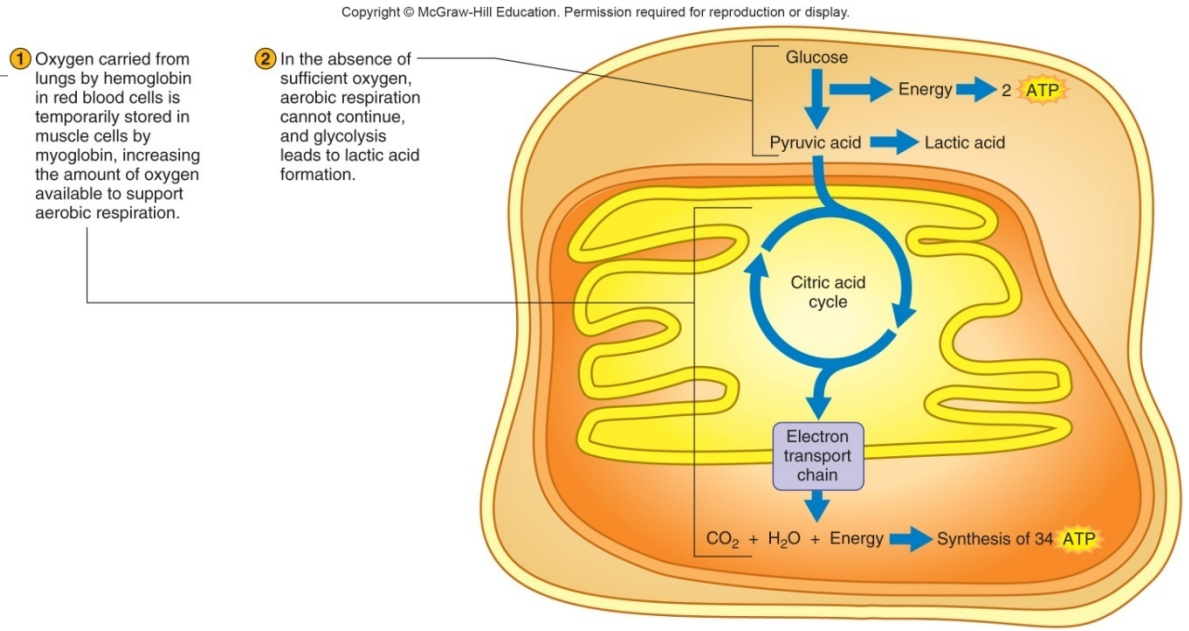
Cellular respiration:

Anaerobic Phase:

- Glycolysis
- Occurs in cytoplasm
- Produces little ATP

Aerobic Phase:

- Citric acid cycle and electron transport system
- Occurs in the mitochondria
- Produces the most ATP
- Myoglobin stores extra oxygen in muscles



Heat Production

- Heat is a by-product of cellular respiration in active cells
- Muscle cells are major source of body heat
- More than half the energy released in cellular respiration becomes heat; less than half is transferred to ATP
- Blood transports heat throughout body core

Skeletal Muscle Actions

Skeletal muscles generate a great variety of body movements

The action of each muscle mostly depends upon

- the type of joint it is associated with	- the way the muscle is attached on either side of the joint

Skeletal Joints: articulation

An *articulation* is a joint or juncture between bones; includes the cartilage on the bones.

This juncture **allows** bone growth and **movement**

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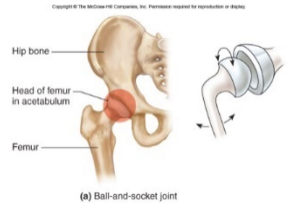
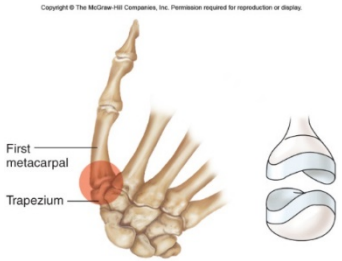
Types of Synovial Joints

Ball & socket



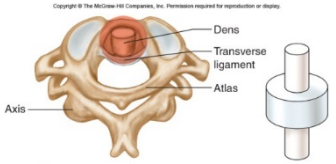
(a) Ball-and-socket joint

Saddle



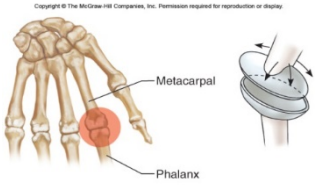
(f) Saddle joint

Pivot



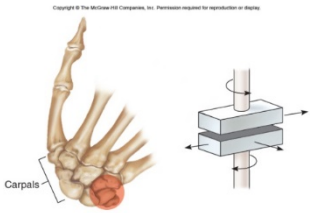
(e) Pivot joint

Condylar



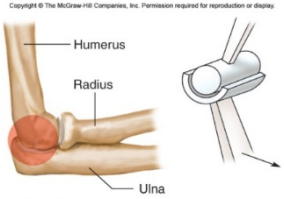
(b) Condylar joint

Plane



(c) Plane joint

Hinge



(d) Hinge joint

Muscle Fatigue & Cramping

Muscle Fatigue:

Inability to contract muscle

Common causes of muscle fatigue:

- Decreased blood flow
- Ion imbalances across the sarcolemma
- Loss of desire to continue exercise

Muscle Cramp:

Sustained, involuntary muscle contraction

May be caused by changes in electrolyte concentration in extracellular fluids in the area