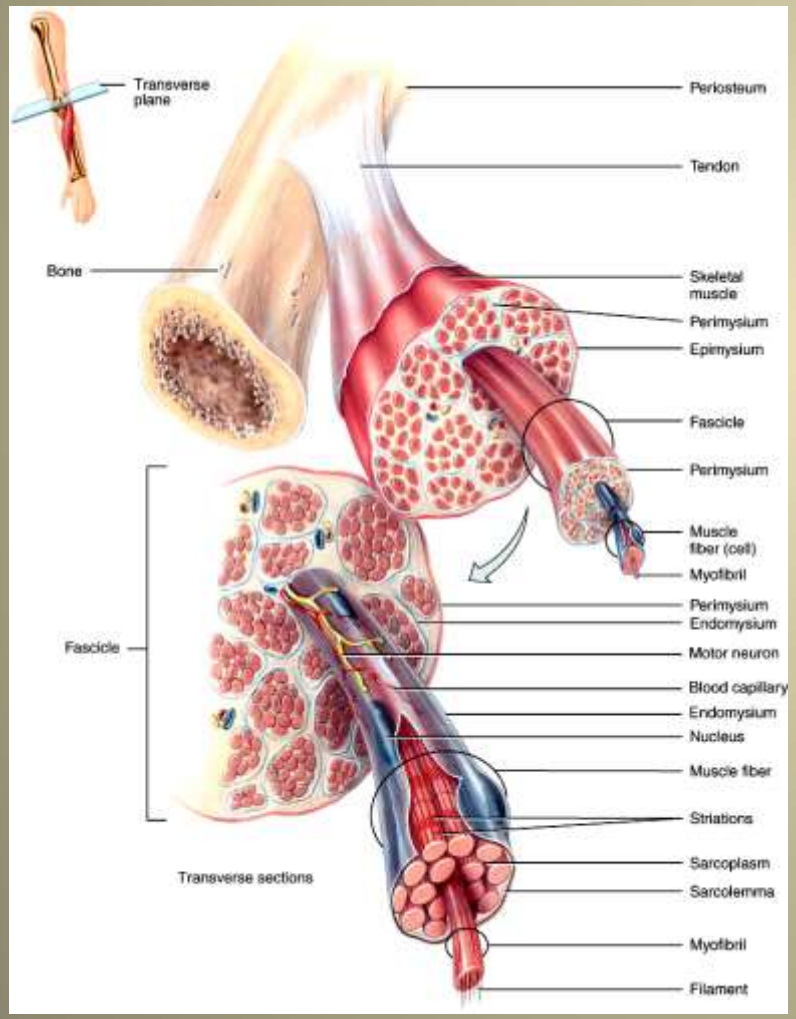
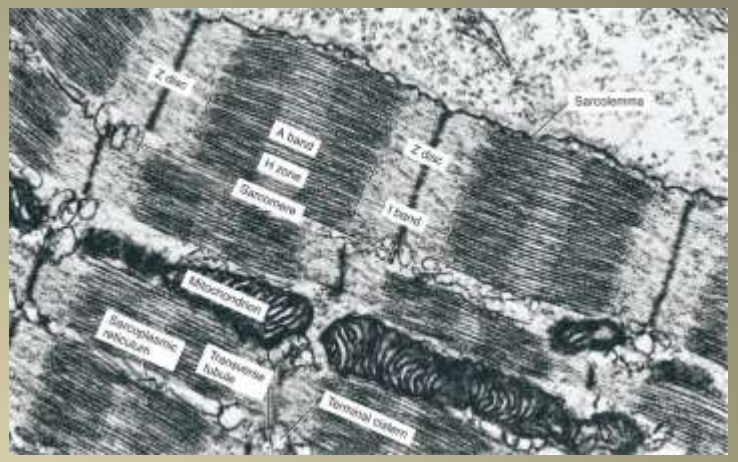
Muscle Physiology

INTRODUCTION

- Motion results from alternating contraction (shortening) and relaxation of muscles; the skeletal system provides leverage and a supportive framework for this movement.
- The scientific study of muscles is known as *myology*.

Chapter 10
Muscle Tissue

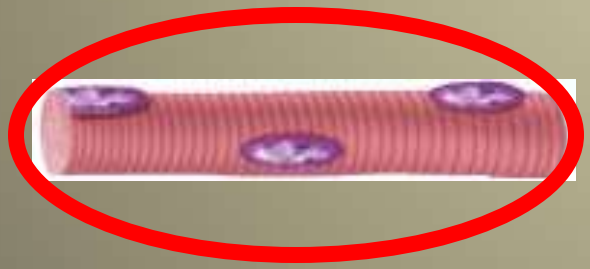




- Alternating contraction and relaxation of cells
- Chemical energy changed into mechanical energy

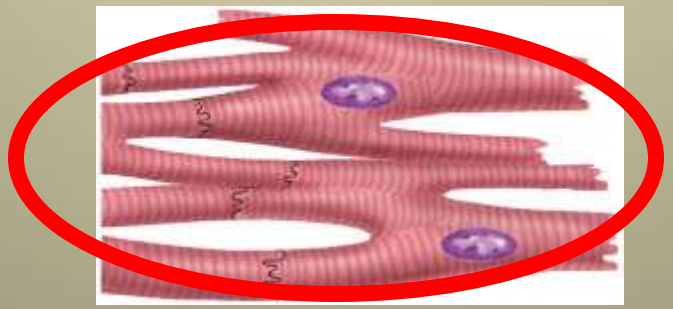
3 Types of Muscle Tissue

1. Skeletal muscle
   - attaches to bone, skin or fascia
   - Long and cylindrical
   - striated with light & dark bands visible with scope
   - voluntary control of contraction & relaxation
   - Multiple nuclei

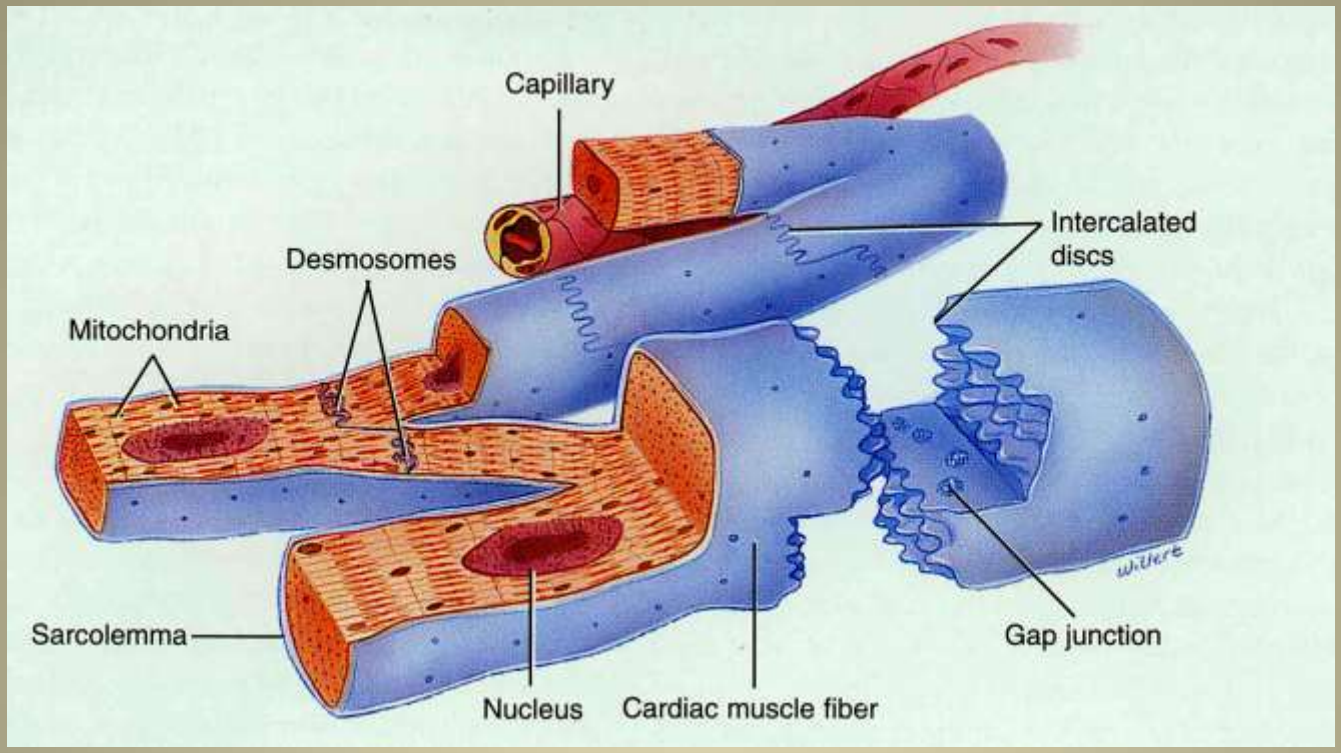


3 Types of Muscle Tissue

2. Cardiac muscle
   - striated in appearance
   - Branched in shape
   - involuntary control
   - autorhythmic because of built in pacemaker
   - 1 nucleus



Anatomy of Cardiac Muscle



- Striated , short, branching fibers
- Single centrally located nucleus
- Cells connected by intercalated discs with gap junctions
- Same arrangement of thick & thin filaments as skeletal
- Prolonged delivery of Ca^{2+} to sarcoplasm, produces a contraction that last 10 -15 times longer than in skeletal muscle

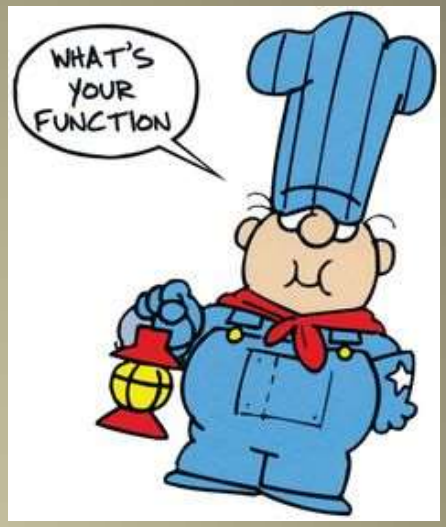
Physiology of Cardiac Muscle

- Autorhythmic cells
  - contract without stimulation (=**myogenic**)
- Contracts 75 times per min & needs lots of O_2
- Larger mitochondria generate ATP aerobically
- Extended contraction is possible due to prolonged Ca^{2+} delivery
  - Ca^{2+} channels to the extracellular fluid stay open

3 Types of Muscle Tissue

3. Smooth muscle
   - attached to hair follicles in skin
   - in walls of hollow organs -- blood vessels & GI
   - Nonstriated and spindle shaped in appearance
   - Involuntary
   - 1 nucleus

Functions of Muscle Tissue



1. Producing body movements
2. Stabilizing body positions
3. Regulating organ volumes
   – bands of smooth muscle called sphincters
4. Movement of substances within the body
   – blood, lymph, urine, air, food and fluids, sperm
5. Producing heat
   – involuntary contractions of skeletal muscle (shivering)

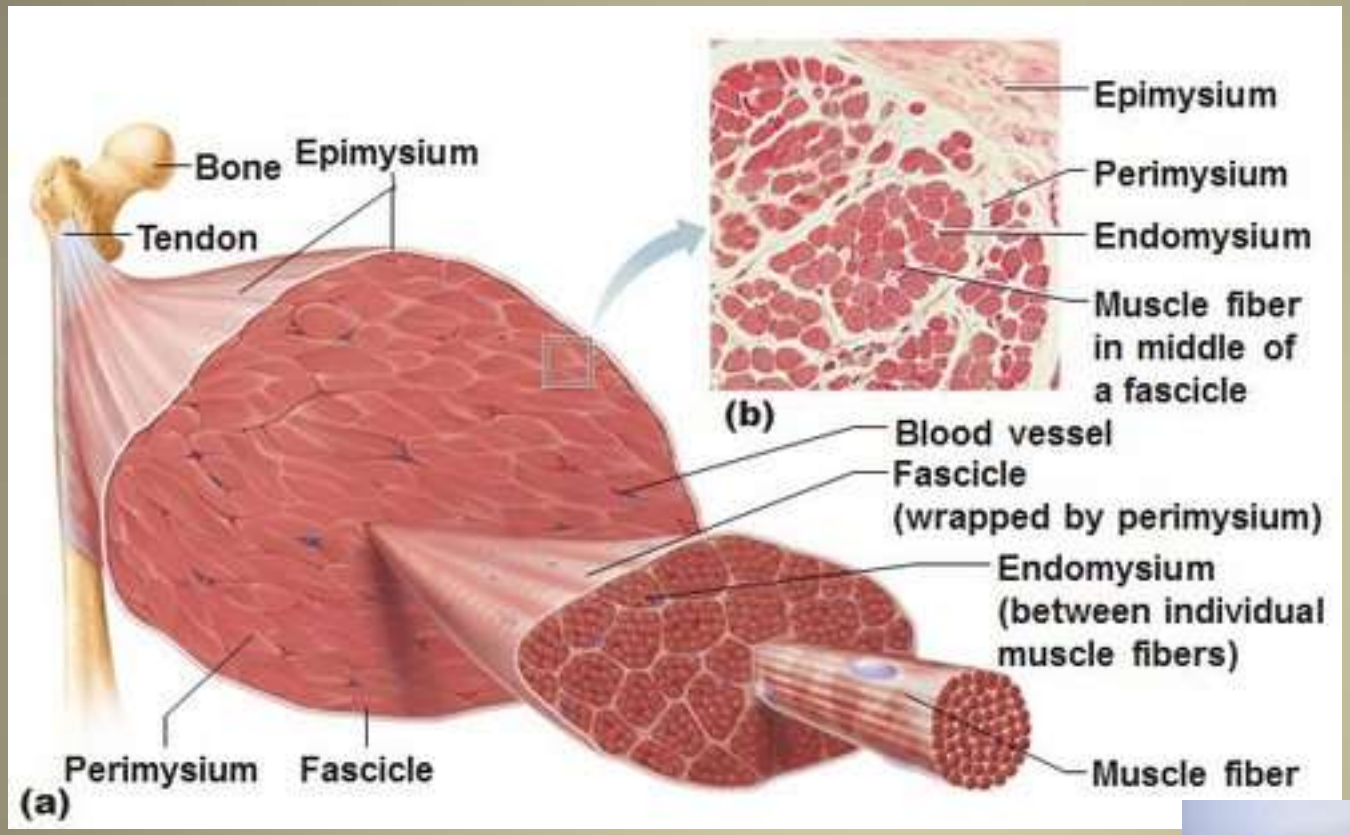
Properties of Muscle Tissue

1. Excitability
   - respond to chemicals released from nerve cells
2. Conductivity
   - ability to propagate electrical signals over membrane
3. Contractility- ability to shorten and generate force
4. Extensibility
   - ability to be stretched without damaging the tissue
5. Elasticity
   - ability to return to original shape after being stretched

Skeletal Muscle -- Connective Tissue

- Superficial fascia- loose connective tissue & fat
- Deep fascia = dense irregular CT around muscle
- Connective tissue components of the muscle include
  - epimysium = surrounds the whole muscle
  - perimysium = surrounds bundles (fascicles)
  - endomysium = separates individual muscle cells
- All these connective tissue layers extend beyond the muscle belly to form the tendon

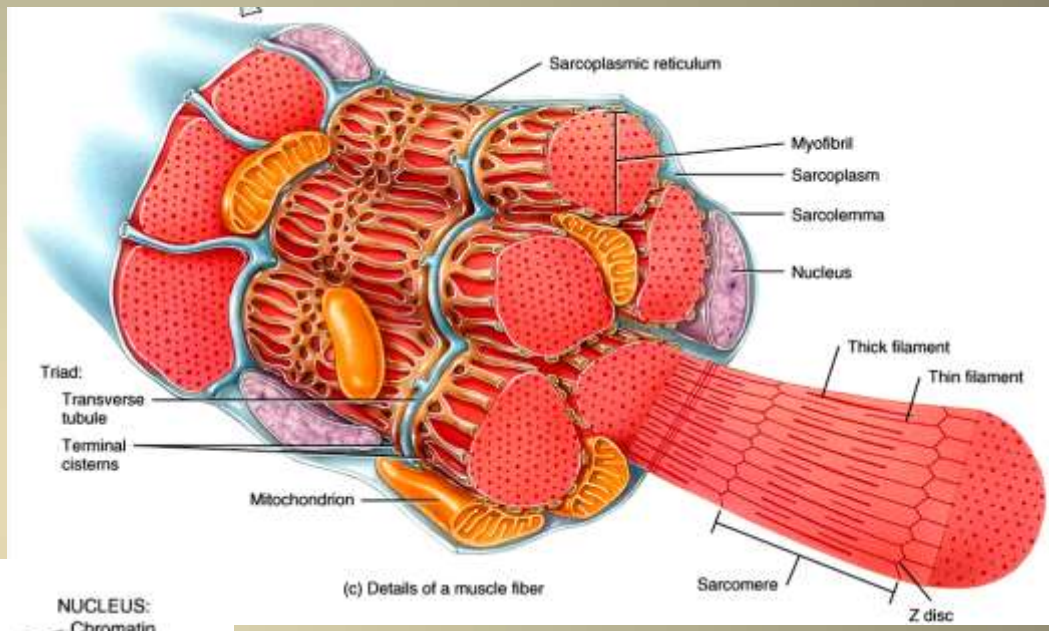
Skeletal Muscle -- Connective Tissue

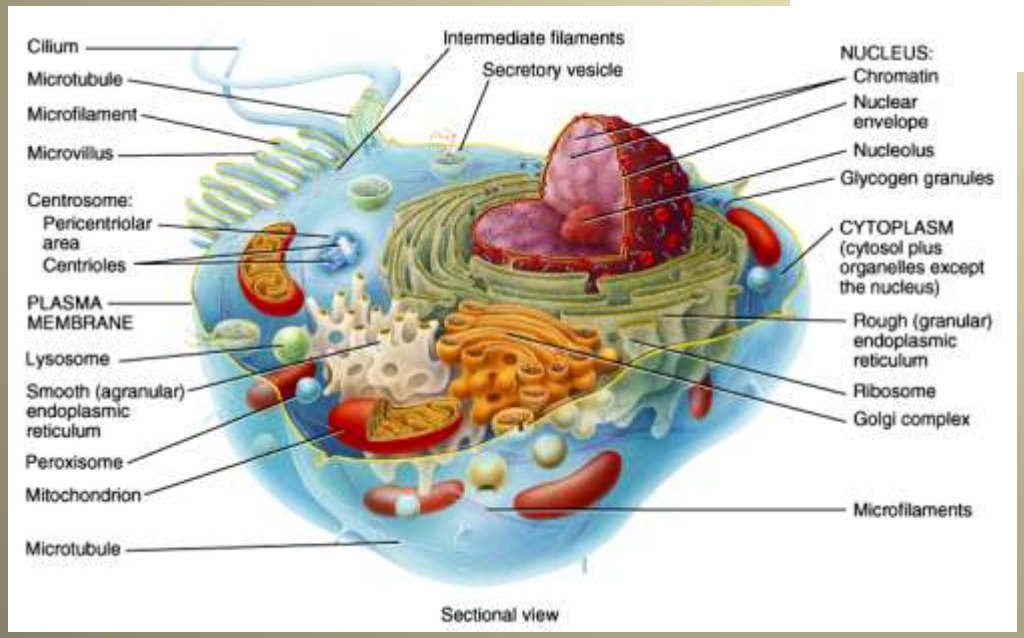


Muscle Fiber or Myofiber

Muscle cells are long, cylindrical & multinucleated

How does it compare to our image of a traditional cell?





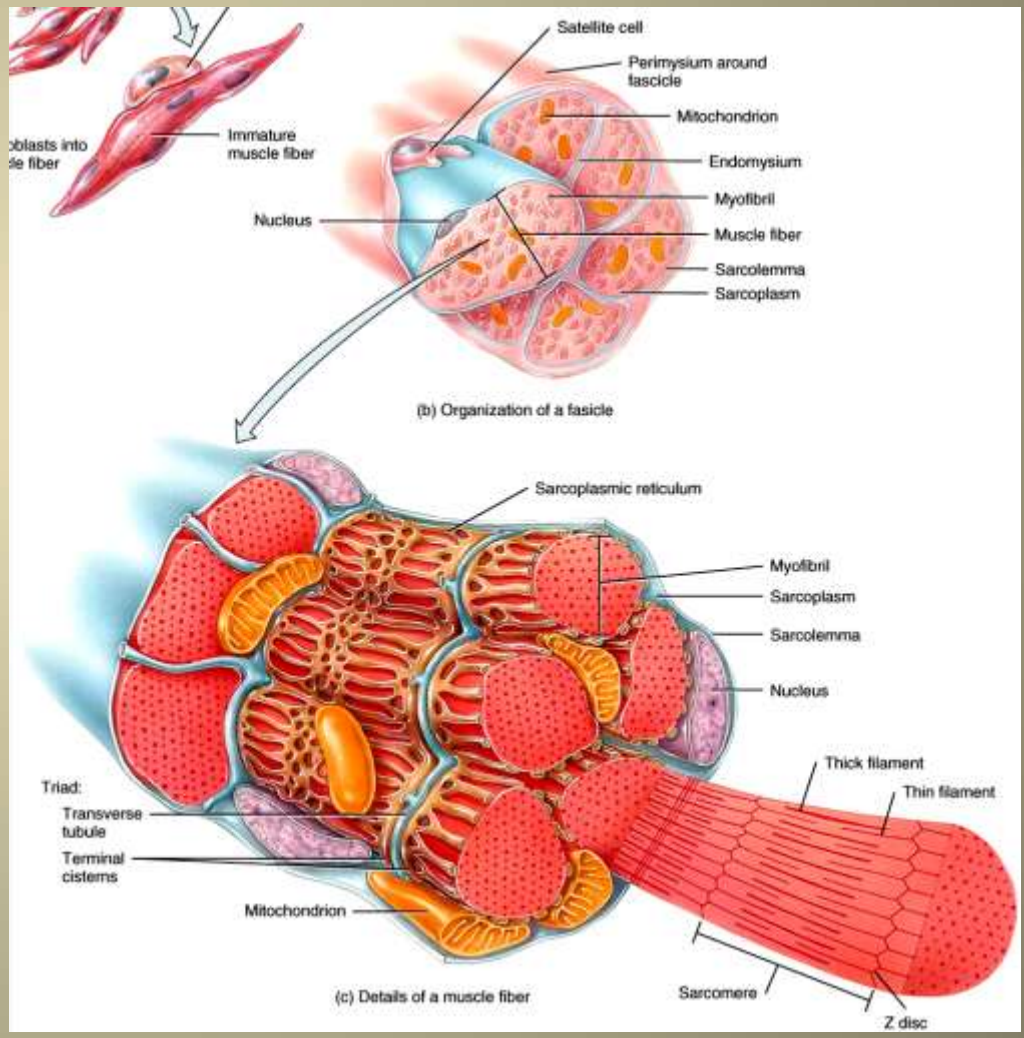
Vocabulary Check

- Sarcolemma
- Sarcoplasm
- Sarcoplasmic reticulum
- Sarcomere

- Muscle cell=myofiber=muscle fiber

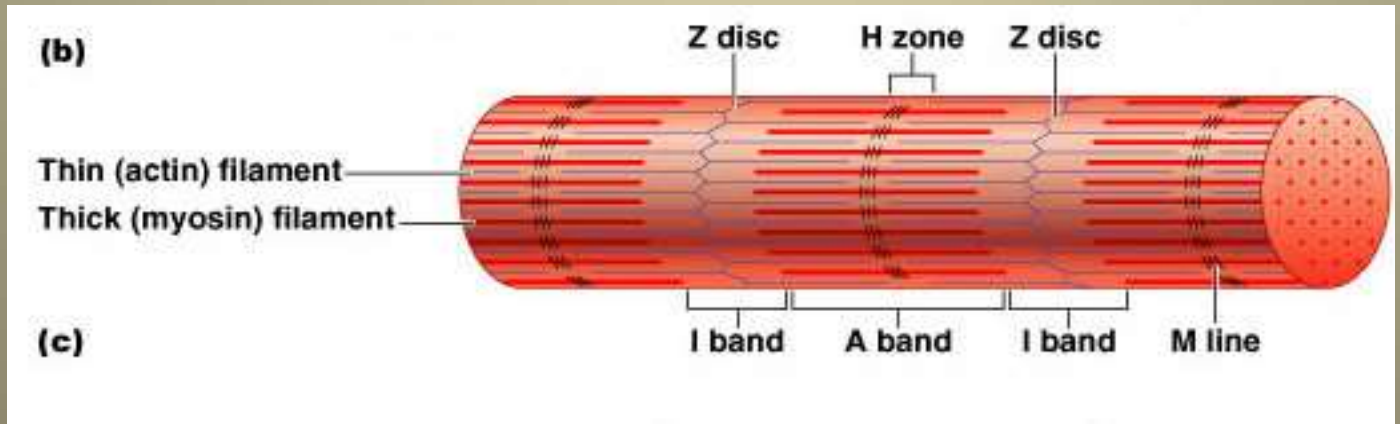
Sarcolemma, T Tubules, and Sarcoplasm

- **sarcolemma** = cell membrane
- **T tubules** are tiny invaginations of the sarcolemma that quickly spread the muscle action potential to all parts of the muscle fiber.
- **Sarcoplasm** = cytoplasm
  - large amount of glycogen for energy production
  - myoglobin for oxygen storage.



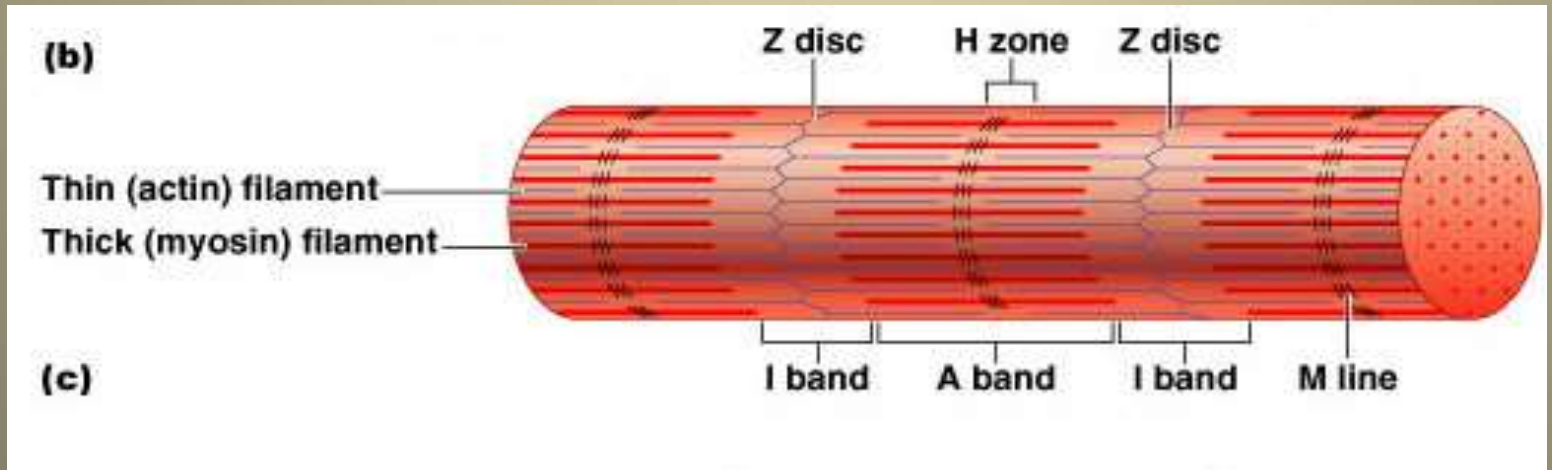
Sarcomere

- The basic unit of contraction of skeletal muscle
  - **Z disc** (Z line) – boundaries of each sarcomere
  - Thin (**actin**) filaments – extend from Z disc toward the center of the sarcomere
  - Thick (**myosin**) filaments – located in the center of the sarcomere
    - Overlap inner ends of the thin filaments
    - Contain ATPase enzymes



Sarcomere Structure

- **A bands** – full length of the thick filament
  - Includes inner end of thin filaments
- **H zone** – center part of A band where no thin filaments occur
- **M line** – in center of H zone
  - Contains tiny rods that hold thick filaments together
- **I band** – region with only thin filaments
  - Lies within two adjacent sarcomeres



The Proteins of Muscle

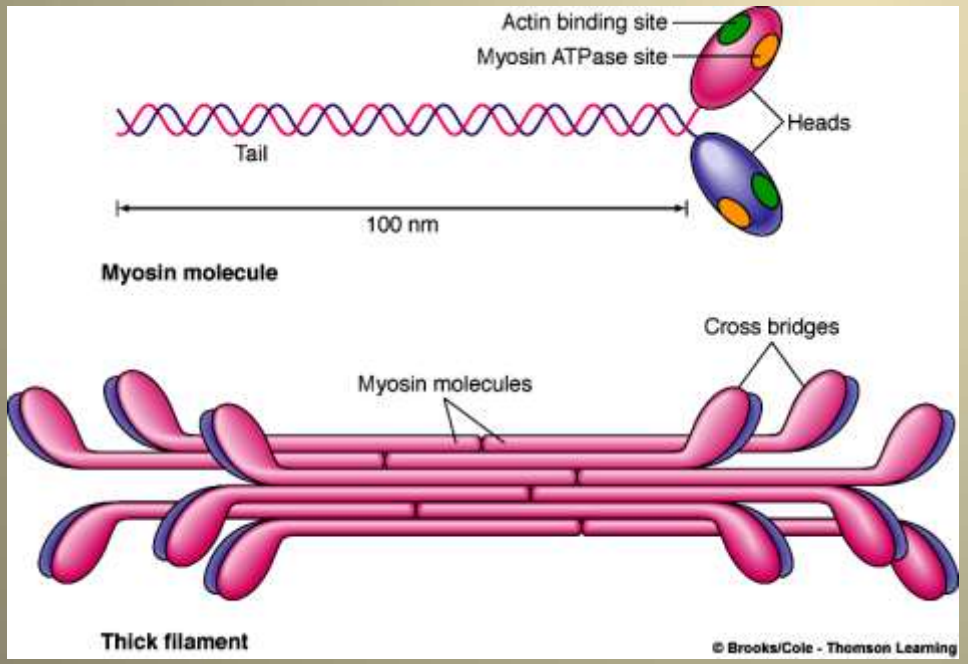
- Myofibrils are built of 3 kinds of protein
  1. contractile proteins
     - myosin and actin
  2. regulatory proteins which turn contraction on & off
     - troponin and tropomyosin
  3. structural proteins which provide proper alignment, elasticity and extensibility
     - titin, myomesin, nebulin and dystrophin

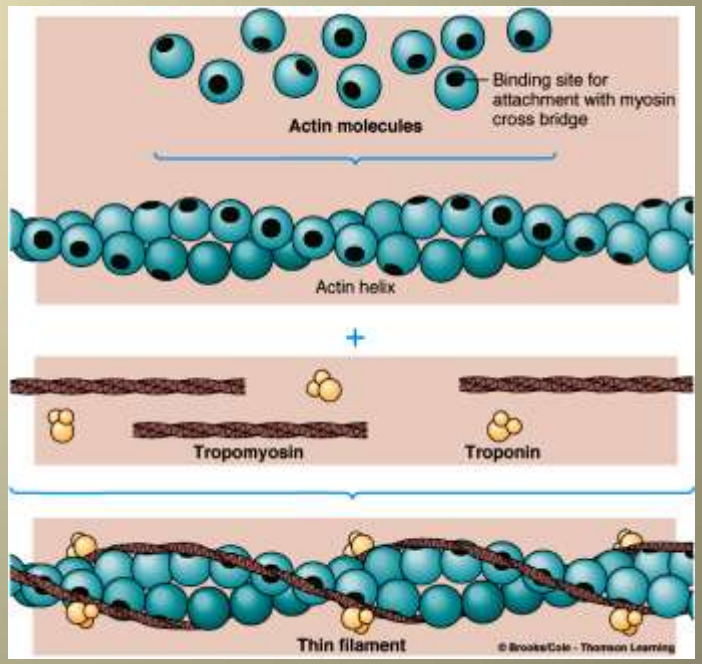
So How Do Muscles Contract?

- The following are key to understanding the physiology of a skeletal muscle contraction:
  - Myosin
  - Actin
  - Troponin
  - Tropomyosin
  - Ca^{2+}
  - ATP/ADP and ATPase

Skeletal muscle contraction is a molecular phenomenon.

- The myosin cross bridges can bind to the actin, pulling these thin filaments toward the center of the sarcomere. This is the sliding filament mechanism.



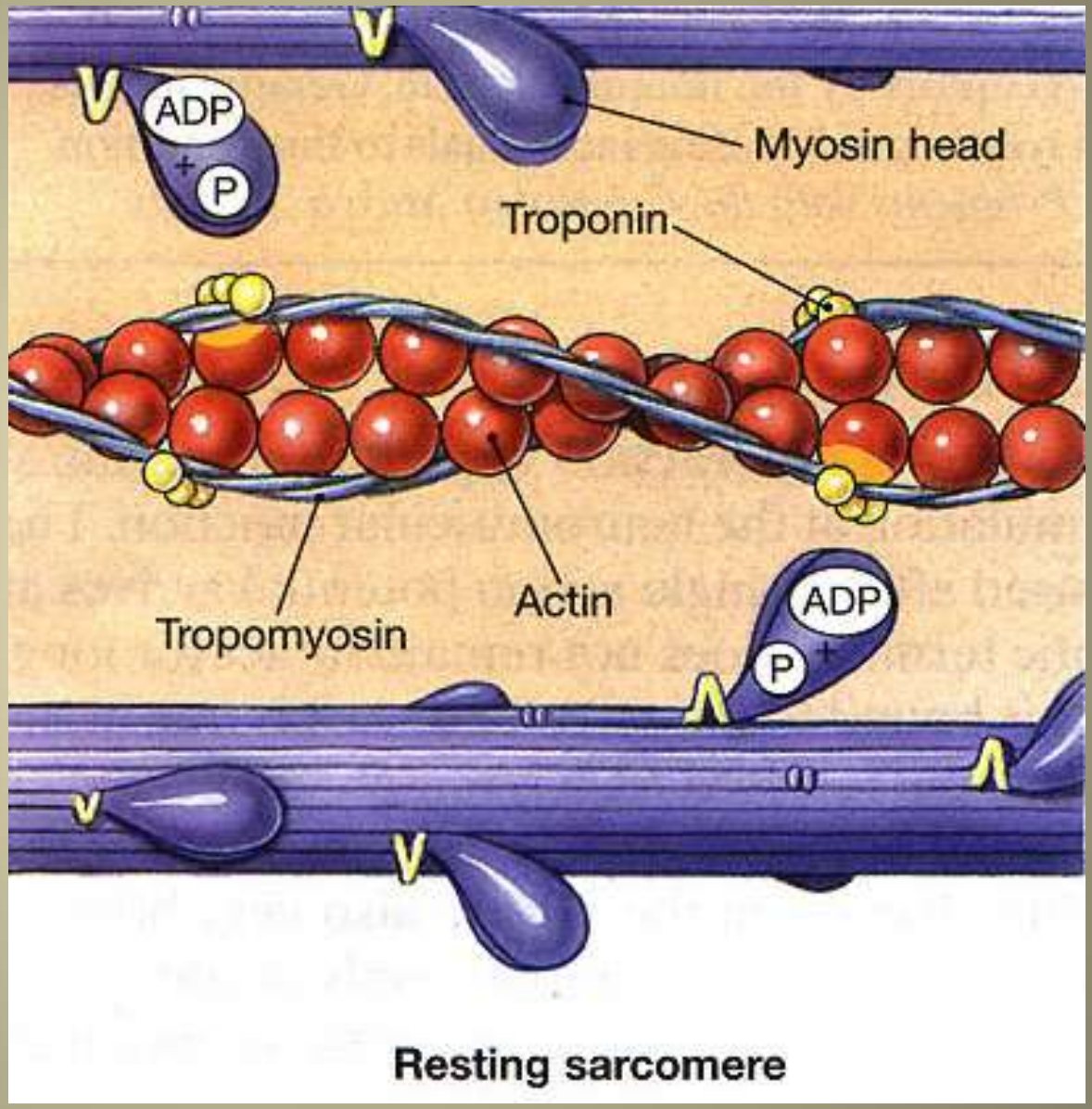


Tropomyosin and troponin are other thin proteins that are regulatory.

- **Tropomyosin** covers the actin binding sites, preventing their union with myosin cross bridges.
- **Troponin** has three binding sites: one binds to tropomyosin, one to actin, and one to Ca
  - When **calcium** combines with troponin, tropomyosin slips away from its blocking position between actin and myosin.
  - With this change actin and myosin can interact and muscle contraction can occur.

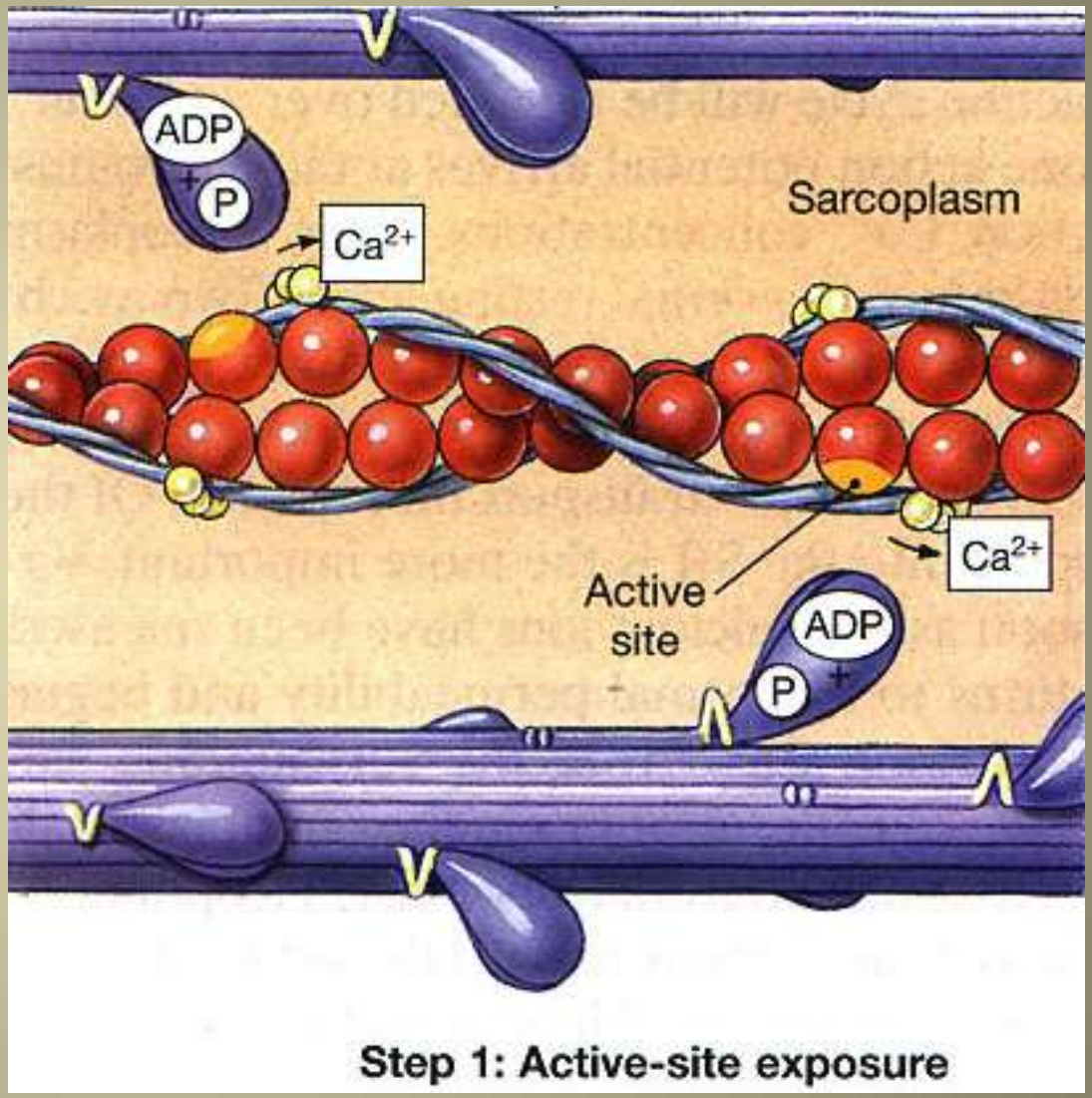
Step 1: Relaxed state

- Myosin heads are disengaged from actin and in the energized state (i.e. ADP + P).
- Troponin/tropomyosin complex covering actin binding site
- Sarcoplasmic Ca^{2+} levels are low



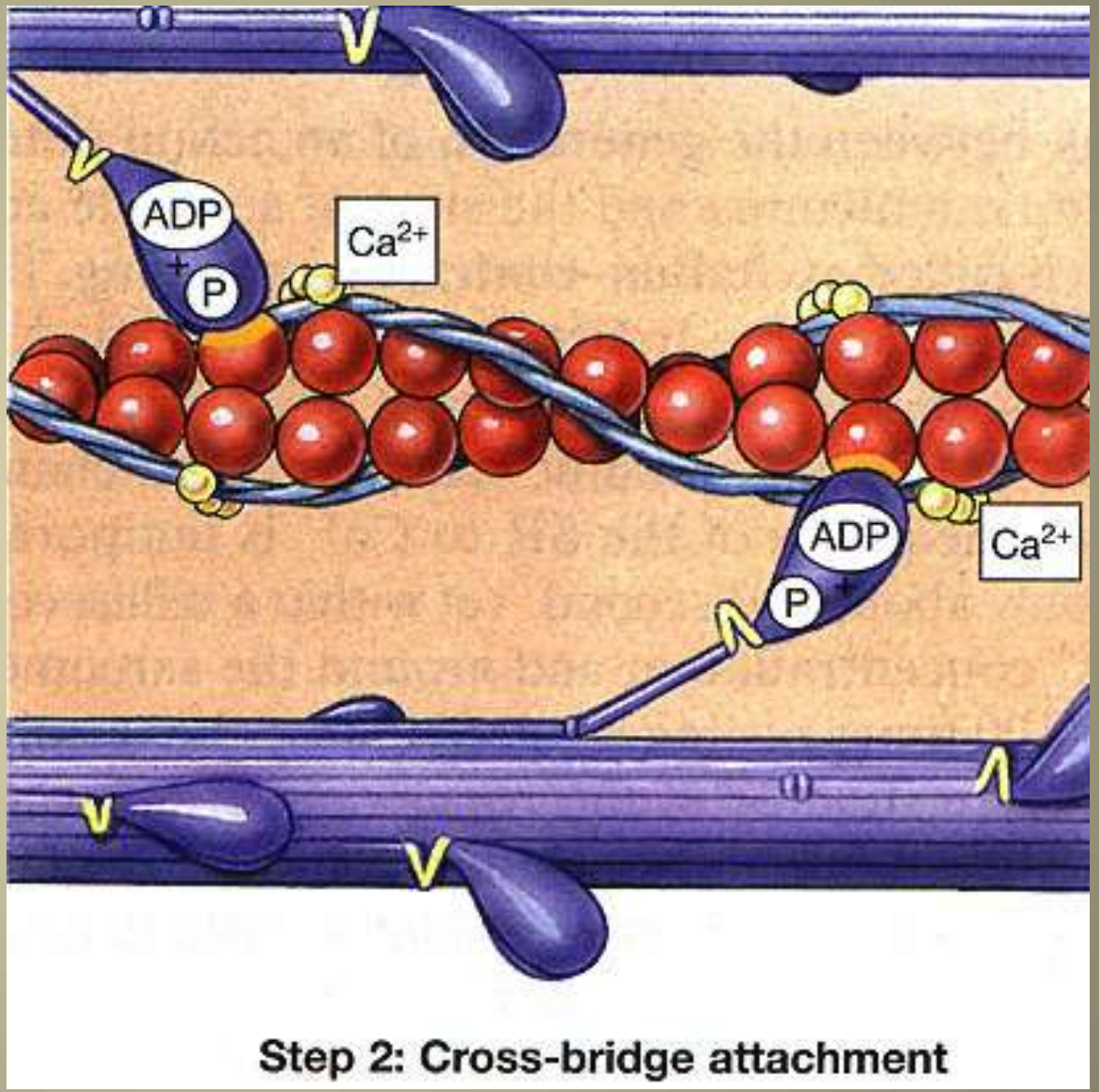
Step 2: Active site exposure

- Action Potential from a motor neuron triggers the release of Ca^{2+} from the sarcoplasmic reticulum
- Ca^{2+} binds to troponin
- Troponin undergoes a conformation change pulling the tropomyosin away from and exposing the active site



Step 3: Cross bridge attachment

• Myosin heads attach to active sites on actin

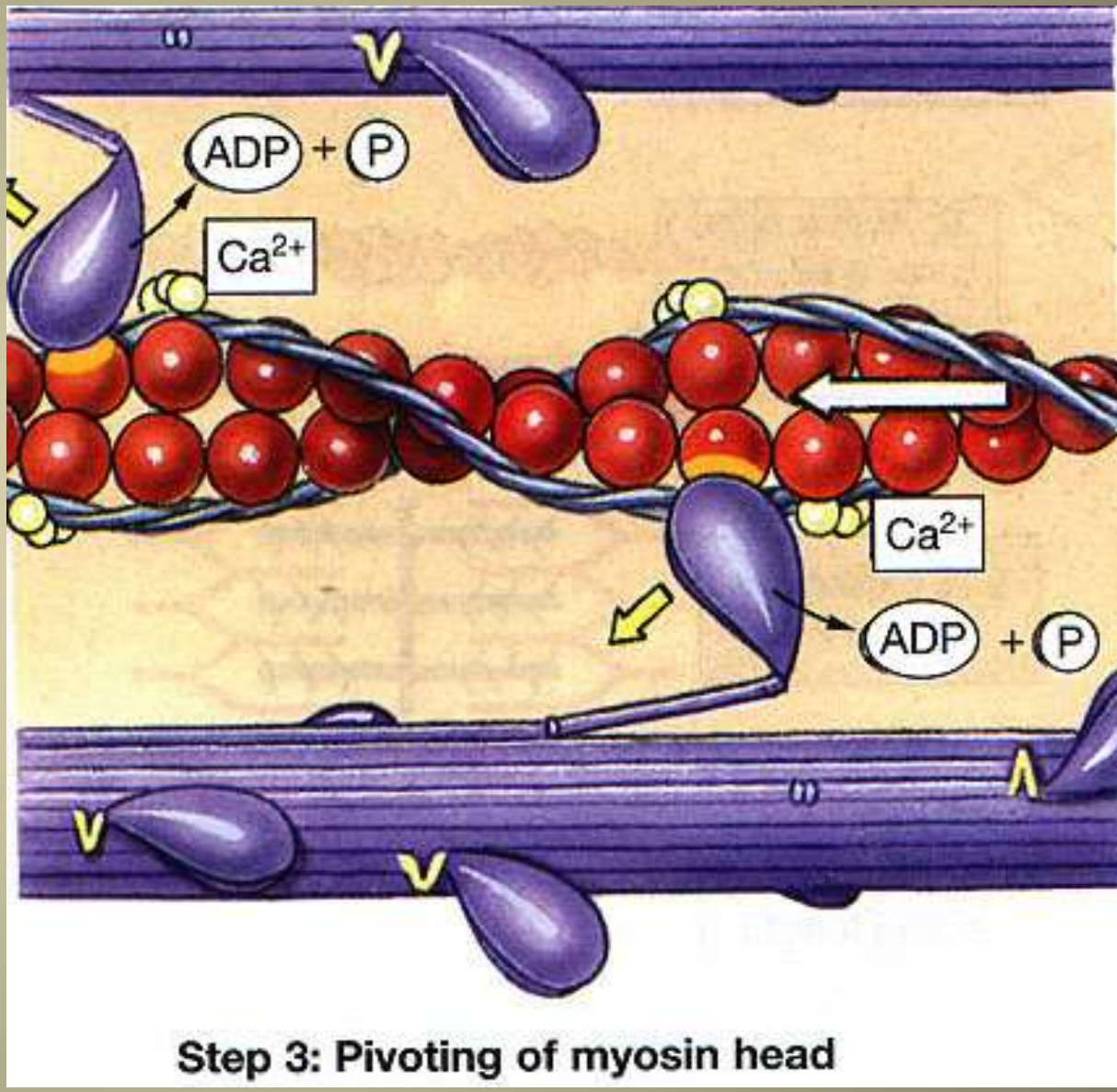


Step 2: Cross-bridge attachment

Step 4: Cross-bridge pivoting

- The attaching of the myosin head to the actin binding site causes ADP + P_i to separate from the myosin head.

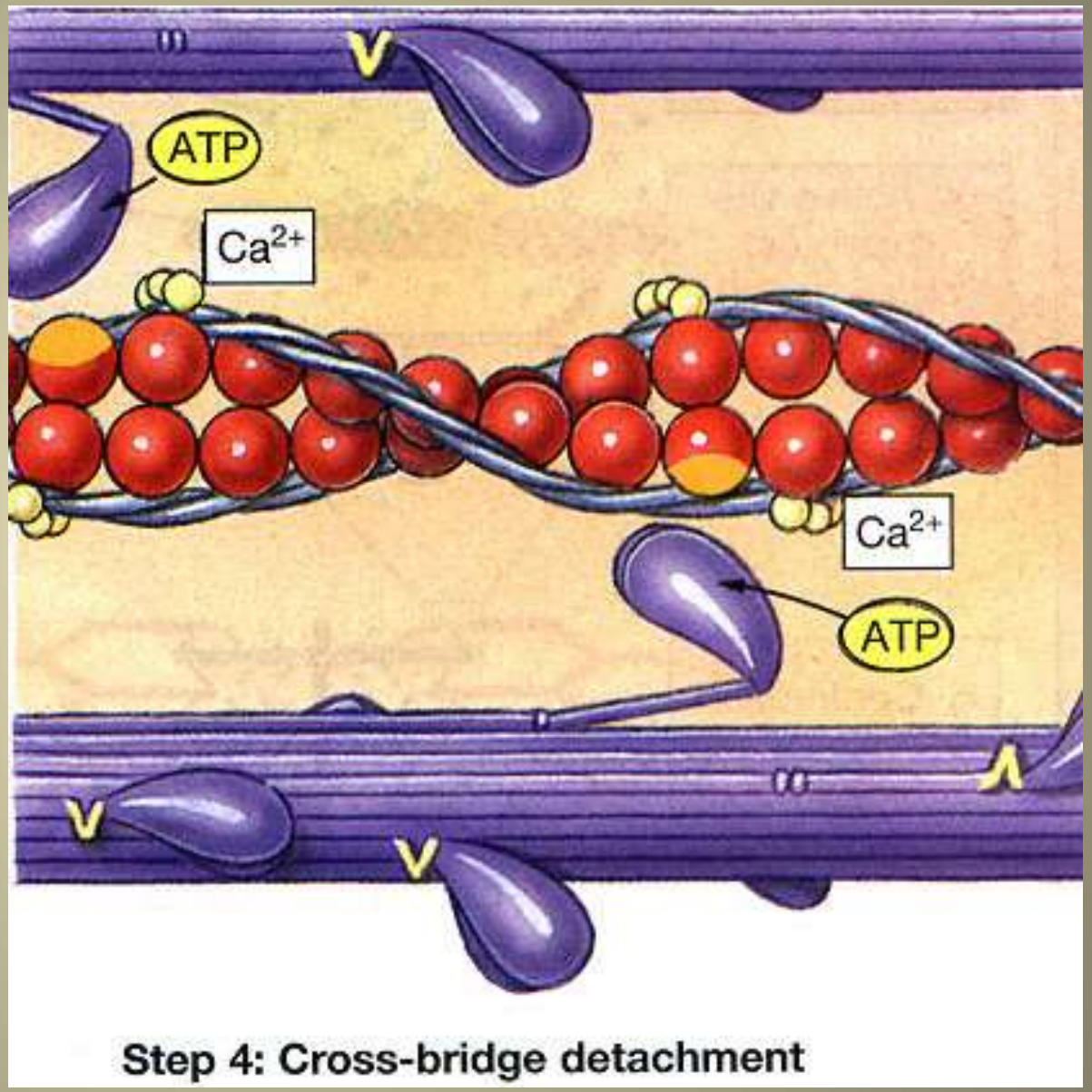
•This causes the myosin head to move, pulling on the actin.



Step 3: Pivoting of myosin head

Step 5: Cross-bridge detachment

- ATP bind to myosin heads
- Myosin heads detach from actin



Step 4: Cross-bridge detachment

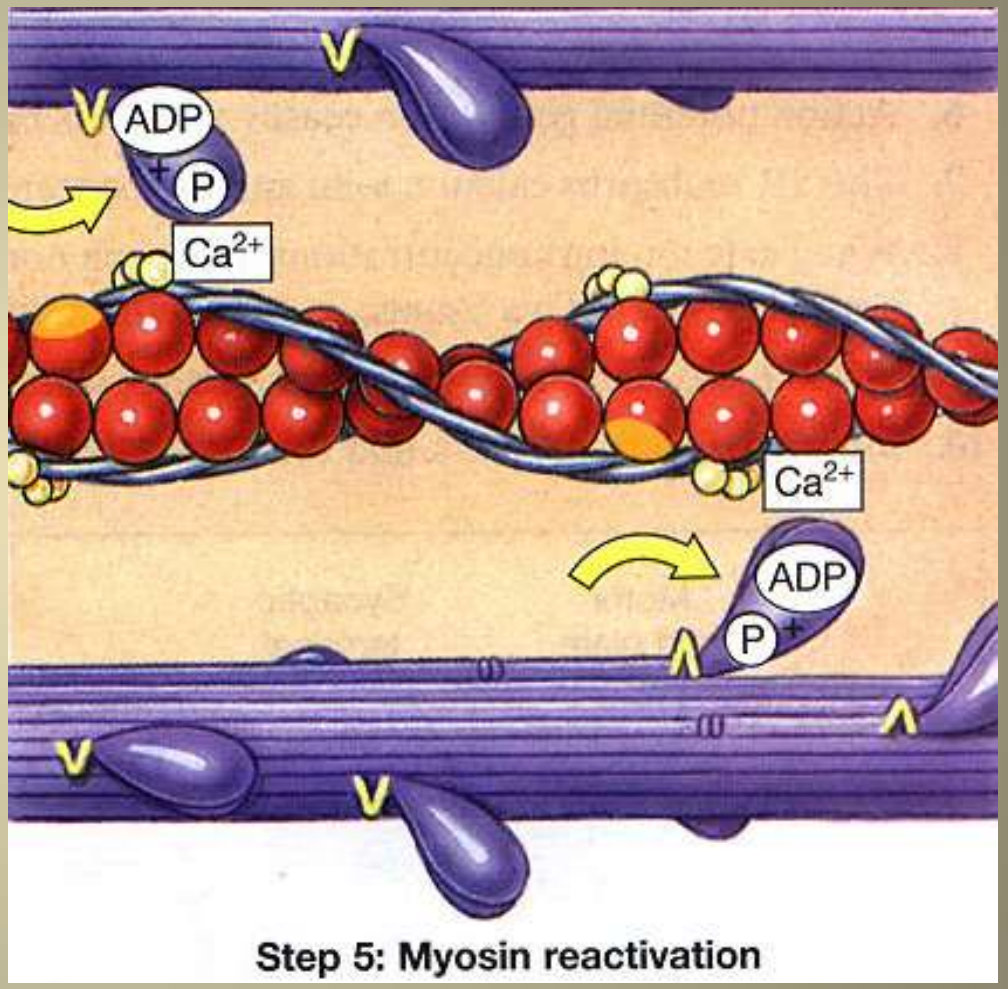
Martini

Step 6: Myosin reactivation

• ATPase hydrolyzes the attached ATP on myosin head and "recocks"

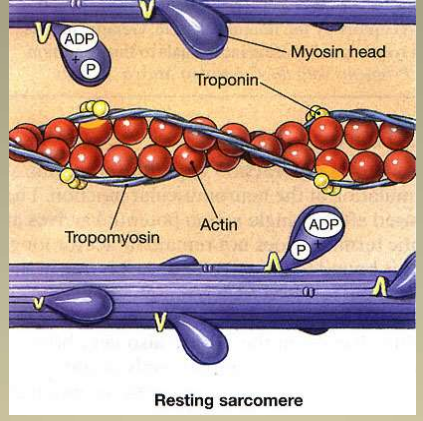
• If Ca^{2+} remains high, other myosin heads attach to active sites

• If the nerve signal stimulation stops, sarcoplasmic Ca^{2+} levels drop and the troponin/tropomyosin chain again covers the actin active site, causing the muscle to relax

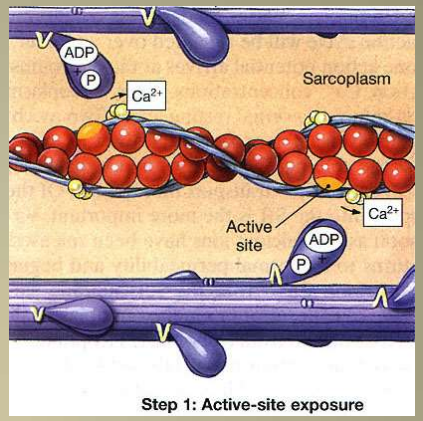


Step 5: Myosin reactivation

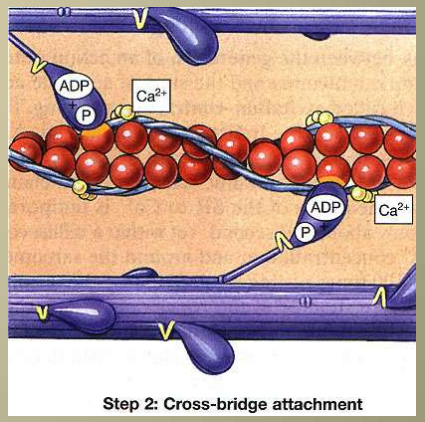
Ratcheting of cross-bridges



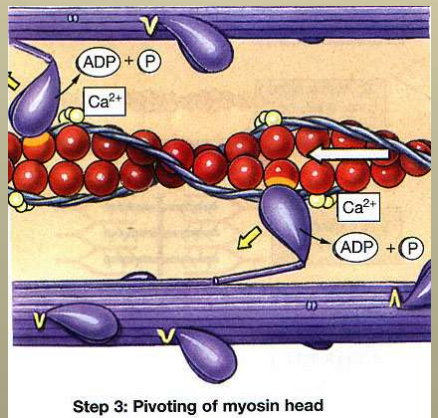
Resting sarcomere



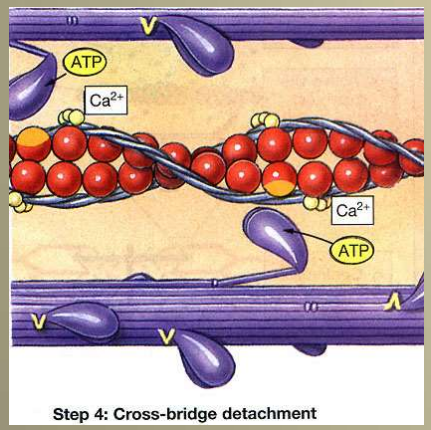
Step 1: Active-site exposure



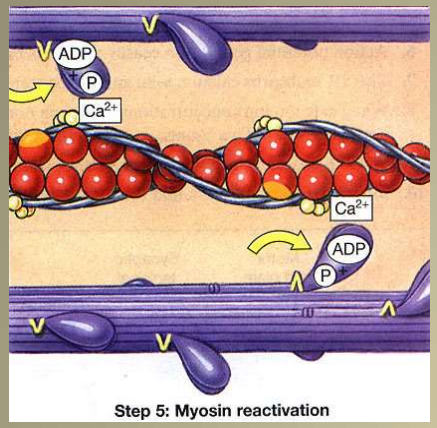
Step 2: Cross-bridge attachment



Step 3: Pivoting of myosin head



Step 4: Cross-bridge detachment



Step 5: Myosin reactivation

Martini

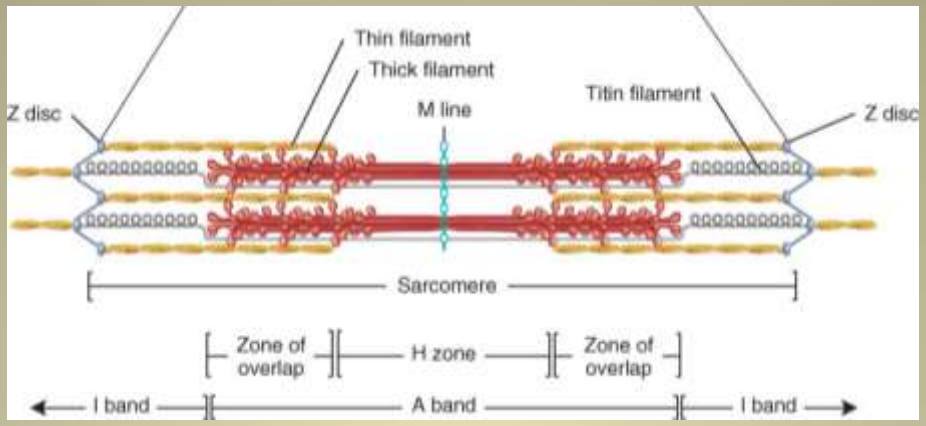
Thought Question

- What causes rigor mortis?

Structural Proteins

- Structural proteins:
  - keep the thick and thin filaments in the proper alignment
  - give the myofibril elasticity and extensibility
  - link the myofibrils to the sarcolemma and extracellular matrix.
  - They are:
    - Titin
    - Myomesin
    - Nebulin
    - Dystrophin

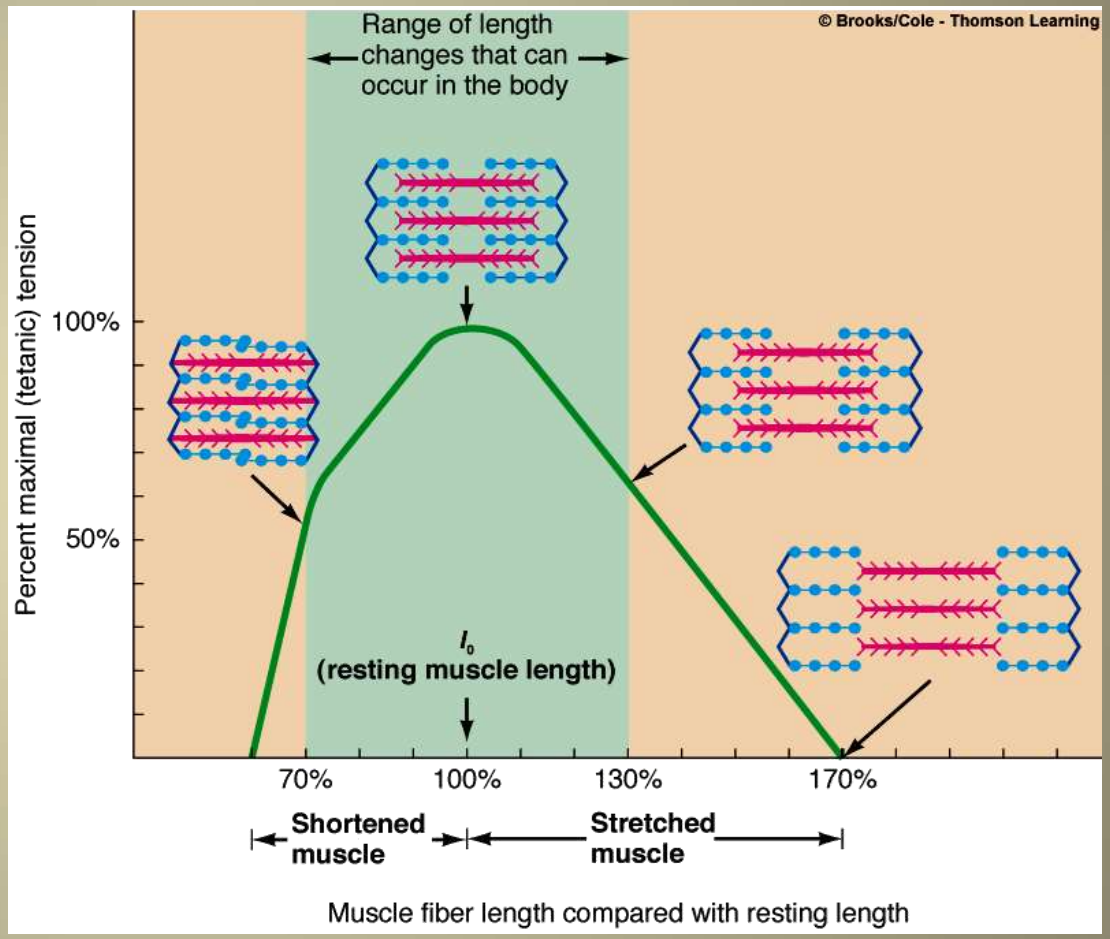
Structural Proteins



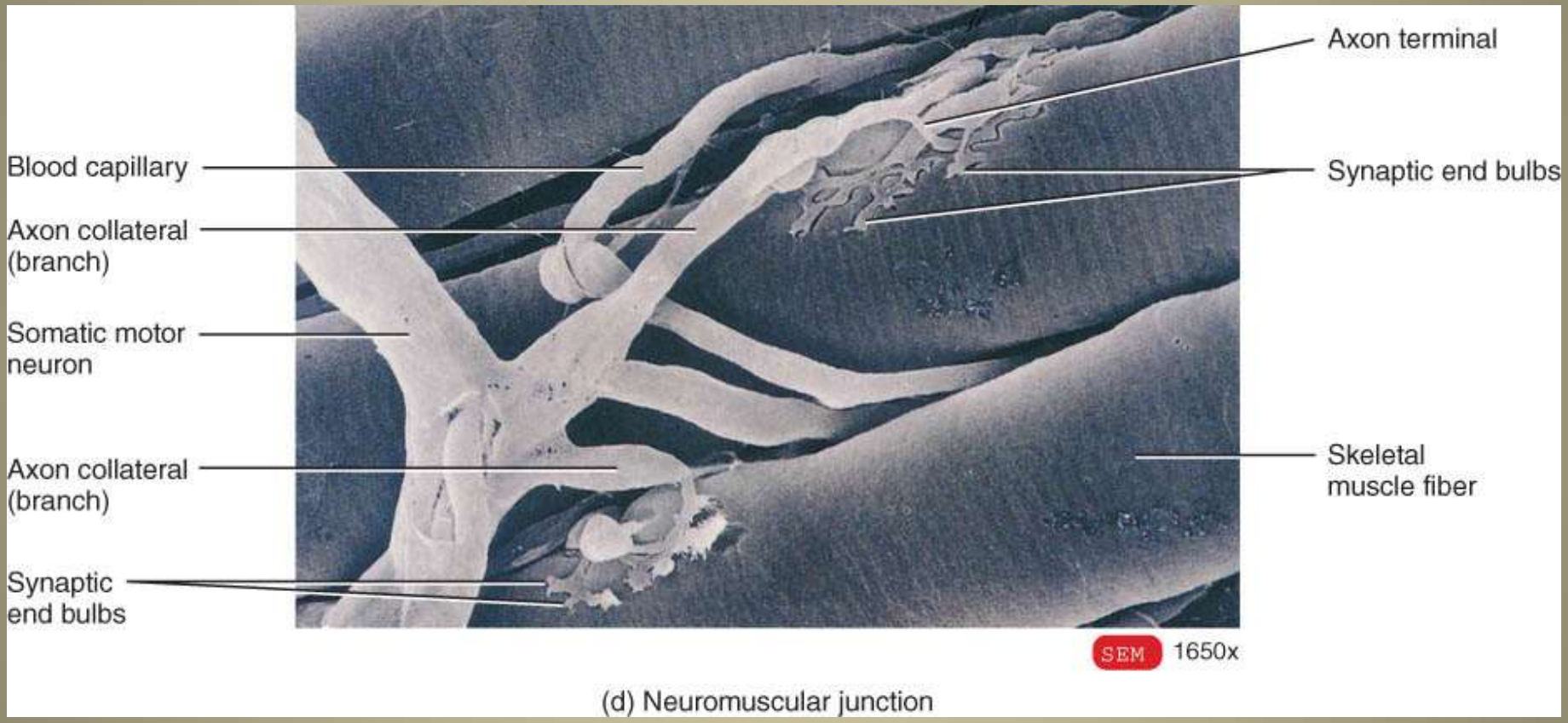
- **Titan** anchors thick filament to the M line and the Z disc.
  - Titan can stretch to 4 times its resting length and spring back unharmed playing an important role in recovery of the muscle from being stretched.
- **Myomesin** (M line) connects to titin and adjacent thick filaments.
- **Nebulin**, an inelastic protein wrapped around the thin filaments that helps align the thin filaments and anchors them to Z disc.
- **Dystrophin** links thin filaments to sarcolemma and transmits the tension generated to the tendon.

Length-Tension Relationship

- The forcefulness of muscle contraction depends on the length of the sarcomeres within a muscle before contraction begins.



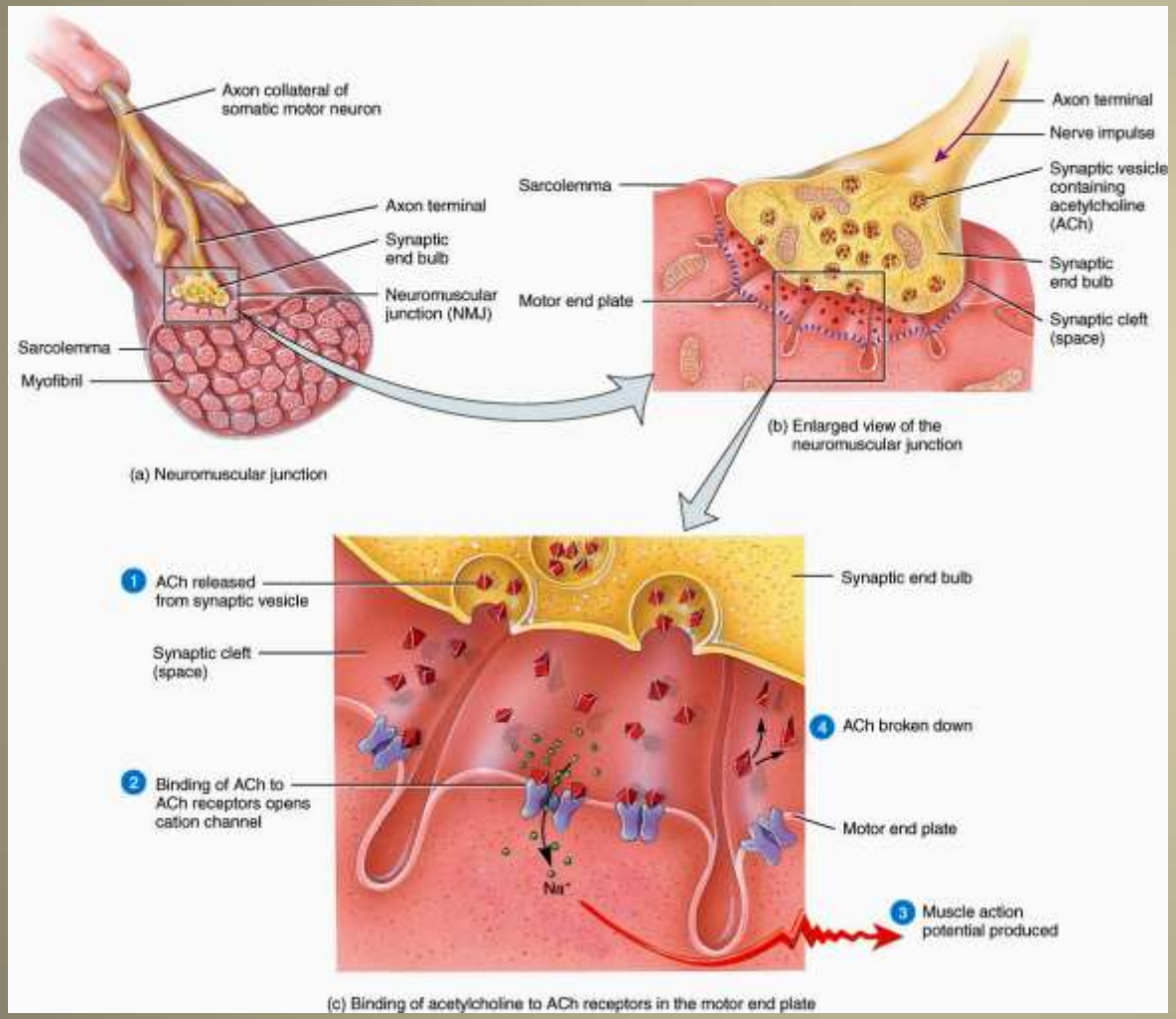
So how does the muscle fiber get the signal to contract? Neuromuscular Junction (NMJ) or Synapse



(d) Neuromuscular junction

- NMJ = myoneural junction or neuromuscular junction
  - **end of axon nears the surface of a muscle fiber at its motor end plate region (remain separated by synaptic cleft or gap)**

Structures of NMJ Region



- Synaptic end bulbs are swellings of axon terminals
- End bulbs contain synaptic vesicles filled with acetylcholine (ACh)
- **Motor end plate** membrane contains 30 million ACh receptors.

Events Occurring After a Nerve Signal

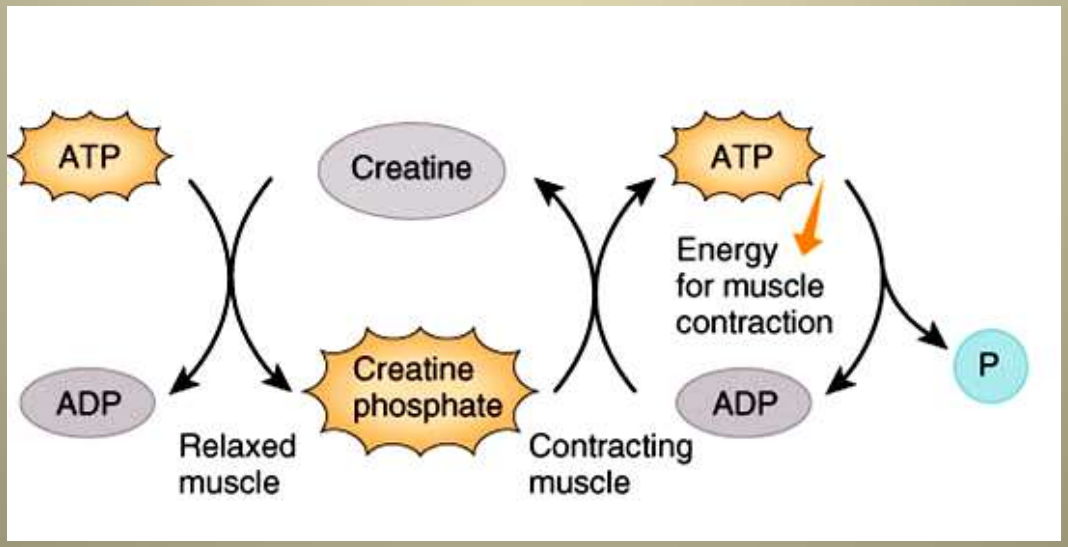
1. Arrival of nerve impulse at nerve terminal causes release of acetylcholine (ACh) from synaptic vesicles
2. ACh binds to receptors on muscle motor end plate opening the gated ion channels so that Na+ can rush into the muscle cell
3. Inside of muscle cell becomes more positive, triggering a muscle action potential that travels over the cell and down the T tubules
4. The release of Ca^{2+} from the SR is triggered and the muscle cell will shorten & generate force
5. **Acetylcholinesterase** breaks down the ACh attached to the receptors on the motor end plate so the muscle action potential will cease and the muscle cell will relax.

Muscle Metabolism
Production of ATP in Muscle Fibers

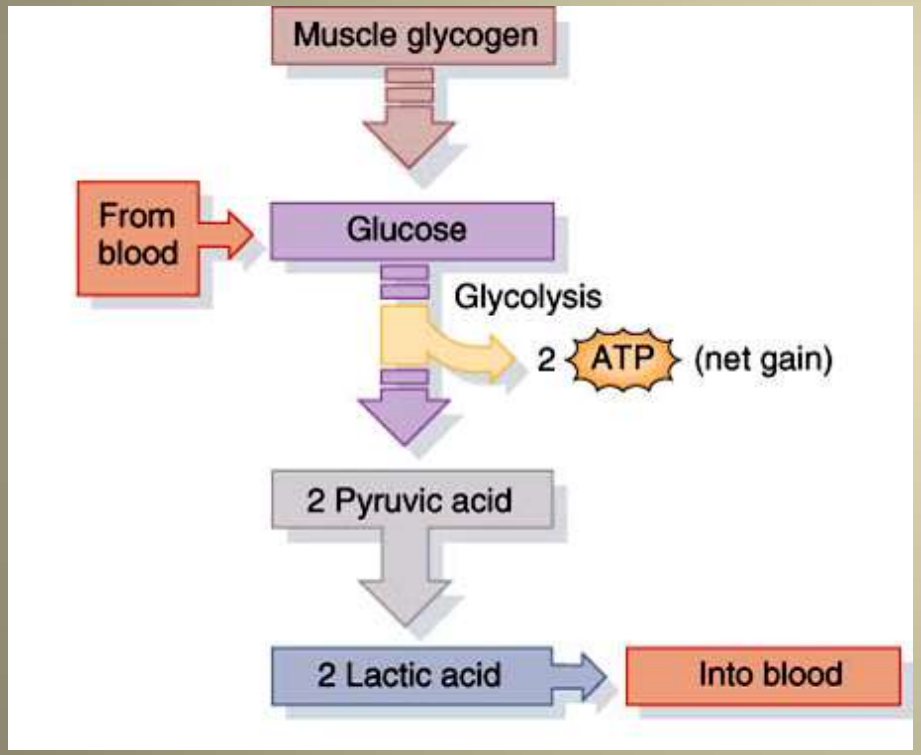
- Muscle uses ATP at a great rate when active
- Sarcoplasmic ATP only lasts for few seconds
- 3 sources of ATP production within muscle
  1. creatine phosphate
  2. anaerobic cellular respiration
  3. aerobic cellular respiration

Creatine Phosphate

- *Creatine phosphate* and ATP can power maximal muscle contraction for about 15 seconds and is used for maximal short bursts of energy (e.g., 100-meter dash)
  - Creatine phosphate is unique to muscle fibers.

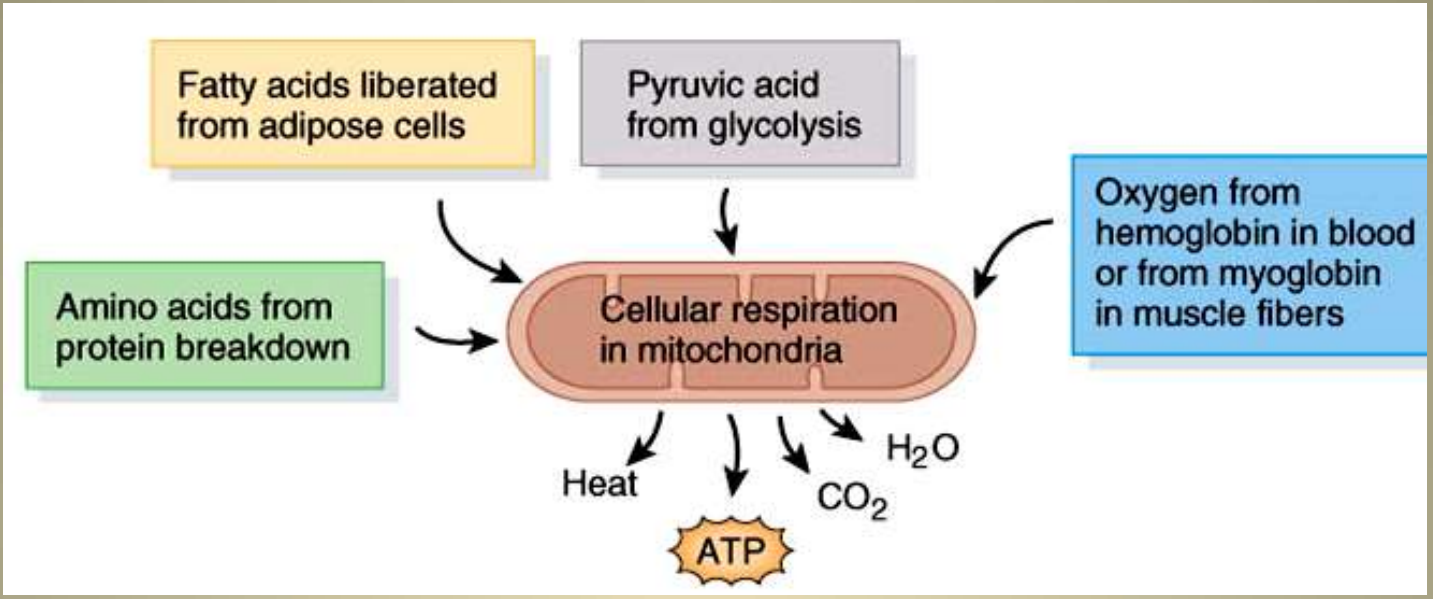


Anaerobic Cellular Respiration: Details



- Glycolysis can continue anaerobically to provide ATP for 30 to 40 seconds of maximal activity (200 meter race)

Aerobic Cellular Respiration



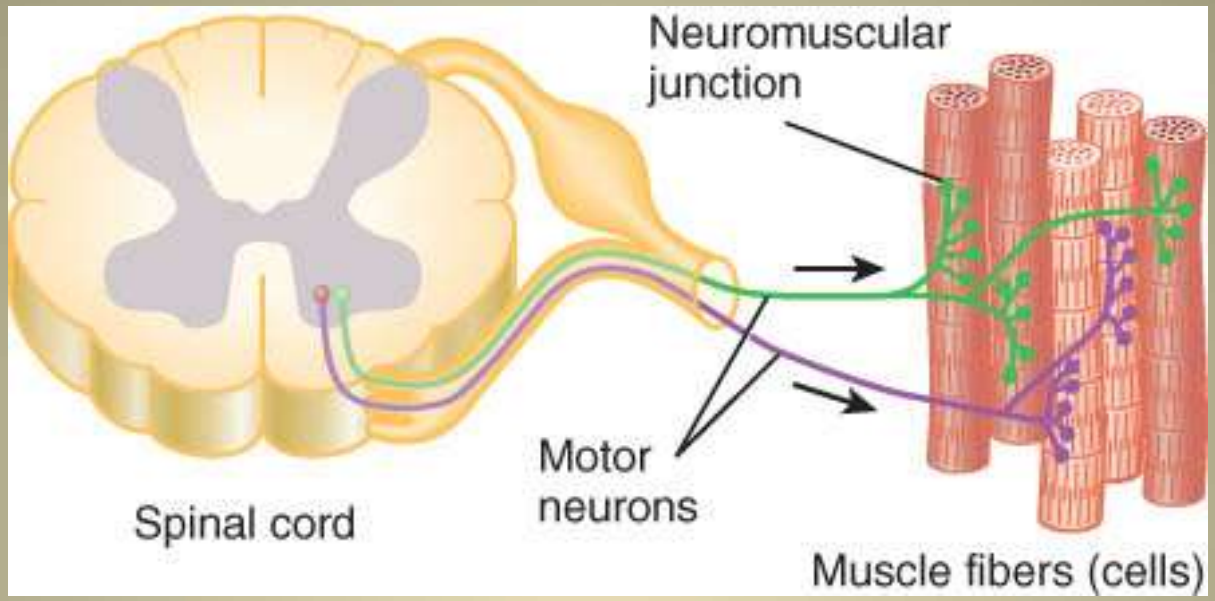
- Production begins after about 30 seconds
- Provides 90% of ATP energy if activity lasts more than 10 minutes
- Almost 100% after long periods of exercise

Muscle Fatigue

- Inability to contract after prolonged activity
- Factors that contribute to fatigue
  - central fatigue is feeling of tiredness and a desire to stop (protective mechanism)
  - insufficient release of acetylcholine from motor neurons
  - depletion of creatine phosphate
  - decline of Ca^{2+} within the sarcoplasm
  - insufficient oxygen or glycogen
  - buildup of lactic acid and ADP
  - heat

How do muscles work together and what kinds of contractions occur?

The Motor Unit



- **Motor unit** = one somatic motor neuron & all the skeletal muscle cells (fibers) it stimulates (10 cells to 2,000 cells)
  - muscle fibers normally scattered throughout belly of muscle
  - One nerve cell supplies on average 150 muscle cells that all contract in unison.

- Total strength of a contraction depends on how many motor units are activated & how large the motor units are

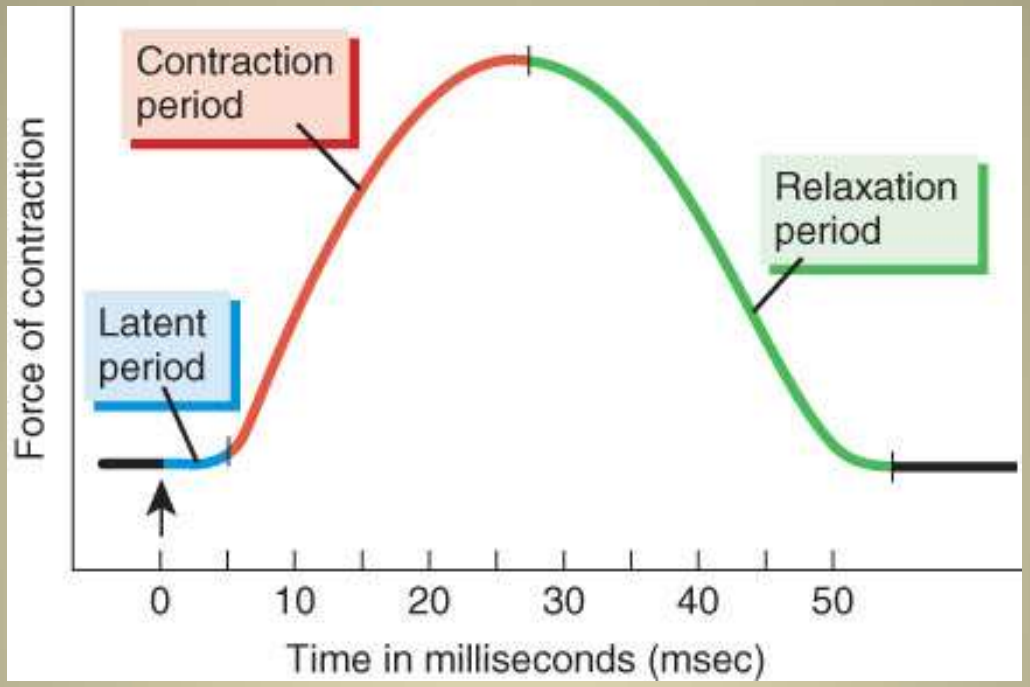
Motor Unit Recruitment

- Motor units in a whole muscle fire asynchronously
  - some fibers are active others are relaxed
  - delays muscle fatigue so contraction can be sustained
- Produces smooth muscular contraction
  - not series of jerky movements
- Precise movements require smaller contractions
  - motor units must be smaller (less fibers/nerve)
- Large motor units are active when large tension is needed

Muscle Tone

- Involuntary contraction of a small number of motor units (alternately active and inactive in a constantly shifting pattern)
  - keeps muscles firm even though relaxed
  - does not produce movement
- Essential for maintaining posture (head upright)
- Important in maintaining blood pressure
  - tone of smooth muscles in walls of blood vessels

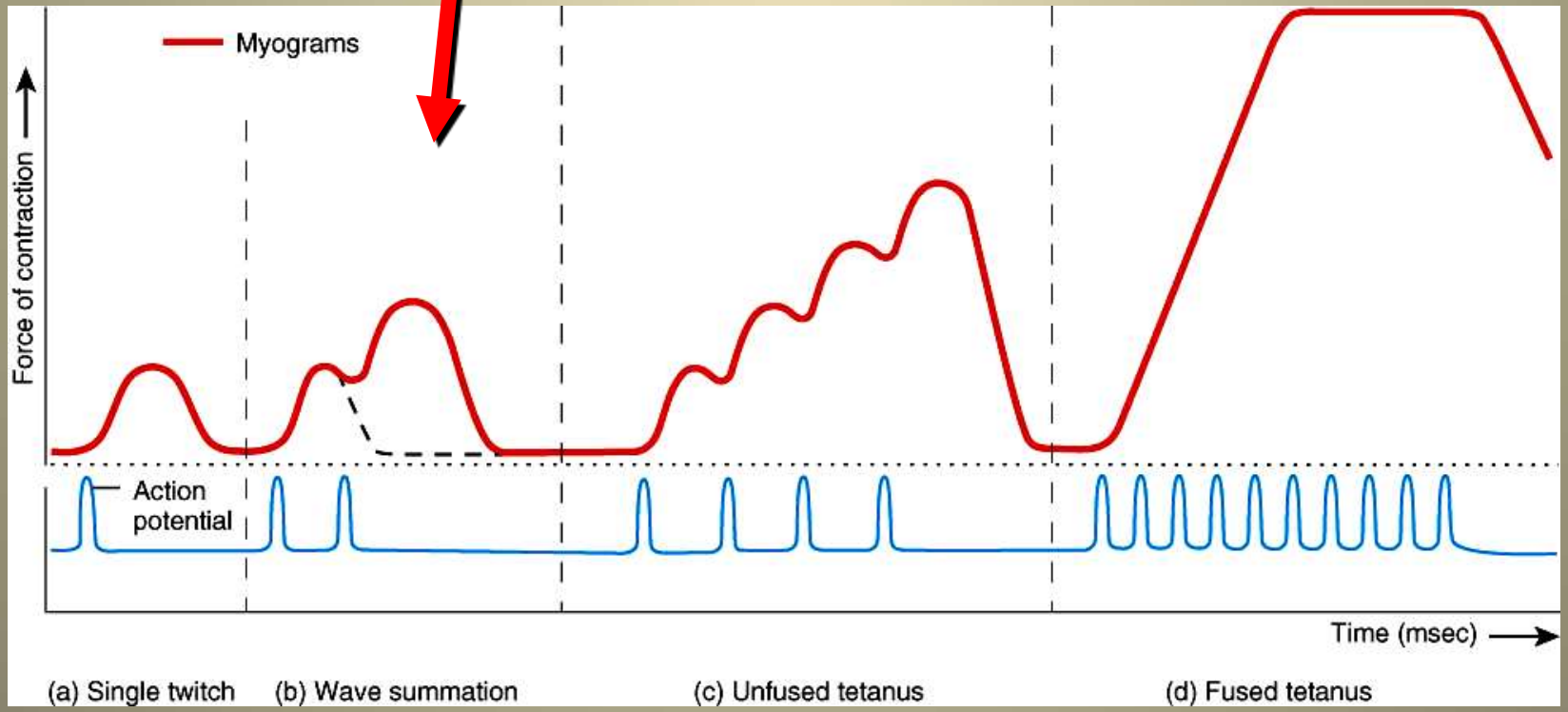
Twitch Contraction



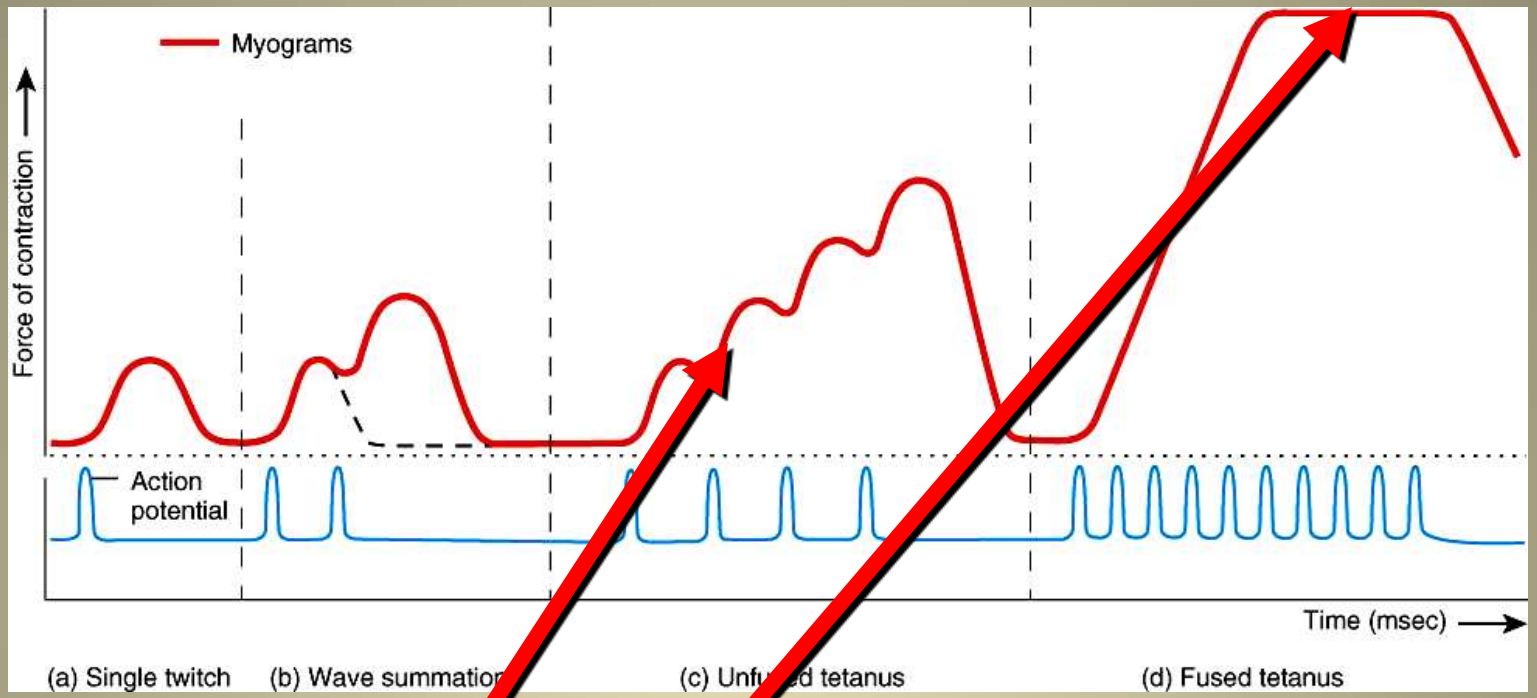
- Brief contraction of all fibers in a motor unit
- **Myogram** = graph of a twitch contraction
  - the action potential lasts 1-2 msec
  - the twitch contraction lasts from 20 to 200 msec

Wave Summation

- If second stimulation applied after the refractory period but before complete muscle relaxation---second contraction is stronger than first

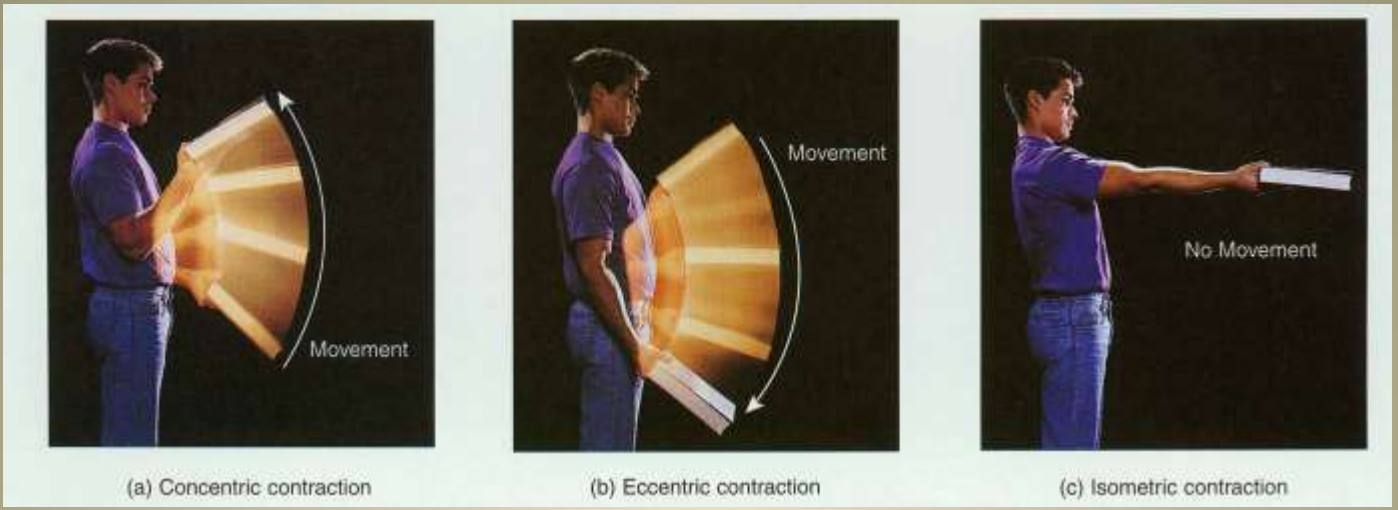


Complete and Incomplete Tetanus



- Unfused tetanus
  - if stimulate at 20-30 times/second, there will be only partial relaxation between stimuli
- Fused tetanus

Isotonic and Isometric Contraction



- Isotonic contractions = a load is moved
  - concentric contraction = a muscle shortens to produce force and movement
  - eccentric contractions = a muscle lengthens while maintaining force and movement
- Isometric contraction = no movement occurs
  - tension is generated without muscle shortening
  - maintaining posture & supports objects in a fixed position