# Muscle Physiology

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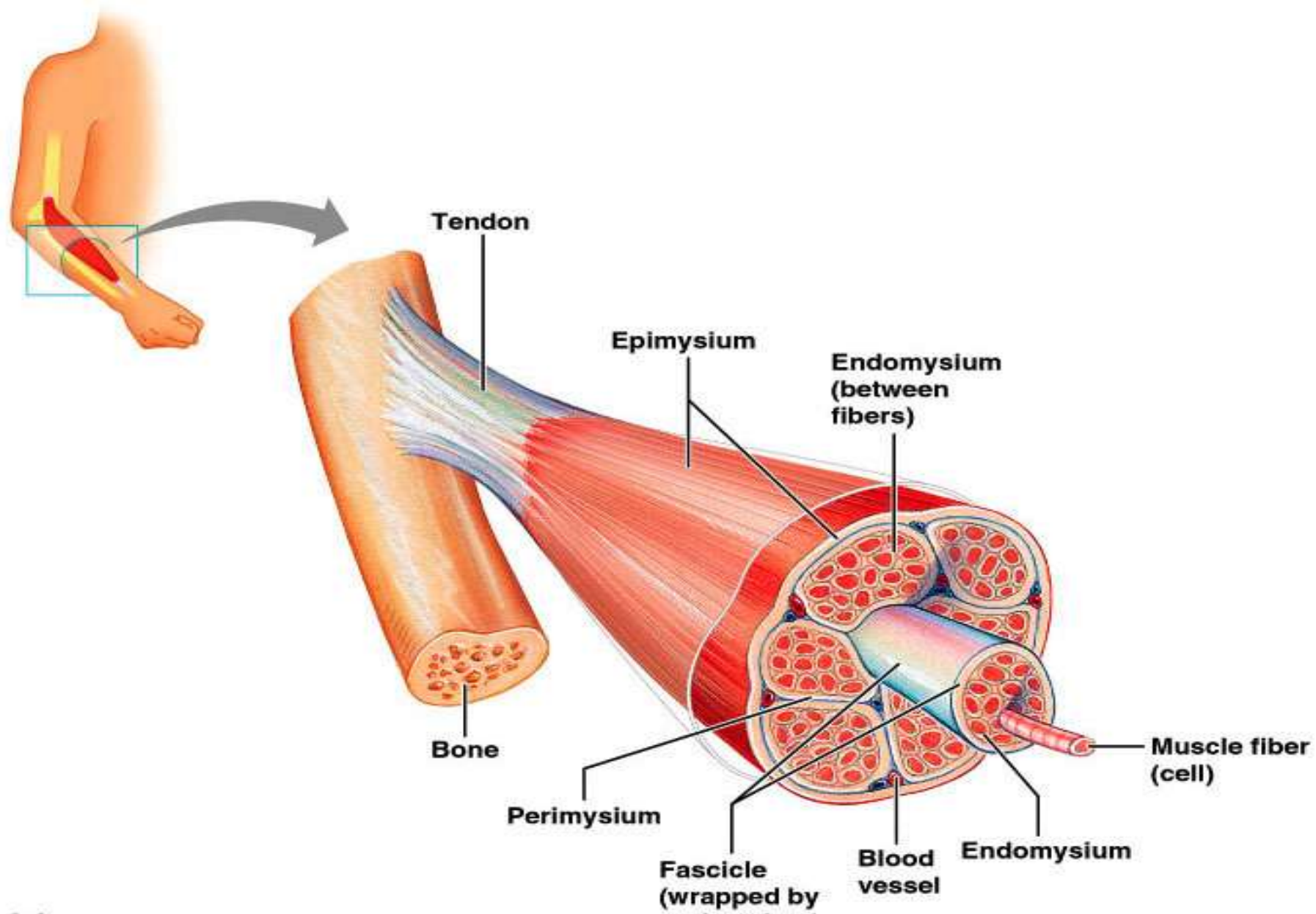
# Skeletal Muscle



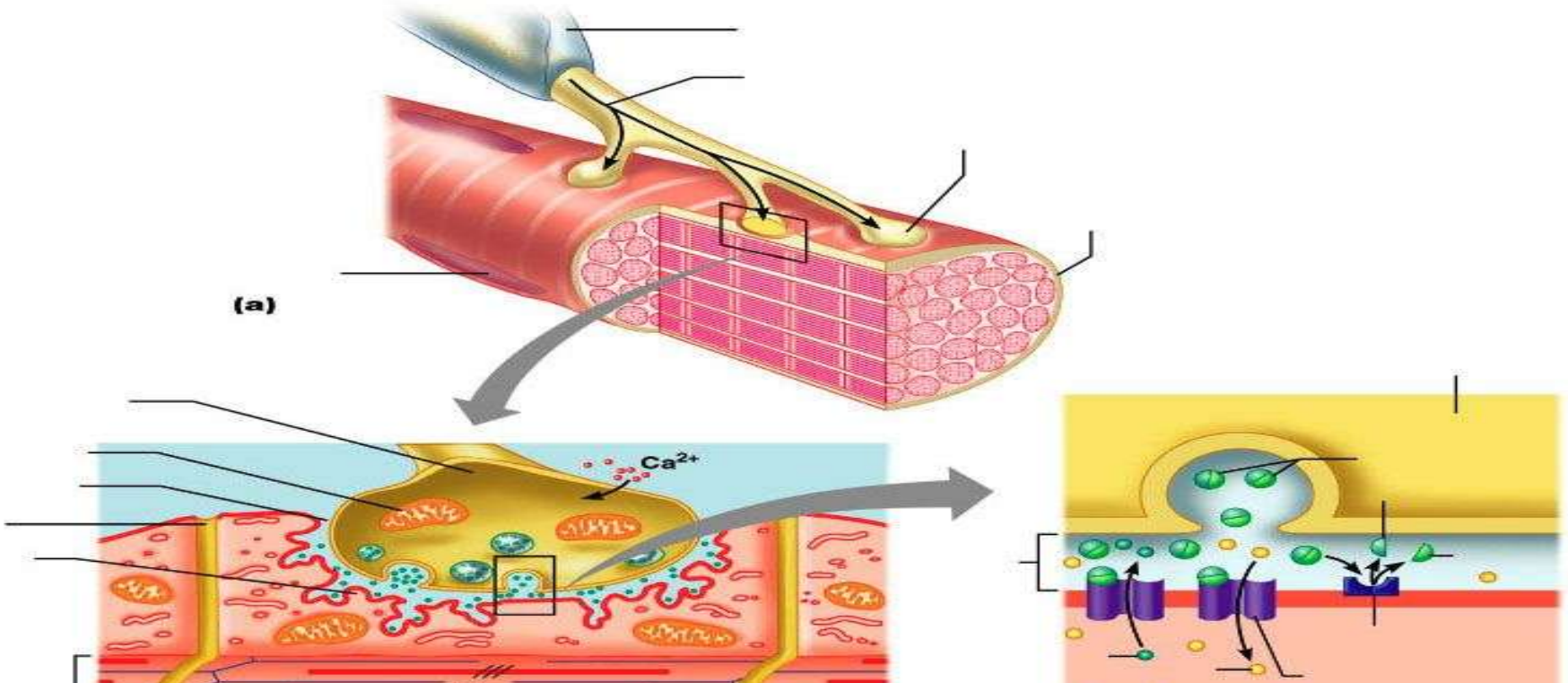
# Functions of the muscular system

- 1. **Locomotion**
- 2. **Vasoconstriction** and **vasodilatation**- constriction and dilation of blood vessel Walls are the results of smooth muscle contraction.
- 3. **Peristalsis** – wavelike motion along the digestive tract is produced by the Smooth muscle.
- 4. **Cardiac motion**
- 5. **Posture maintenance-** contraction of skeletal muscles maintains body posture and muscle tone.
- 6. **Heat generation** – about 75% of **ATP** energy used in muscle contraction is released as heat.

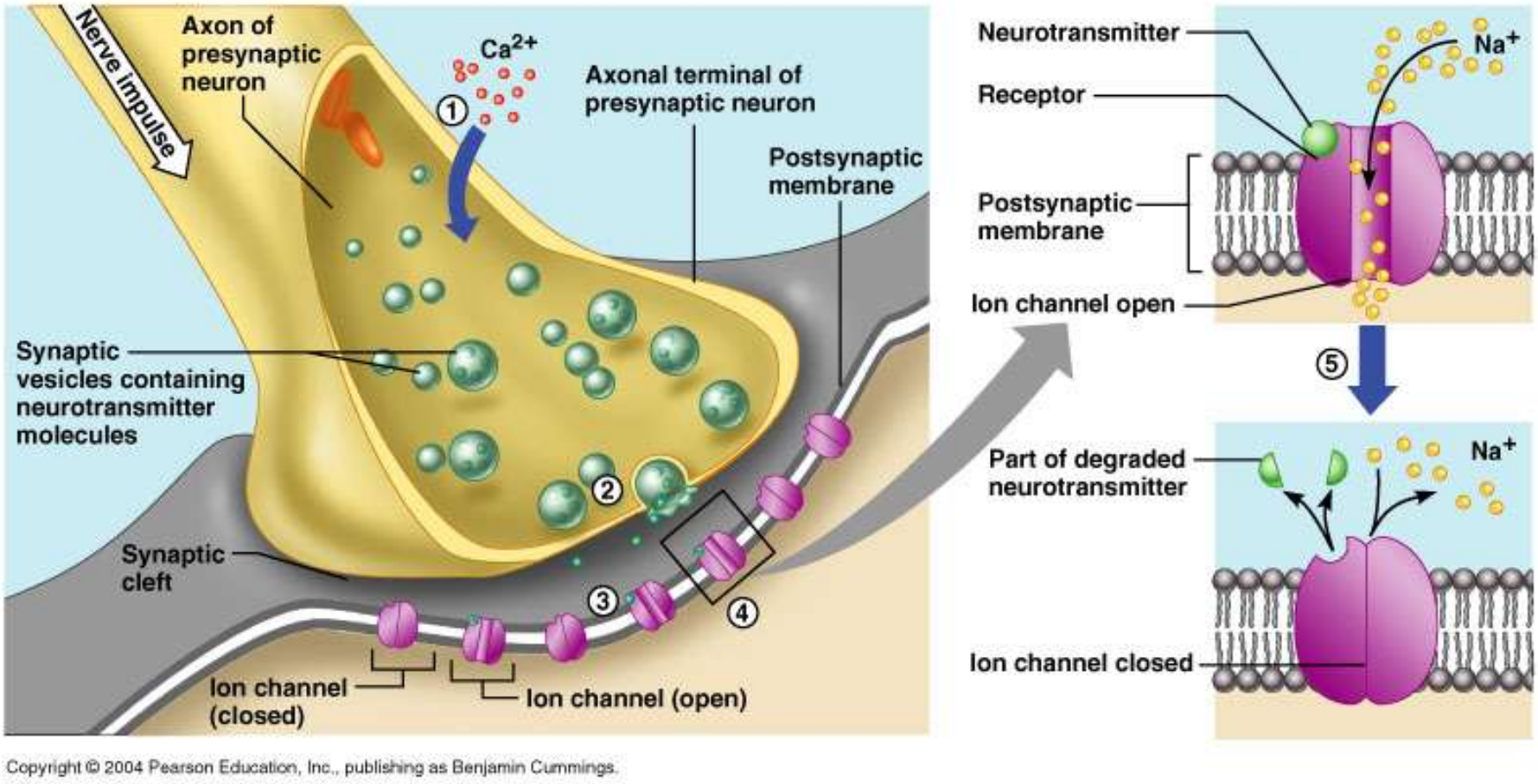
- **Striation:** only present in skeletal and cardiac muscles. Absent in smooth muscle.
- **Nucleus:** smooth and cardiac muscles are uninculcated (one nucleus per cell), skeletal muscle is multinucleated (several nuclei per cell ).
- **Transverse tubule ( T tubule ):** well developed in skeletal and cardiac muscles to transport calcium. Absent in smooth muscle.
- **Intercalated disk:** specialized intercellular junction that only occurs in cardiac muscle.
- **Control:** skeletal muscle is always under voluntary control, with some exceptions ( the tongue and pili arrector muscles in the dermis). smooth and cardiac muscles are under involuntary control.

# Innervation: motor unit

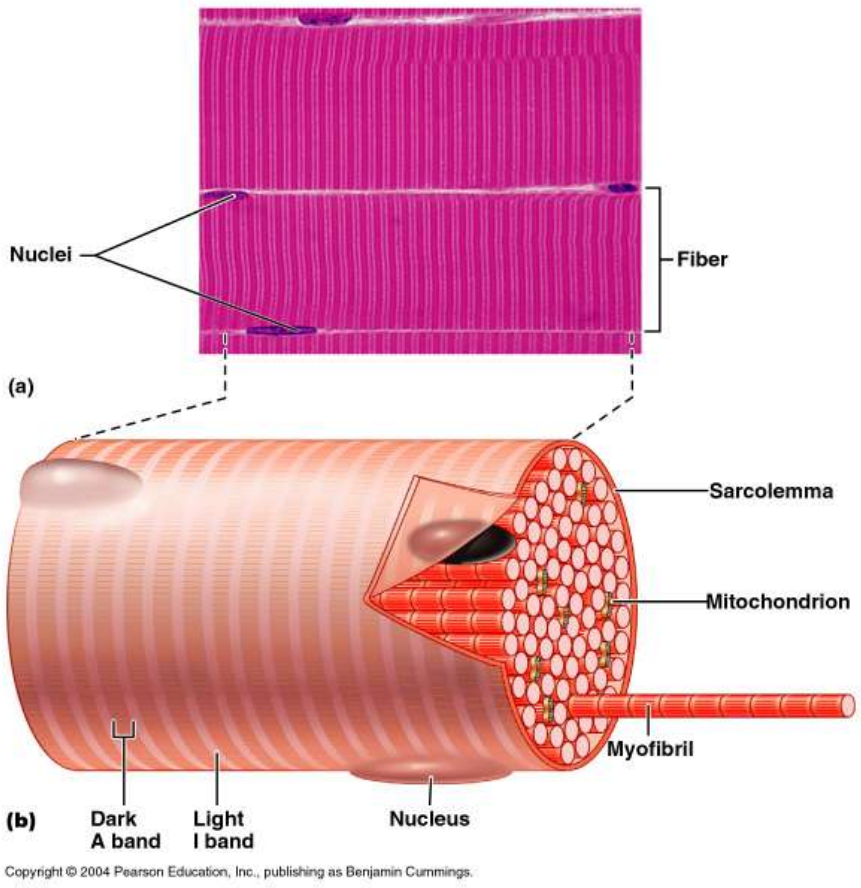
- a) a **motor nerve** and a **myofibril** from a **neuromuscular junction** where gap (called **synapse**) occurs between the two structures. at the end of motor nerve, neurotransmitter (i.e. acetylcholine) is stored in **synaptic vesicles** which will release the neurotransmitter using exocytosis upon the stimulation of a nerve impulse. Across the synapse the surface the of myofibril contains **receptors** that can bind with the neurotransmitter.



# Neuromuscular junction



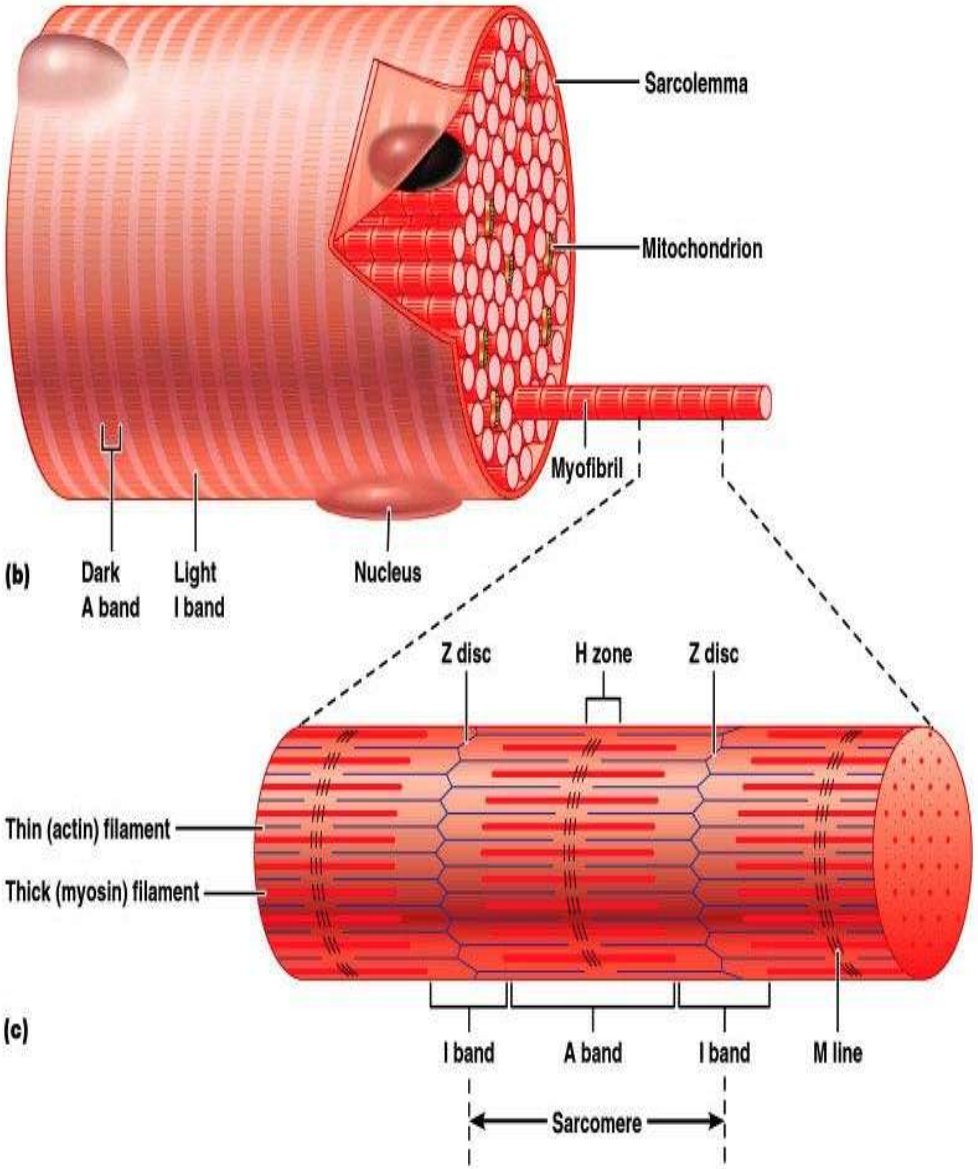
# Skeletal muscle fiber





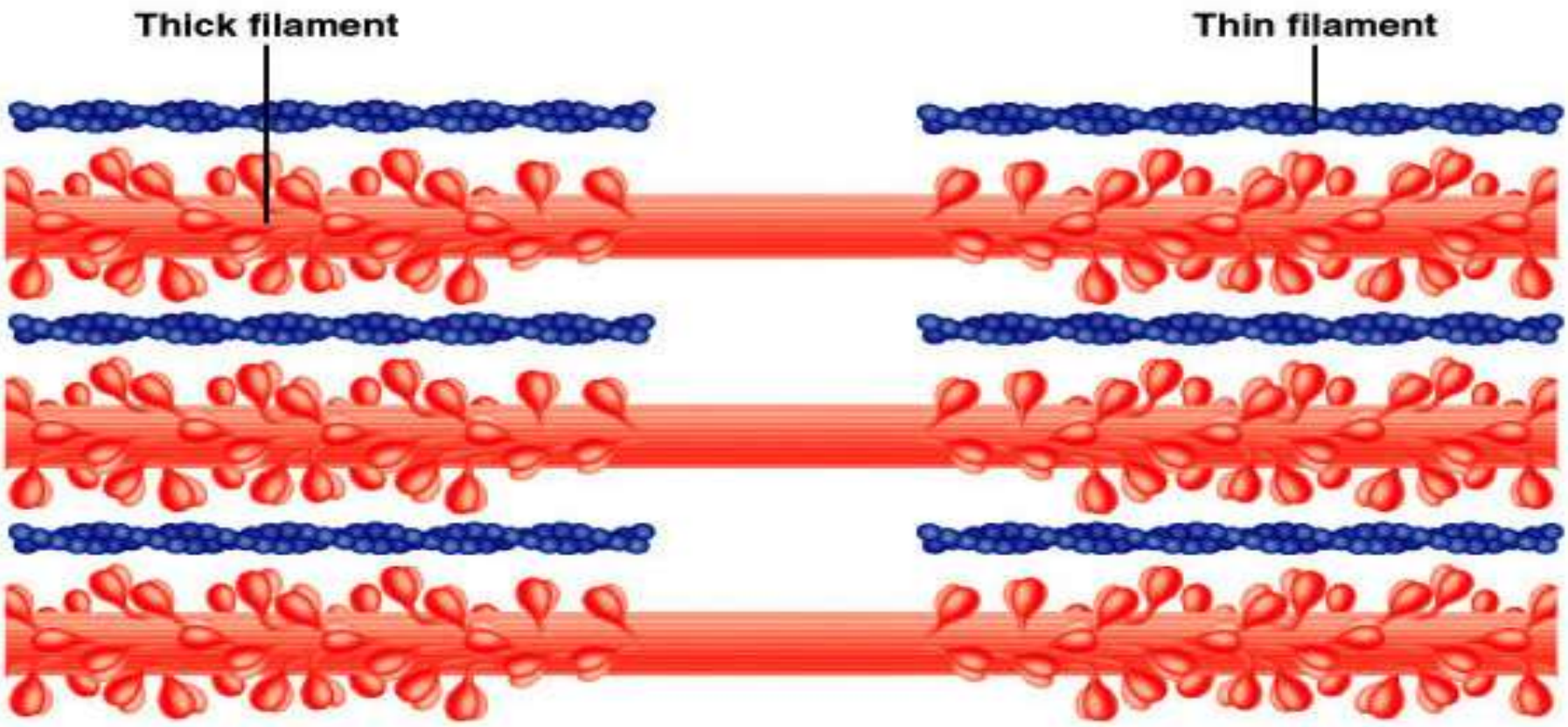
- 1. Each skeletal muscle fiber is a single muscle cell , which is the unit of contraction .
- 2. Muscle fibers are cylindrical cells with many nuclei .
- 3. The cell membrane is called . Sarcolemma, the cytoplasm is called sarcoplasm .
- 4. The sarcoplasm contains abundant , parallel thread like myofibrils , that run in parallel fashion .

- 5. The myofibrils contain 2 kinds of protein filaments .
- a. Thick filaments – composed of myosin .
- b. Thin filaments – composed of Actin , troponin and tropomyosin .
- c. striations are produced by alternating light and dark filaments .



# Arrangement of the Filaments in a Sarcomere

- Longitudinal section within one sarcomere




(d) Longitudinal section of filaments within one sarcomere of a myofibril

# Ultrastructure of Myofilaments: Thick Filaments

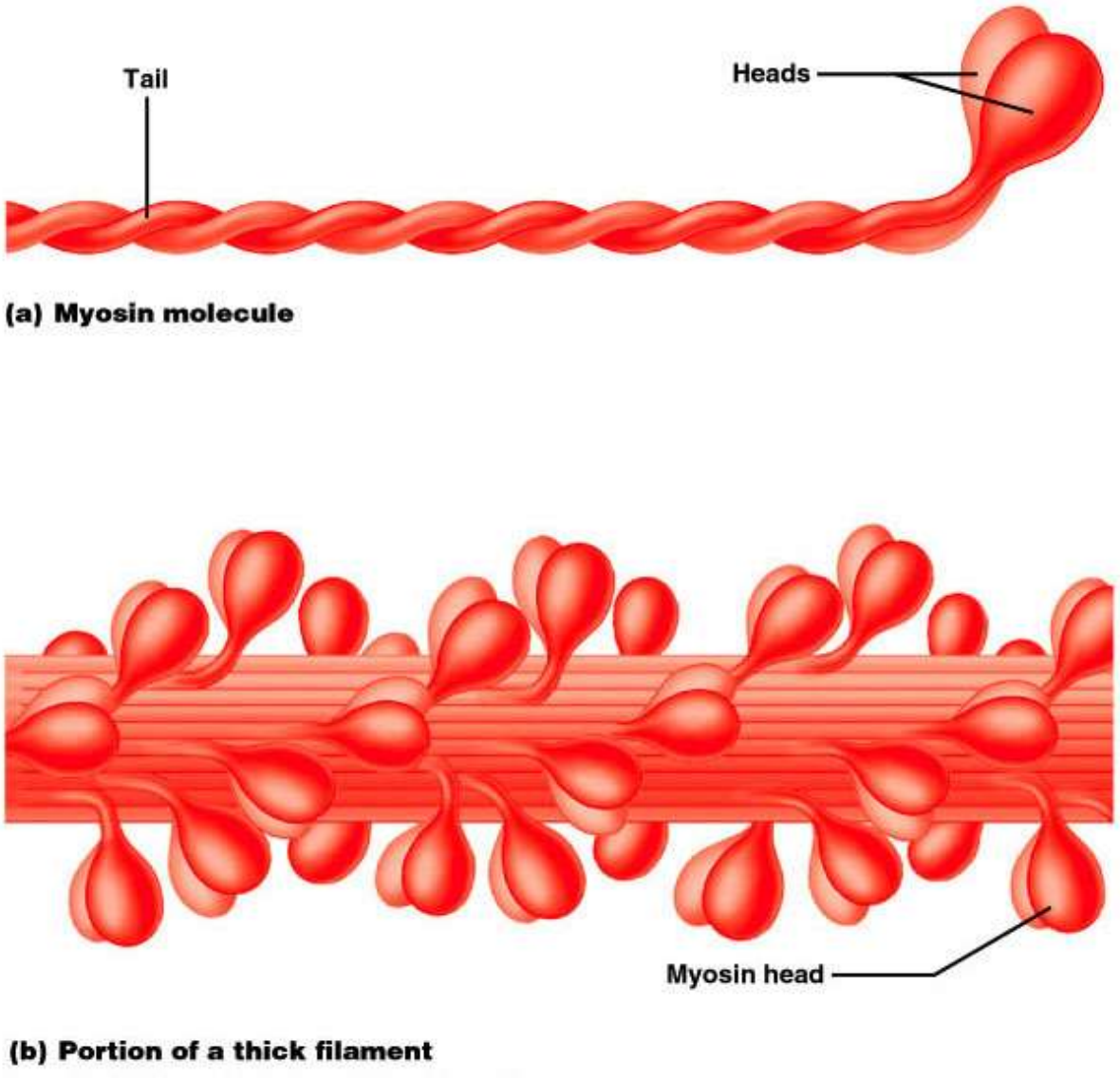
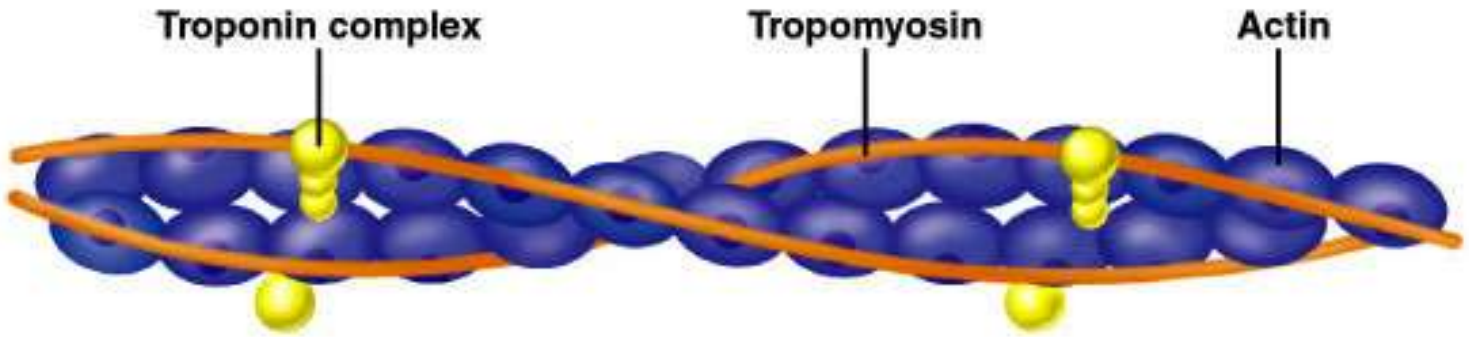



Figure 9.4 (a)(b)

# Ultrastructure of Myofilaments: Thin Filaments

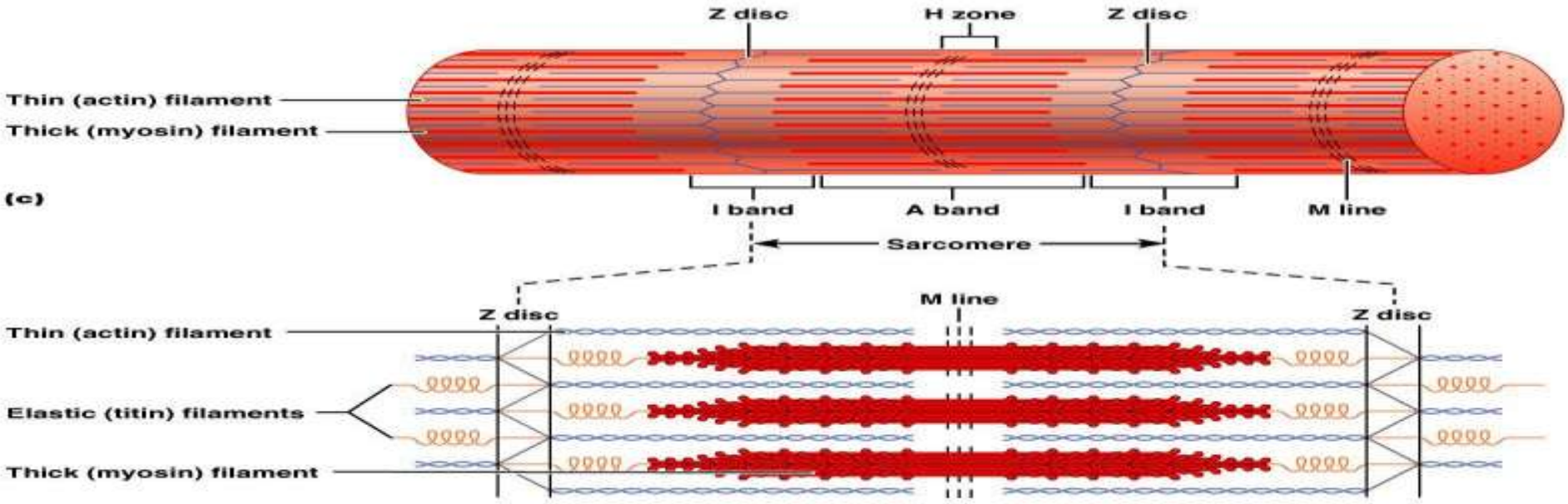


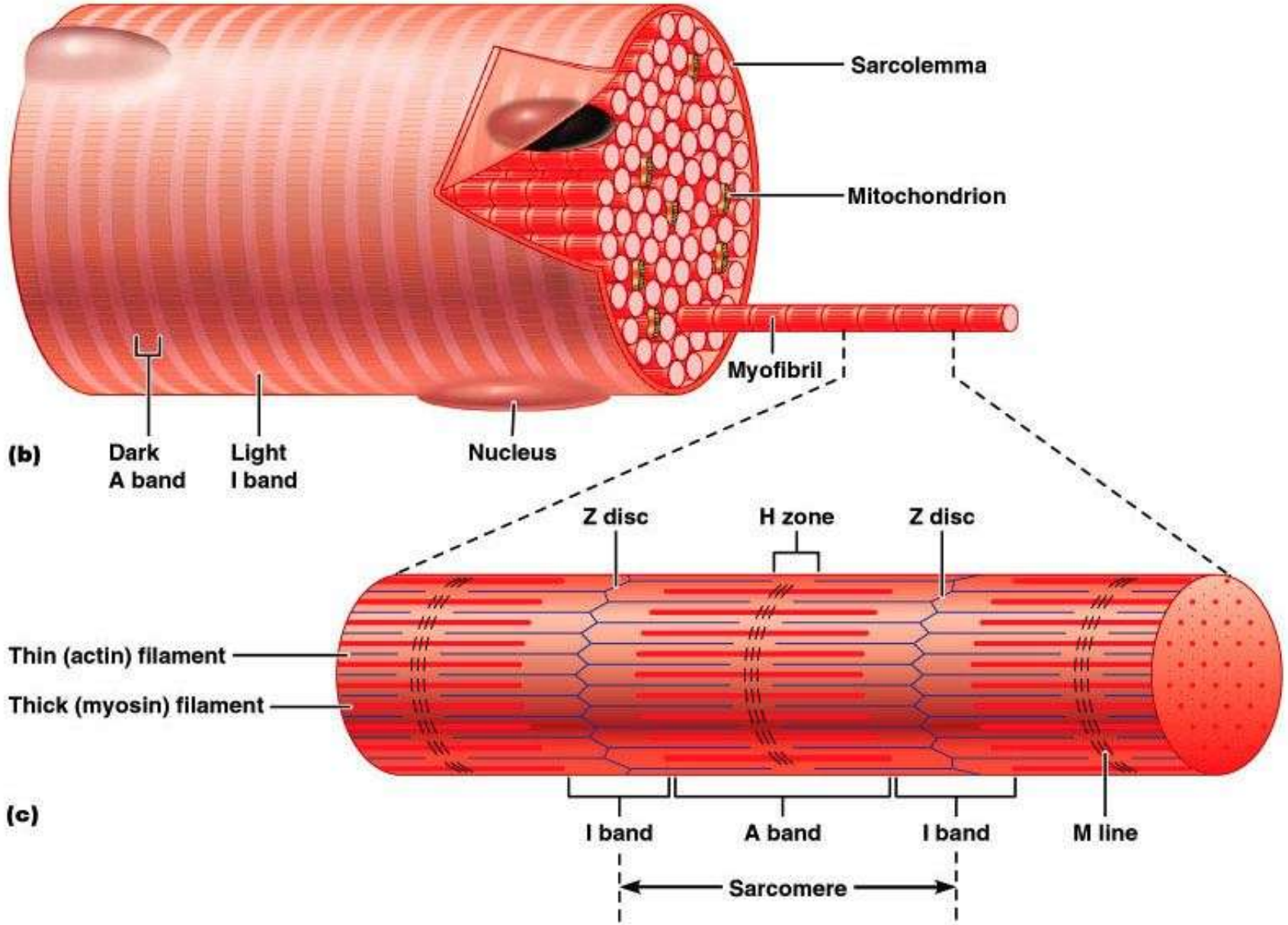

(c) Portion of a thin filament

Figure 9.4 (c)

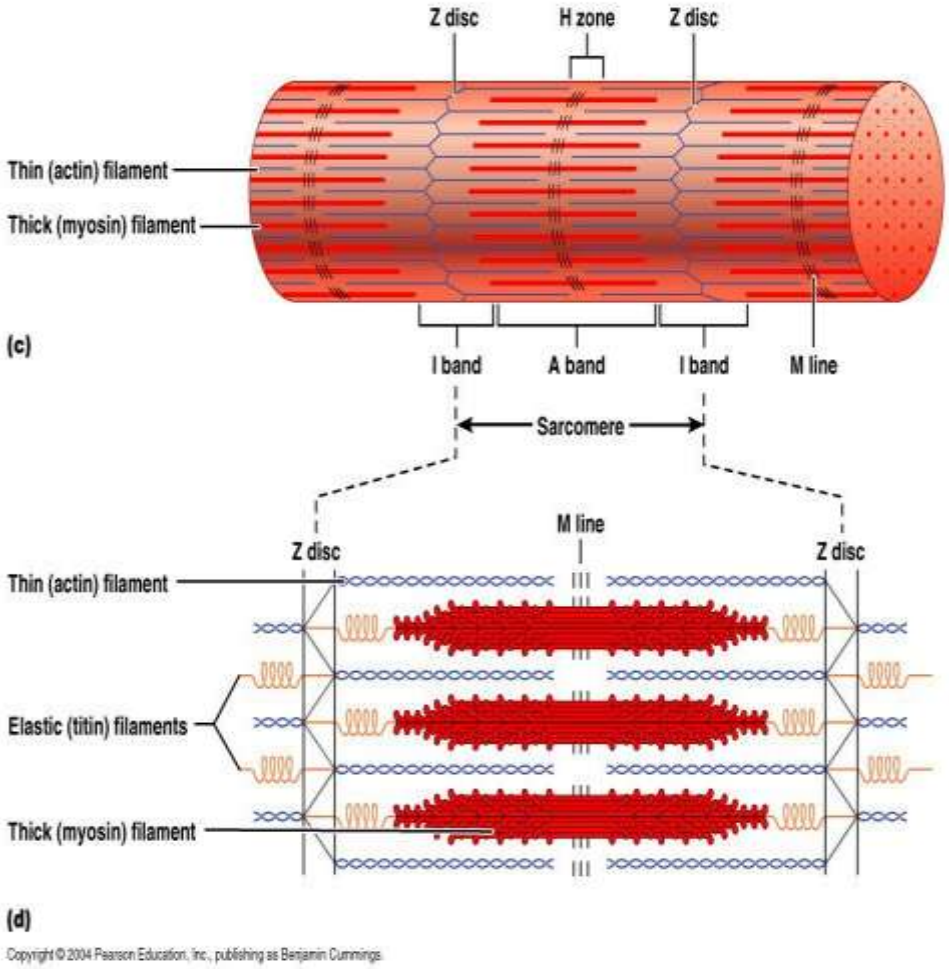
# Striation pattern of skeletal muscles: 2 parts

- 1. The I bands (The light bands) -
- Extends from the edge of one stack of thick filaments to the edge of next stack of thick filaments .
- - The I band is composed of thin actin filaments .
- 2. The A bands (The dark bands) – composed of thick myosin filaments , overlapping thin filaments (actin) .



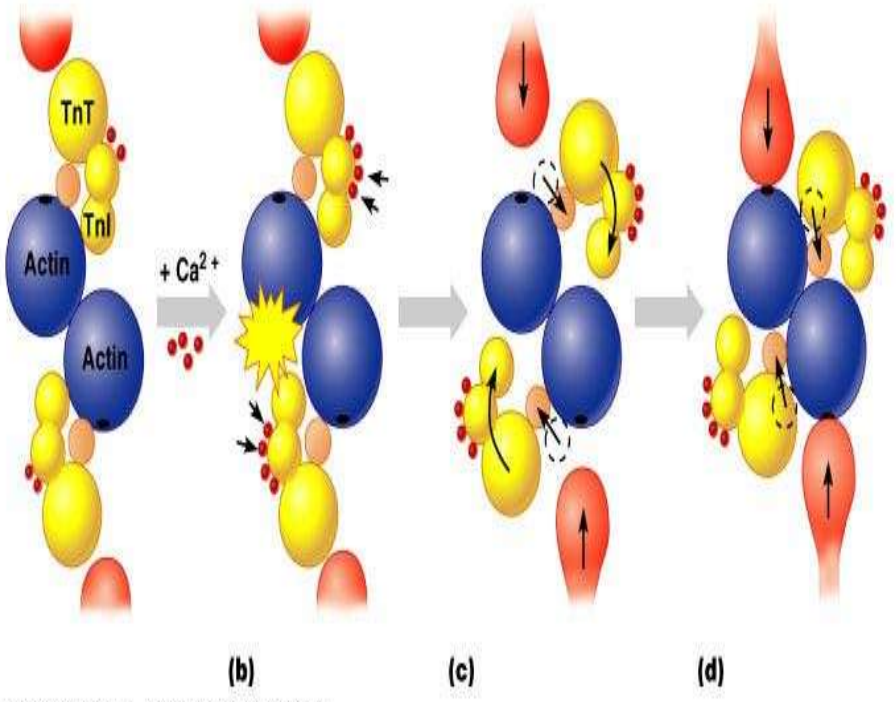


- - myosin filaments are held together by Z lines (not attached) .
- - A band consist of a region Where the thick and thin filaments overlap , and a region called central region (H zone) , consisting of only thick filaments . In the center of A band is a dark band called the M line .
- Sarcomere : The segment of myofibrils that extends from one Z line to the next Z line.



- **Cross bridge Attachment:** The activated myosin heads are attracted to the exposed binding sites on actin and cross bridge attachment occurs .

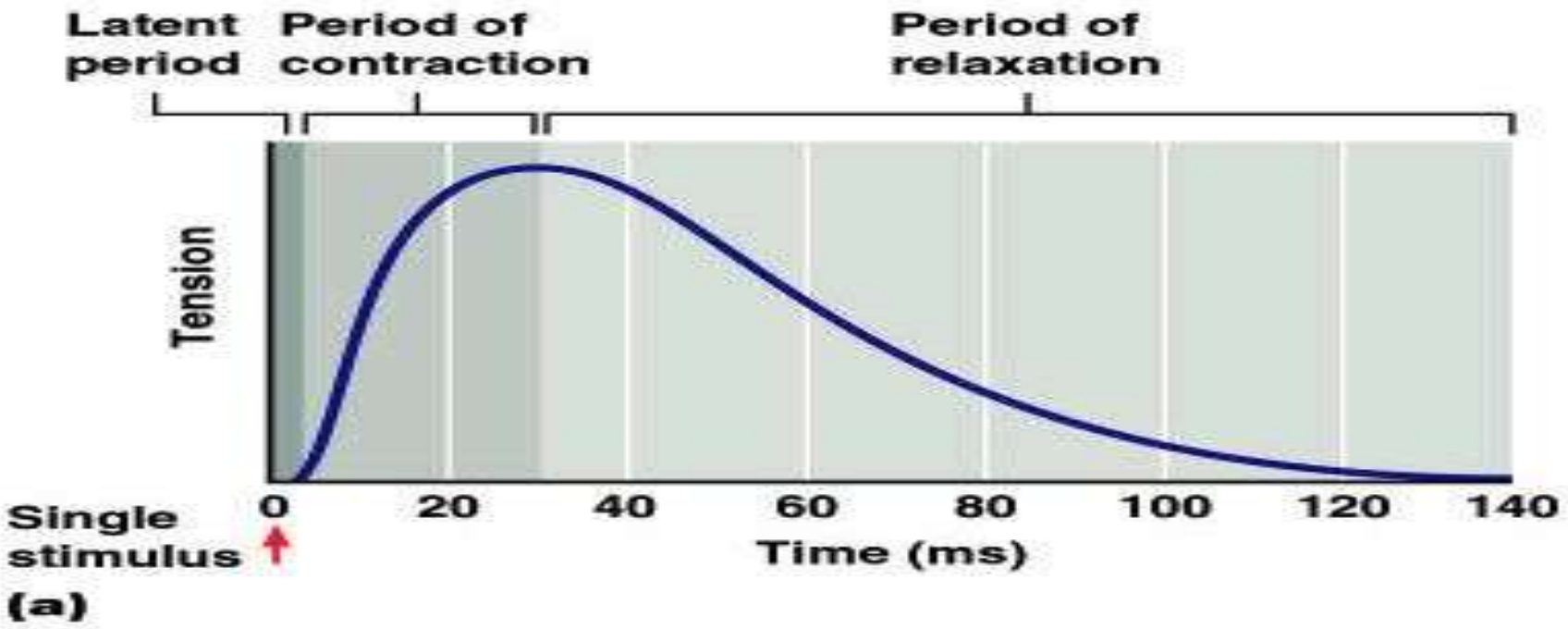

- **Power stroke :** The sliding action , which occurs at the same time for thousands of actin and myosin molecules is referred to as the power stroke .

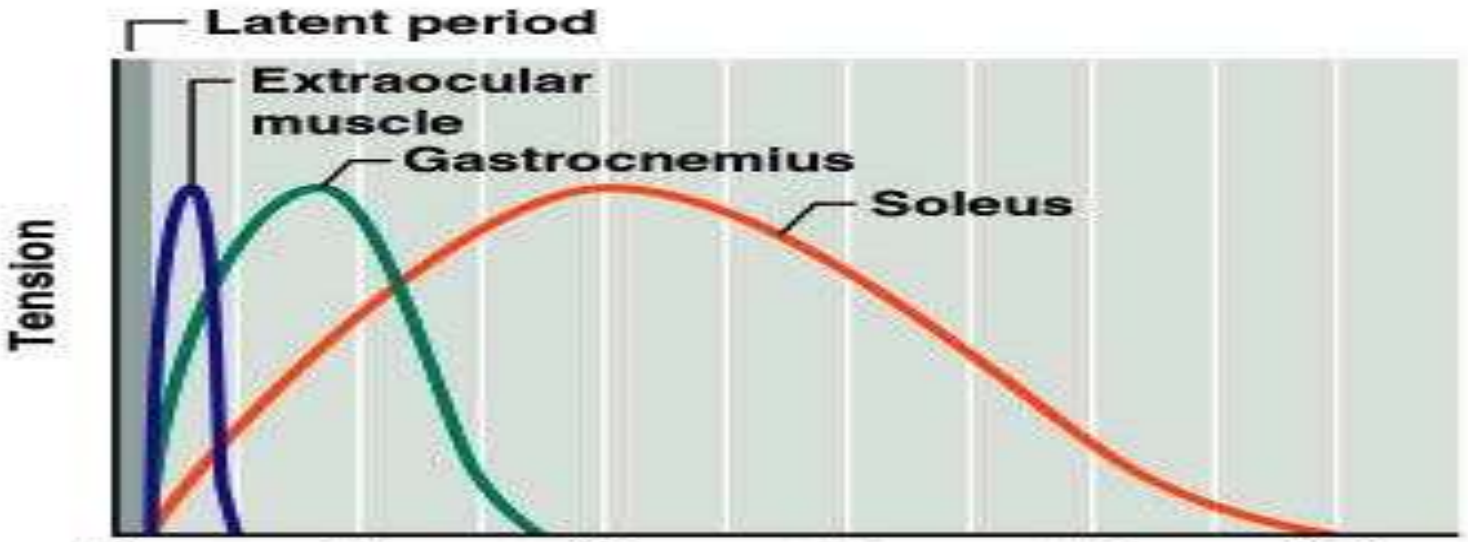


# Muscle Response:

- All – or – none response
- a. if a muscle fiber contracts at all , it will contract completely .
- b. motor units respond in an all – or – none manner .
- - Threshold stimulus is the minimal stimulus needed to elicit a muscular contraction .
- Twitch : single , short contraction reflecting stimulation of some motor units in a muscle .
- - Latent period is the time between stimulus and responding muscle contraction .
- - refractory period : During his period immediately following contraction , a muscle can not respond .

# The muscle twitch

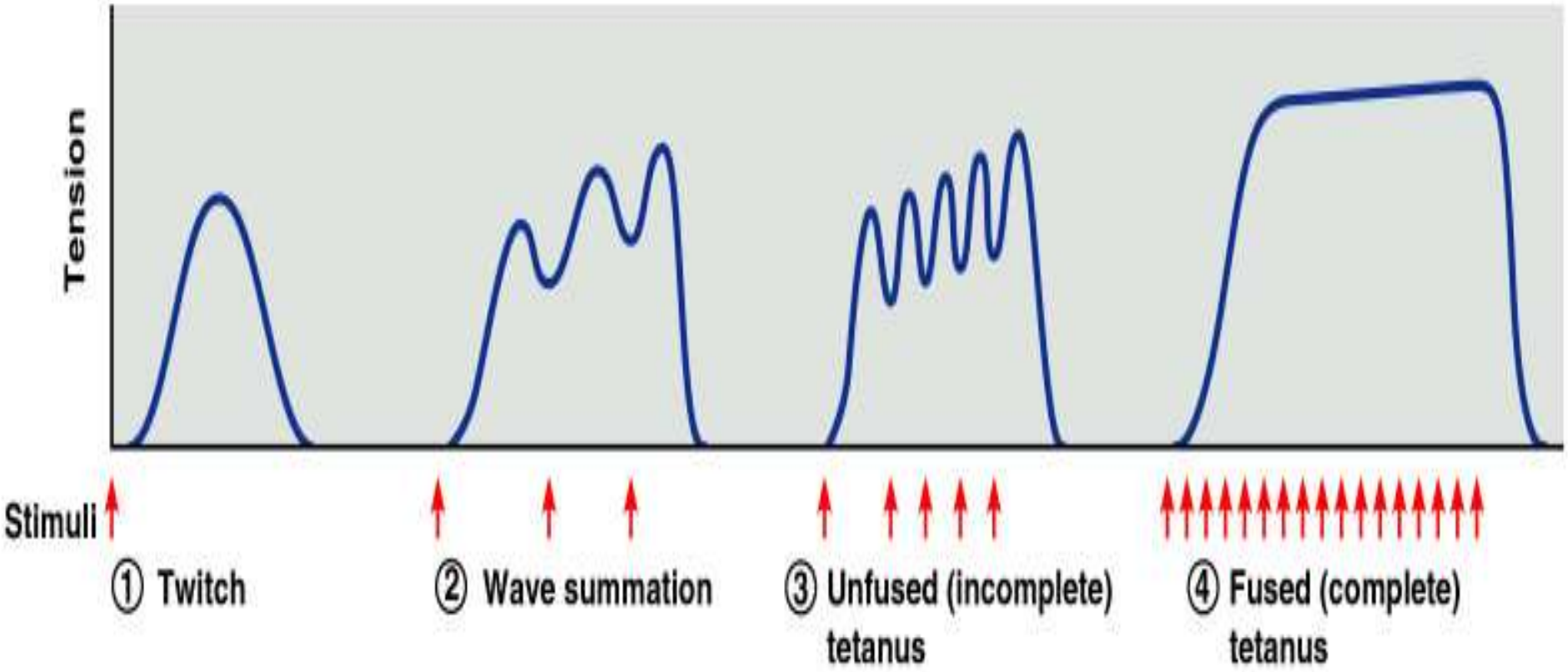


# Summation

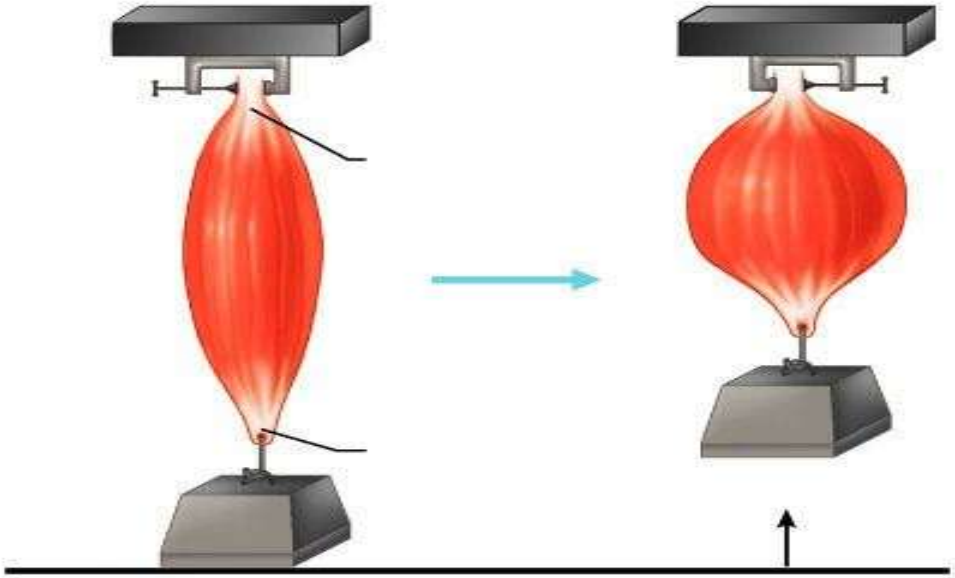
Summation : A rapid series of stimuli may produce summation of twitches and a sustained contraction .

- Forceful , sustained contraction without relaxation is a tetanic contraction .
- Tetany is the result of low $Ca^{2+}$ concentrations .



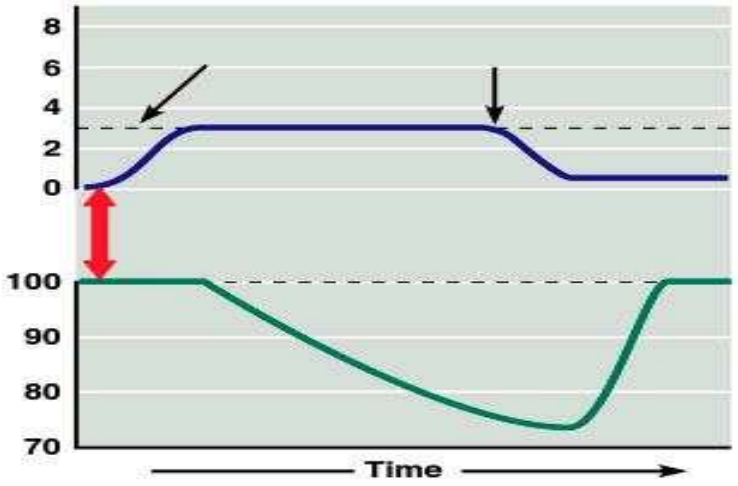
# Types of Contractions:

- Isotonic : when a muscle contracts and its ends are pulled closer together .
- Isometric : when a muscle contracts but attachments do not move
- Isokinetic : when the force a muscle generates is less than that required to move or lift an object , the contraction is called isokinetic .



(a) Isotonic (concentric) contraction





# Fast & Slow Muscles

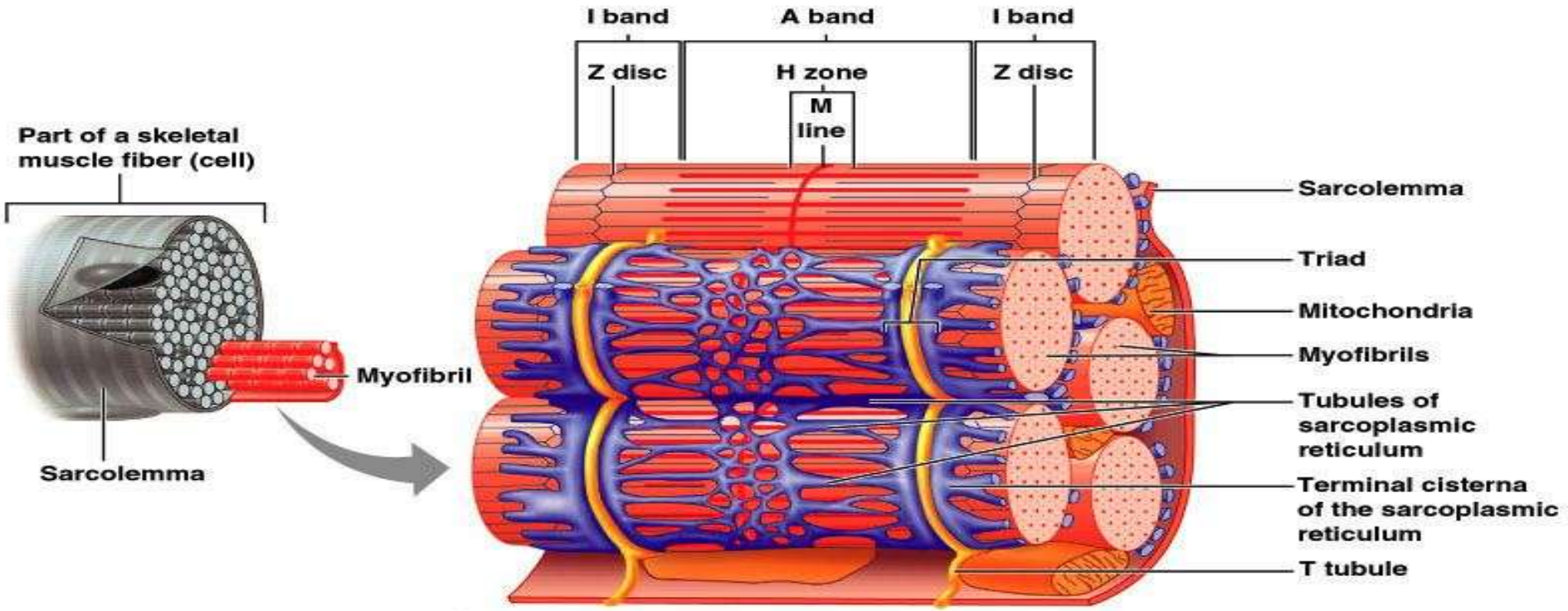
- a. white or fast skeletal muscle fibers , have few mitochondria , reduced ability to carry on aerobic respiration and tend to fatigue rapidly . (ex. extra ocular muscles) . Designed for speed , fatigue easily.
- b. Red or slow skeletal muscle fibers , have many mitochondria , are designed for enduration , and can contract for long periods of time (ex. Solues) .
- **Muscle Fatigue :**
- - a fatigued muscle loses its ability to contract .
- - muscle fatigue is due to accumulation of lactic acid and ATP exhaustion.

# Oxygen debt:

- a. During rest or moderate exercise , $O_2$ is sufficient to support aerobic respiration (using many ATP molecules) .
- b. During strenuous exercise , $O_2$ deficiency may develop and lactic acid may accumulate as a result of anaerobic respiration .
- c. The amount of $O_2$ needed to convert accumulated lactic acid to glucose and restore supplies of ATP and creatine phosphate is called oxygen dept .

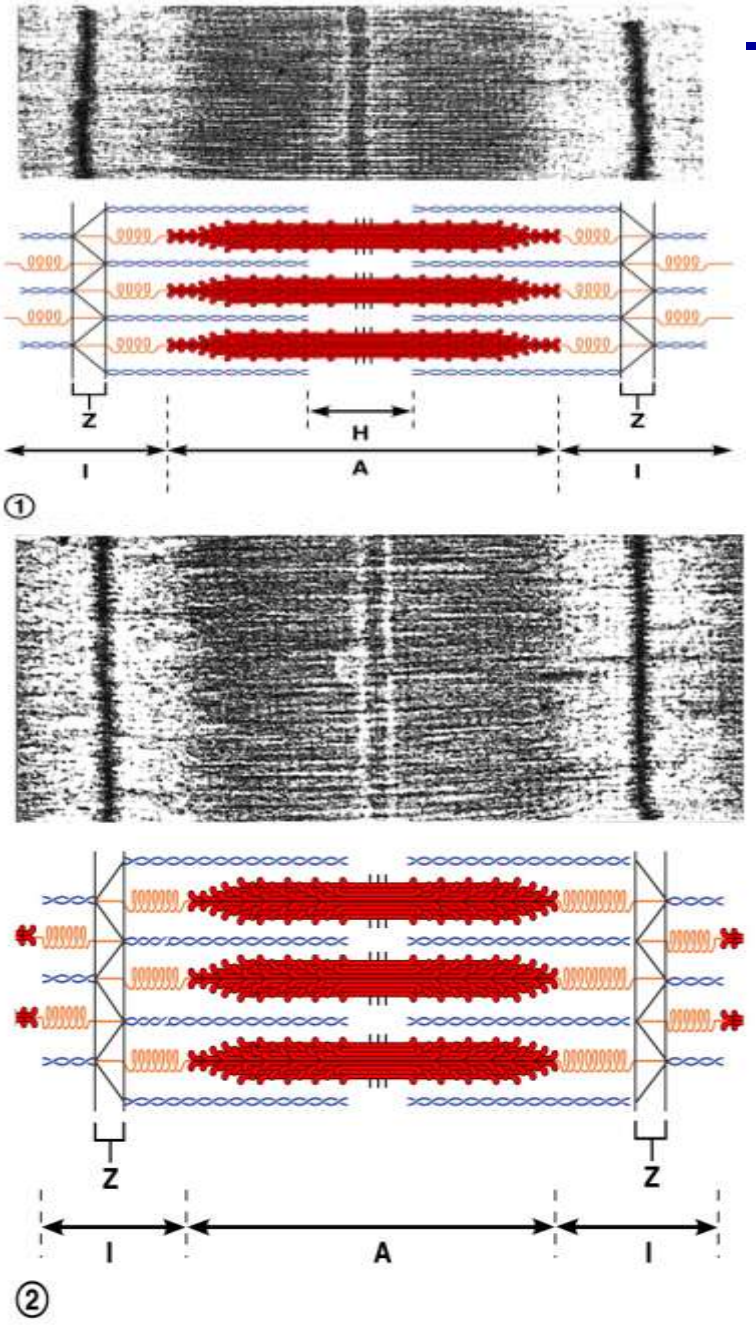
# Role of Ca+ in muscle contraction:

- 1. promotes neurotransmitter release .
- 2. Triggers $Ca^{+}$ release from SR .
- 3. Triggers sliding of my filaments and ATpase activity .
- 4. promotes glycogen breakdown & ATP synthesis .

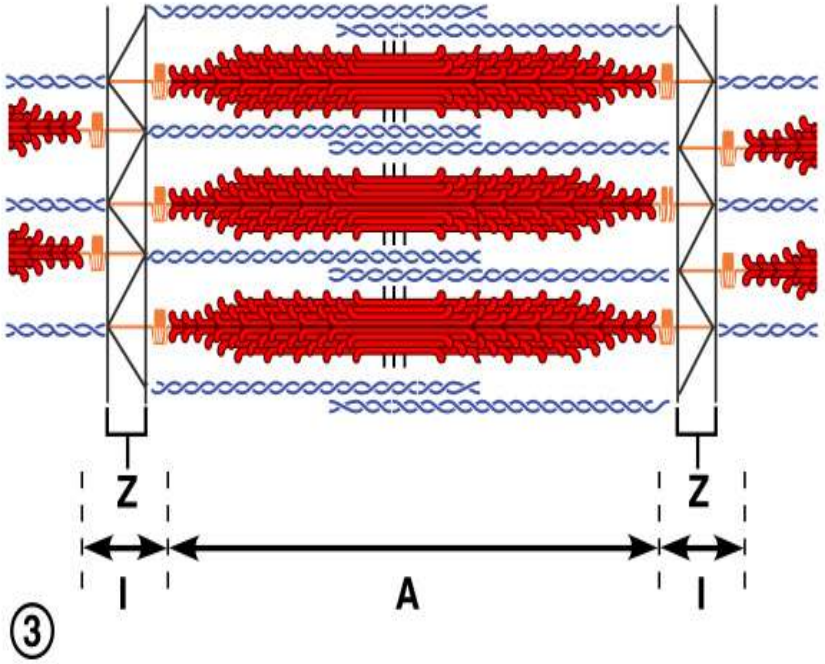


# Sliding Filament Theory

- 1. A myofiber , together with all of its myofibrils , shortens by movement of the insertion towards the origin of the muscle .
- 2. shortening of the myofibrils is caused by shortening of the sarcomere (The distance between Z lines is reduced) .
- 3. shortening of the sarcomere is accomplished by each filament remains the same during contraction .

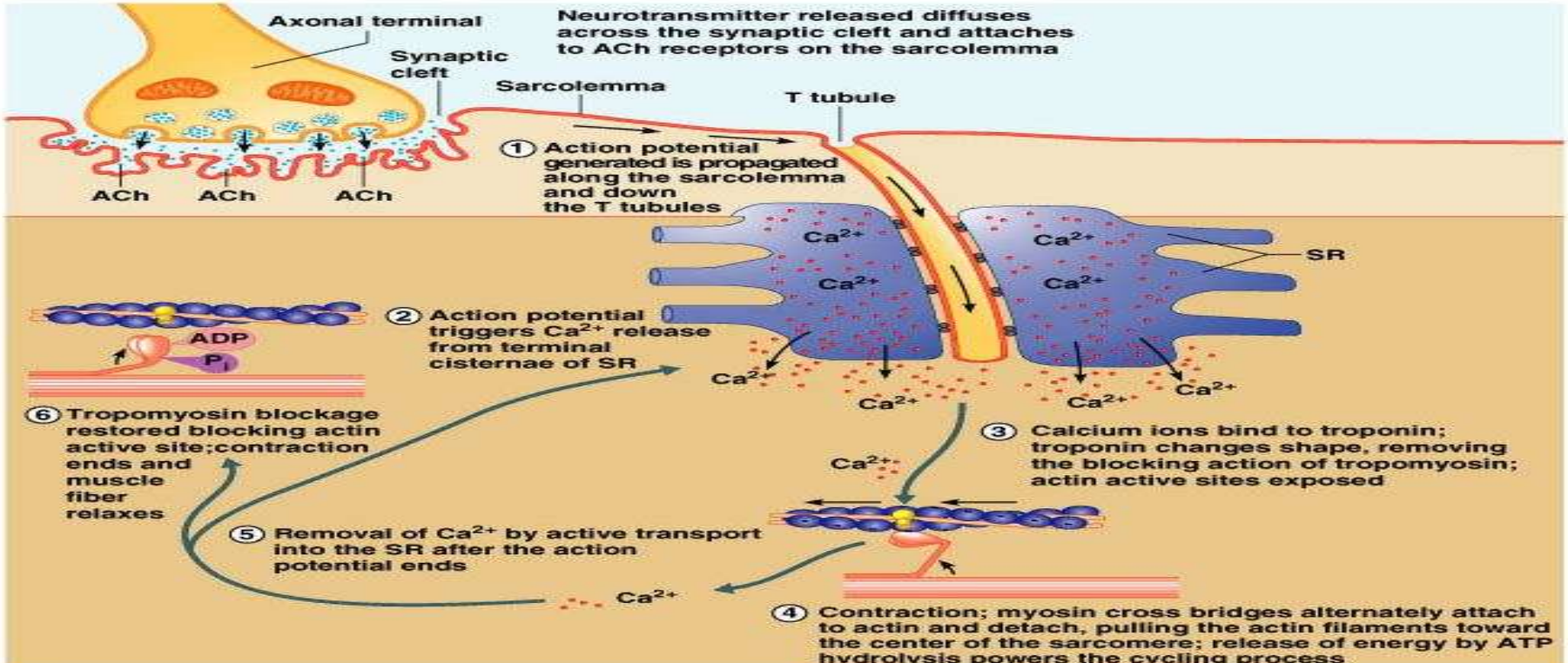


- 4. sliding is produced by power strokes of myosin cross bridges , which pull the thin actin over the thick myosin .
- 5. The A band remains the same length during contraction , but are pulled toward the origin of the muscle .
- 6. Adjacent A bands are pulled closer together as the I bands between them shorten .
- 7. The H band shorten during contraction as the thin filaments on the sides of the sarcomeres are pulled towards the middle .

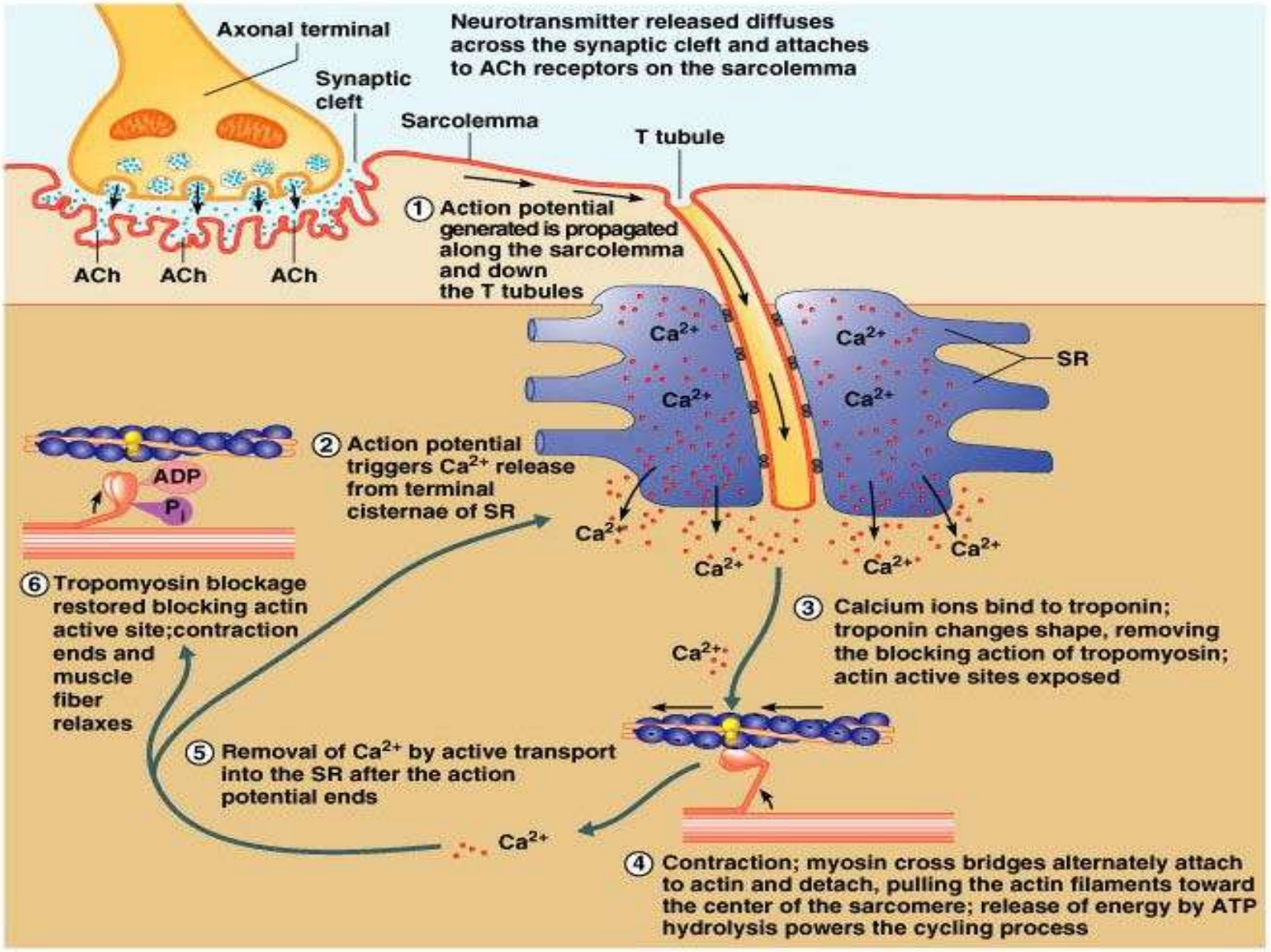


# Major Events of muscle contraction :

1. The distal end of a motor neuron releases Acetylcholine .
2. Acetylcholine diffuse across the gap at the neuromuscular junction .
3. The sarcolemma is stimulated , and a muscle impulse travels over the surface of the muscle fiber and deep into the fiber through the transverse tubules and reaches the sarcoplasmic reticulum .
4. $Ca^{2+}$ ions diffuse from the sarcoplasmic reticulum into the sarcoplasm bind to troponin molecules .



# Neuromuscular Junction:

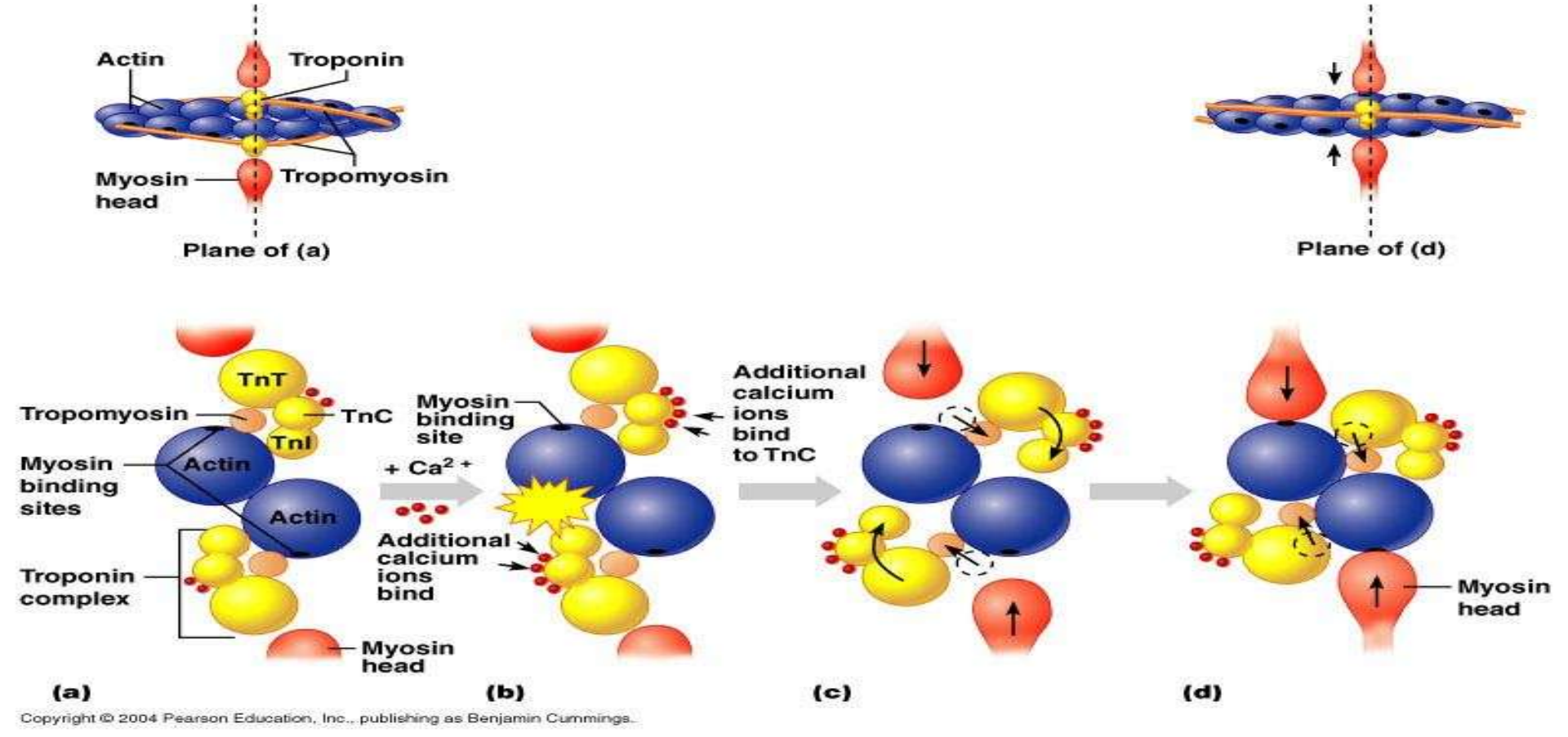


5. Tropomyosin molecules move and expose specific sites on actin filament .

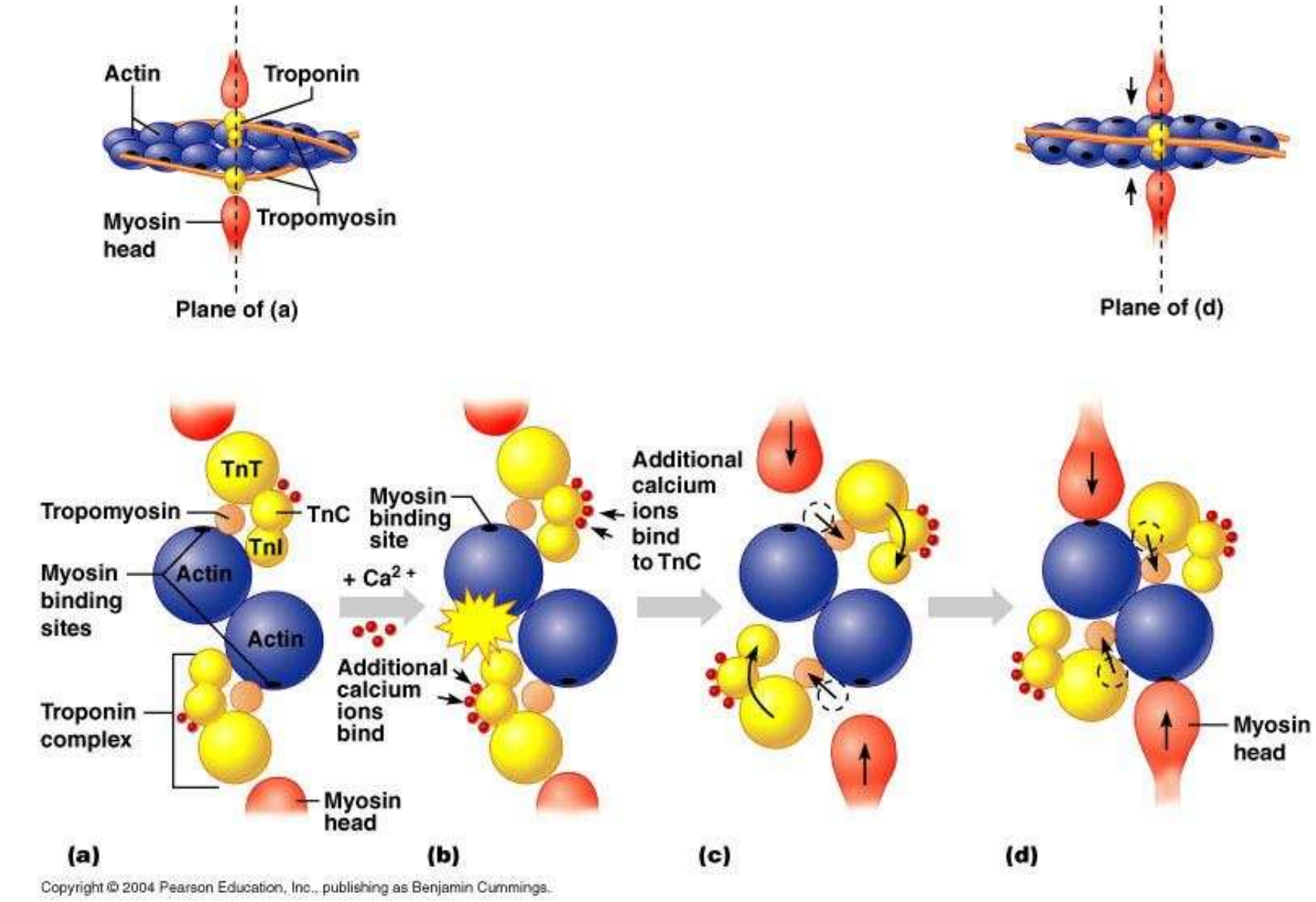
6. Actin and myosin filaments form linkages .

7. Actin filaments are pulled inward by myosin cross – bridges .

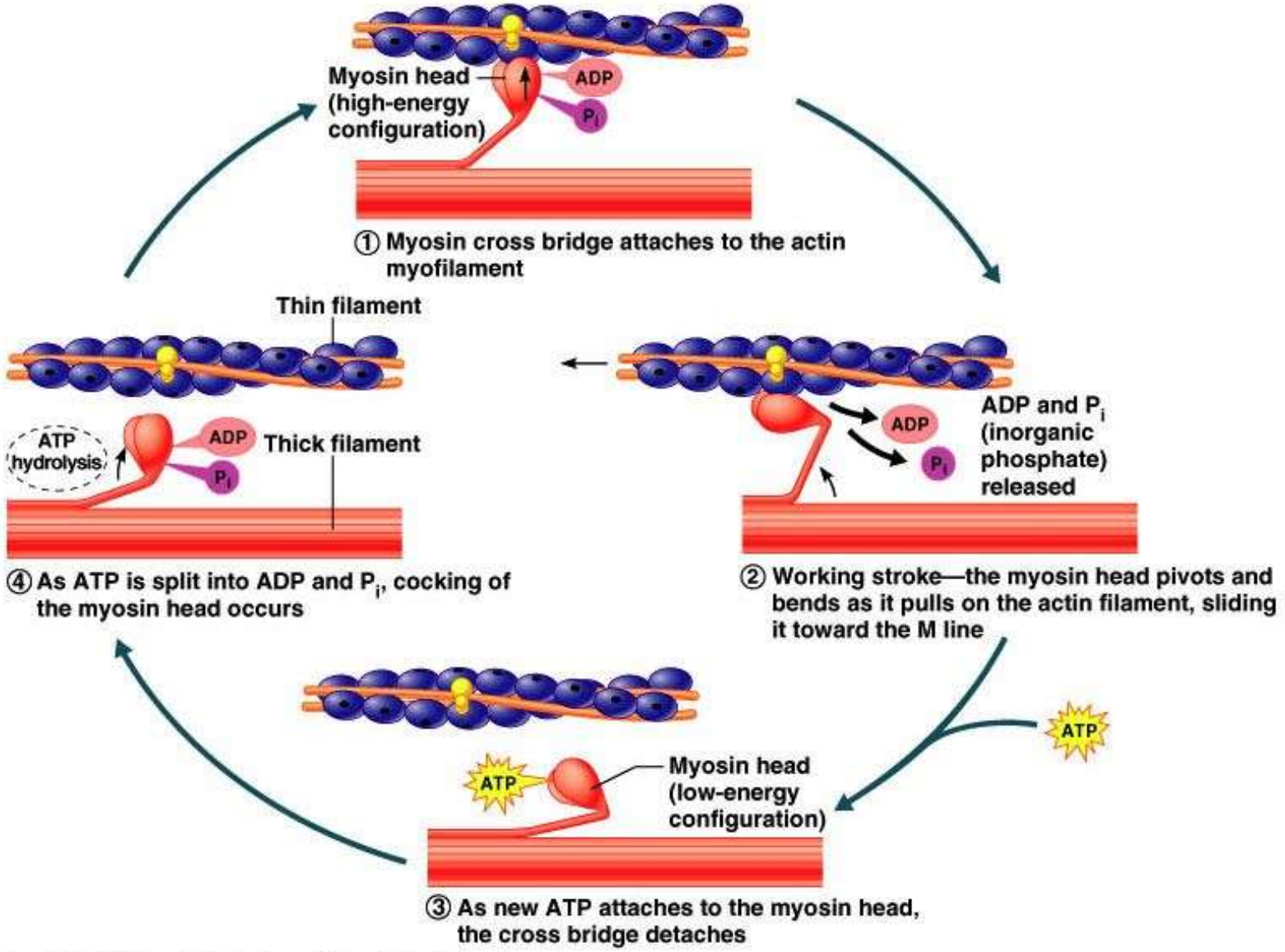
8. muscle fiber shortens as a contraction occurs .



# Muscle contraction: Role of Ca+

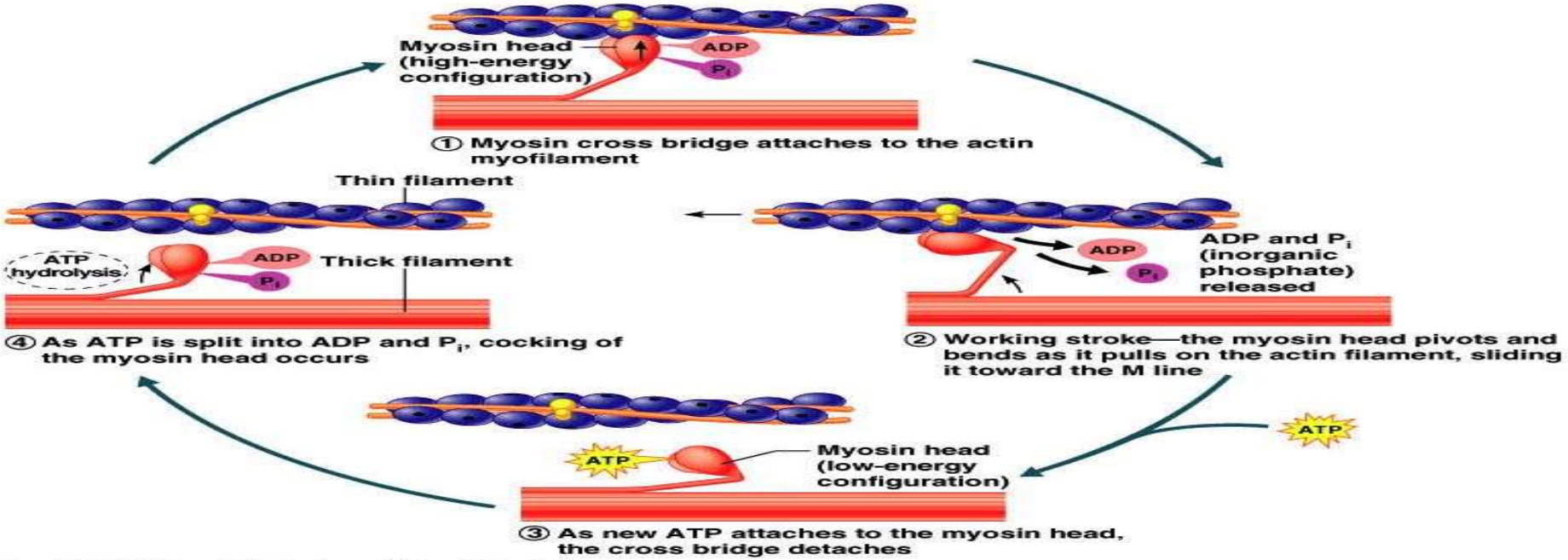


# Sliding of actin filament over myosin



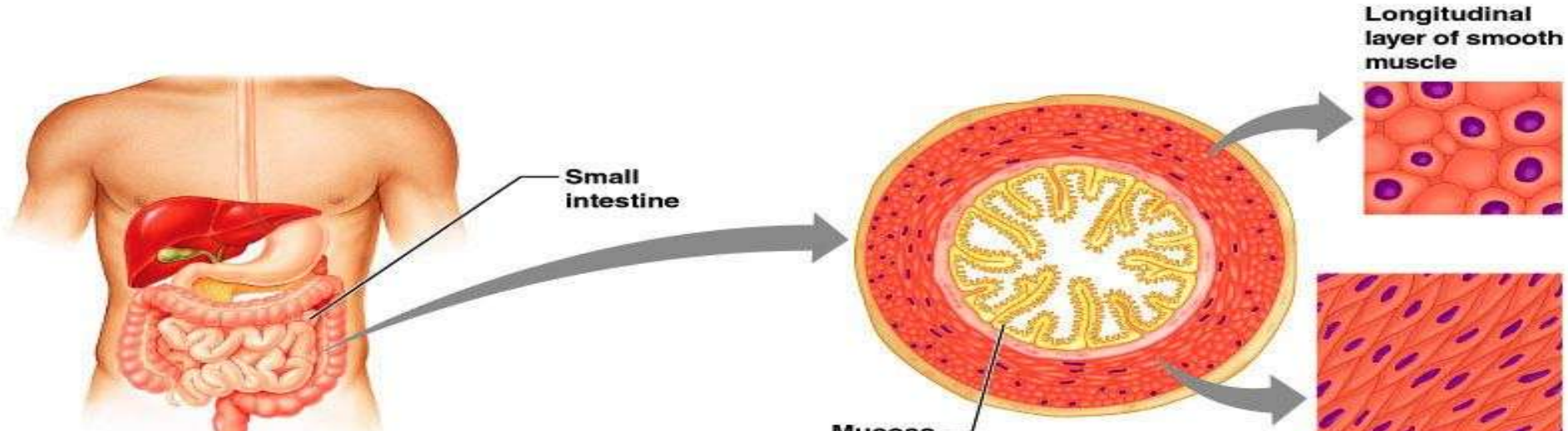
# Major events of muscle relaxation :

1. Acetylcholinestrase decomposes acetylcholine , and the muscle fiber membrane is no longer stimulated .
2. $Ca^{2+}$ ions are actively transported into the sarcoplasmic reticulum .
3. ATP causes linkage between actin and myosin filaments to break .
4. Cross–bridges re–open .
5. Troponin & tropomysin molecules inhibit the interaction between myosin and actin filaments .
6. Muscle fiber remain relaxed , yet ready until stimulated again .



# Smooth Muscle Contraction

1. Smooth muscles contain filaments of actin and myosin .
2. Lack transverse tubules and S.R. is not well developed .
3. Display rhythmieity (spontaneous repeated contractions) , responsible for peristalsis (alternate contraction and relaxation) .
4. Lack troponin (protein that binds to $Ca^{2+}$) , instead calmodulin binds to $Ca^{2+}$ .
5. Both Acetylcholine & norepinephrine are neurotransmitters for smooth muscles .
6. Hormones and stretching affect smooth muscle contractions .
7. Can contract for a long period of time .

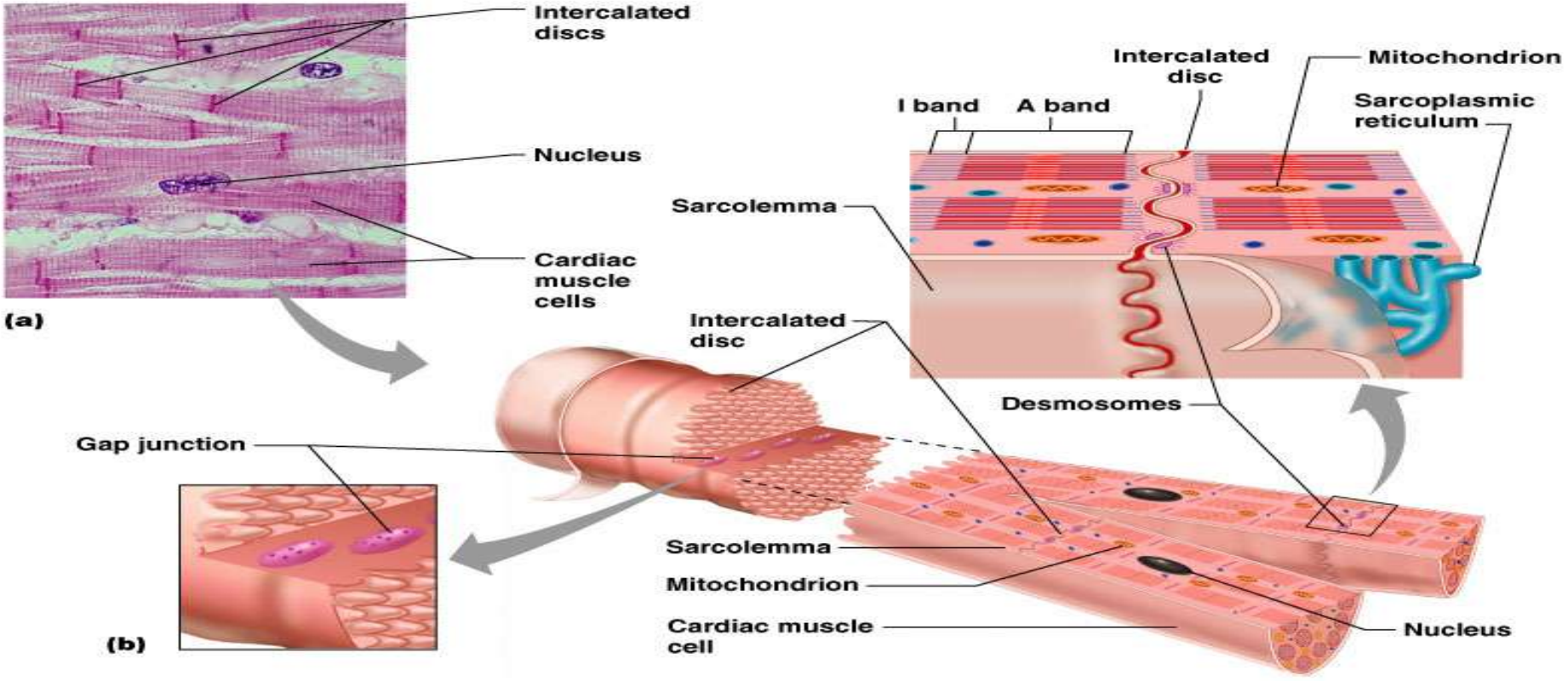


# Cardiac muscle

- a) unique arrangement of actin and myosin filaments produces the cross- striations (an optical illusion the microscope), and rapid contraction with powerful forces involved.
- b) muscle cells are joined by **intercalated disks**, and allow muscle groups to form branching networks - both features are necessary for cardiac muscle to function as a unit (″ sancytium″ ).
- c) **SR** and **T** tubules are well developed, so a large amount of calcium can be released rapidly through the T tubules.
- d) contains more mitochondria in each muscle cell than skeletal and smooth muscles, providing more ATP energy for continuous contraction.

# Cardiac Muscle

- self- exciting muscle fibers form "pacemakers" which initiate spontaneous nerve impulses for autorthymic contraction . These pacemakers can be influenced by the autonomic nervous system and hormones.

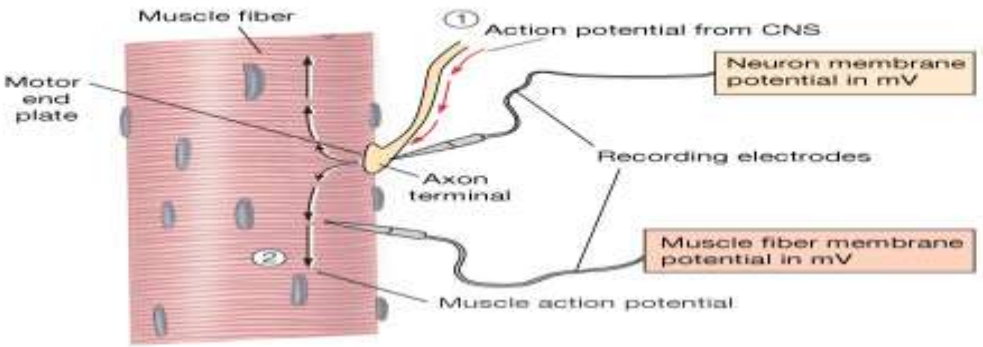


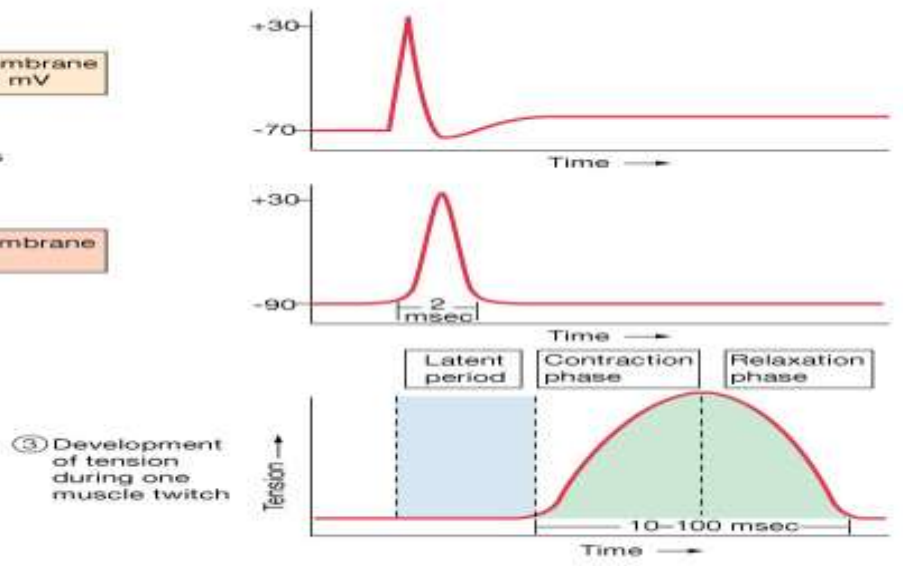
# Cardiac Muscle:

- 1. Contracts for a longer time than skeletal muscle because transverse tubules supply extra $Ca^{+2}$ ions .
- 2. intercalated disc connects the ends of adjacent muscles and hold cells together as a unit (syncytium) .
- 3. Fibers contracts as a unit .
- 4. Muscle fibers are self – exiting , rhythmic , and remain refractory until a contraction is completed.
- 5. **No Tetanic contractions**.

# Electromyogram (EMG):

- **a**) **Latent period** – chemical reactions and physical changes that occur preceding the actual contraction of a skeletal muscle.
- b) **Period of contraction** – actin causing the shortening of macromere and the contraction of muscle.
- c) **period of relaxation**- actin returns to its original position, causing the lengthening of sarcomeres and the relaxation of muscle.



# Clinical Terms:

- Convulsion : series of involuntary contractions of various voluntary muscles .
- Fibrosis : Degenerative disease in which connective tissue replaces skeletal muscle tissue .
- Myalgia : pain resulting from any muscular disorder .
- Myasthenia gravis : an autoimmune , chronic disease characterized by muscles that are weak and easily fatigue . it results from the immunes systems attack on neuromuscular junctions .
- Paresis : partial or slight paralysis of the muscle .
- Muscular dystrophy : progressive muscle weakness and atrophy caused by deficient dystrophin protein .

# Clinical Terms

- Myopathy : Any muscular disease .
- Paralysis : loss of ability to move a body part .
- Myotonia : prolonged muscular spasm .
- Myositis : inflammation of skeletal muscle tissue .
- Spasm : A sudden , involuntary smooth or skeletal muscle twitch , can range from mild to very painful irritation .
- Tics : spasm of eye–lid or facial muscles .
- Cramp : a prolonged spasm that cause a muscle to become taut and painful .