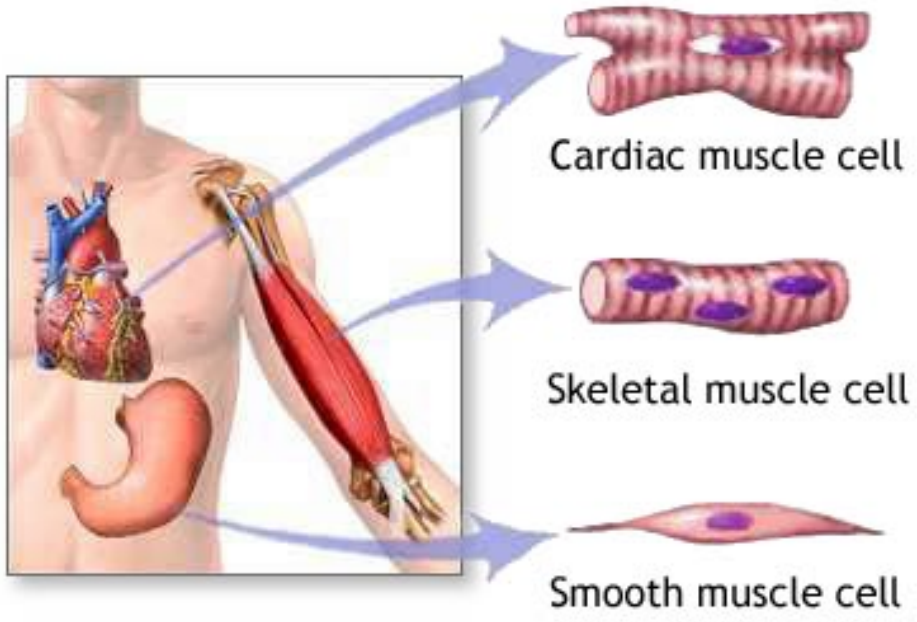
Muscles and Animal Movement

Evolution of Muscle and Movement

- Animals are the only multicellular organisms that actively move.
- Movement is due to muscle cells (motor proteins)
- Muscle proteins have homologues in other eukaryotes (eg. Dynein, Kinesin)
- First muscle-like cells in Cnidarians (e.g. Hydra)
- Muscle complexity has increased with more recent and larger animals
- Vertebrates have the greatest diversity in muscle types (especially terrestrials vertebrates)

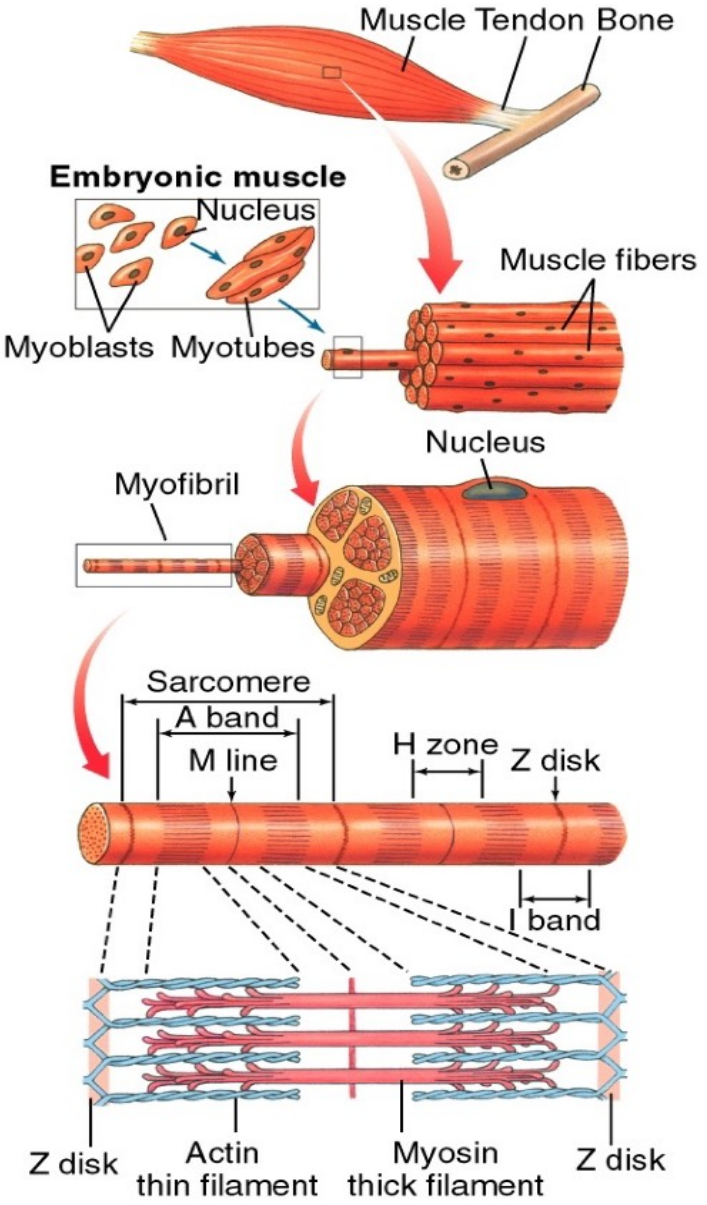
2 types of vertebrate muscle

- Striated
  - Skeletal (movements)
  - Cardiac (heart)
- Smooth (blood vessels, intestines, etc.)
- Use very similar contraction mechanisms



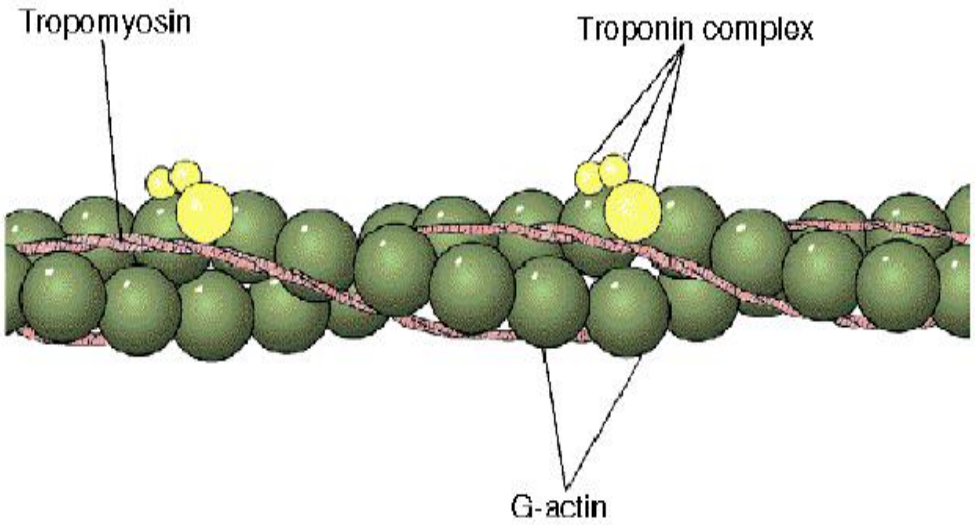
Skeletal Muscle Structure/Organization

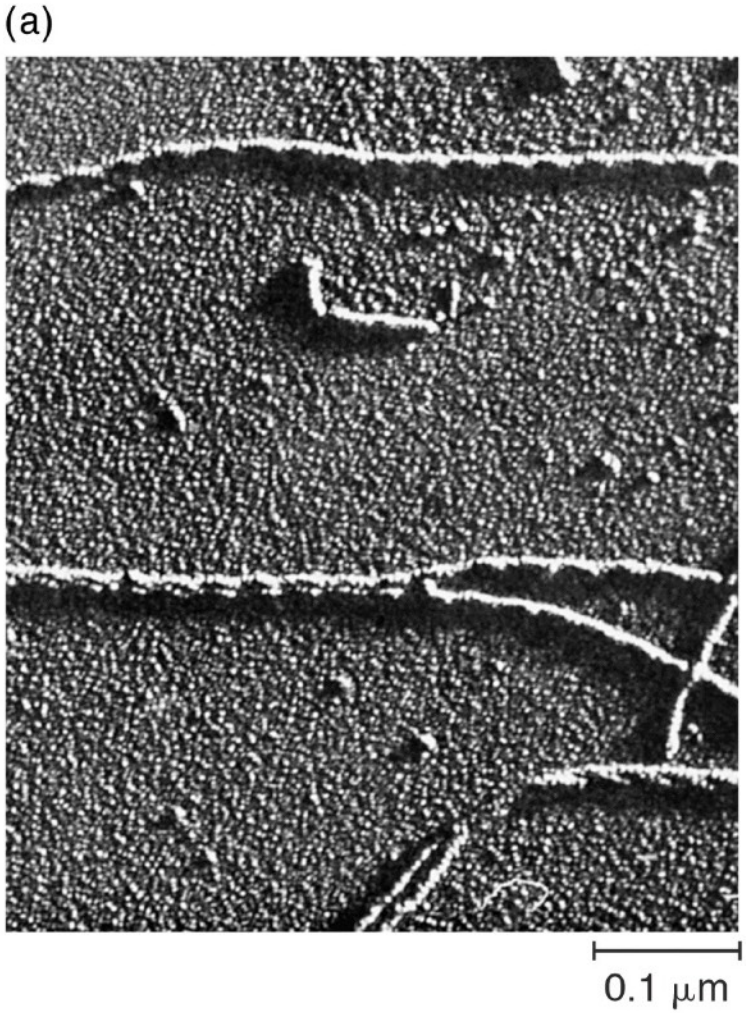
- Muscle Fibers
  - Long, cylindrical, multinucleate
- Myofibrils
  - Sarcomeres
- Sarcomere
  - The functional unit of striated muscle
  - Made up of myofilaments
    - Thin filaments (actin)
    - Thick filaments (myosin)
    - Structural proteins (titin & nebulin)



Actin (thin filament)

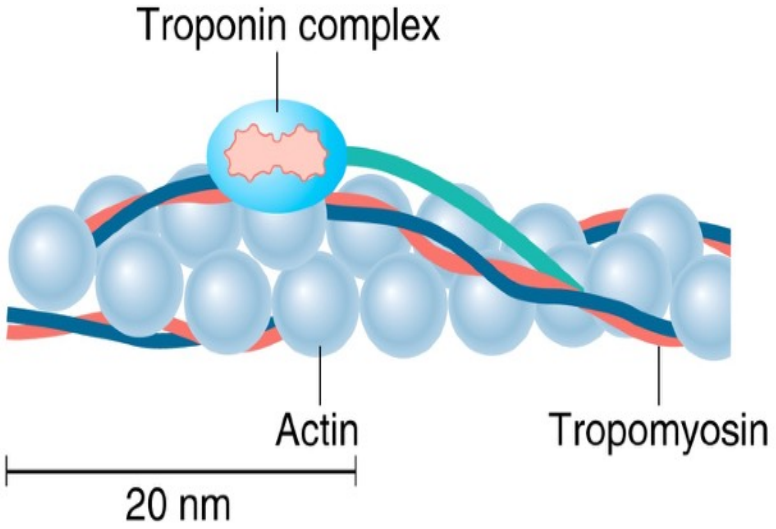
Helical protein



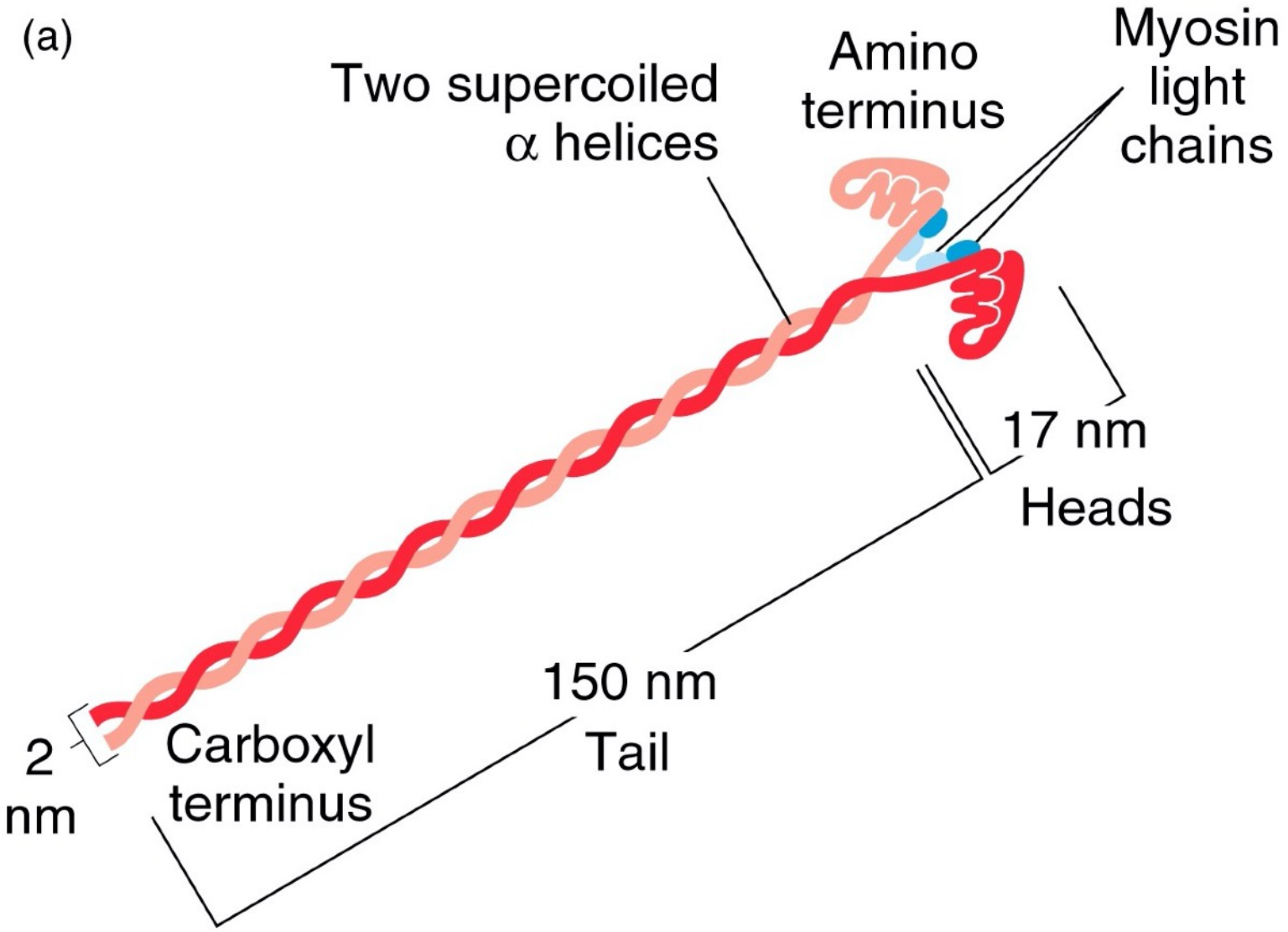


Troponin & Tropomyosin

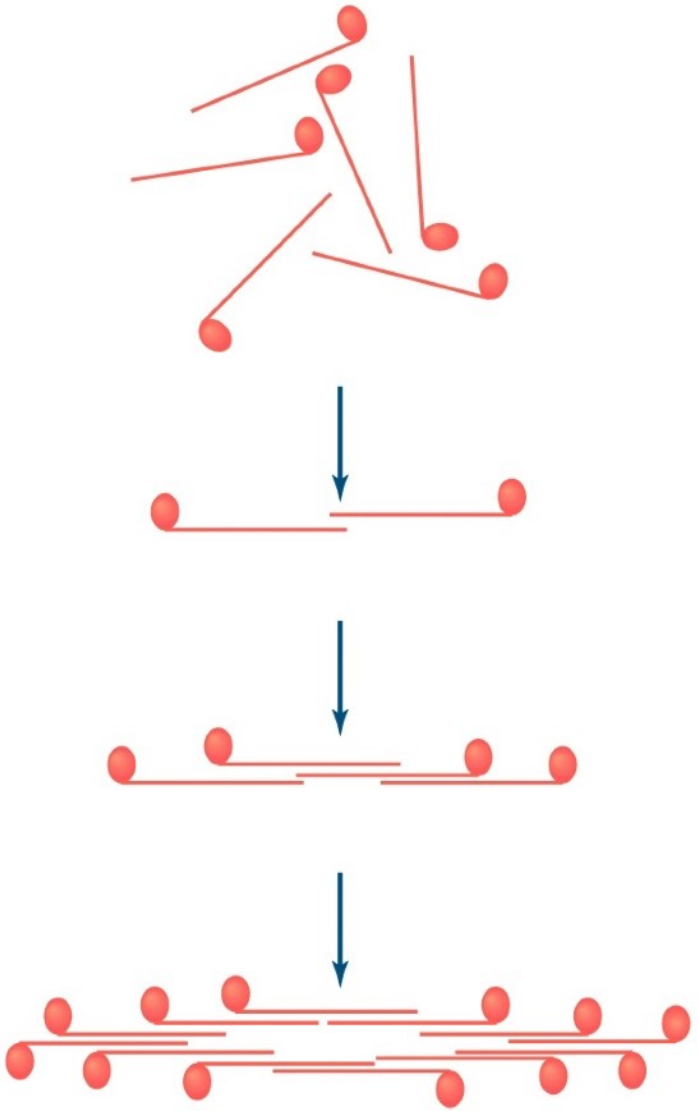
- Tropomyosin
  - (filamentous protein)
- Troponin Complex (3 protein subunits)
  - TnC - binds to Ca2+
  - TnT - binds to tropomyosin
  - TnI - binds to actin and TnC



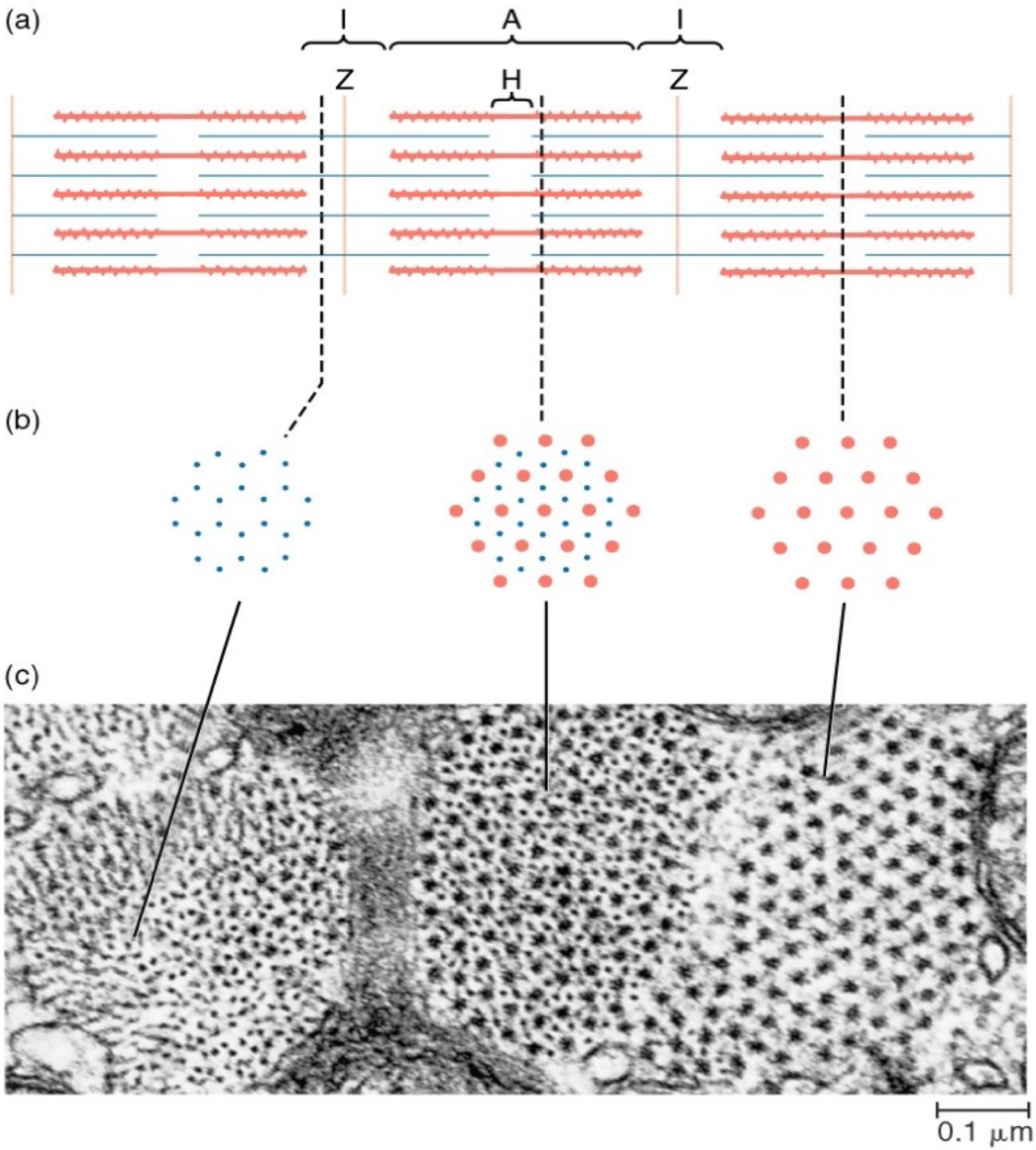
Myosin


(a)
Two supercoiled
α helices
Amino
terminus
Myosin
light
chains
17 nm
Heads
150 nm
Tail
2
nm
Carboxyl
terminus

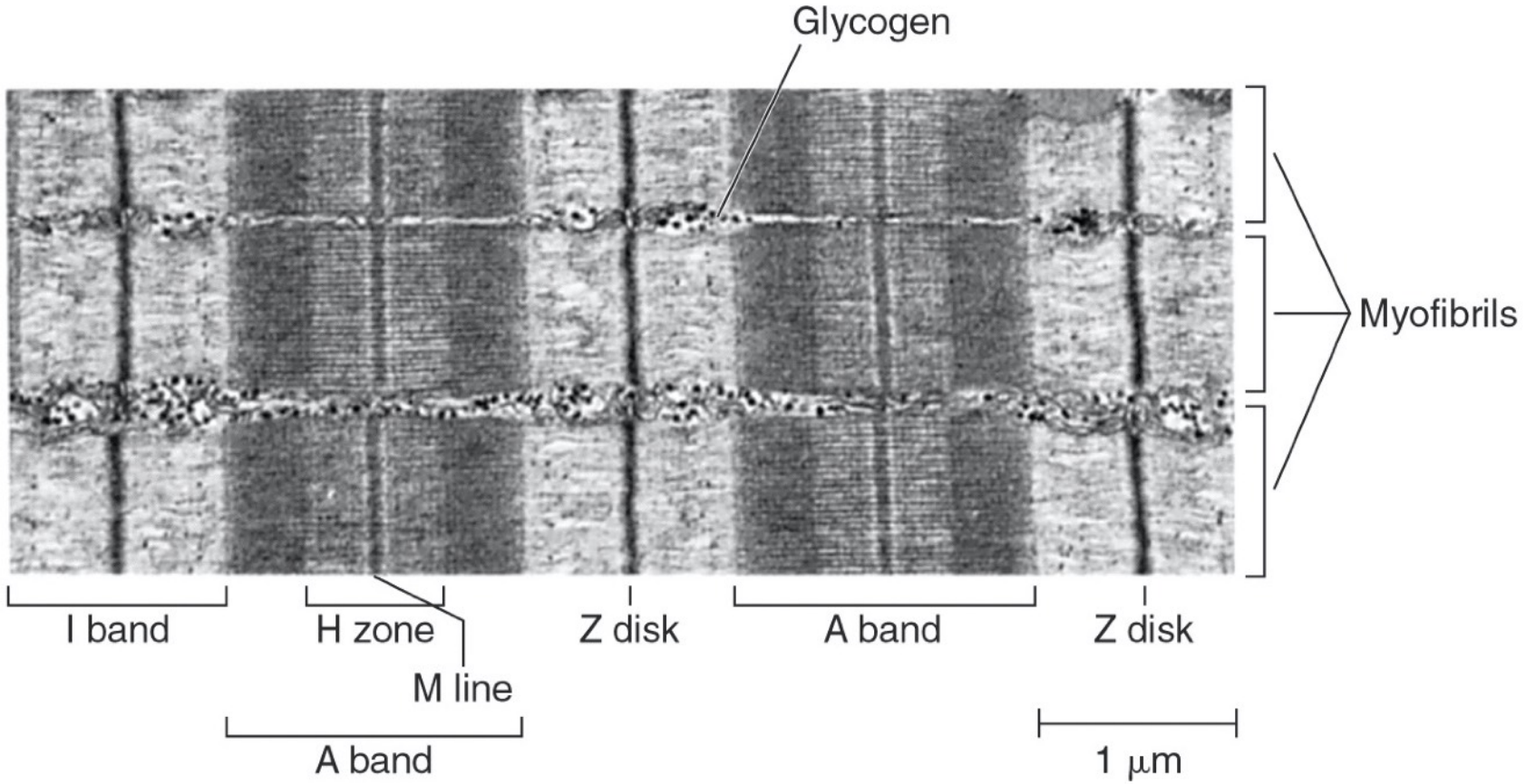
Thick filament structure



Sarcomeres

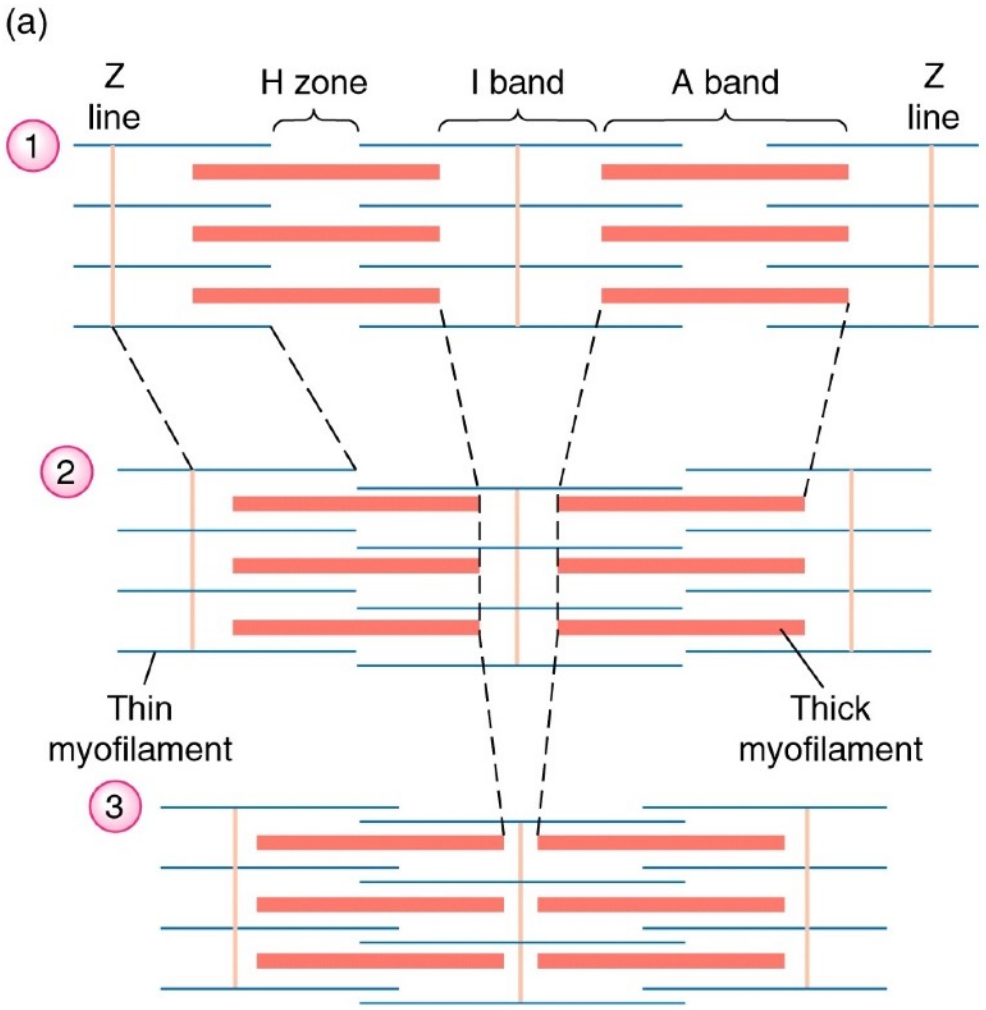


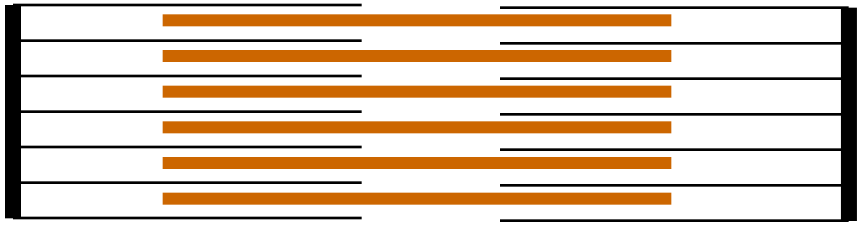
Sarcomeres

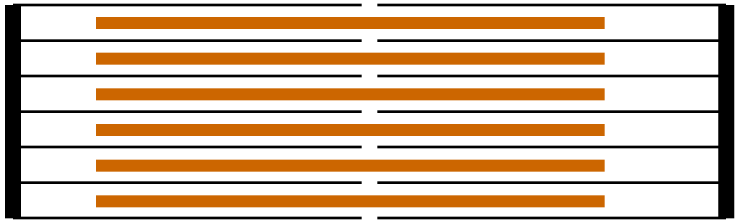

Glycogen
Myofibrils
I band
H zone
Z disk
A band
Z disk
M line
A band
1 μm

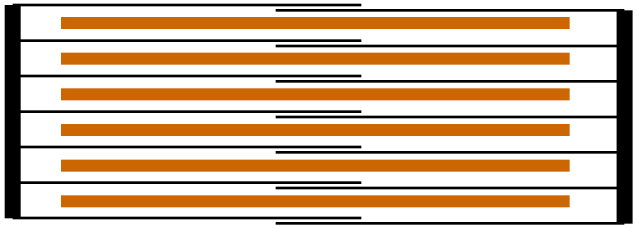
How do Sarcomeres (Muscles) Shorten?

- Sliding-Filament Theory
  - Pulling a rope
    - Actin = rope
    - Myosin = your arm

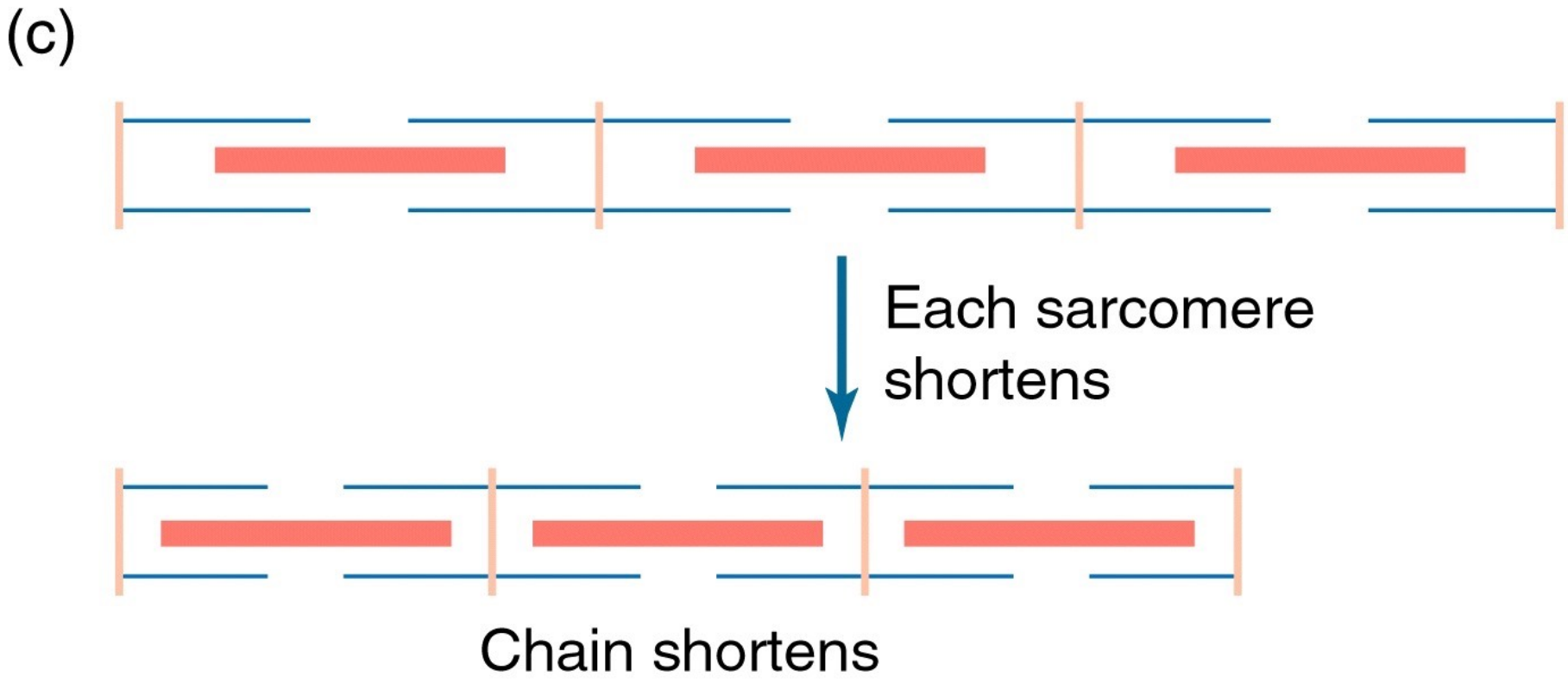






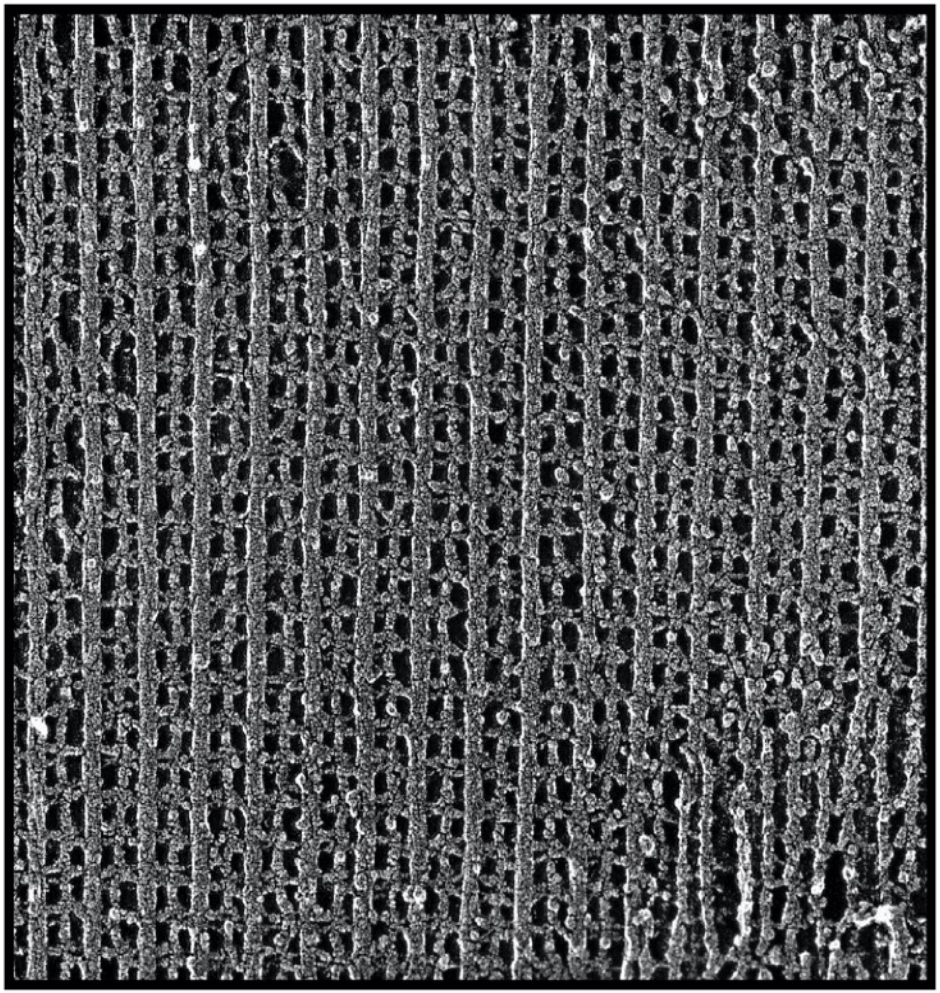


Sliding-Filaments Continued



How do the filaments slide?

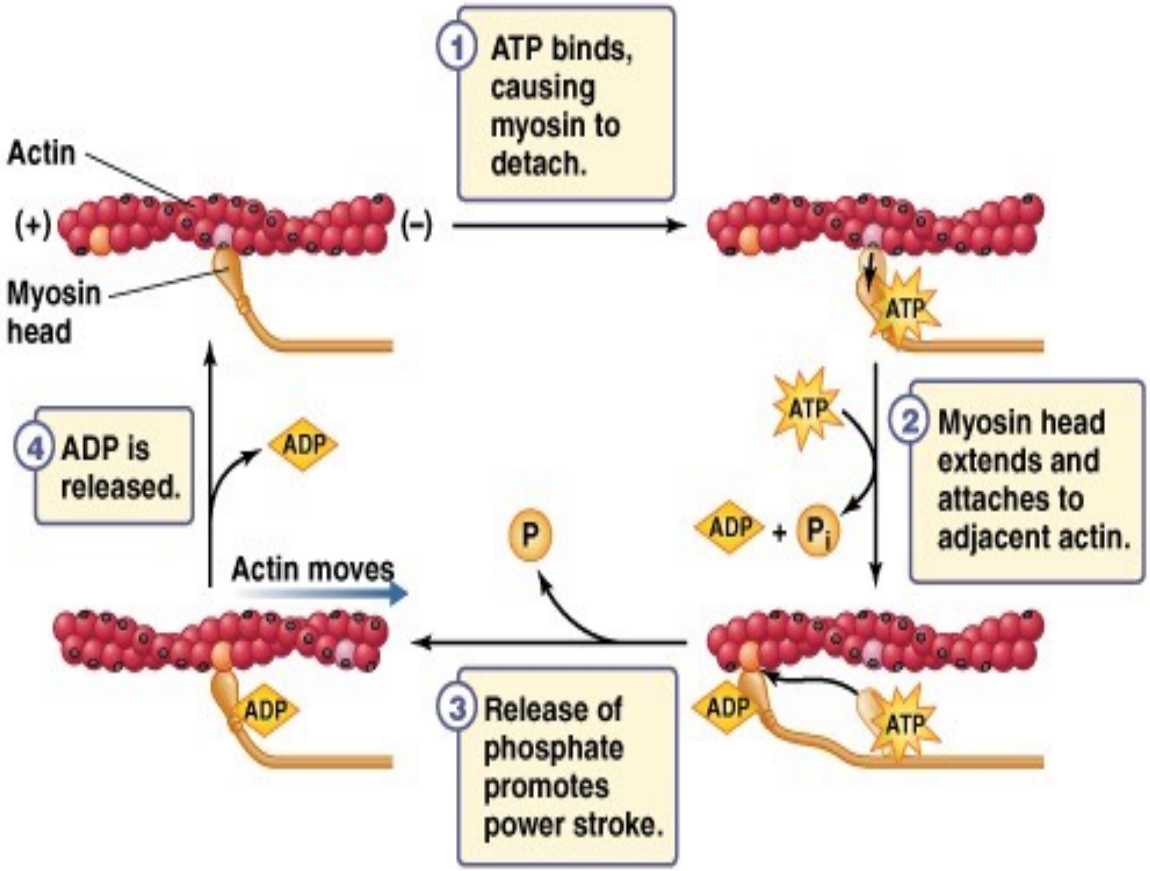
- Cross-bridge cycle!
- Cross-bridge
  - Projection from myosin thick filament that binds on actin thin filaments
- 3 steps
  - Formation of cross-bridge
  - power stroke
  - release
- Main players
  - Actin, myosin, & ATP



Cross-Bridge Cycle

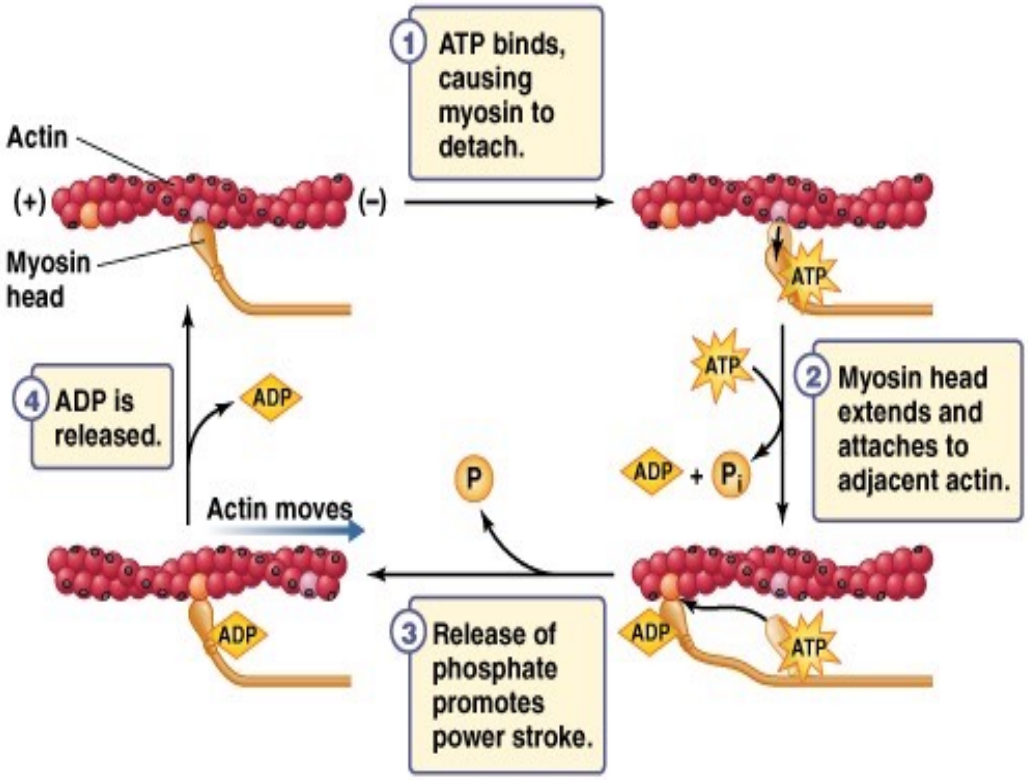
Two processes

- Chemical
  - Myosin binds to actin (*Cross-bridge*)
- Structural
  - Myosin bends (*Power stroke*)
- Need ATP to release and attach in a cycle.



Cross-bridge cycle continued

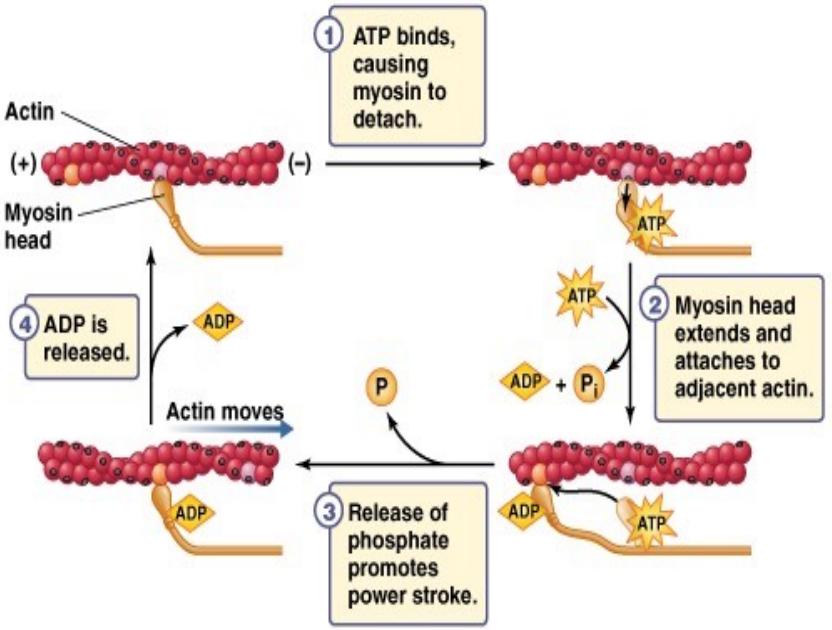
- ATP breaks bond b/t actin & myosin
- Myosin head extends, hydrolizes ATP to ADP+Pi (but slowly), & attaches to actin.
- Energy released is used to generate force.
- Once attached, Pi is released which:
  - Bond b/t actin & myosin strengthened
  - Energy is released
- ADP is removed from myosin & replaced by ATP



Force production & Movement

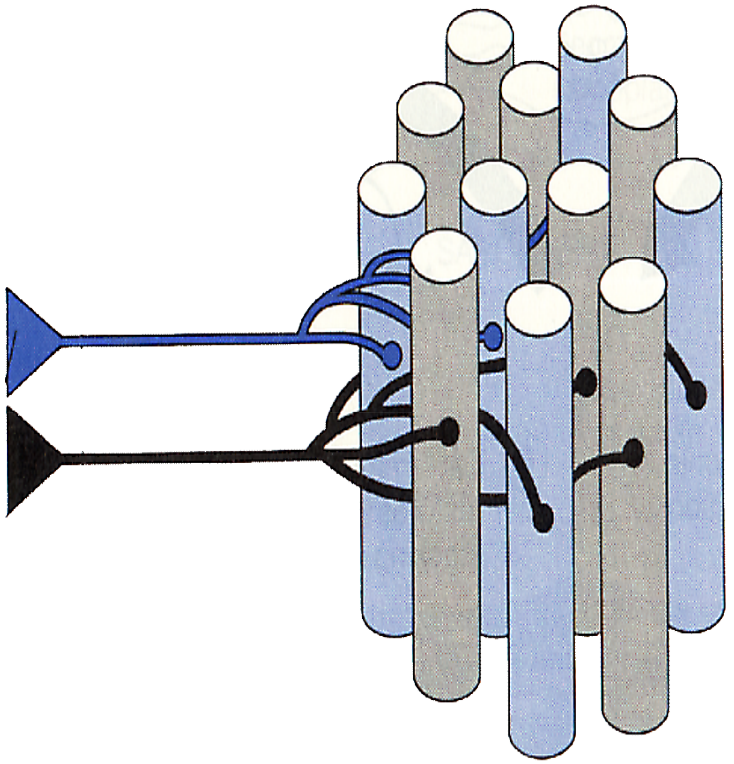
- Cross-bridges
  - Develop force
- Power stroke
  - Produces movement
- ***Force*** $\propto$ # of Cross-bridges in parallel

  $\propto$ cross-sectional area
- ***Velocity*** $\propto$ # of Sarcomeres in series

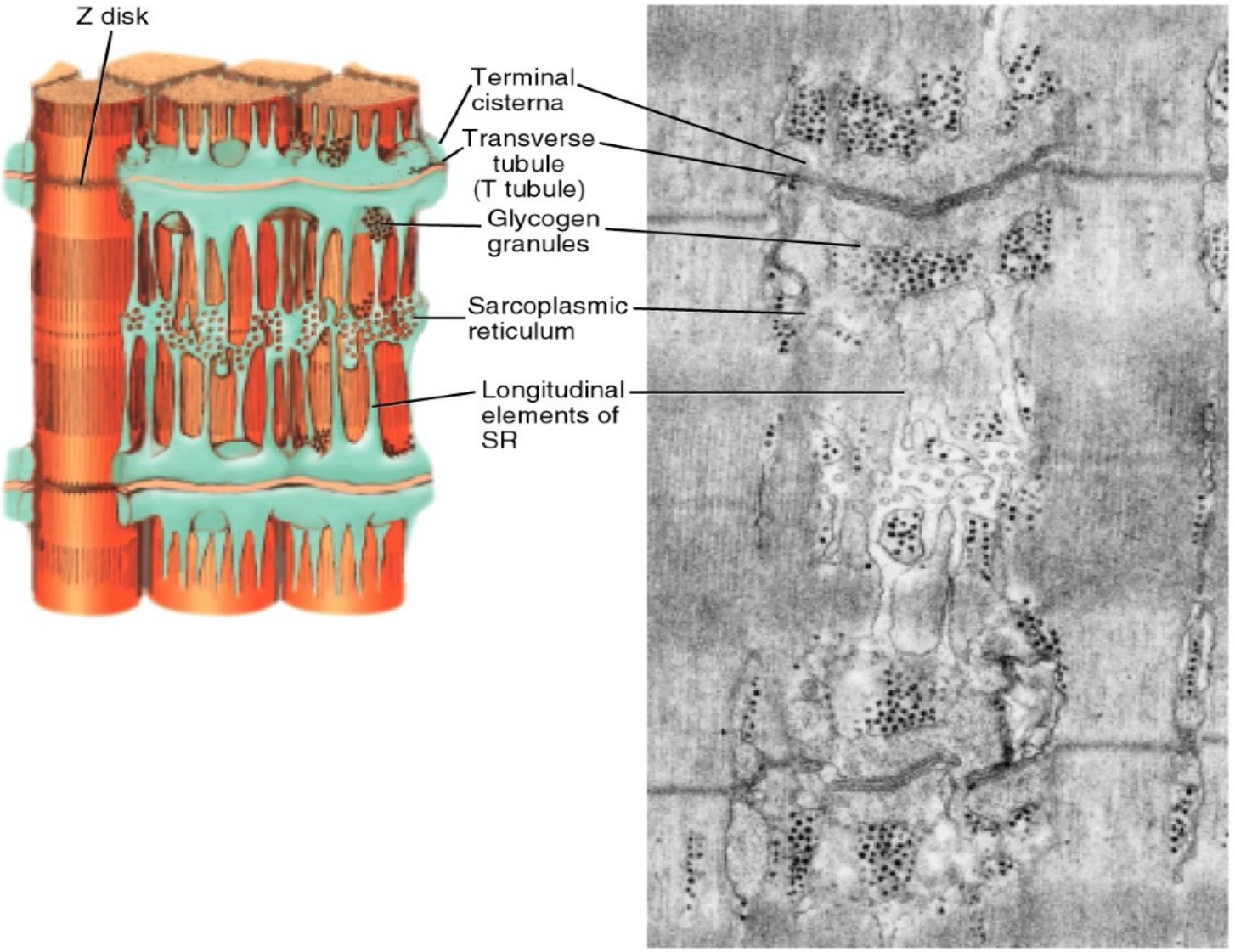


How do you get a muscle contraction?

- Excitation Contraction Coupling
  - Muscles are activated by motor neurons.
  - Motorneurons, motorendplates & motor pool.
- Inward flow of depolarization conducted through transverse-tubule system (T tubules)



T tubules


Z disk
Terminal cisterna
Transverse tubule (T tubule)
Glycogen granules
Sarcoplasmic reticulum
Longitudinal elements of SR

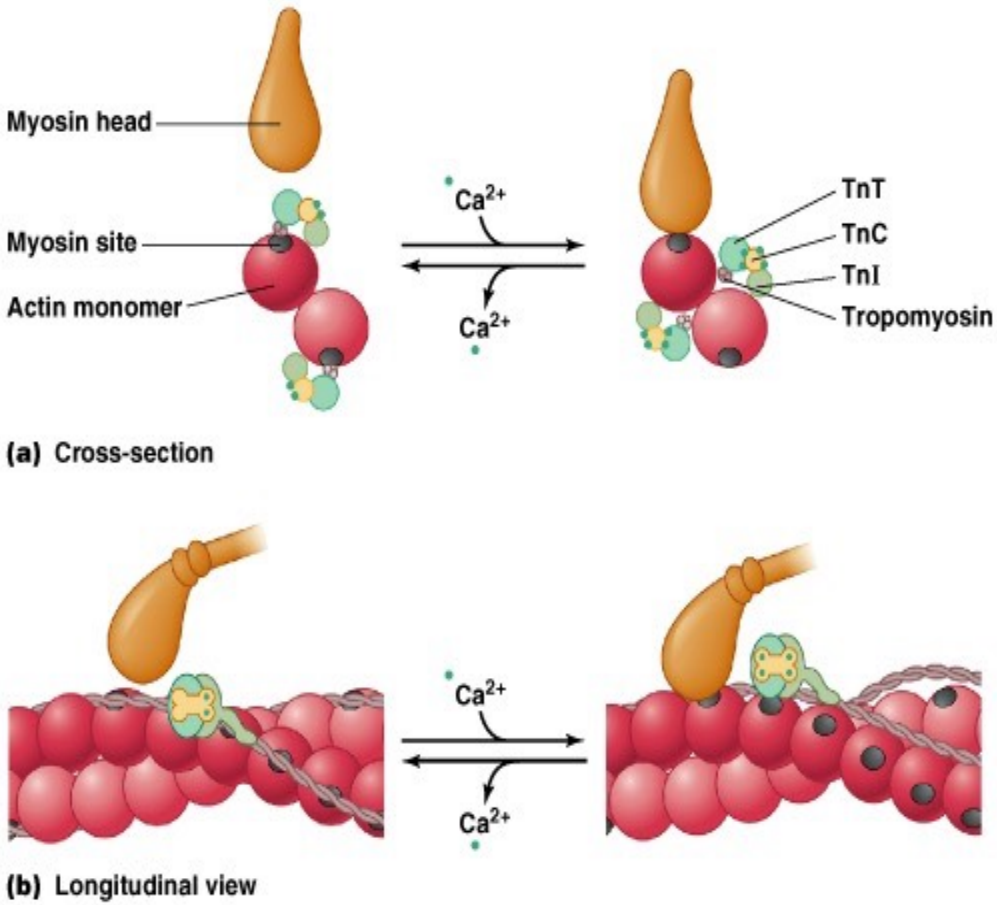
Depolarization of muscle fibers & action potential triggers release of Ca^{2+}

- Why is Ca^{2+} important for muscle contractions?
  - Troponin & Tropomyosin block the Myosin binding site!
    - This is why muscles don't always contract in the presence of ATP.
  - The presence of calcium moves troponin & tropomyosin

How Does Ca^{2+} Allow for Contractions?

1. Ca^{2+} binds to troponin (*TnC)*
2. Reorganization of *troponin-tropomyosin*
3. Expose myosin-binding site on actin

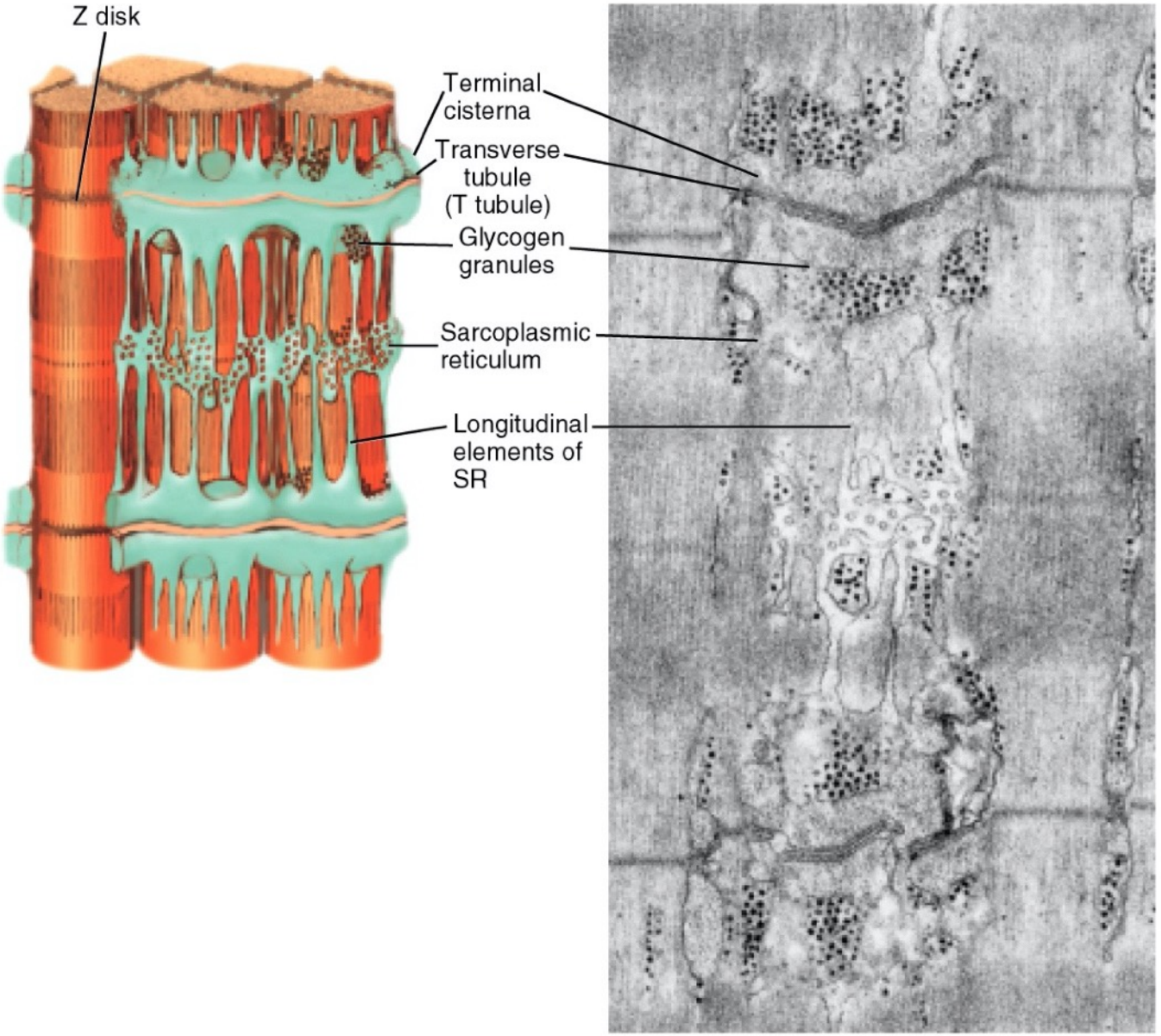
(No contraction without Ca^{2+})



Calcium is Regulated by the Sarcoplasmic Reticulum

- Sarcoplasmic Reticulum (SR) Functions:
  - Actively uptakes Ca^{2+} from surrounding medium.
  - Sequesters Ca^{2+} to keep Ca^{2+} concentration low during resting (using Ca^{2+}/Mg^{2+} pumps).
  - Action potential along muscle triggers SR to release of Ca^{2+}

Sarcoplasmic Reticulum



Summary of Muscle Activation & Contraction

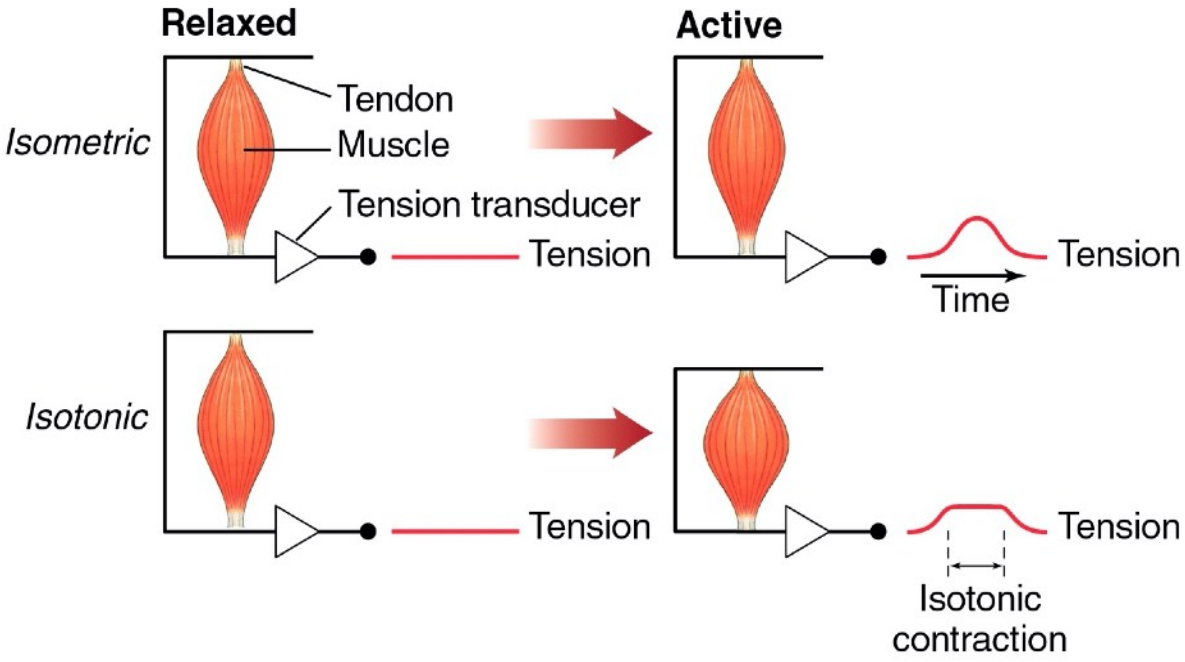
- Motor neuron stimulates muscle.
  - AP travels down T tubules
- Depolarization of membrane triggers release of Ca^{2+} from SR.
- Ca^{2+} binds to troponin.
  - Troponin & tropomyosin reorganize to expose myosin binding site on actin

Summary continued

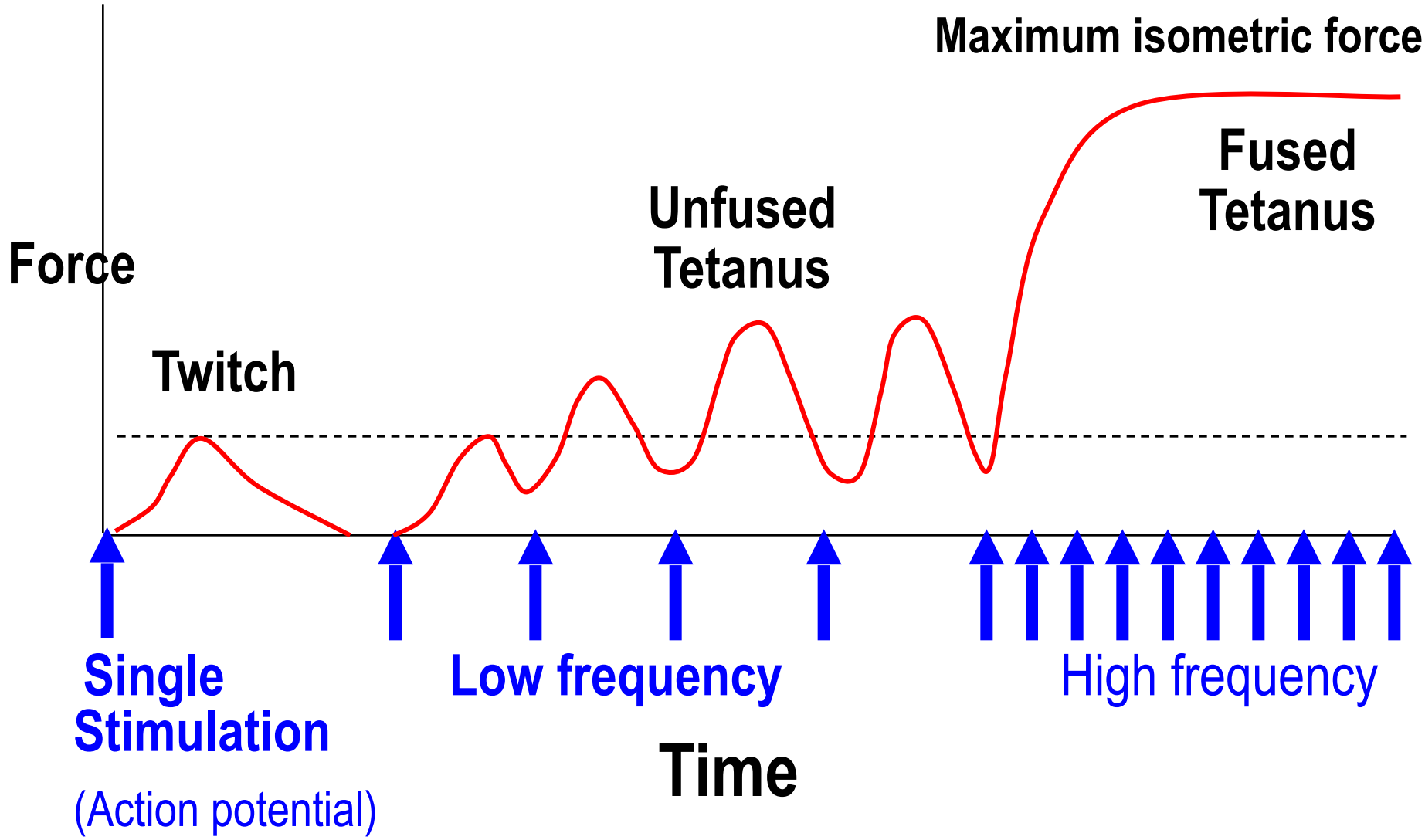
- Breakdown of ATP allows myosin head to attach & detach from actin (cross-bridge cycle).
  - When cross bridges form (and energy is released), force is developed
- Myosin (thick filament) pull along actin (thin filament) and Sarcomere shortens (sliding filament theory).
- Sarcomeres shorten and muscle shortens pulling on elastic or skeletal elements resulting in movement.

Function of Muscles is to Produce Force/ Movement

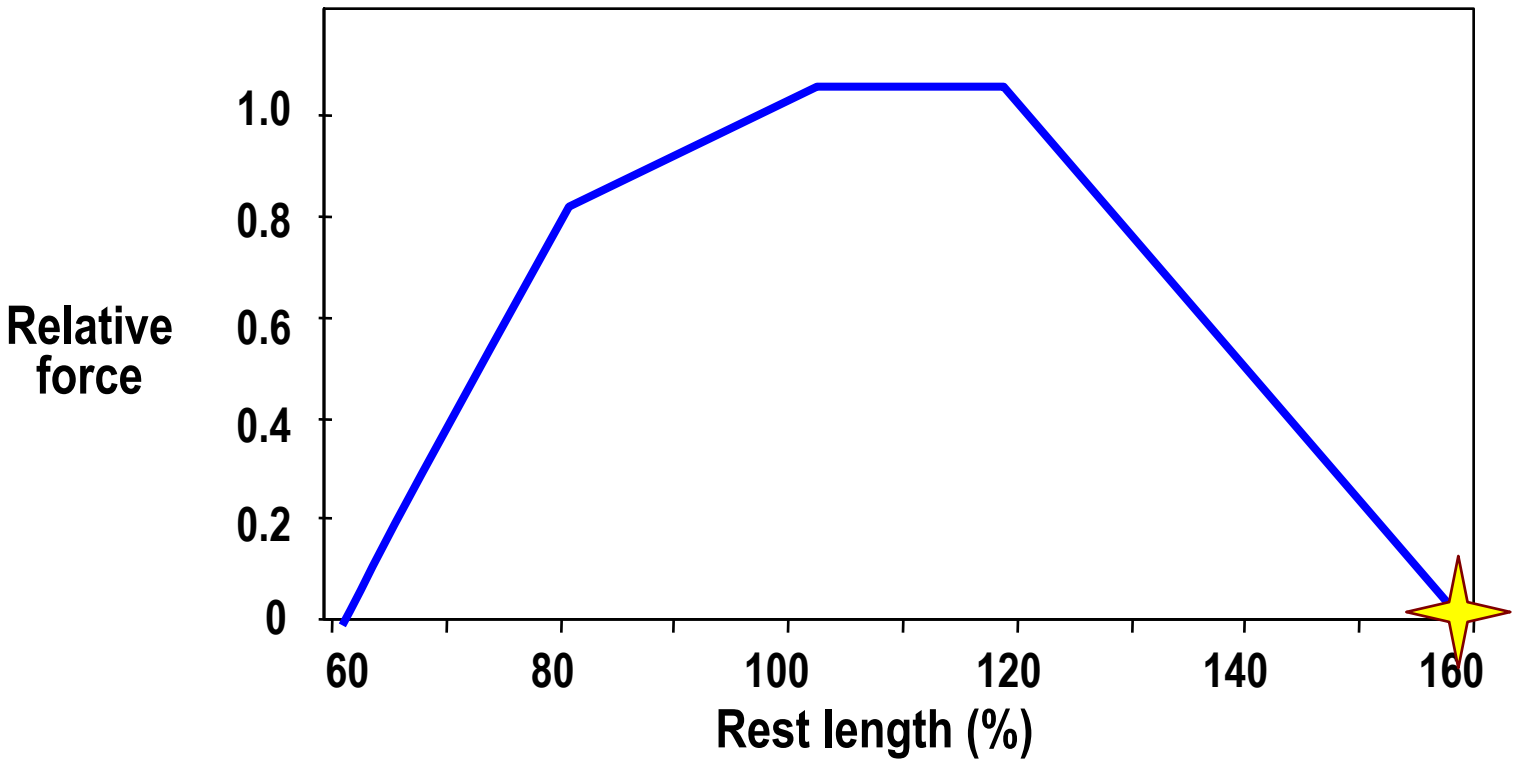
- Important Factors in force development
  - Summation
  - Length of Sarcomeres
  - Velocity of shortening
- Work (produces movement)
  - Isometric
  - Isotonic
- Force & velocity (and thus, Power) of contraction is important for movement

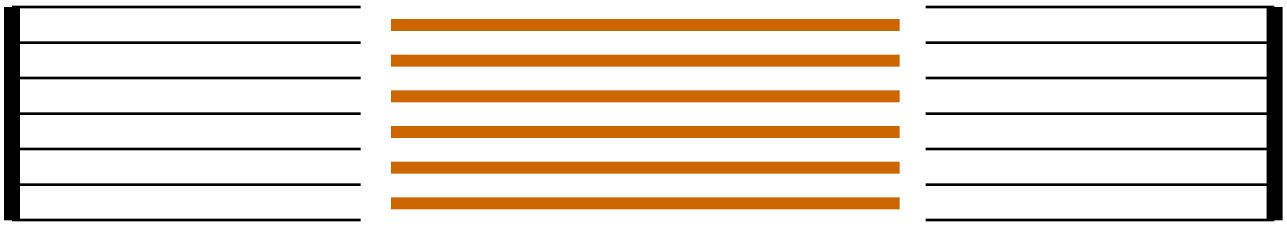


Activation & Summation

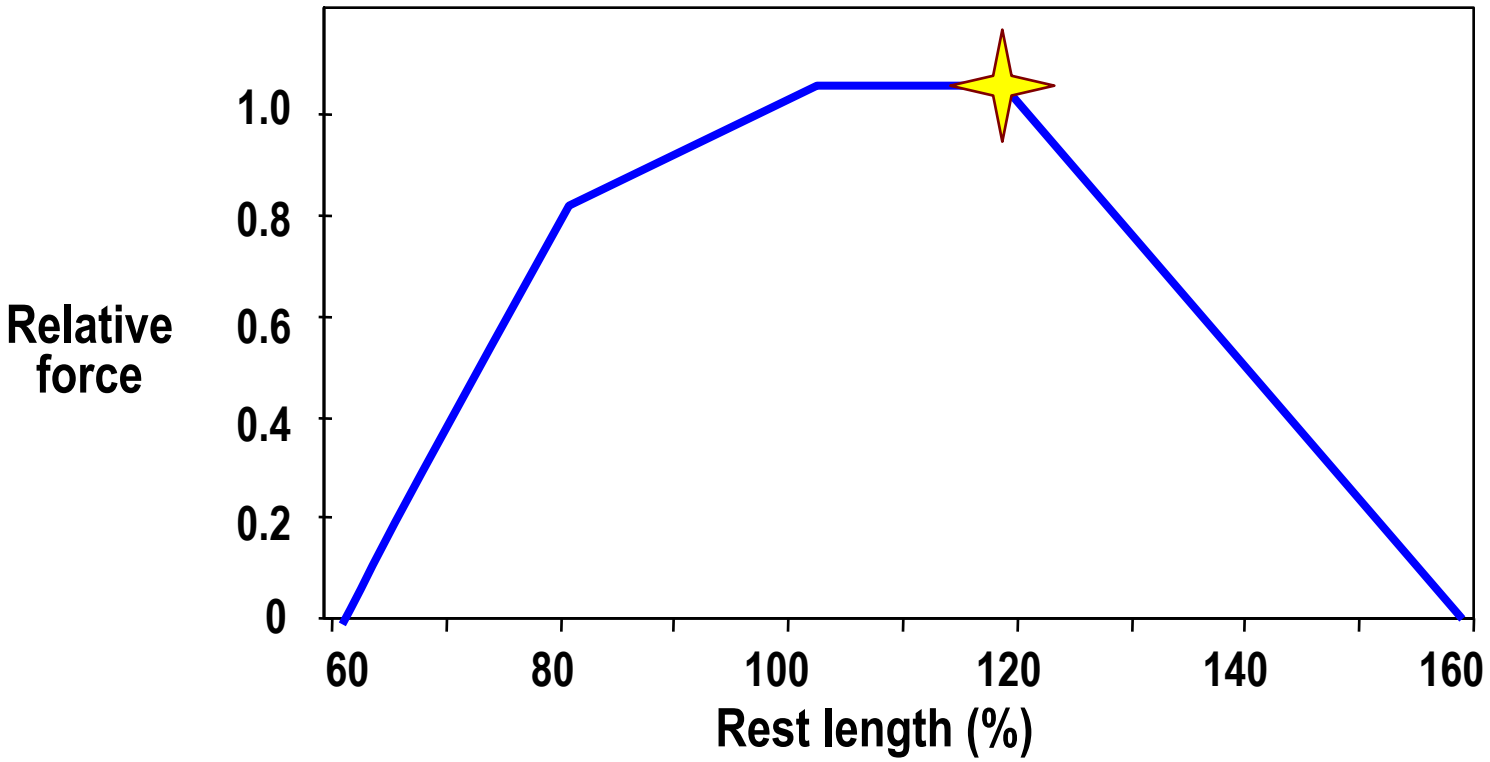


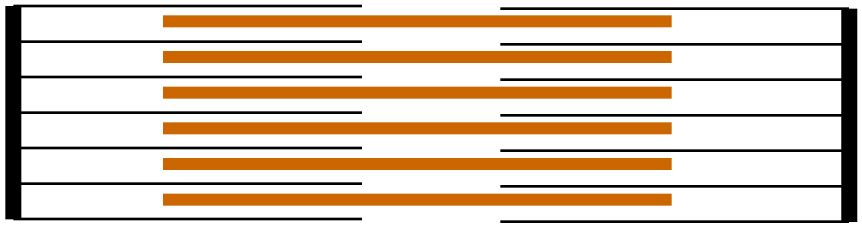
Length Effects Force (Length-tension curves)



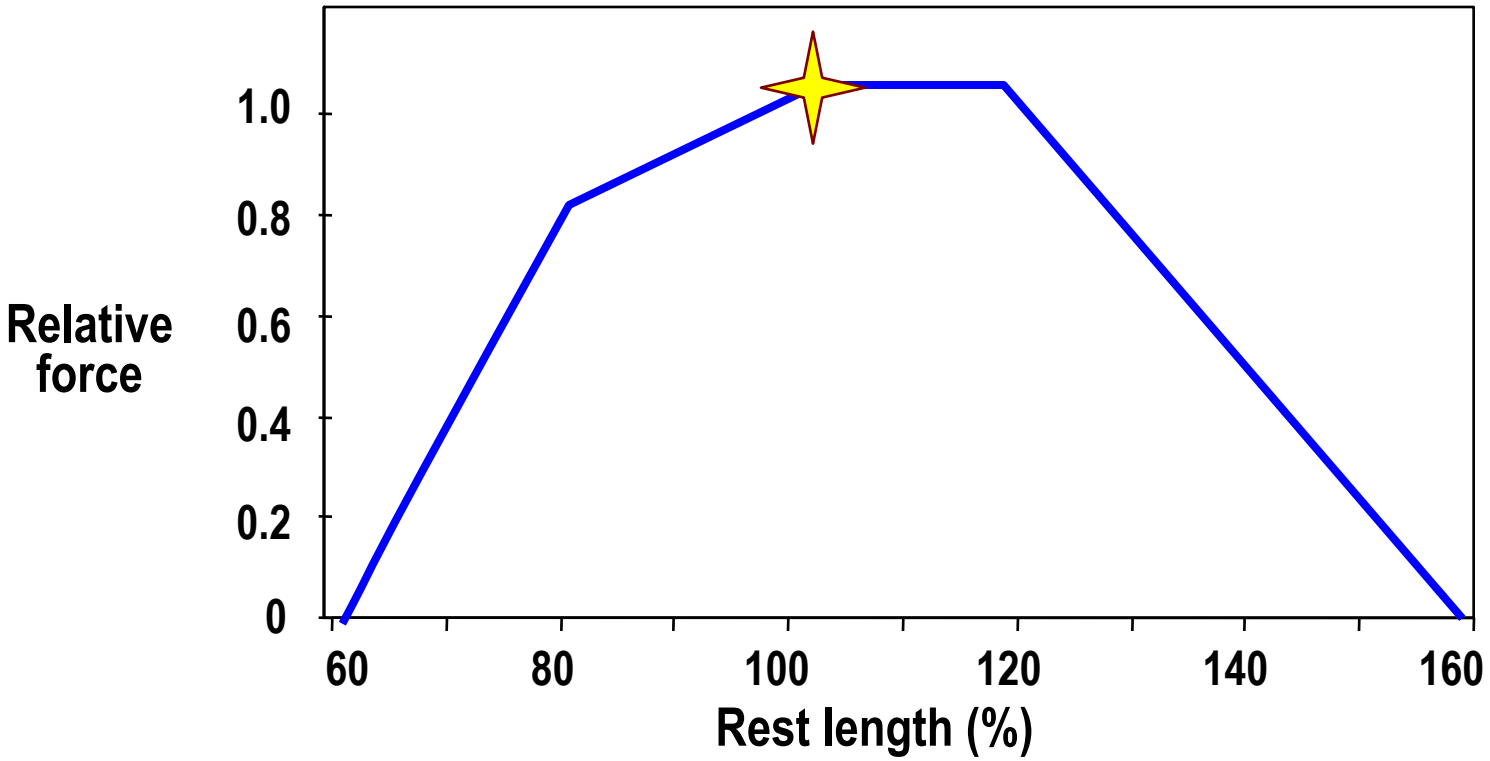


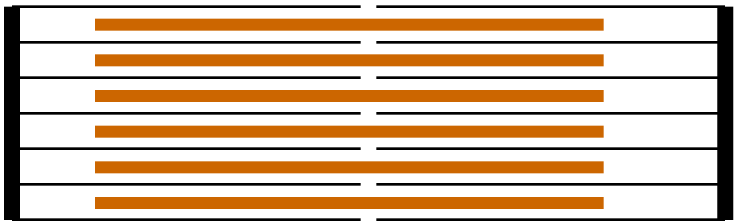
Length-tension curves continued



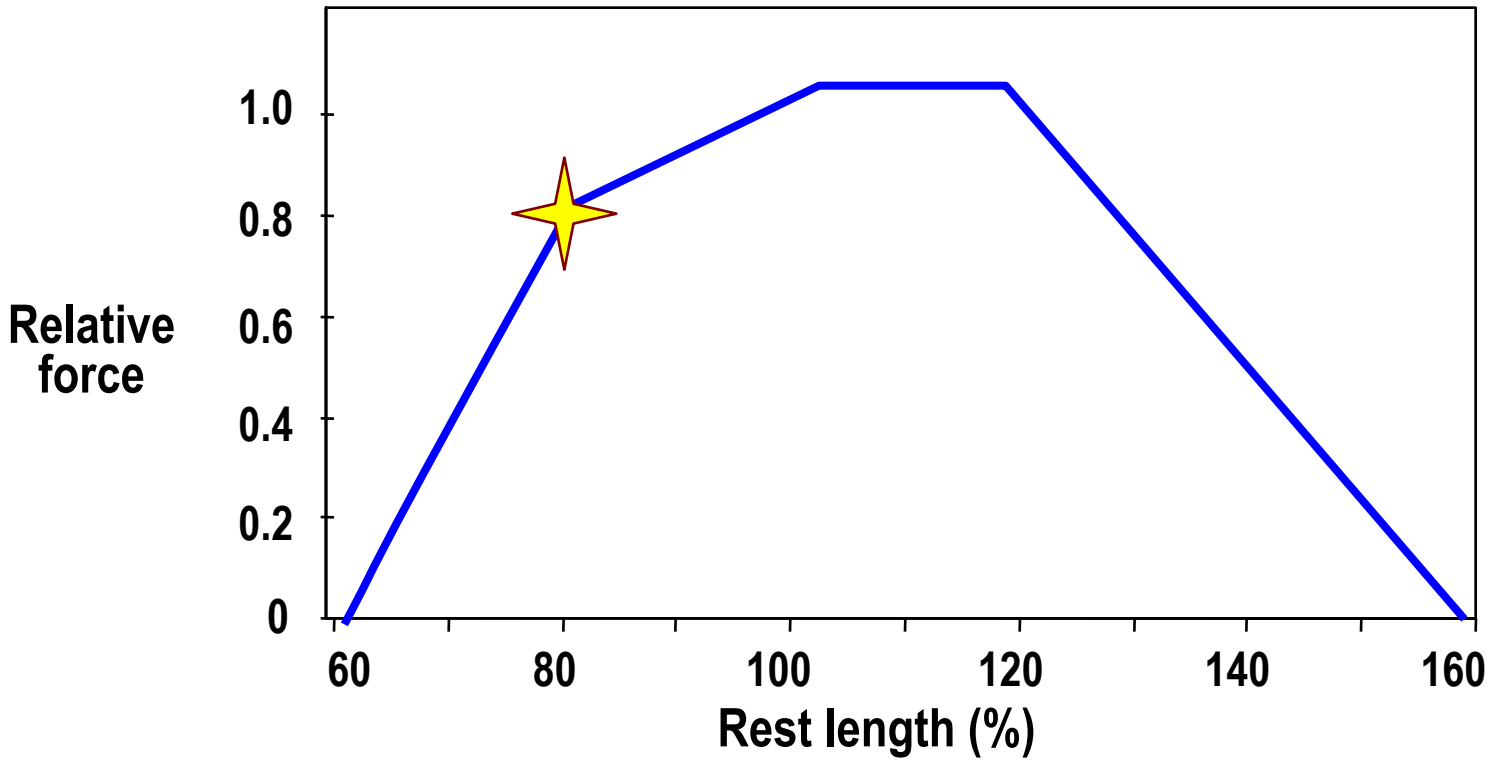


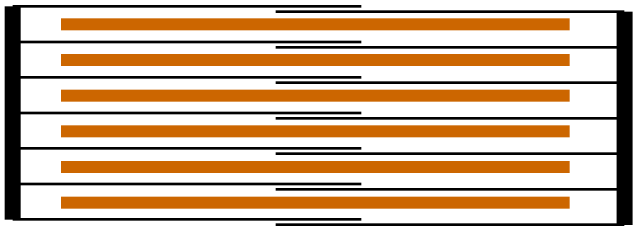
Length-tension curves continued



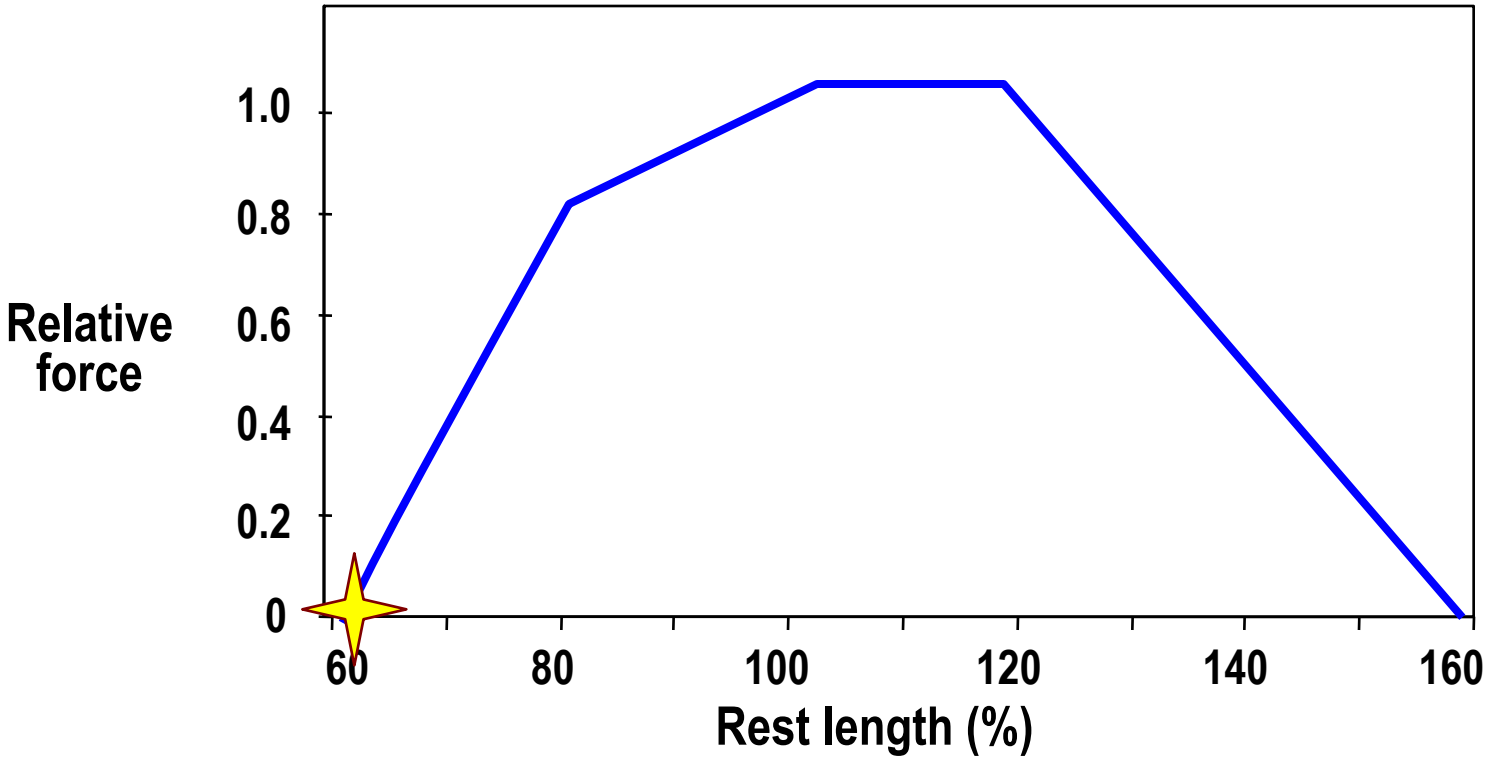


Length-tension curves continued

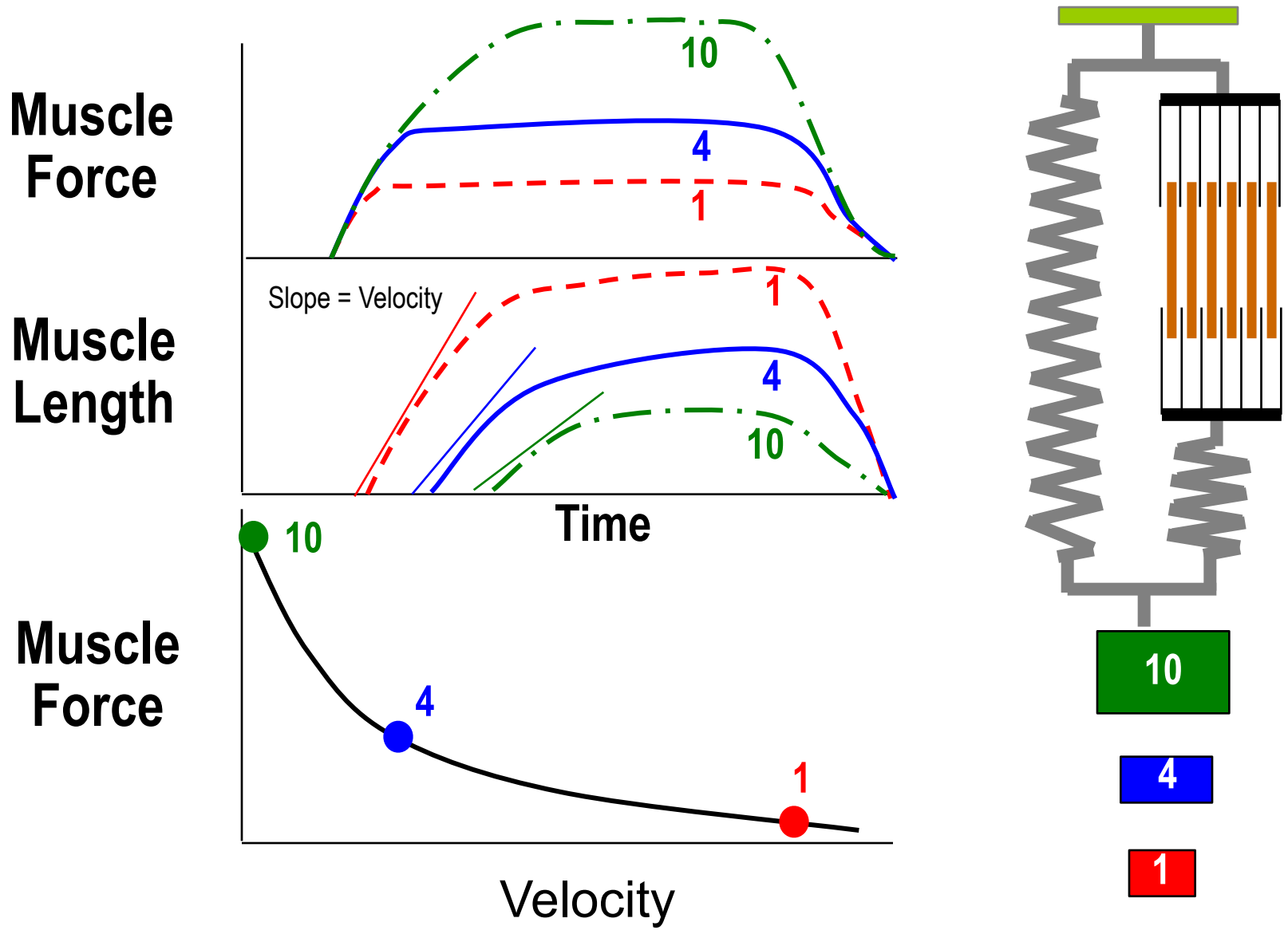




Length-tension curves continued

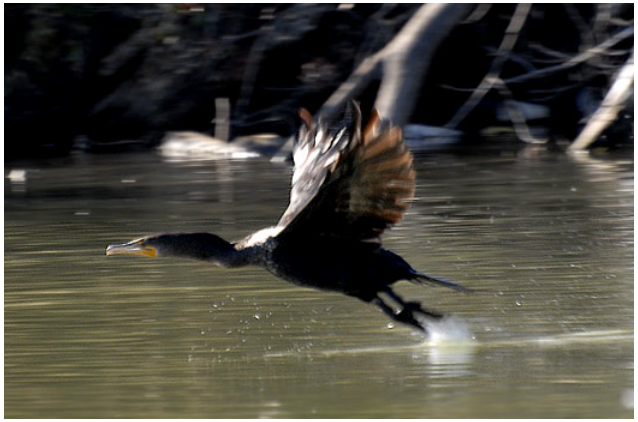


Velocity Affects Force



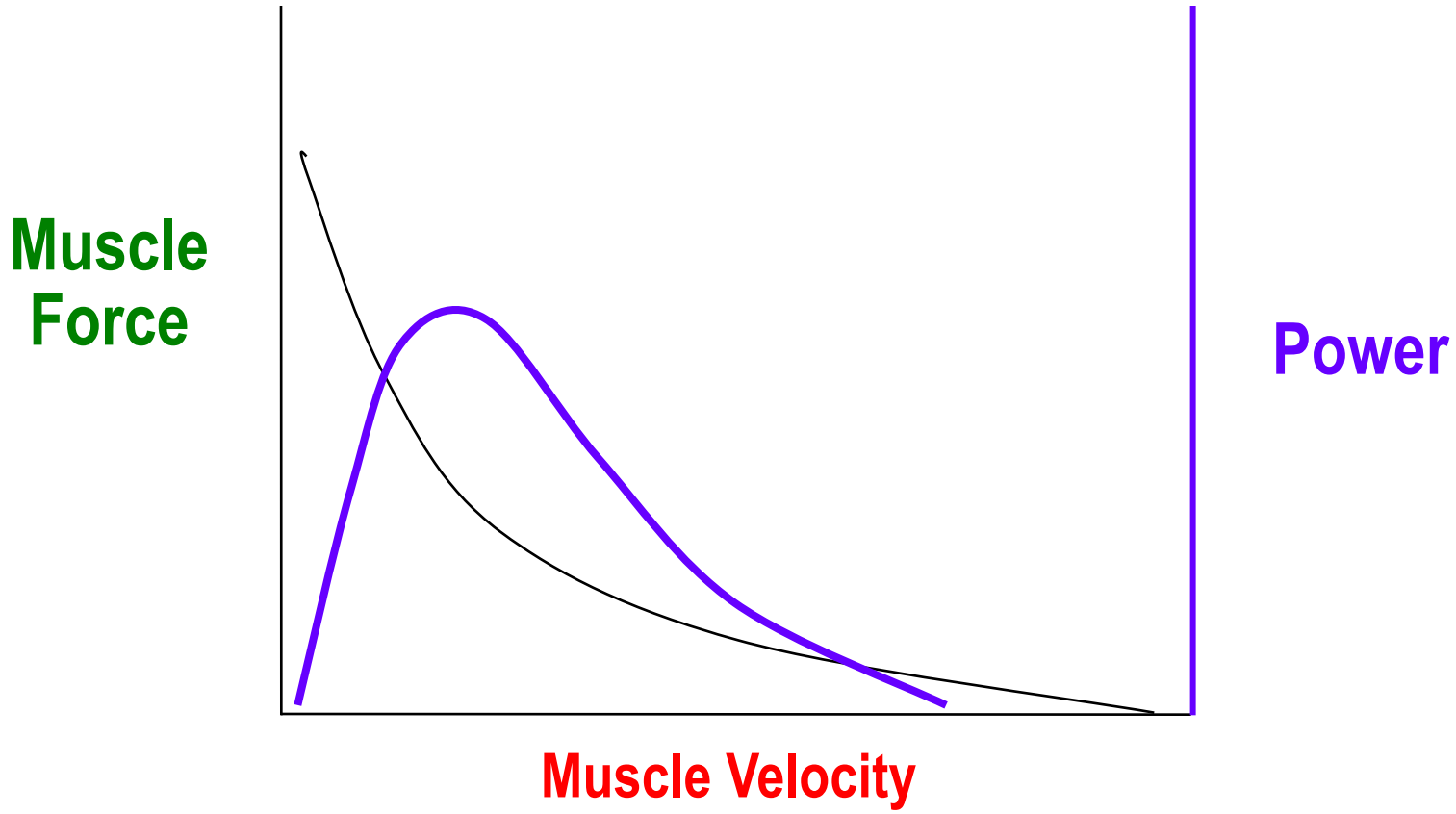
Power

- Power = work/time = (force*Δ L)/time
- Power = force * velocity (shortening)
- Power is important for many movements.
  - Jumping, flying, acceleration



Power production

Power = Force * Velocity



Determinants of Power

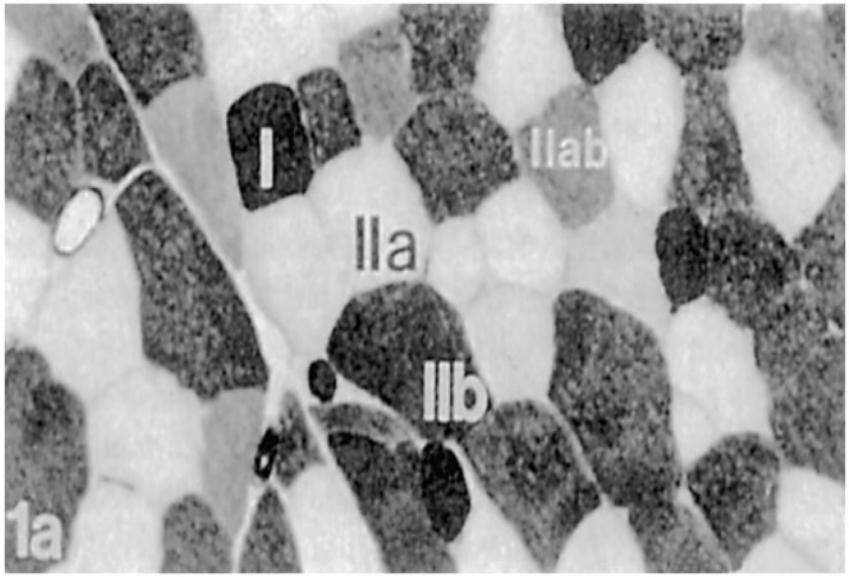
- ***Power is greatest at intermediate shortening velocities***
  - ***Ratio of V/V_{max} is important***
  - ***Velocity*** $\propto$ # of Sarcomeres in series
  - ***Force*** $\propto$ # of Cross-bridges in parallel

    $\propto$ cross-sectional area

Muscle & Fiber Design takes into account Power, speed, & energetics.

- A wide variety of motor tasks are required by muscle.
- Some require high speed contractions, powerful contraction, repetitive sustained contraction, or forceful sustained contractions.
- By altering the traits and design of fibers/ muscle a muscle can be specialized for a specific function.
- Energetics are also important (faster contracting muscles use ATP faster).

- Fast glycolytic (FG)
- Fast oxidative glycolytic (FOG)
- Slow oxidative (SO)



Property	FG	FOG	SO
Force/fiber	High	Intermediate	Low
Contractile speed	Fast	Intermediate	Slow
Endurance	Low	Intermediate	High