MUSCULAR SYSTEM

Muscular System

Components: Skeletal muscles.

Functions:

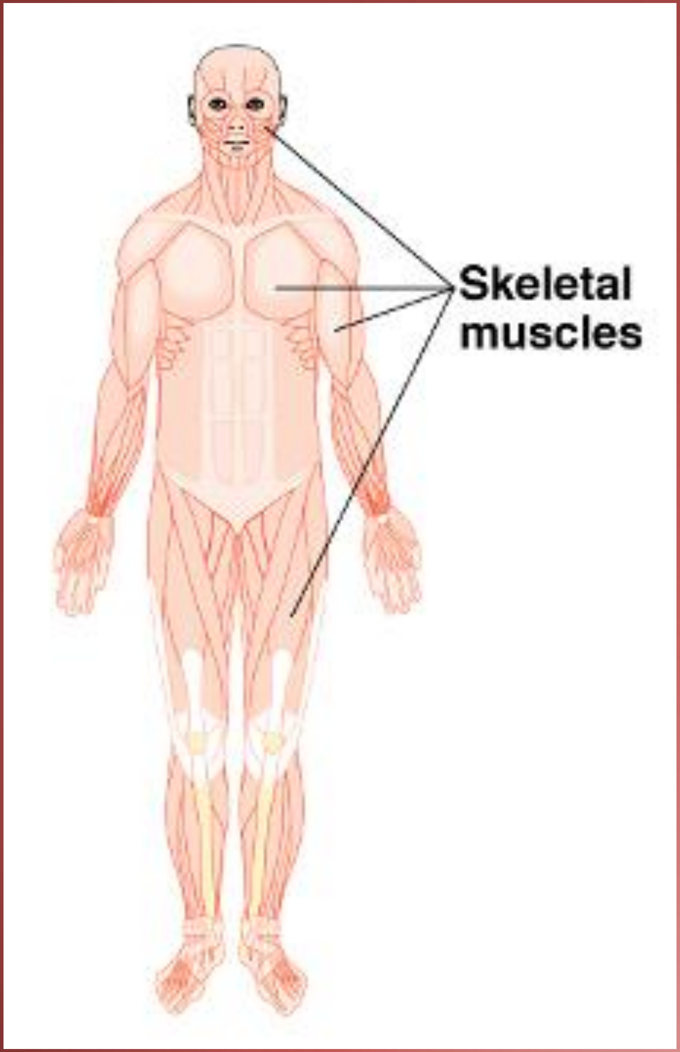
Skeletal muscle contraction allows for voluntary movement:

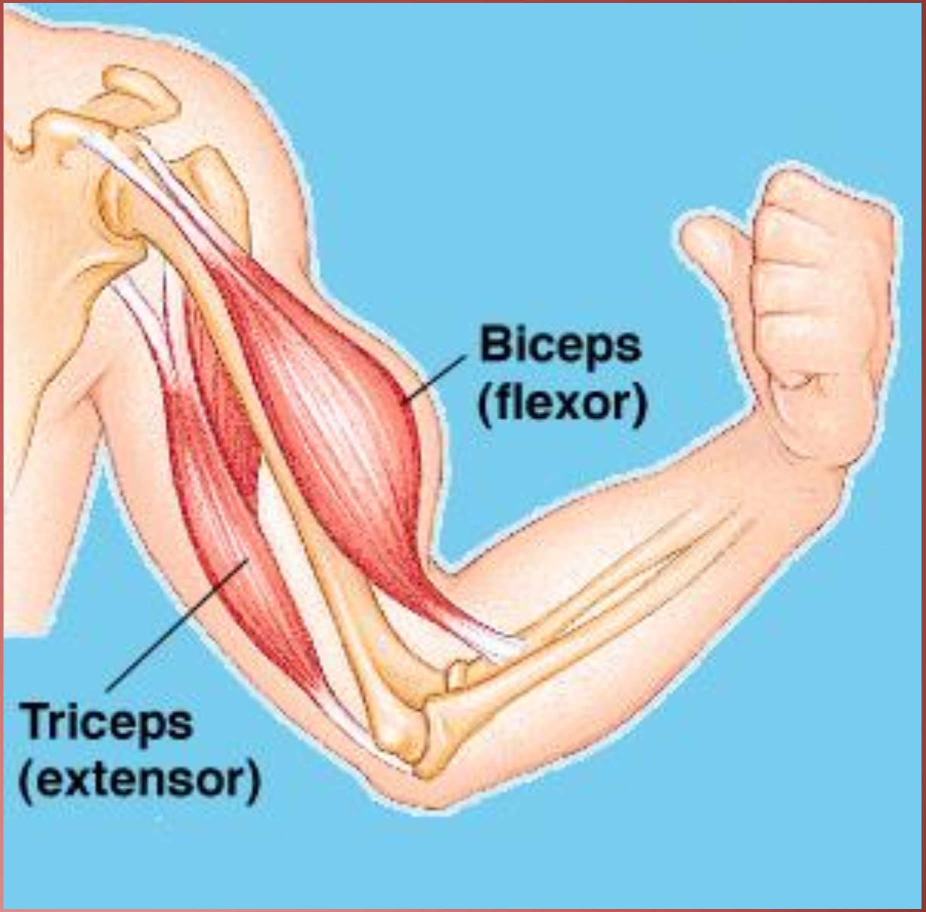
- **Movement and locomotion.**
- **Mechanical work: Lifting, pulling, pushing objects.**
- **Communication: Body language and facial expression.**

Homeostatic Role:

- **Allows animals to respond to and control their environment.**

Muscular System: Skeletal Muscle Allows Voluntary Movement





Skeletal Muscle

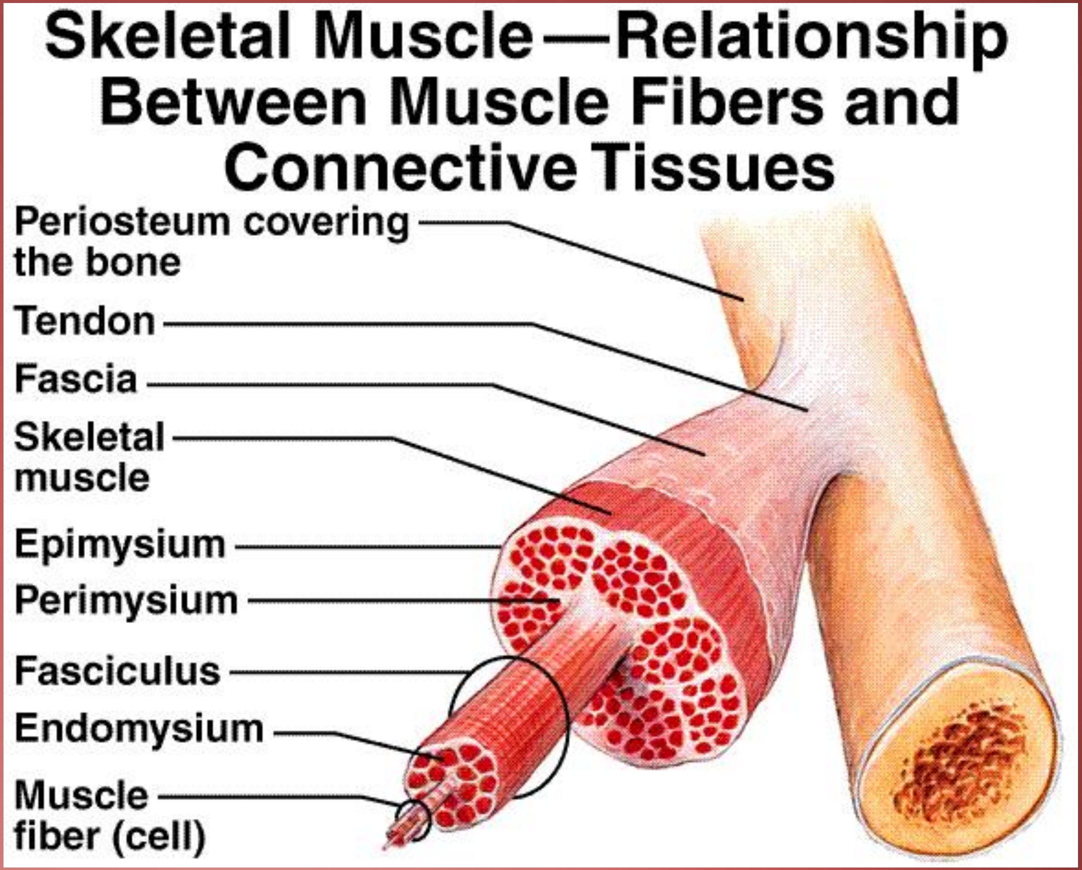
- Composed of individual muscle fibers.
- Contract when stimulated by **motor neuron.**
- Motor neuron innervates # of muscle fibers.
- Activation of varying # of muscle fibers causes gradations of strength of contraction.

Structure and Actions

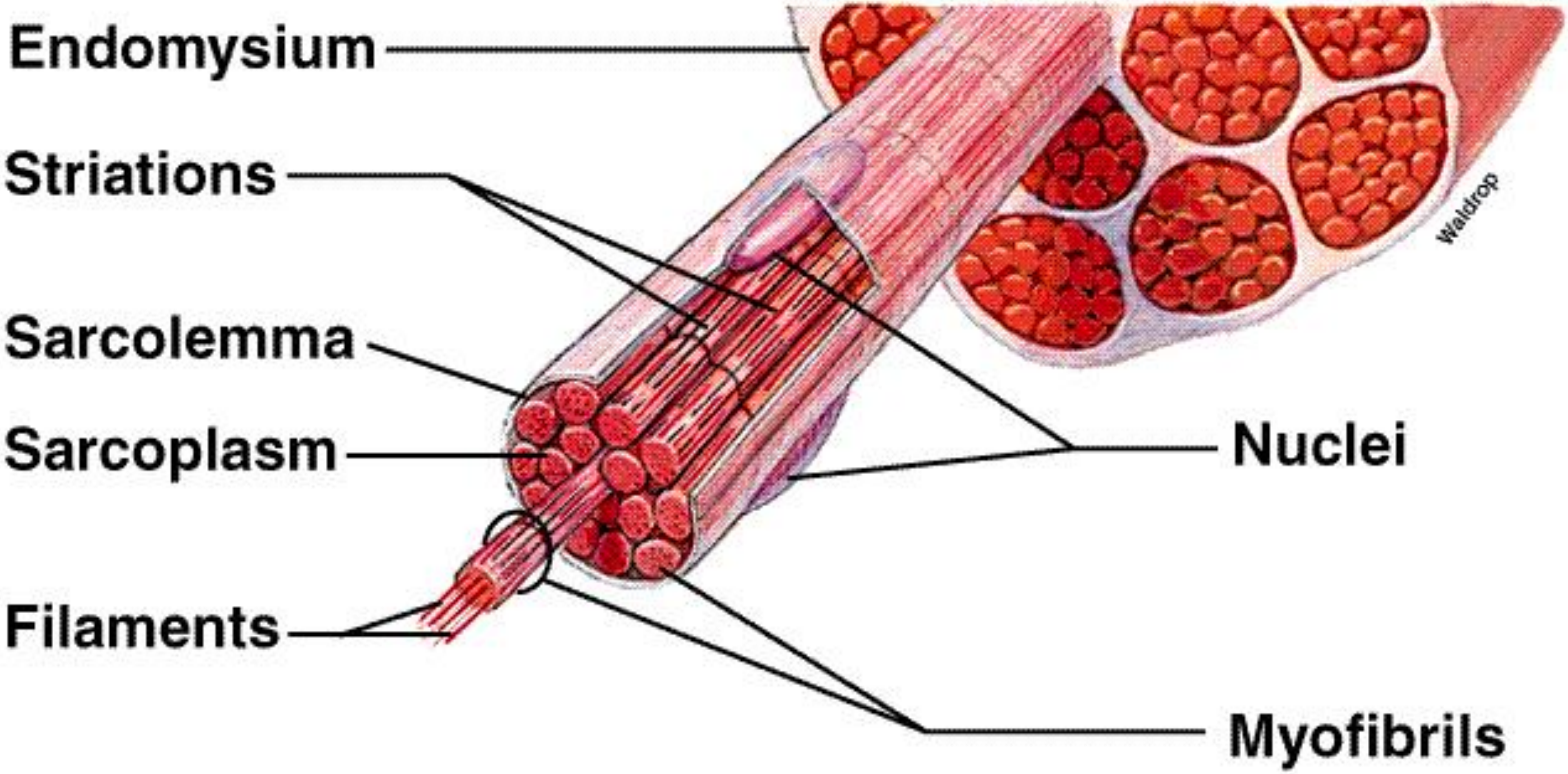
- Skeletal muscle attached to bone on each end by tendons.
- Tension on tendons by muscles cause movement of the bones.
- Insertion:
  - More movable attachment.
- Origin:
  - Less movable attachment.

Structure of Skeletal Muscle

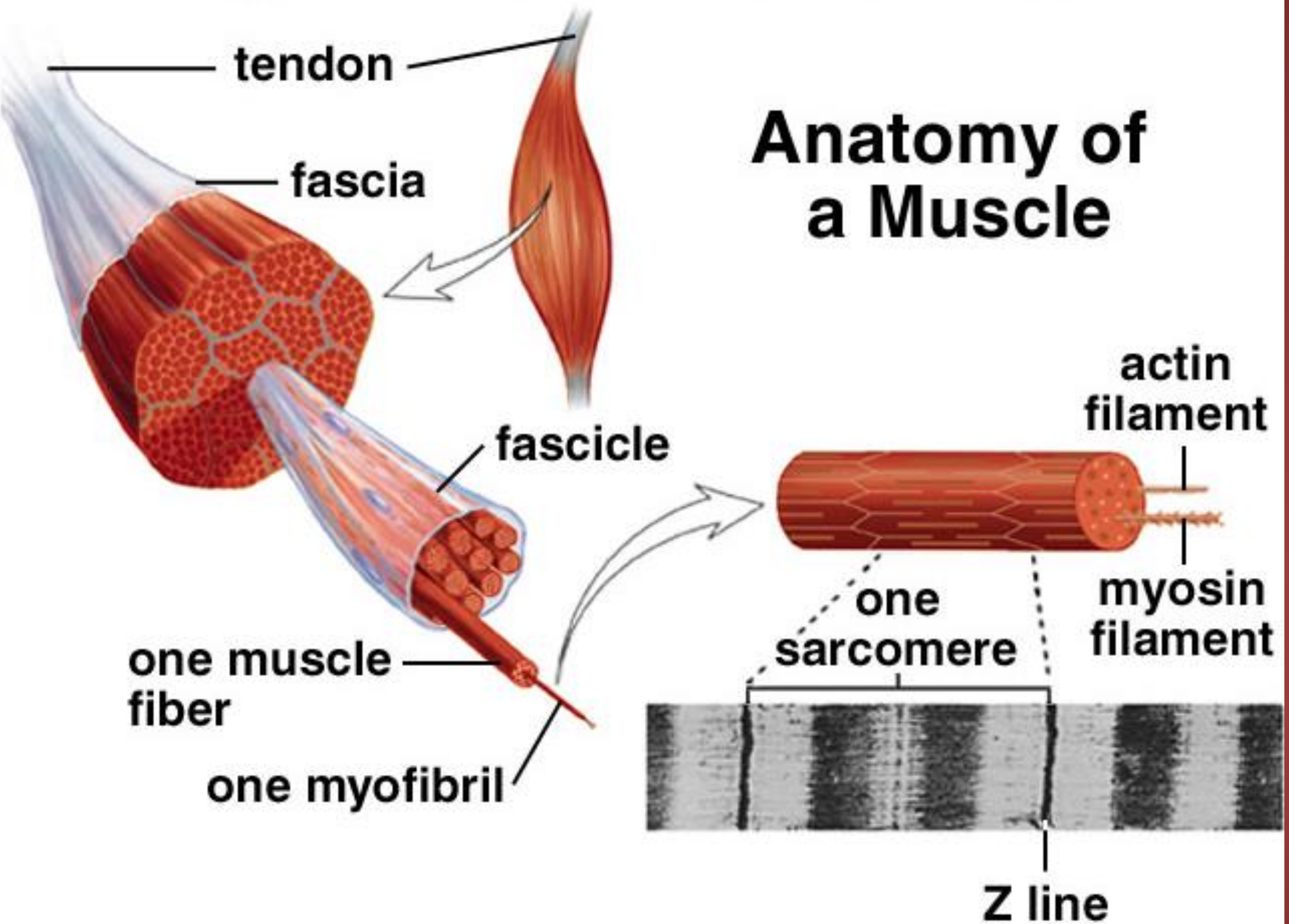
- Epimysium:
  - Fibrous sheath.
- Fascicles:
  - Columns of muscle fibers.
- Contain same organelles as other cells.



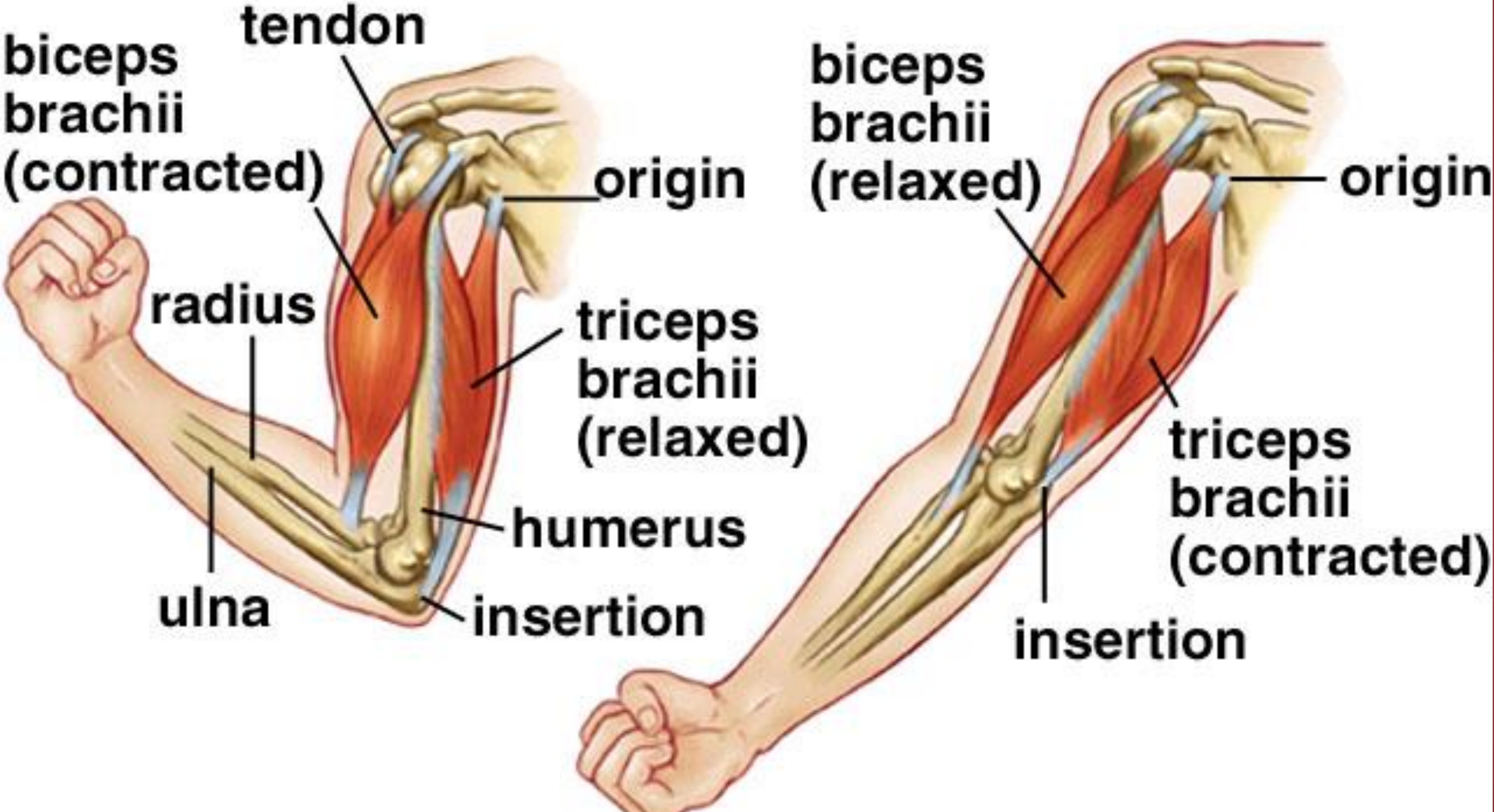
Skeletal Muscle—Single Muscle Fiber



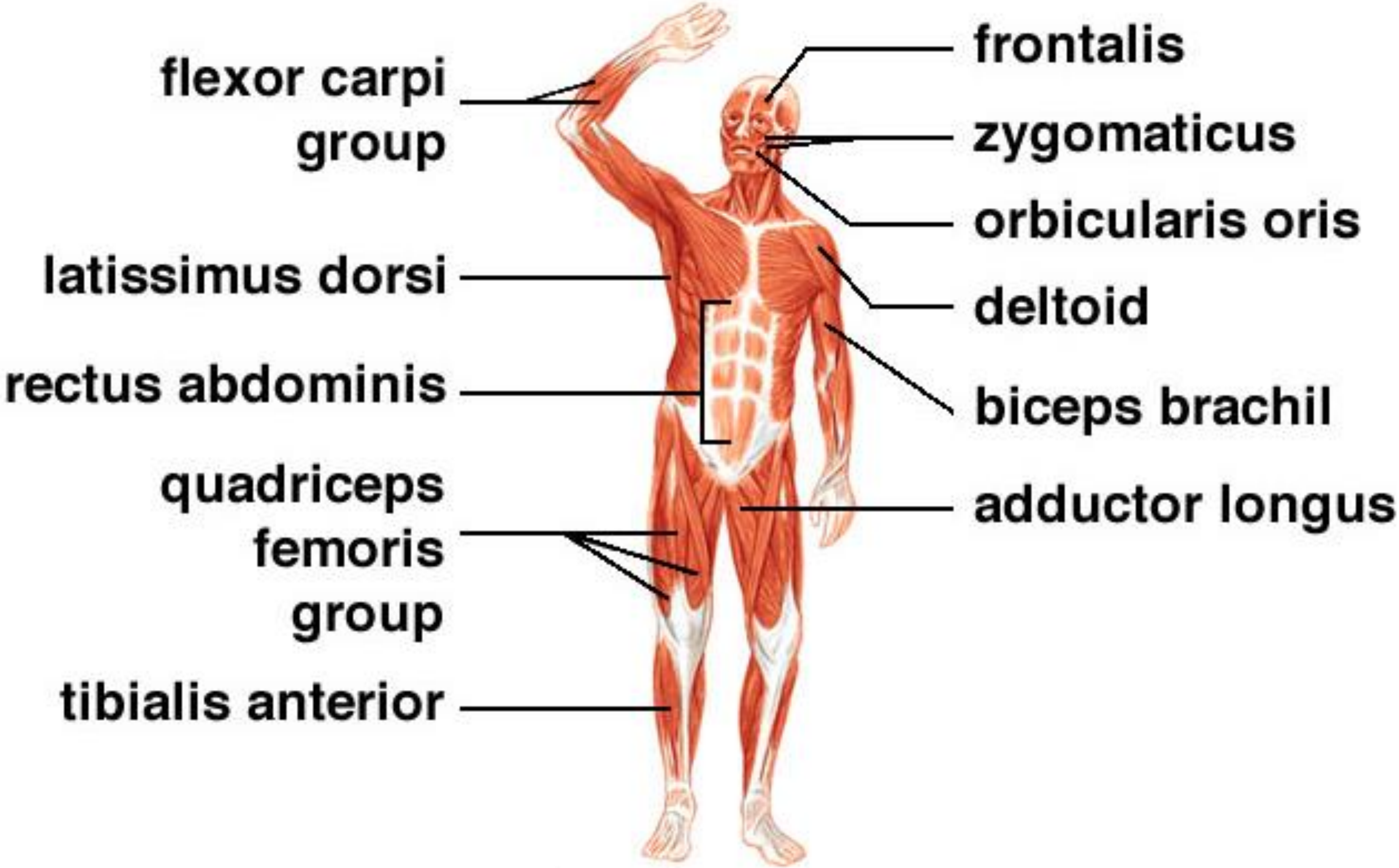
Anatomy of a Muscle



Attachment of the Skeletal Muscles

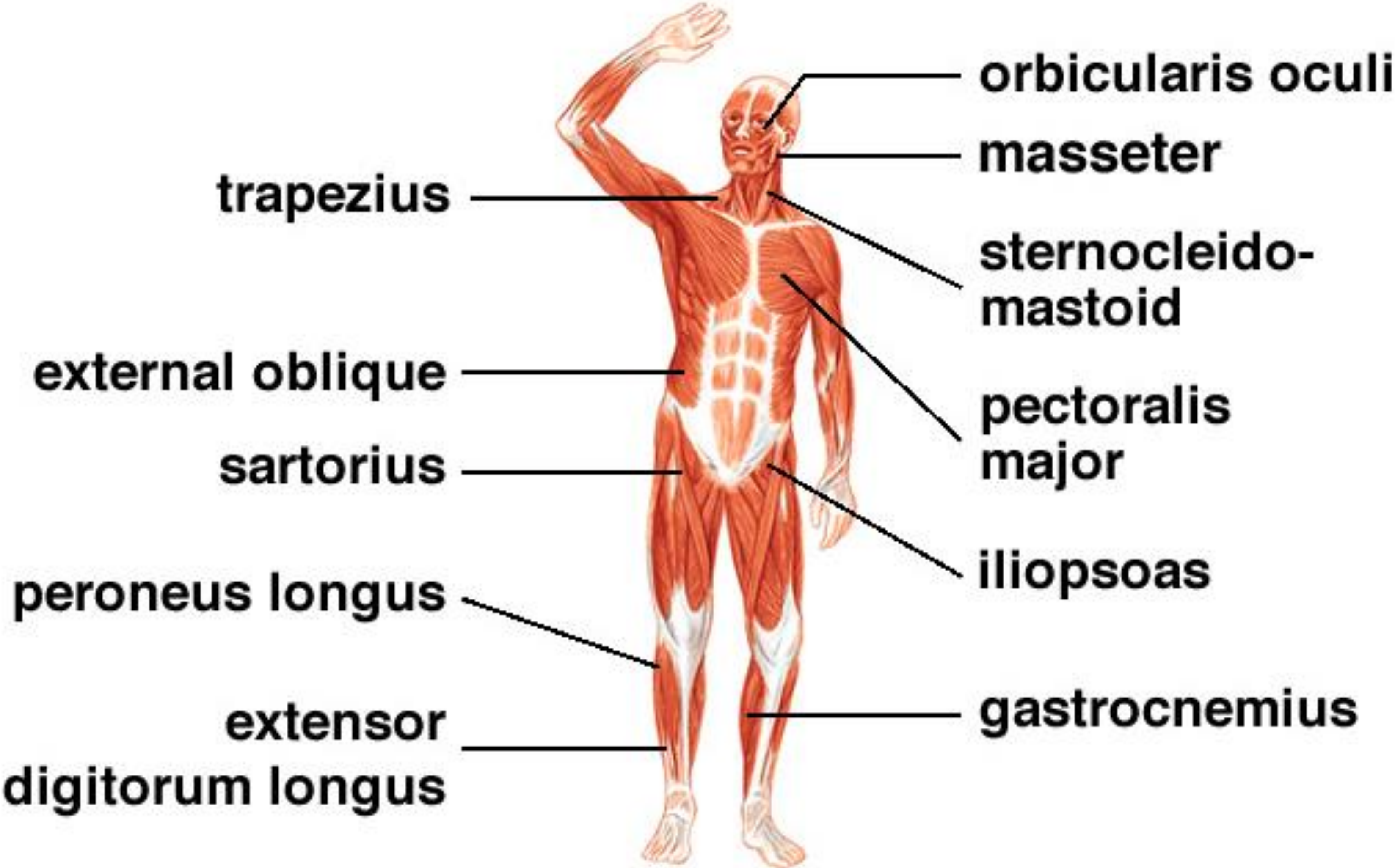


Human Musculature



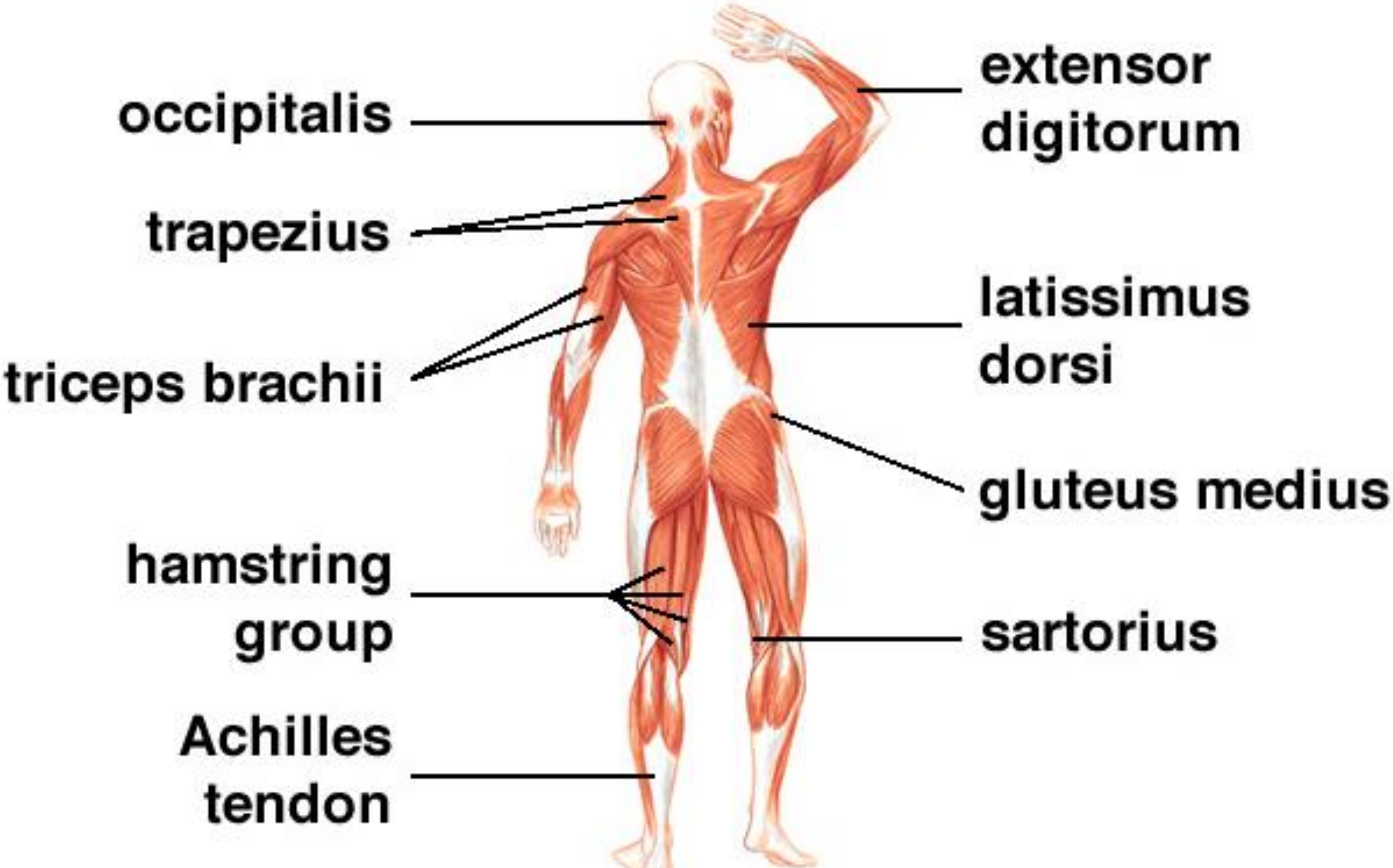
Anterior view

Human Musculature



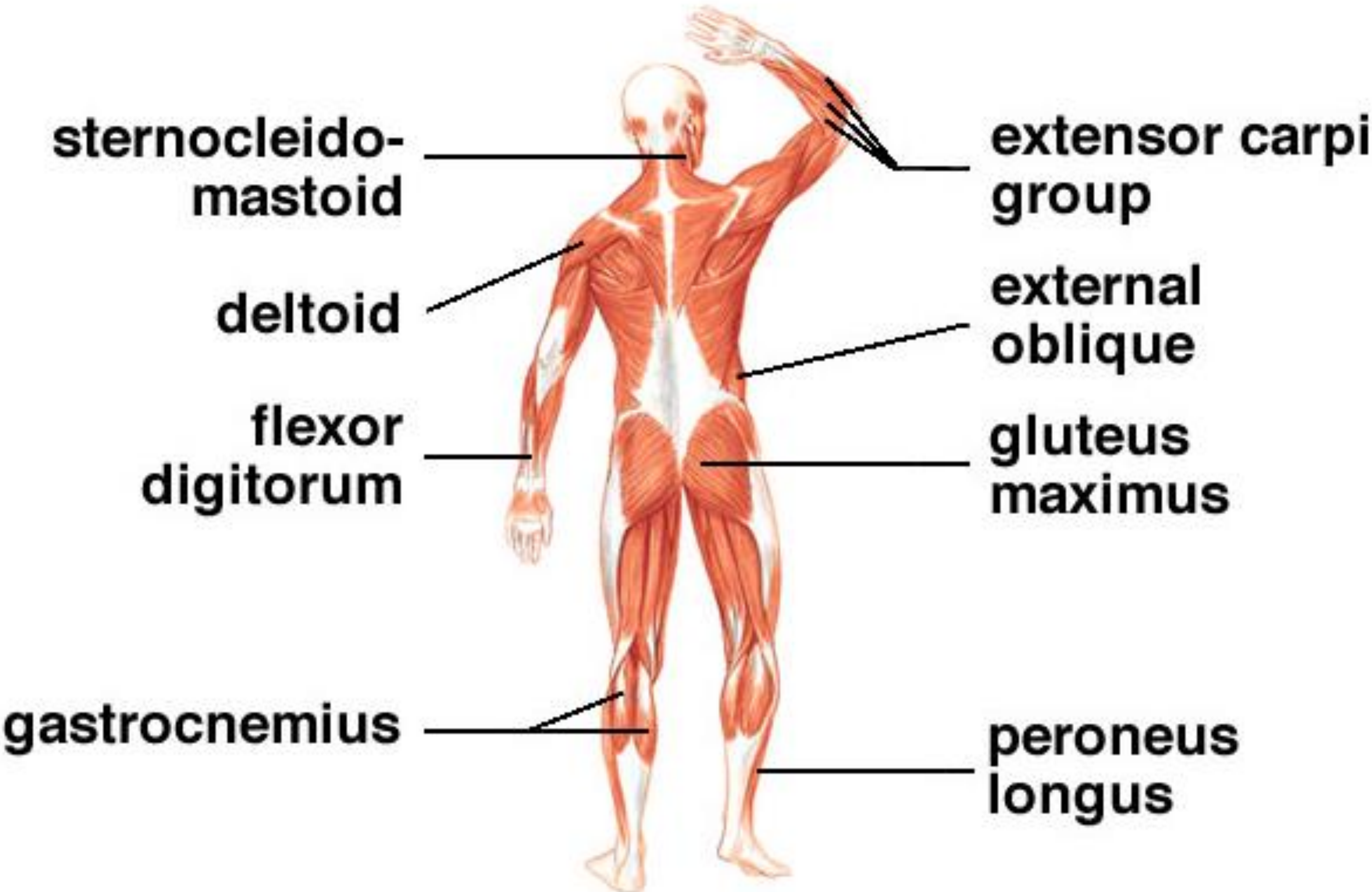
Anterior view

Human Musculature



Posterior view

Human Musculature



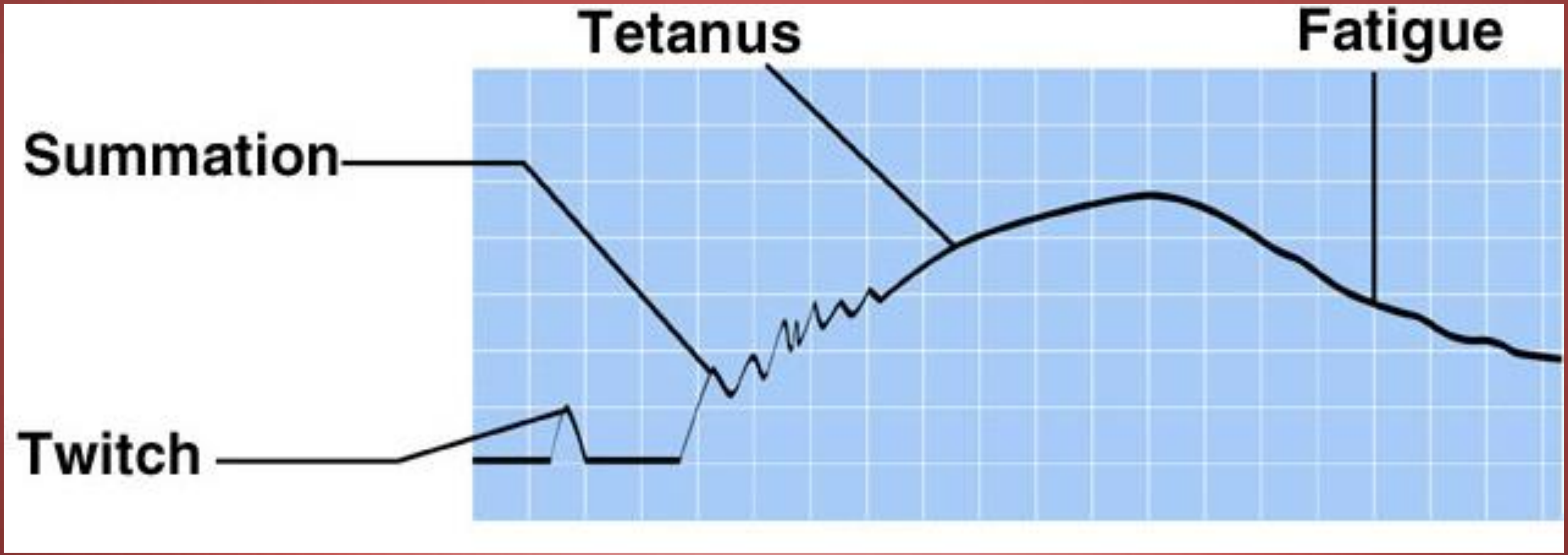
Posterior view

Types of Muscle Contractions

- Twitch:
  - Muscle is stimulated with a single electrical shock (above threshold).
  - Quickly contracts and then relaxes.
  - Increasing stimulus increases the strength of the twitch (up to maximum).

Types of Muscle Contractions

- Summation:
  - If second electrical shock is administered before complete relaxation of muscle.



Types of Muscle Contractions

- Incomplete tetanus:
  - Stimulator delivers an increasing frequency of electrical shocks.
  - Relaxation period shortens between twitches.
  - Strength of contraction increases.
- Complete tetanus:
  - Fusion frequency of stimulation.
  - No visible relaxation between twitches.
  - Smooth sustained contraction.

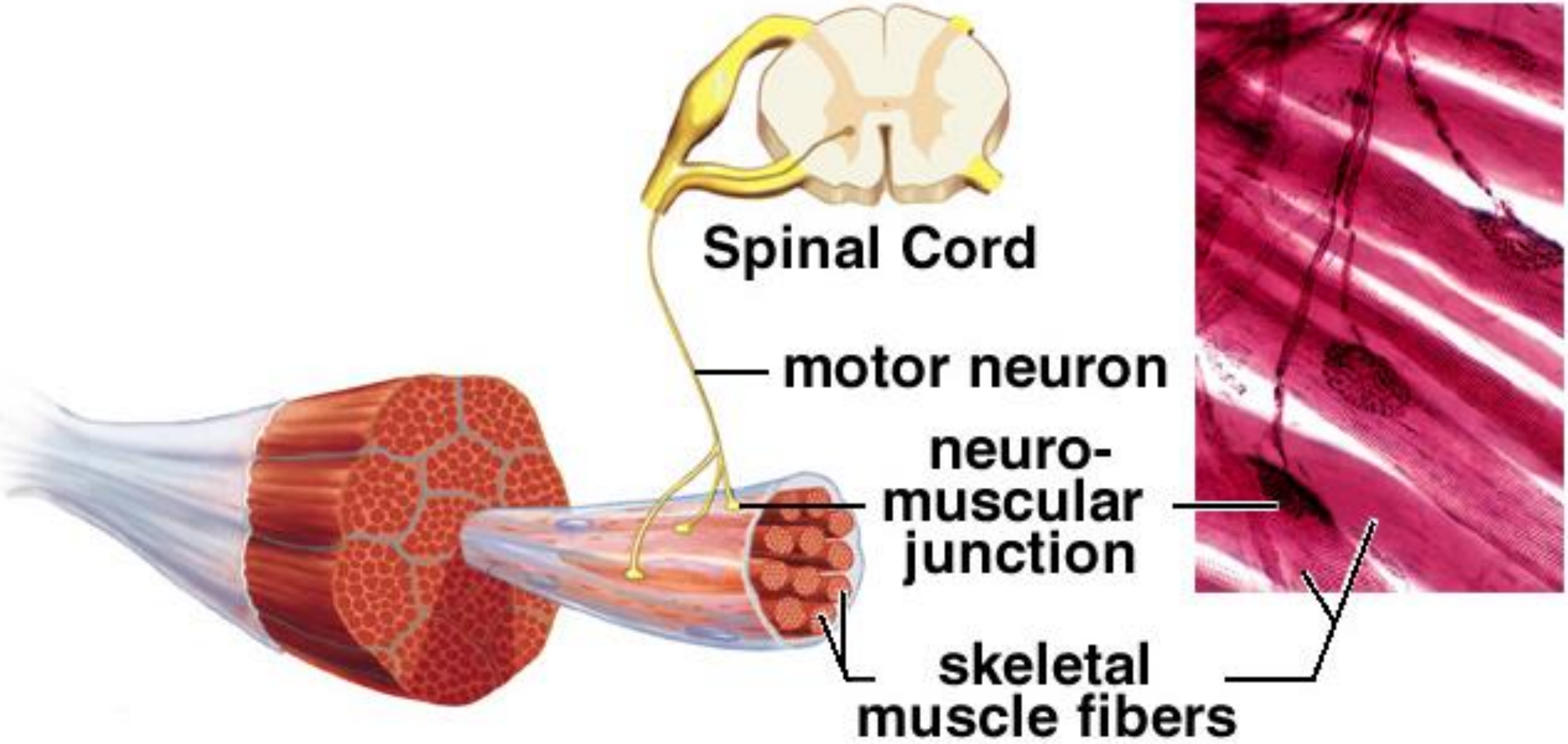
Types of Muscle Contractions

- Treppe:
- Staircase effect.
  - Electrical shocks are delivered at maximal voltage.
  - Each shock produces a separate, stronger twitch (up to maximum).
  - Due to an increase in intracellular Ca^{++}.

Types of Muscle Contractions

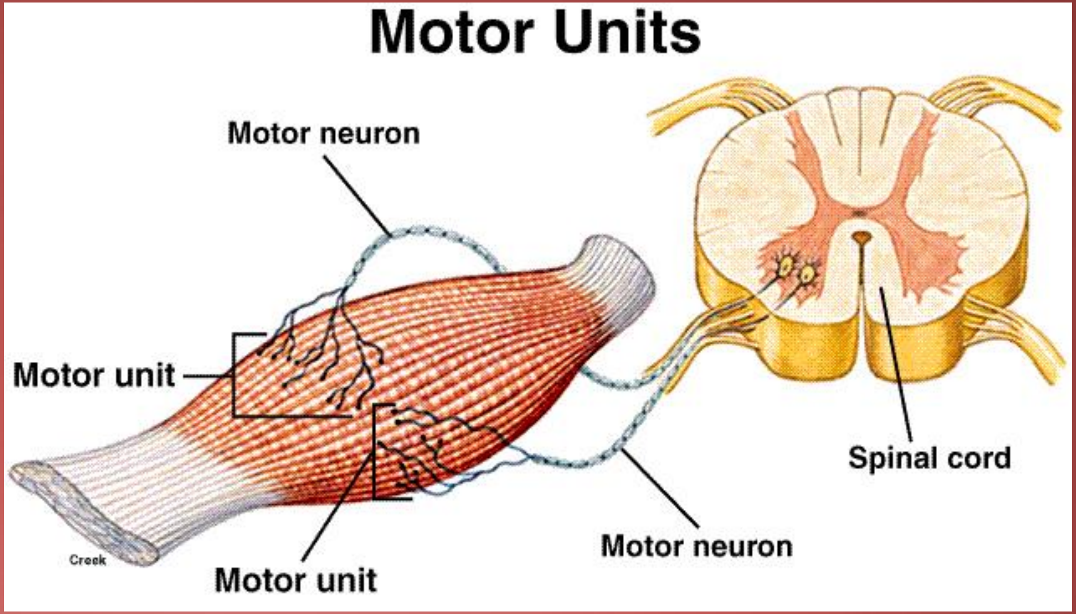
- In order for a muscle to shorten, they must generate a force grater than the opposing forces that act to prevent movement.
- Isotonic Contractions:
  - Force of contraction remains constant throughout the shortening process.
- Isometric Contractions:
  - Length of muscle fibers remain constant, if the number of muscle fibers activated is too few to shorten the muscle.

Contraction of a Muscle



Motor Unit

- Each somatic neuron together with all the muscle fibers it innervates.
- Each muscle fiber receives a single axon terminal from a somatic neuron.
- Each axon can have collateral branches to innervate an equal # of fibers.



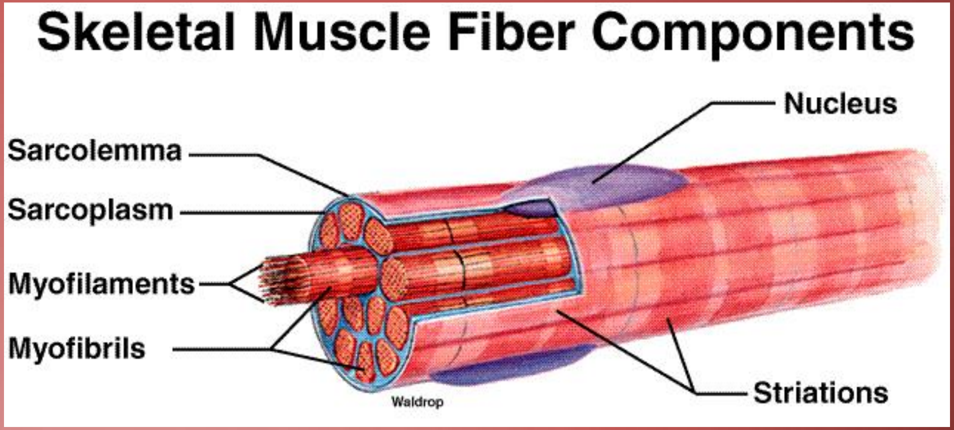
Motor Unit

When somatic neuron activated, all the muscle fibers it innervates contract with all or none contractions.

- Innervation ratio:
  - Ratio of motor neuron: muscle fibers.
    - Fine neural control over the strength occurs when many small motor units are involved.
- Recruitment:
  - Larger and larger motor units are activated to produce greater strength.

Mechanisms of Contraction

- Each myofibril contains myofilaments.
- Thick filaments:
  - A bands contain thick filaments (primarily composed of myosin).
- Thin filaments:
  - I band contain thin filaments (primarily composed of actin).
  - Center of each I band is Z line.
  - Sarcomere:
    - Z line to Z line.

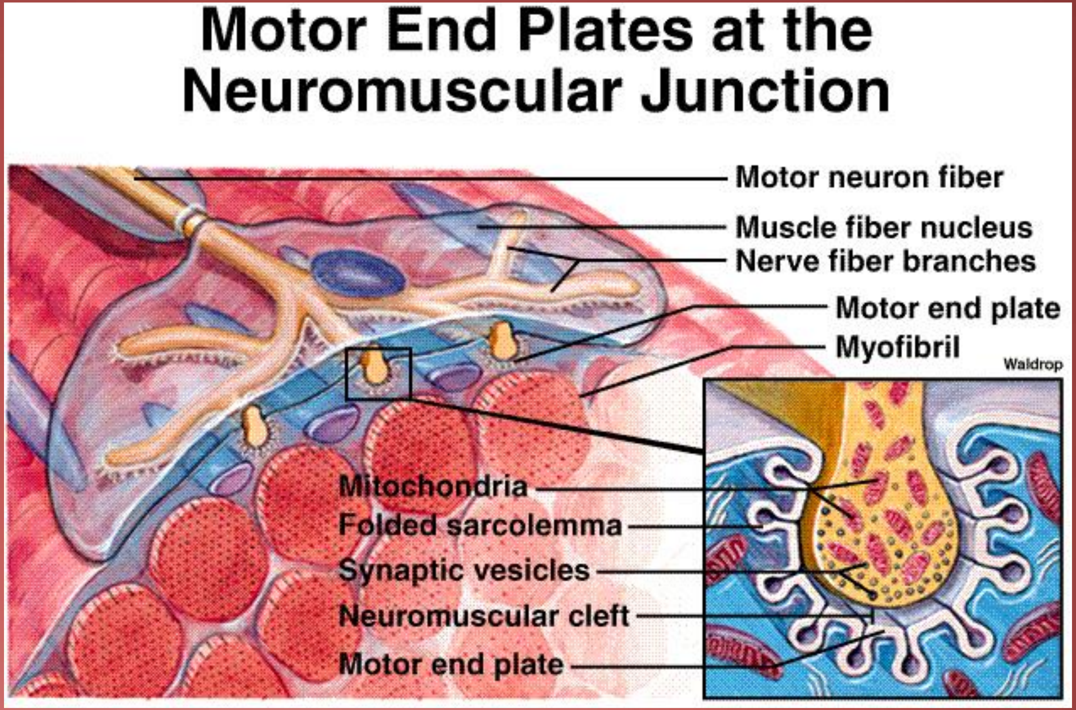


Mechanisms of Contraction

- AP travels down the motor neuron to bouton.
- VG Ca^{++} channels open, Ca^{++} diffuses into the bouton.
- Ca^{++} binds to vesicles of NT.
- ACh released into neuromuscular junction.
- ACh binds onto receptor.
- Chemical gated channel for Na^{+} and K^{+}open.

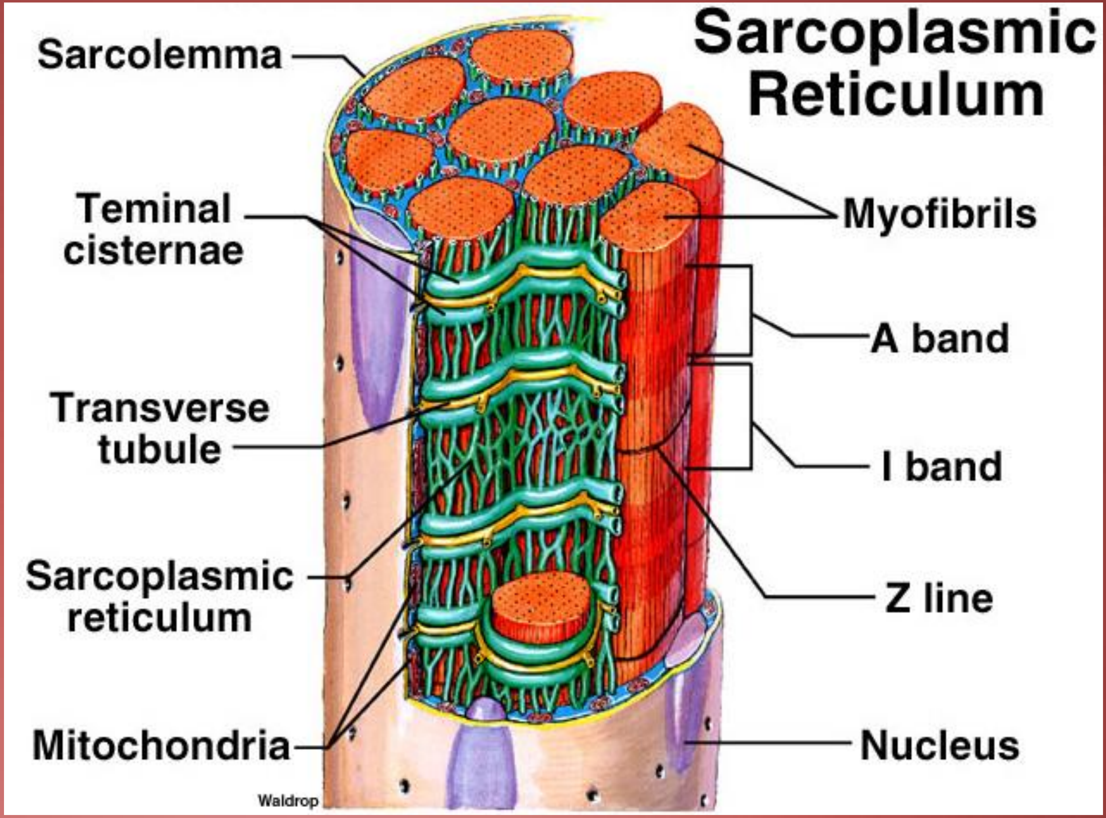
Mechanisms of Contraction

- Na^+ diffuses into and K^+ out of the membrane.
- End-plate potential occurs (depolarization).
- + ions are attracted to negative membrane.
- If depolarization sufficient, threshold occurs, producing AP.



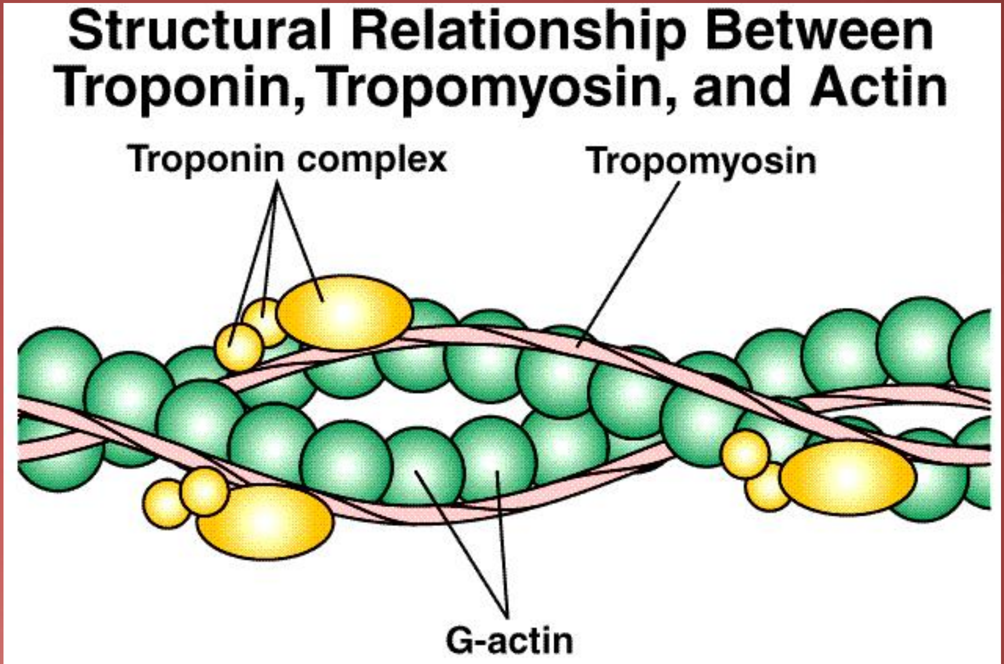
Mechanisms of Contraction

- AP travels down sarcolema and T tubules.
- Terminal cisternae release Ca^{++}.



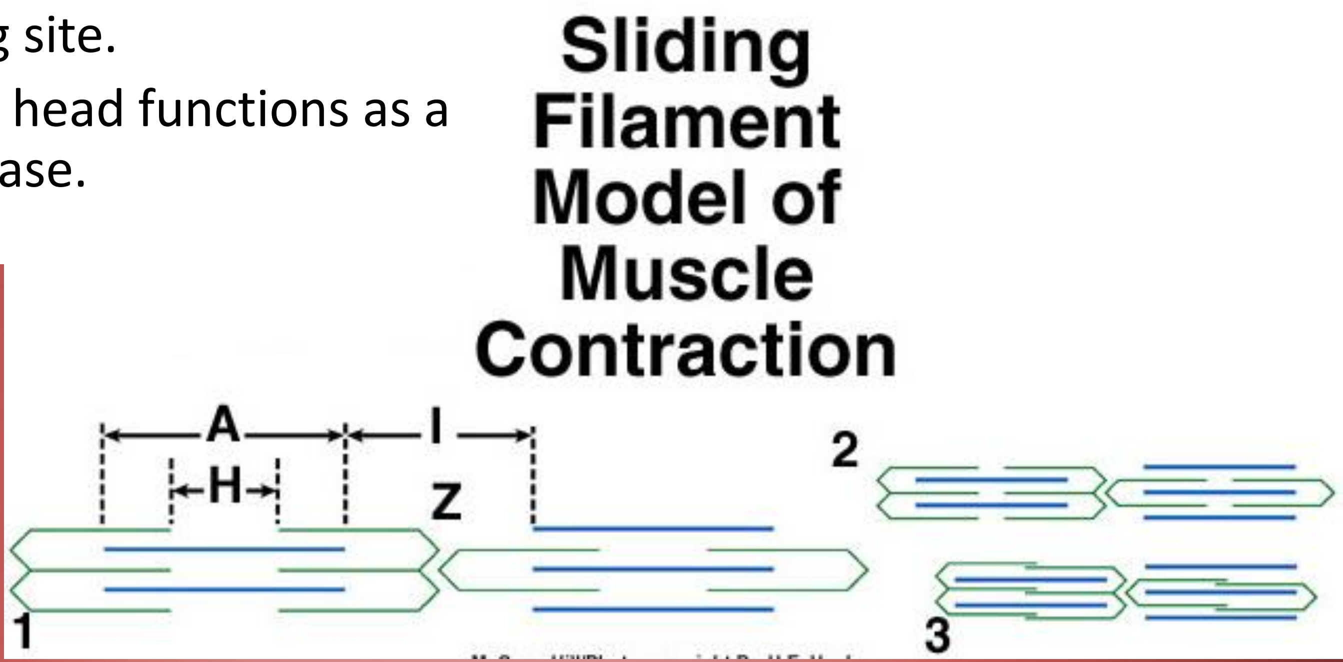
Mechanisms of Contraction

- Ca^{++}binds to troponin.
- Troponin-tropomyosin complex moves.
- Active binding site on actin disclosed.

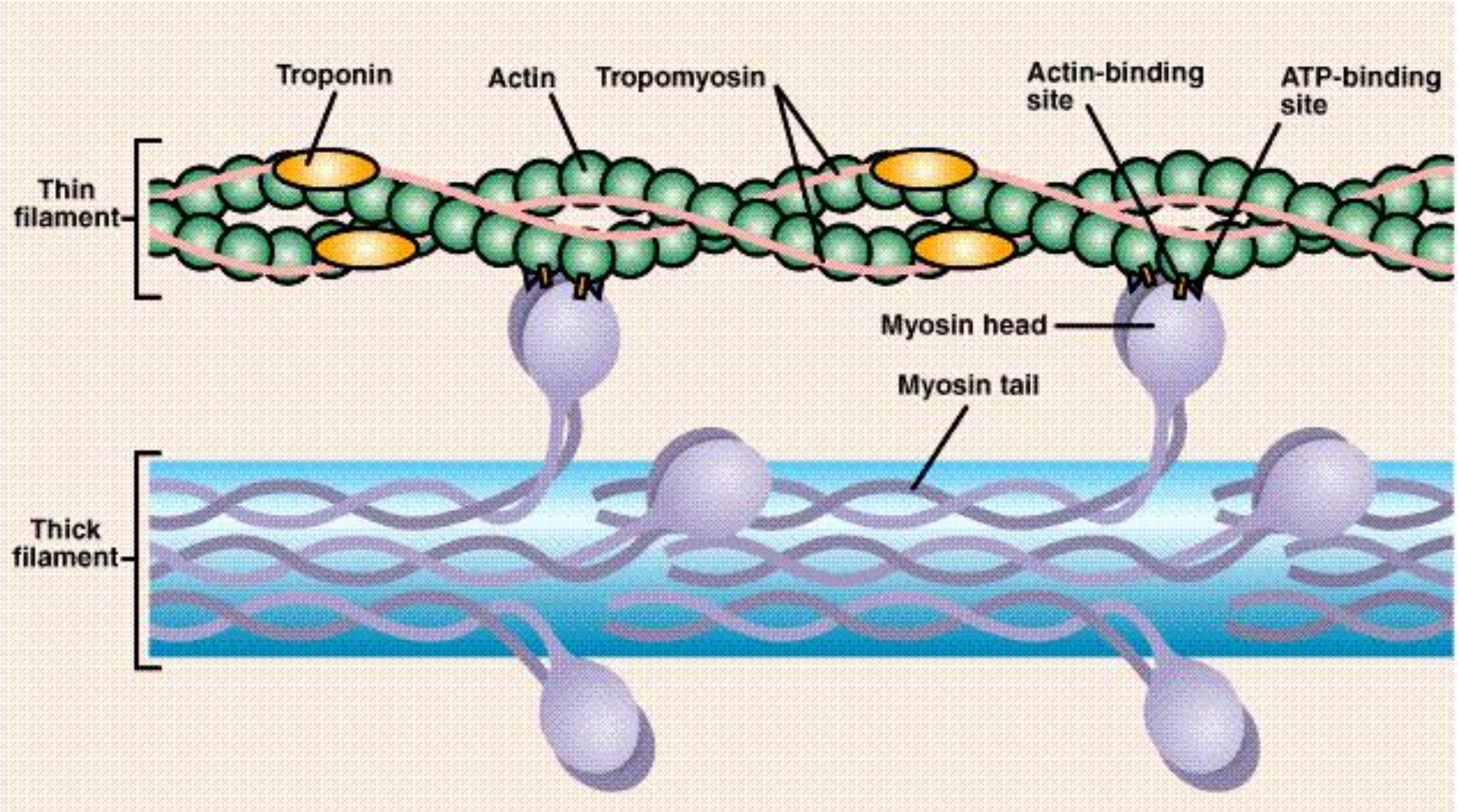


Sliding Filament Theory

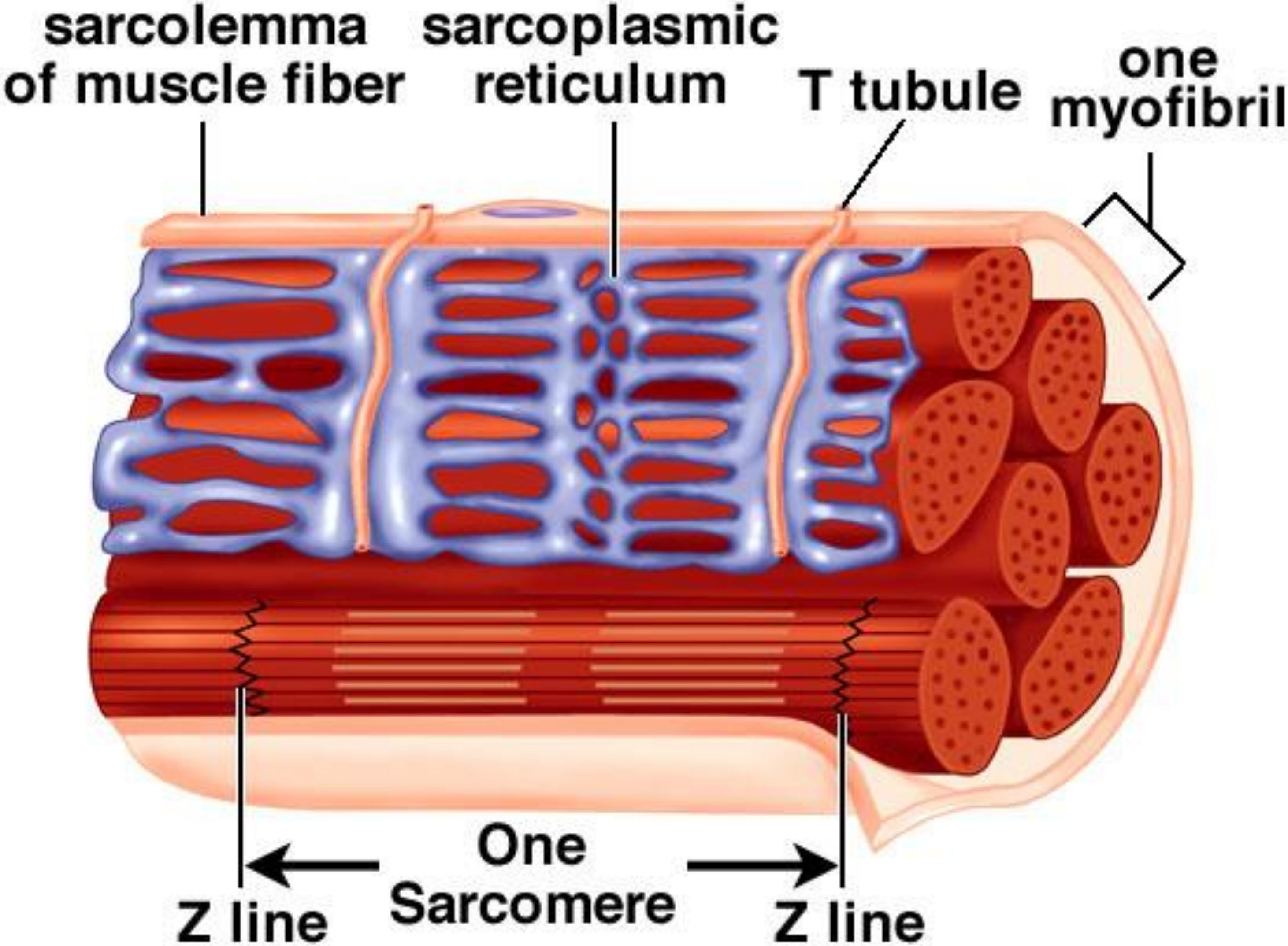
- Sliding of filaments is produced by the actions of **cross bridges.**
- Cross bridges are part of the myosin proteins that form arms that terminate in heads.
- Each myosin head contains an ATP-binding site.
- The myosin head functions as a myosin ATPase.



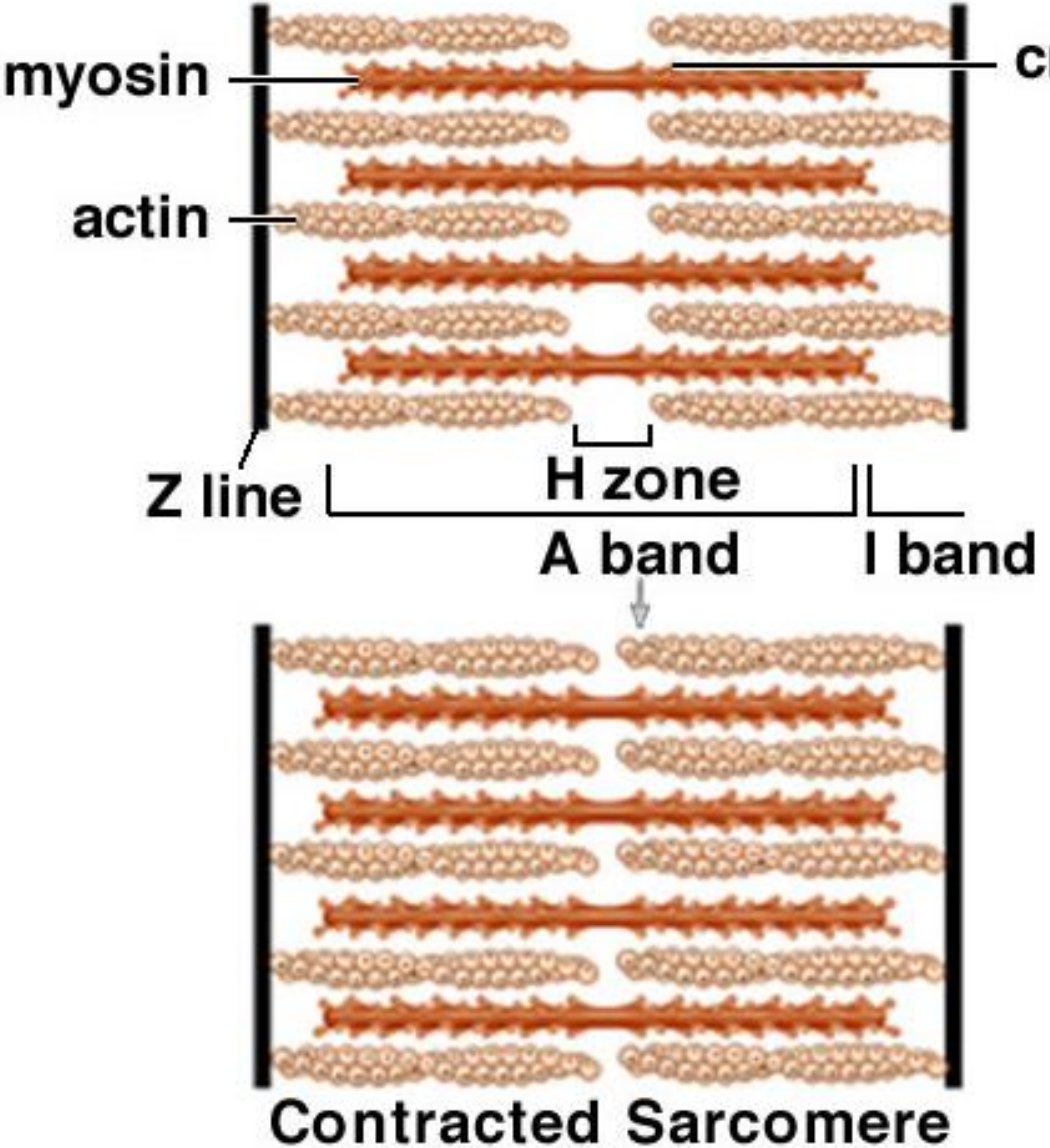
Myosin and its Binding Sites for ATP and Actin



Contraction of a Muscle



Contraction of a Muscle



Contraction

- Myosin binding site splits ATP to ADP and Pi.
- ADP and Pi remain bound to myosin until myosin heads attach to actin.
- Pi is released, causing the power stroke to occur.

Contraction

- Power stroke pulls actin toward the center of the A band.
- ADP is released, when myosin binds to a fresh ATP at the end of the power stroke.
- Release of ADP upon binding to another ATP, causes the cross bridge bond to break.
- Cross bridges detach, ready to bind again.

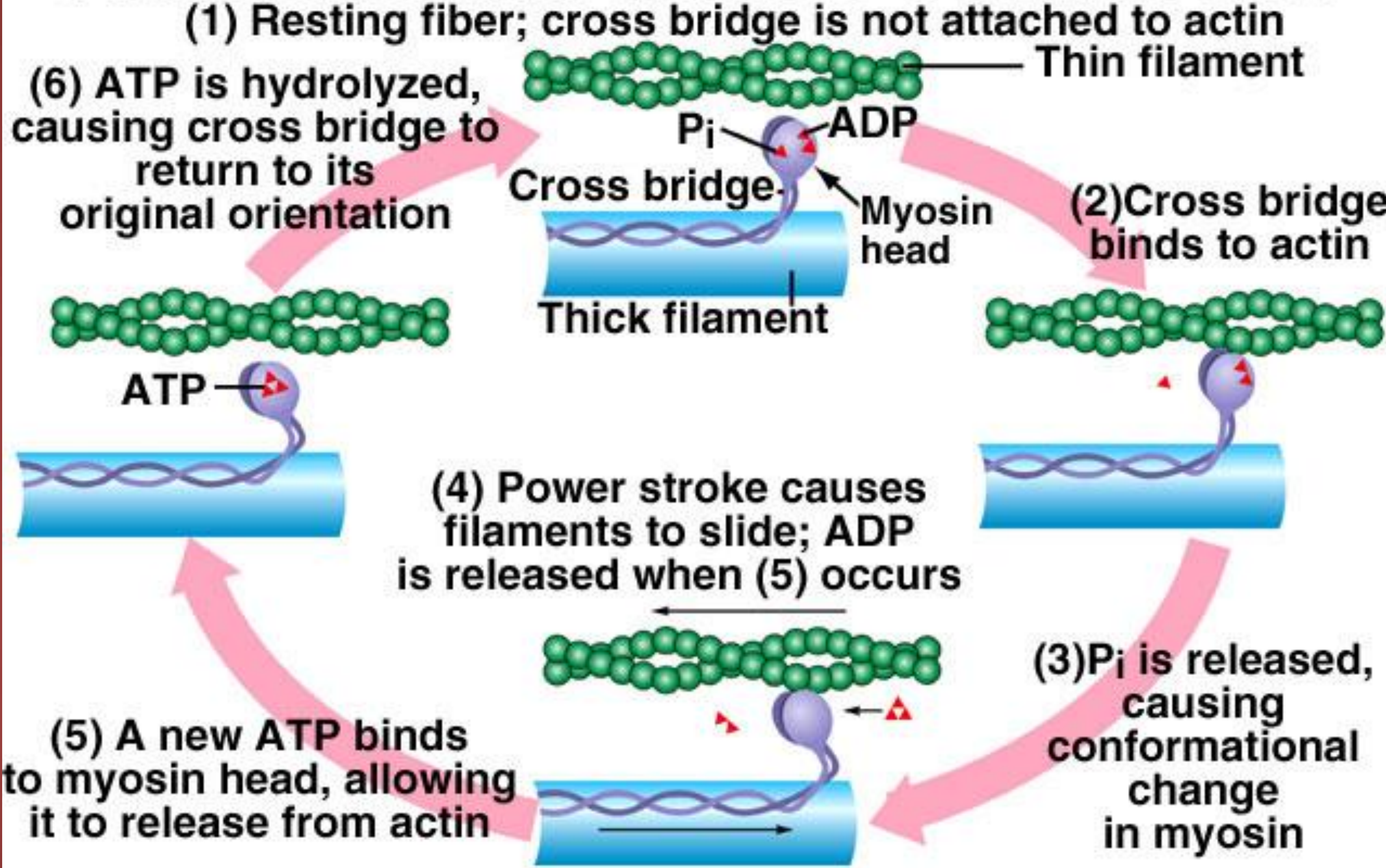
Contraction

- ACh-esterase degrades ACh.
- Ca^{++} pumped back into SR.
- Choline recycled to make more ACh.
- Only about 50% if cross bridges are attached at any given time.
  - Asynchronous action.

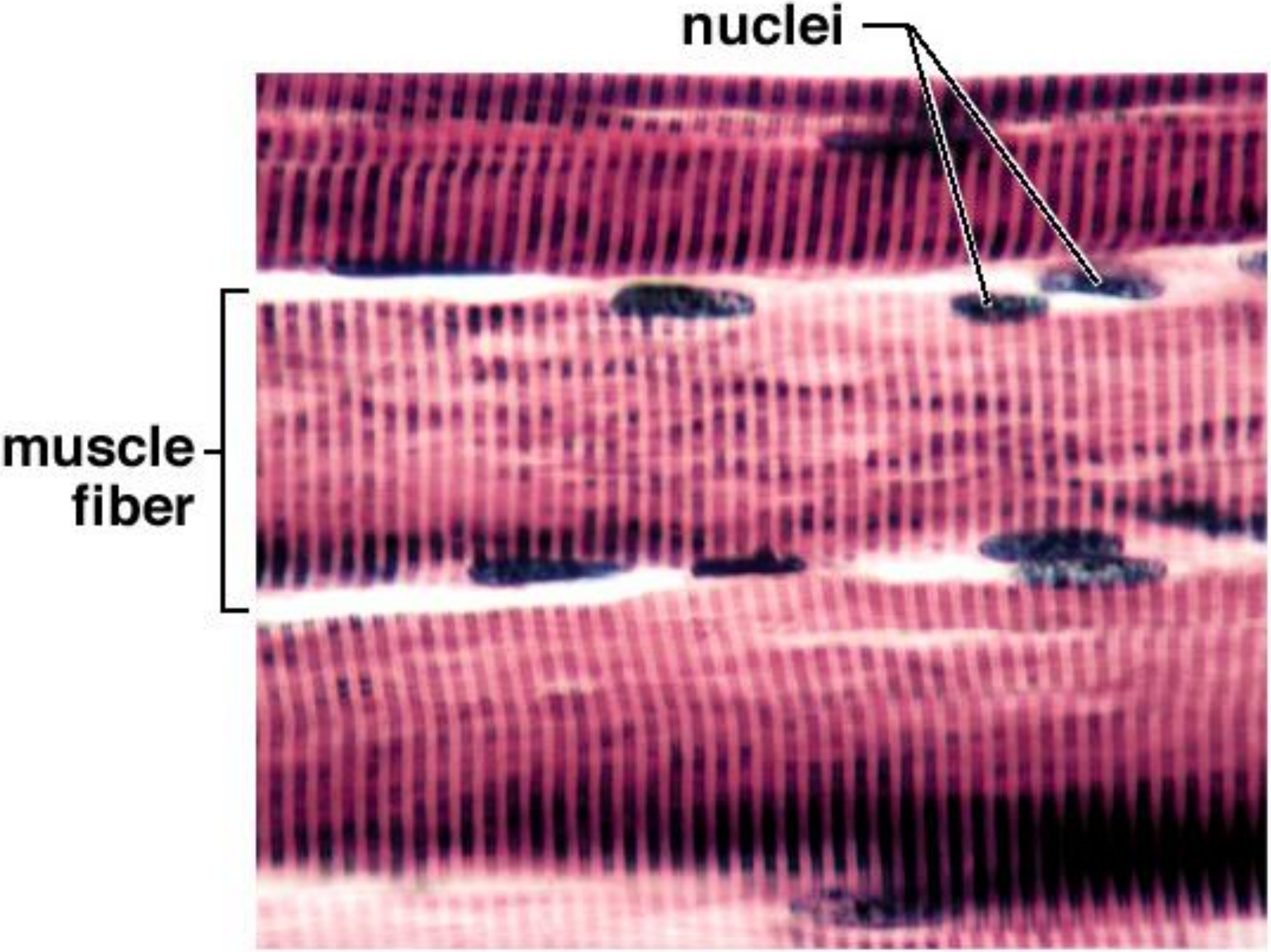
Contraction

- A bands:
  - Move closer together.
  - Do not shorten.
- I band:
  - Distance between A bands of successive sarcomeres.
  - Decrease in length.
- Occurs because of sliding of thin filaments over and between thick filaments.
- H band shortens.
  - Contains only thick filaments.

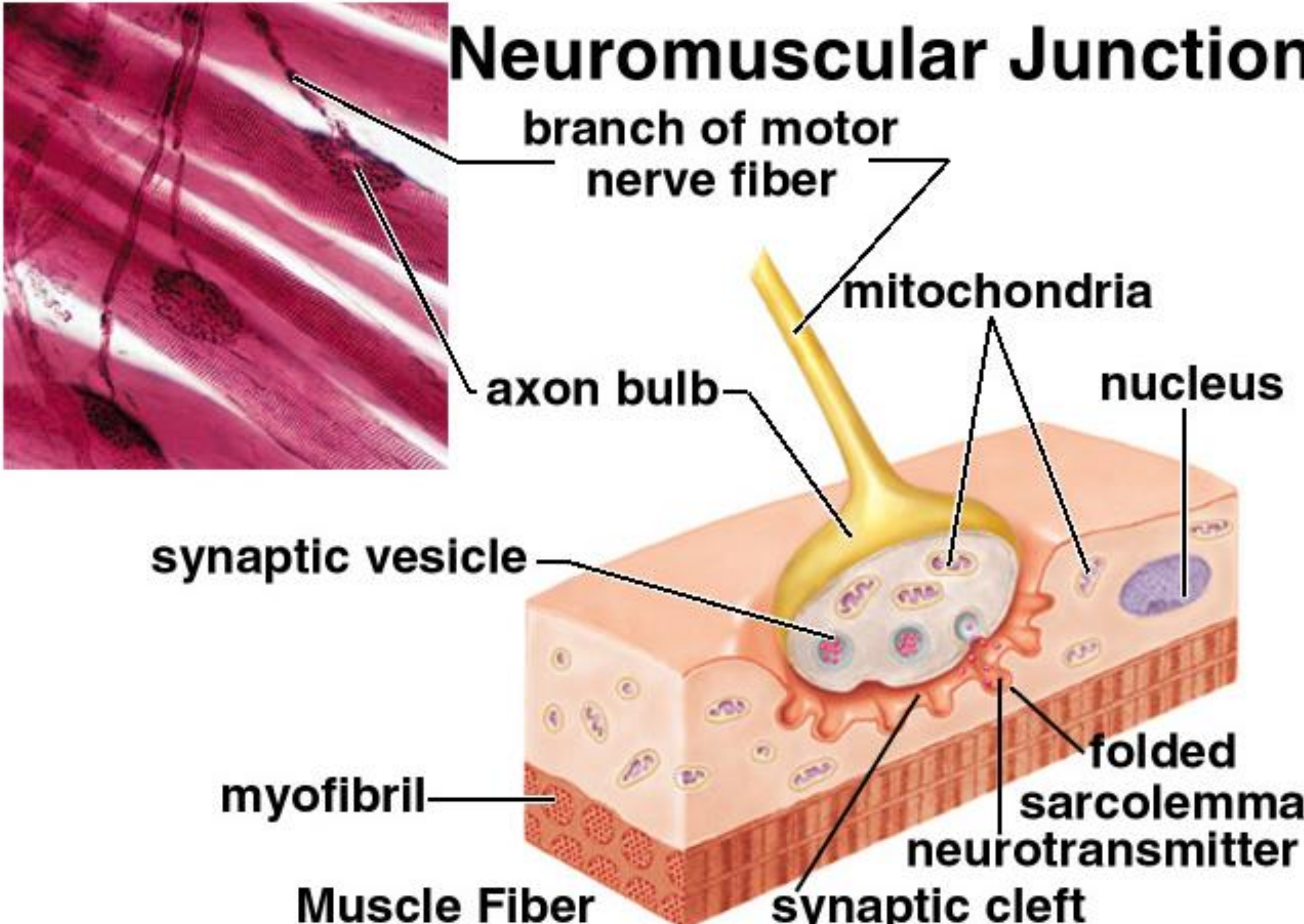
Cross-bridge Cycle Causing Sliding Filaments and Muscle Contraction



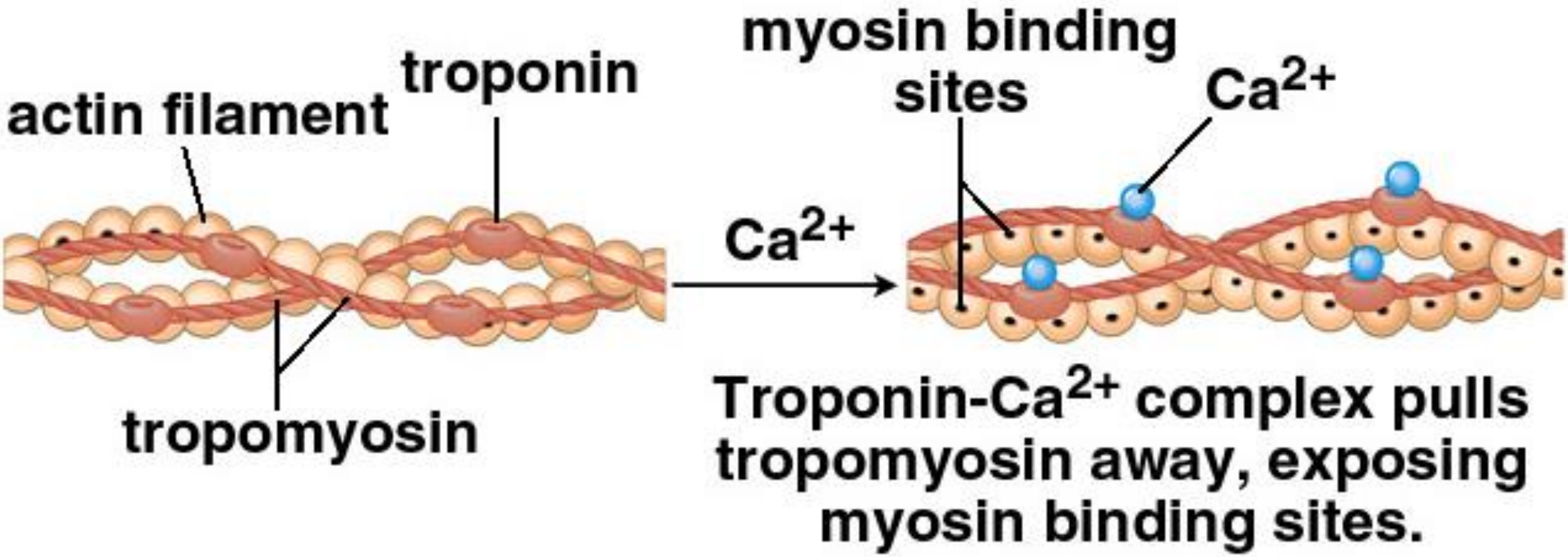
Light Micrograph of Skeletal Muscle



Neuromuscular Junction



Role of Calcium and Myosin in Muscle Contraction

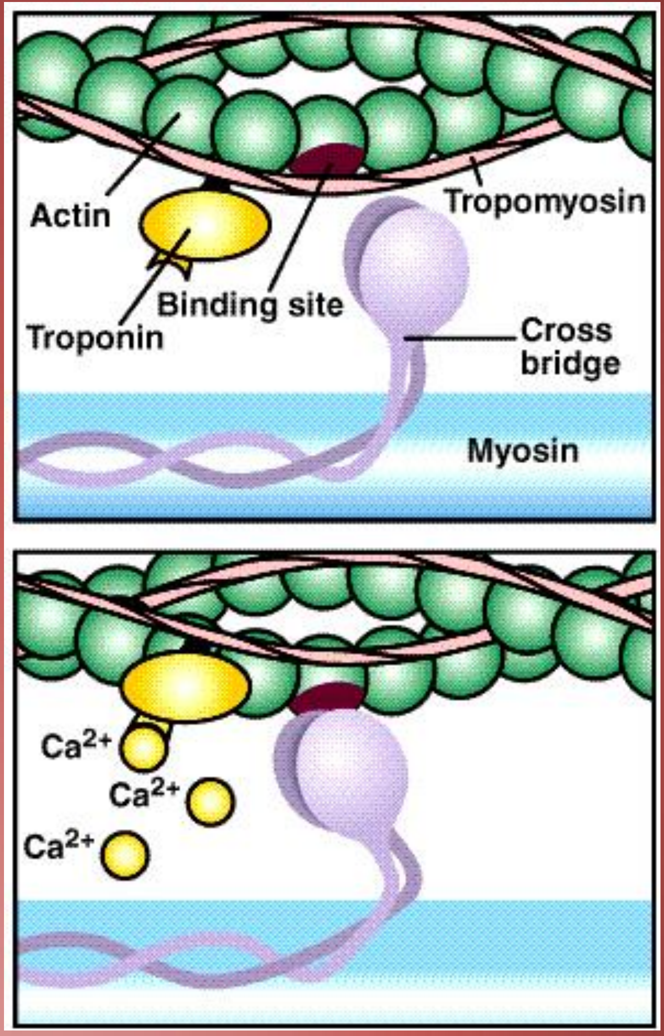


Role of Ca^{++}

- Relaxation:
  - [Ca^{++}] in sarcoplasm low when tropomyosin block attachment.
  - Ca^{++} is pumped back into the SR in the terminal cisternae.
  - Muscle relaxes.

Role of Ca^{++} in Muscle Contraction

- Stimulated:
- Ca^{++} is released from SR.
- Ca^{++} attaches to troponin
- Tropomyosin-troponin configuration change



Metabolism of Skeletal Muscles

- Skeletal muscle respire anaerobically first 45 - 90 sec.
- If exercise is moderate, aerobic respiration contributes following the first 2 min. of exercise.
- Maximum oxygen uptake (aerobic capacity):
  - Maximum rate of oxygen consumption ($\dot{V}_{02}$ max).
  - Determined by age, gender, and size.

Metabolism of Skeletal Muscles

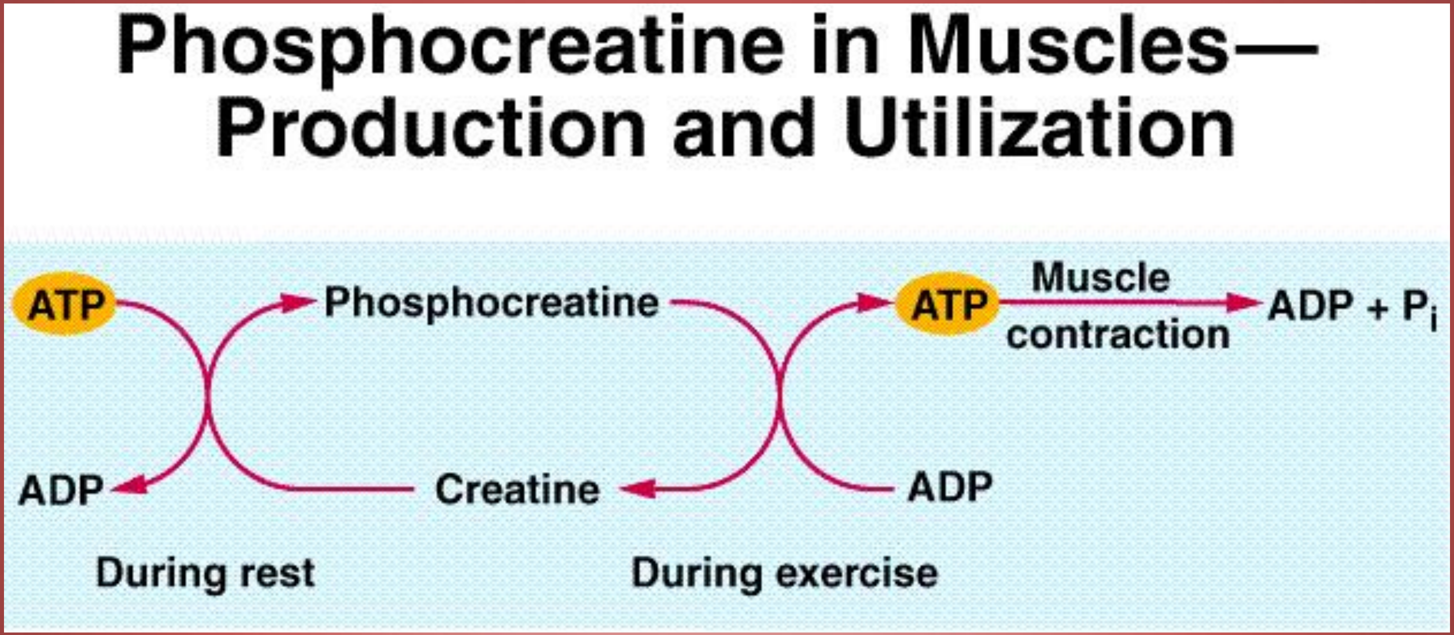
- Lactate threshold:
  - Intensity of exercise
  - % of max. 0_2 at which there is a significant rise in blood lactate.
  - Healthy individual, significant amount or blood lactate appears at 50 – 70% $\dot{V}_{02}$ max.
- During light exercise, most energy is derived from aerobic respiration of fatty acids.
- During moderate exercise, energy is derived equally from fatty acids and glucose.
- During heavy exercise, glucose supplies majority of energy.

Metabolism of Skeletal Muscles

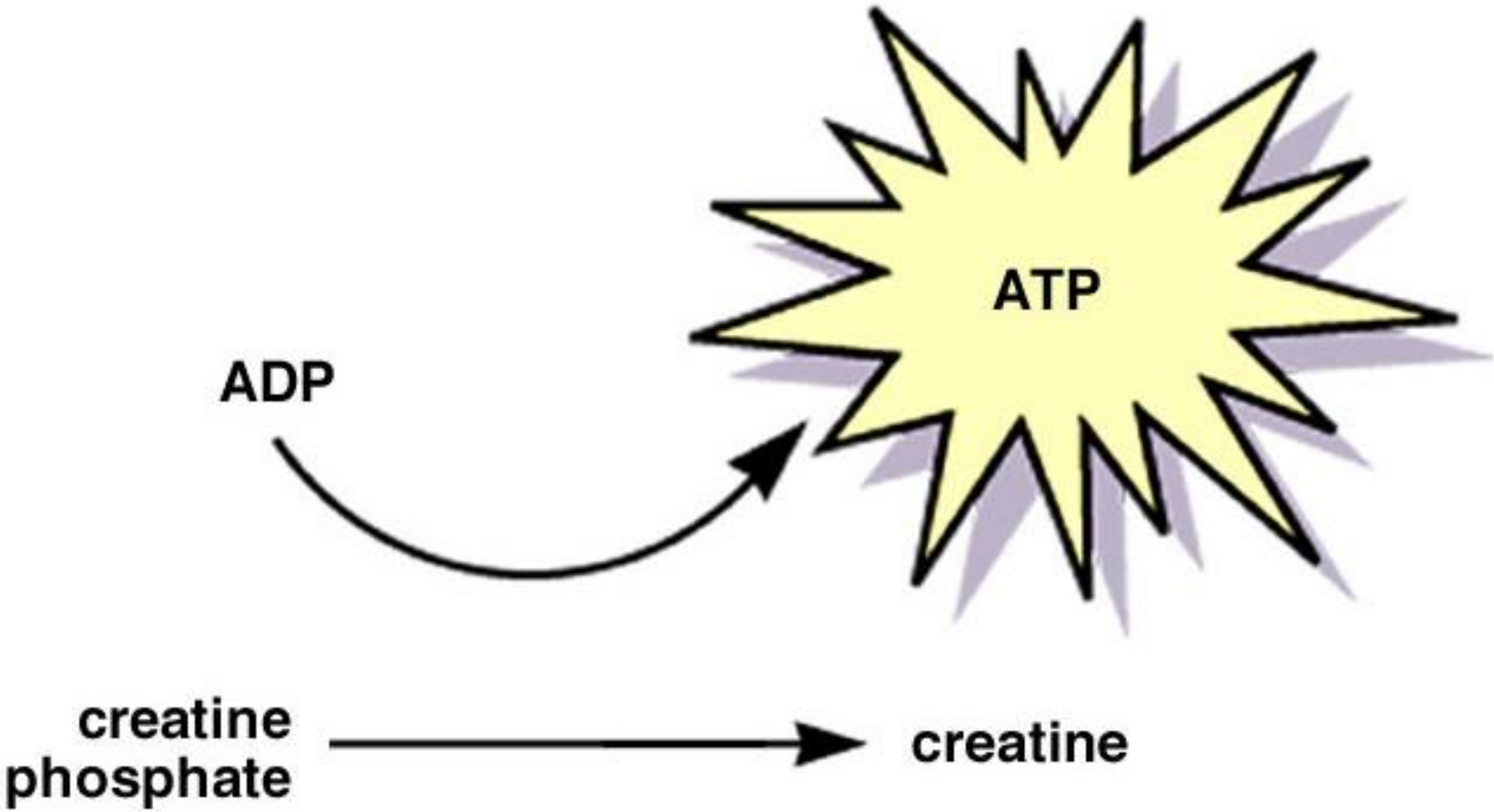
- Oxygen debt:
  - Oxygen that was withdrawn from hemoglobin and myoglobin during exercise.
- When person stops exercising, rate of oxygen uptake does not immediately return to pre-exercise levels to repay oxygen debt.

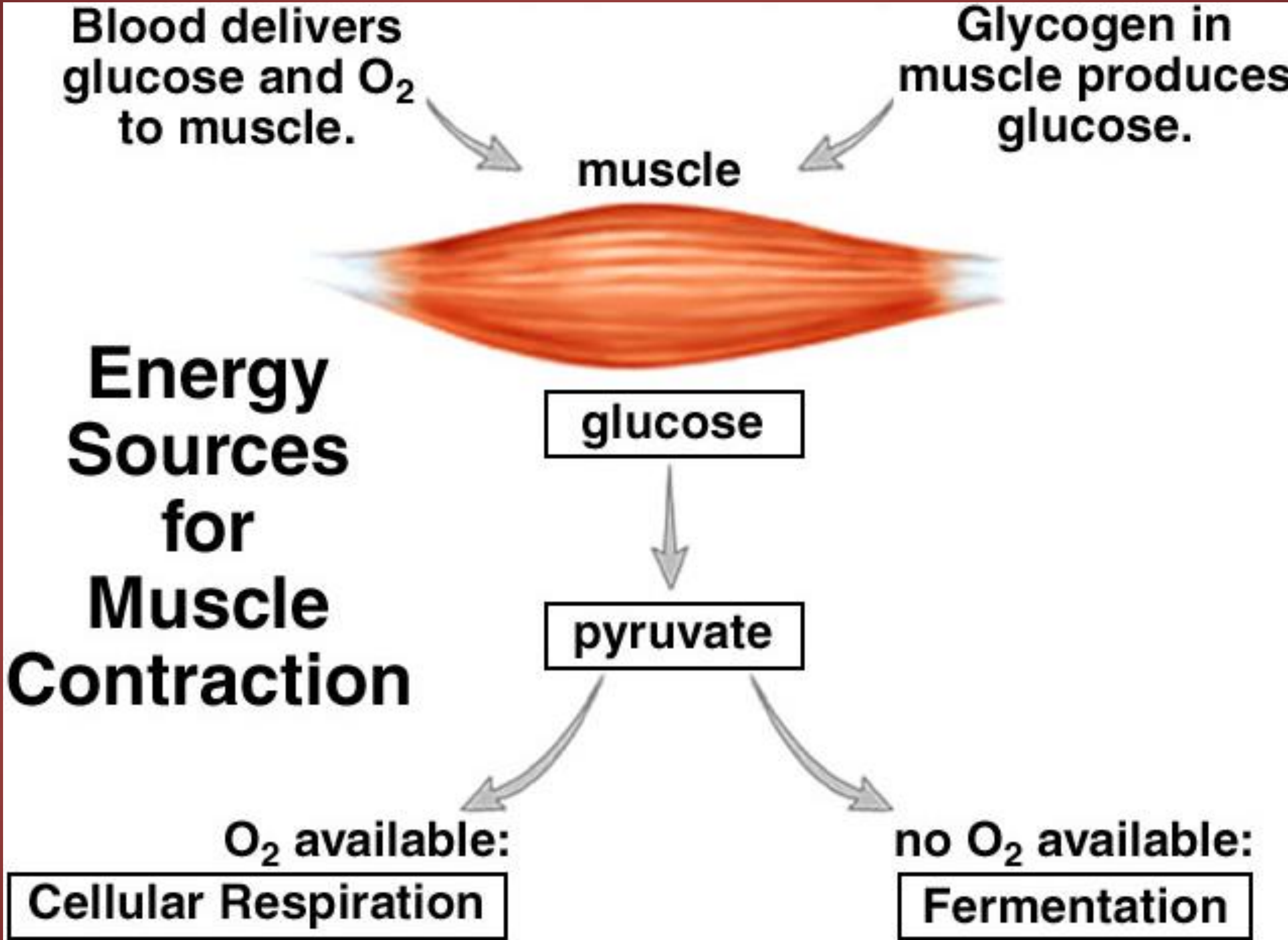
Metabolism of Skeletal Muscles

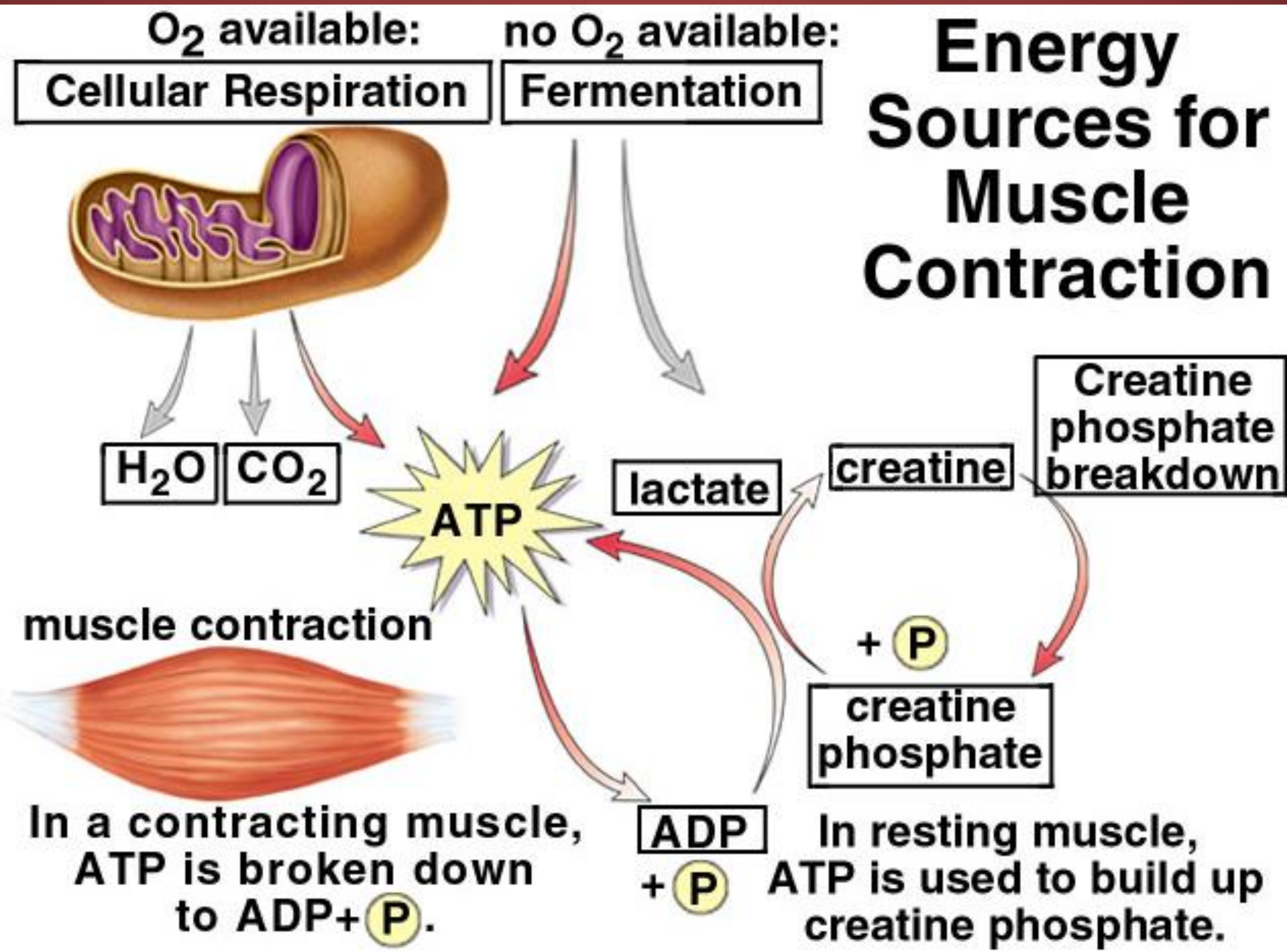
- Phosphcreatine:
- Rapid source of renewal of ATP.
- ADP combines with creatine phosphate.
- Phosphocreatine concentration is 3 times concentration of ATP.



ATP Regeneration




Blood delivers glucose and O_2 to muscle.
Glycogen in muscle produces glucose.
muscle
Energy Sources for Muscle Contraction
glucose
pyruvate
O_2 available:
Cellular Respiration
no O_2 available:
Fermentation



O2 available:
no O2 available:
Energy Sources for Muscle Contraction
Cellular Respiration
Fermentation
H2O
CO2
ATP
lactate
creatine
Creatine phosphate breakdown
+ P
creatine phosphate
muscle contraction
ADP
+ P
In a contracting muscle, ATP is broken down to ADP+ P.
In resting muscle, ATP is used to build up creatine phosphate.

Adaptations to Exercise Training

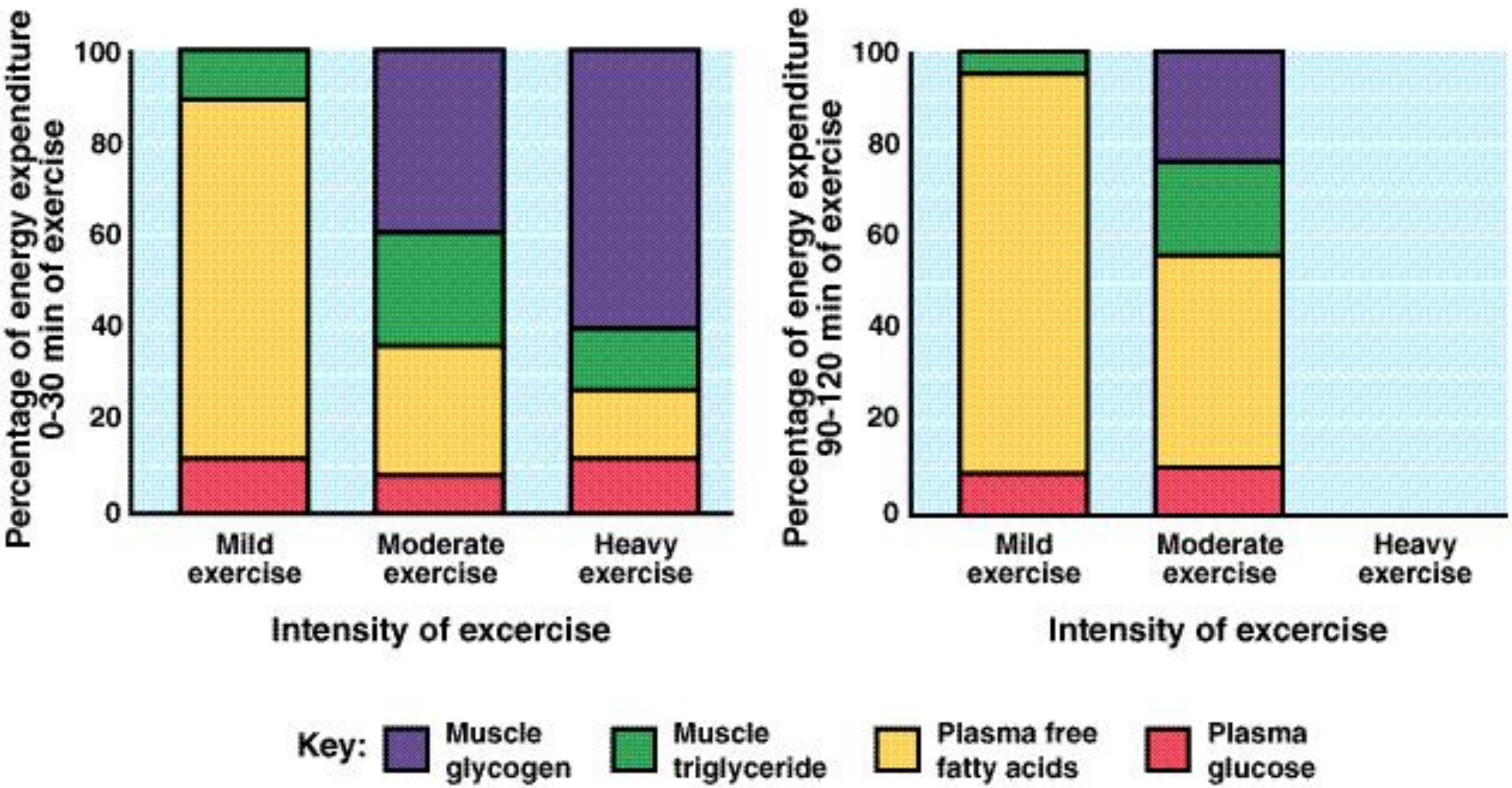
- Maximum oxygen uptake in trained endurance athletes increases up to 86 ml of 0_2/min.
- Increases lactate threshold.
- Increase proportion of energy derived from fatty acids.
- Lower depletion of glycogen stores.
- Endurance training increase in type IIA fibers and decrease in type IIB fibers.

Energy Sources for Muscle Contraction

In athletes, there is

- better blood supply to muscles;
- more myoglobin stored in muscles;
- an increase in fatty acid metabolism that spares blood glucose;
- a smaller O_2 debt due to a more rapid increase in O_2 uptake at the onset of work;
- a reduction in lactate and H^+ formation.

Muscle Fuel Consumption During Exercise



Slow- and Fast-Twitch Fibers

- Skeletal muscle fibers can be divided on basis of contraction speed:
- Slow-twitch (type I fibers):
- Fast-twitch (type II fibers):
- Differences due to different myosin ATPase isoenzymes.

Slow- and Fast-Twitch Fibers

- Slow-twitch (type I fibers):
  - High oxidative capacity:
  - Resistant to fatigue.
  - Have rich capillary supply.
  - Numerous mitochondria and aerobic enzymes.
  - High concentration of myoglobin.

Slow- and Fast-Twitch Fibers

- Fast-twitch (type IIB fibers):
  - Adapted to respire anaerobically.
  - Have large stores of glycogen.
  - Have few capillaries.
  - Have few mitochondria.
  - Extraocular muscles.

Table 12.4 Characteristics of Muscle Fiber Types

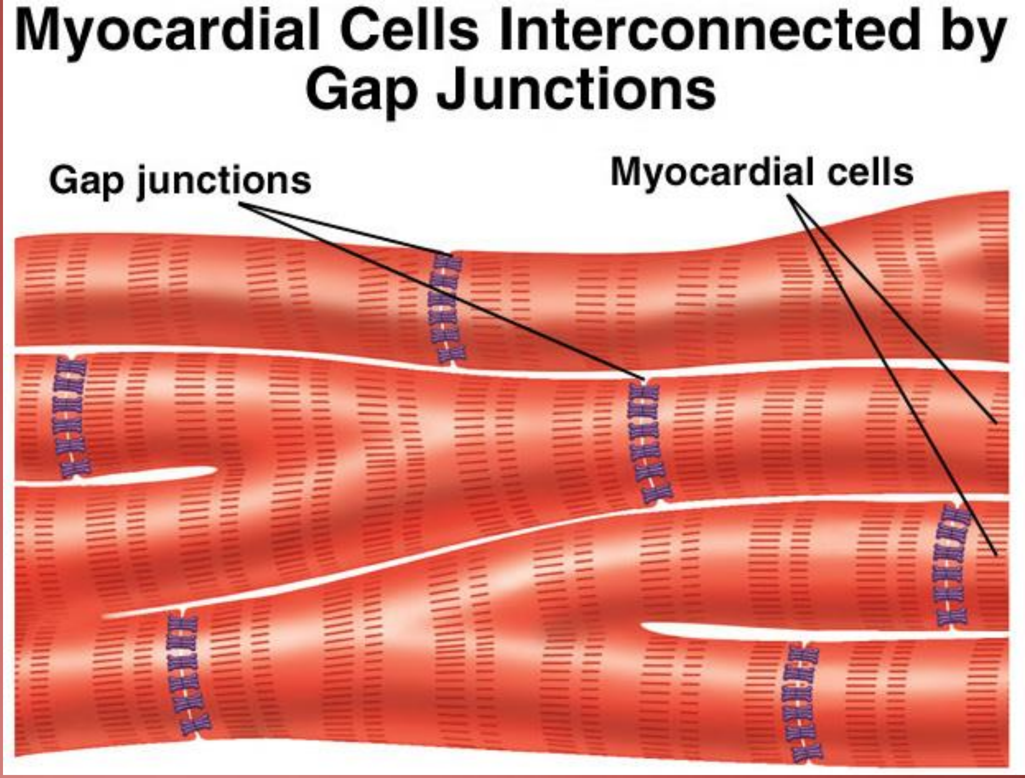
Feature	**Slow Oxidative/Red (Type I)**	**Fast Oxidative/White (Type II A)**	**Fast Glycolytic/White Type II B)**
Diameter	Small	Intermediate	Large
Z-line thickness	Wide	Intermediate	Narrow
Glycogen content	Low	Intermediate	High
Resistance to fatigue	High	Intermediate	Low
Capillaries	Many	Many	Few
Myoglobin content	High	High	Low
Respiration	Aerobic	Aerobic	Anaerobic
Oxidative capacity	High	High	Low
Glycolytic ability	Low	High	High
Twitch rate	Slow	Fast	Fast
Myosin ATPase content	Low	High	High

Muscle Fatigue

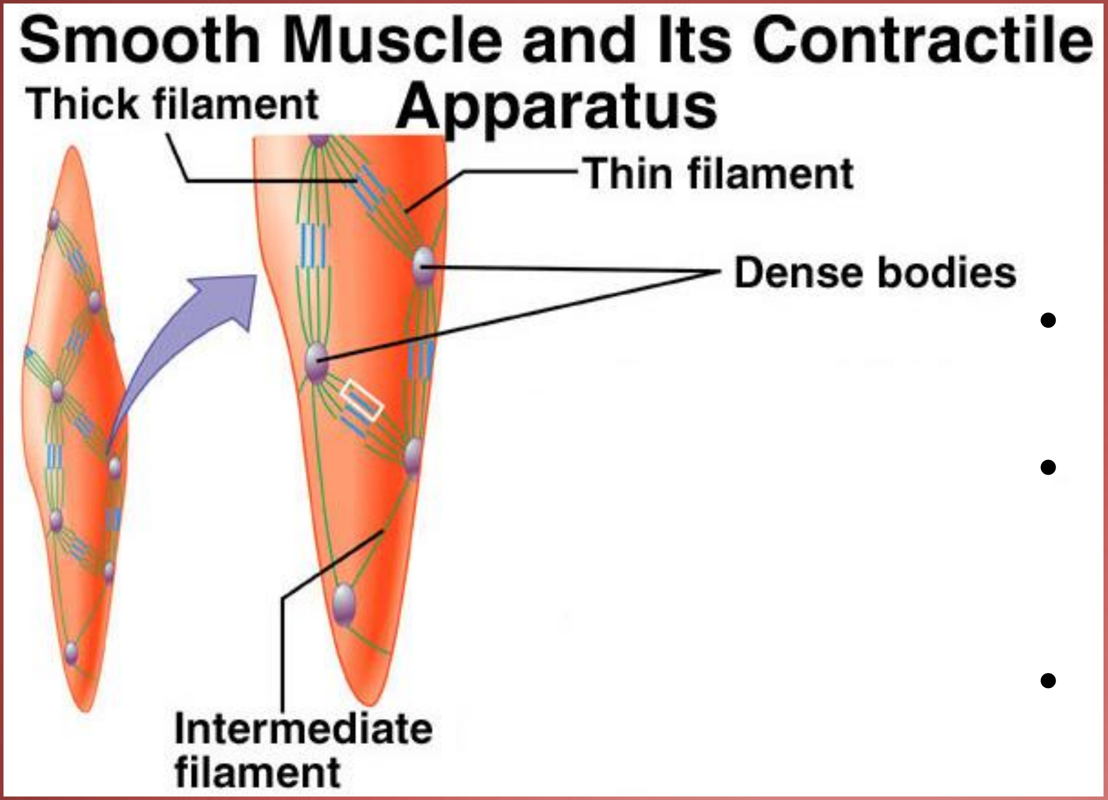
- Inability to maintain a muscle tension when the contraction is sustained.
  - Due to an accumulation of ECF K^+ due to repolarization phase of AP.
- During moderate exercise fatigue occurs when slow-twitch fibers deplete their glycogen reserve.
- Fast twitch fibers are recruited, converting glucose to lactic acid.
  - Interferes with Ca^{++} transport.

Cardiac Muscle

- Contain actin and myosin arranged in sarcomeres.
- Contract via sliding-filament mechanism..
- Adjacent myocardial cells joined by gap junctions.
  - AP spread through cardiac muscle through gap junctions.
  - Behaves as one unit.
  - All cells contribute to contraction.



Smooth Muscle

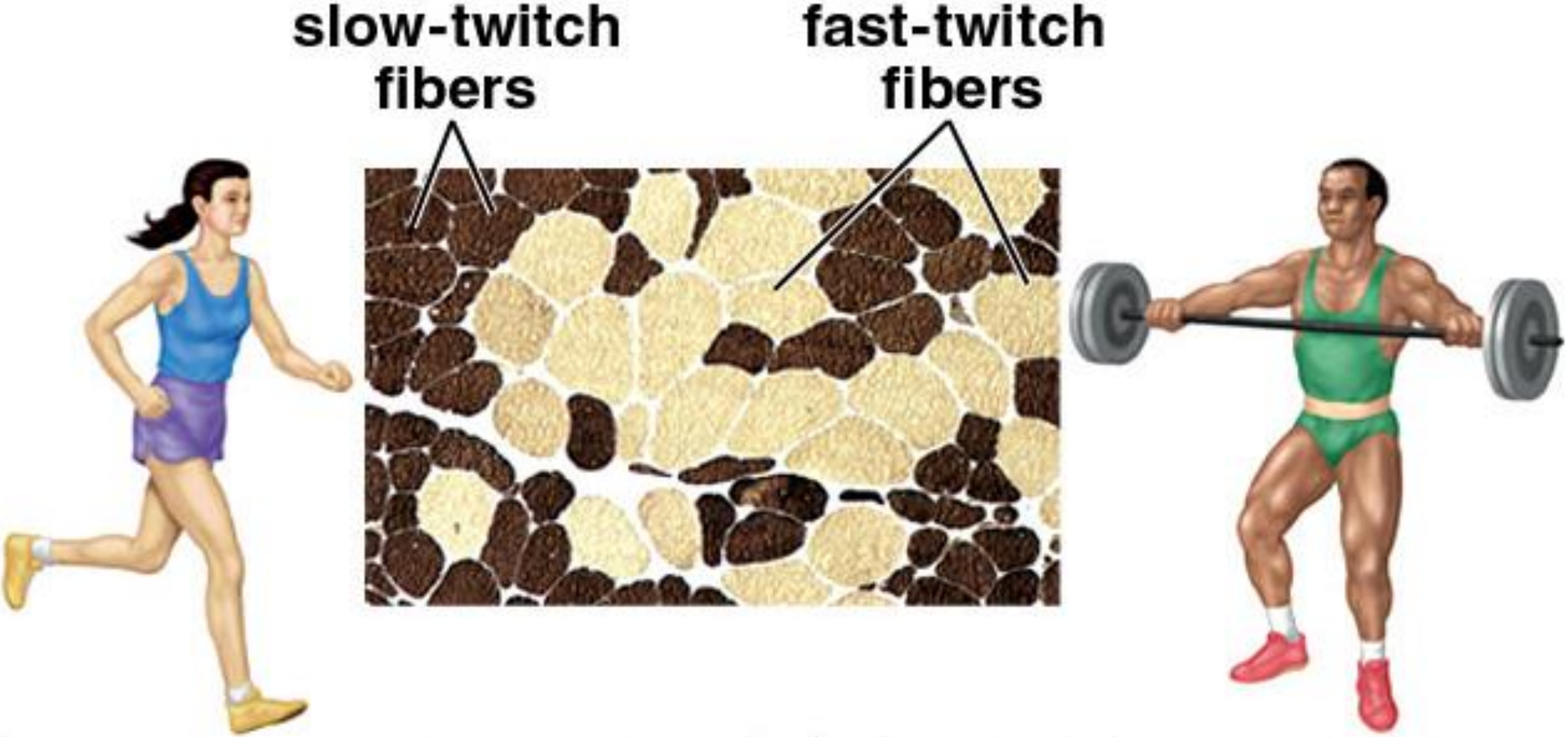


- Do not contain sarcomeres.
- Contain > content of actin than myosin (ratio of 16:1).
- Myosin filaments attached at ends of the cell to dense bodies.

Smooth Muscle Contraction

- Depends on rise in free intracellular Ca^{++} .
- Ca^{++} binds with calmodulin.
- Ca^{++} calmodulin complex joins with and activates myosin light chain kinase.
- Myosin heads are phosphorylated.
- Myosin head binds with actin.
- Relaxation occurs when Ca^{++} concentration decreases.

Slow- and Fast-Twitch Fibers



Slow-twitch muscle fiber:
- Is aerobic
- Has steady power
- Has endurance

Fast-twitch muscle fiber:
- Is anaerobic
- Has explosive power
- Fatigues easily

Human Systems

How the Muscular System works with other body systems

Integumentary System

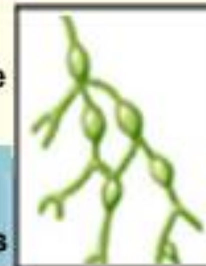
Muscle contraction provides heat to warm skin.

Skin protects muscles; rids the body of heat produced by muscle contraction.

Lymphatic System/Immunity

Skeletal muscle contraction moves lymph; physical exercise enhances immunity.

Lymphatic vessels pick up excess tissue fluid; immune system protects against infections.



Skeletal System

Muscle contraction causes bones to move joints; muscles help protect bones.

Bones provide attachment sites for muscles; store Ca^{2+} for muscle function.

Respiratory System

Muscle contraction assists breathing; physical exercise increases respiratory capacity.

Lungs provide oxygen for, and rid the body of, carbon dioxide from contracting muscles.

Human Systems

Nervous System

Muscle contraction moves eyes, permits speech, creates facial expressions.

Brain controls nerves that innervate muscles; receptors send sensory input from muscles to brain.

Endocrine System

Muscles help protect glands.

Androgens promote growth of skeletal muscle; epinephrine stimulates heart and constricts blood vessels.

Cardiovascular System

Muscle contraction keeps blood moving in heart and blood vessels.

Blood vessels deliver nutrients and oxygen to muscles, carry away wastes.

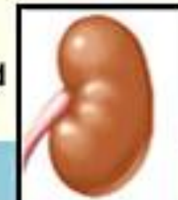
Digestive System

Smooth muscle contraction accounts for peristalsis; skeletal muscles support and help protect abdominal organs.

Digestive tract provides glucose for muscle activity;liver metabolizes lactic acid following anaerobic muscle activity.

Urinary System

Smooth muscle contraction assists voiding of urine; skeletal muscles support and help protect urinary organs.



Kidneys maintain blood levels of Na^+, K^+, and Ca^{2+}, which are needed for muscle innervation, and eliminate creatinine, a muscle waste.

Reproductive System

Muscle contraction occurs during orgasm and moves gametes; abdominal and uterine muscle contraction occurs during childbirth.

Androgens promote growth of skeletal muscle.

Questions

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