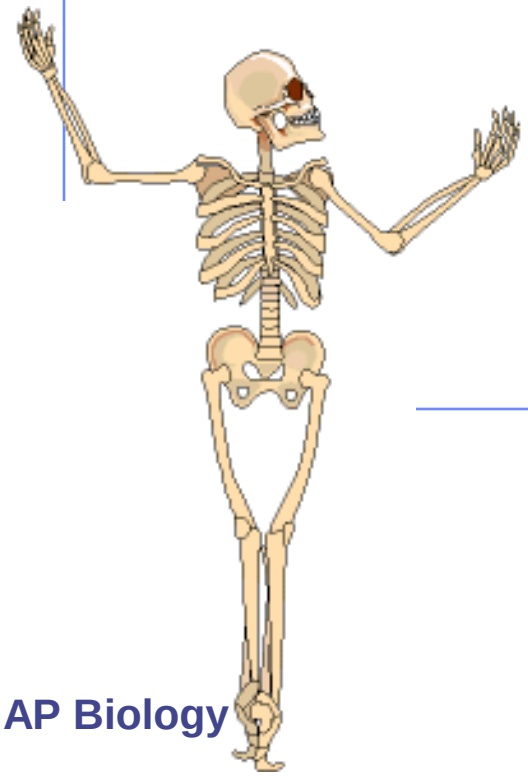
Muscles & Motor Locomotion



Why Do We Need All That ATP?

Animal Locomotion

What are the advantages of locomotion?

sessile

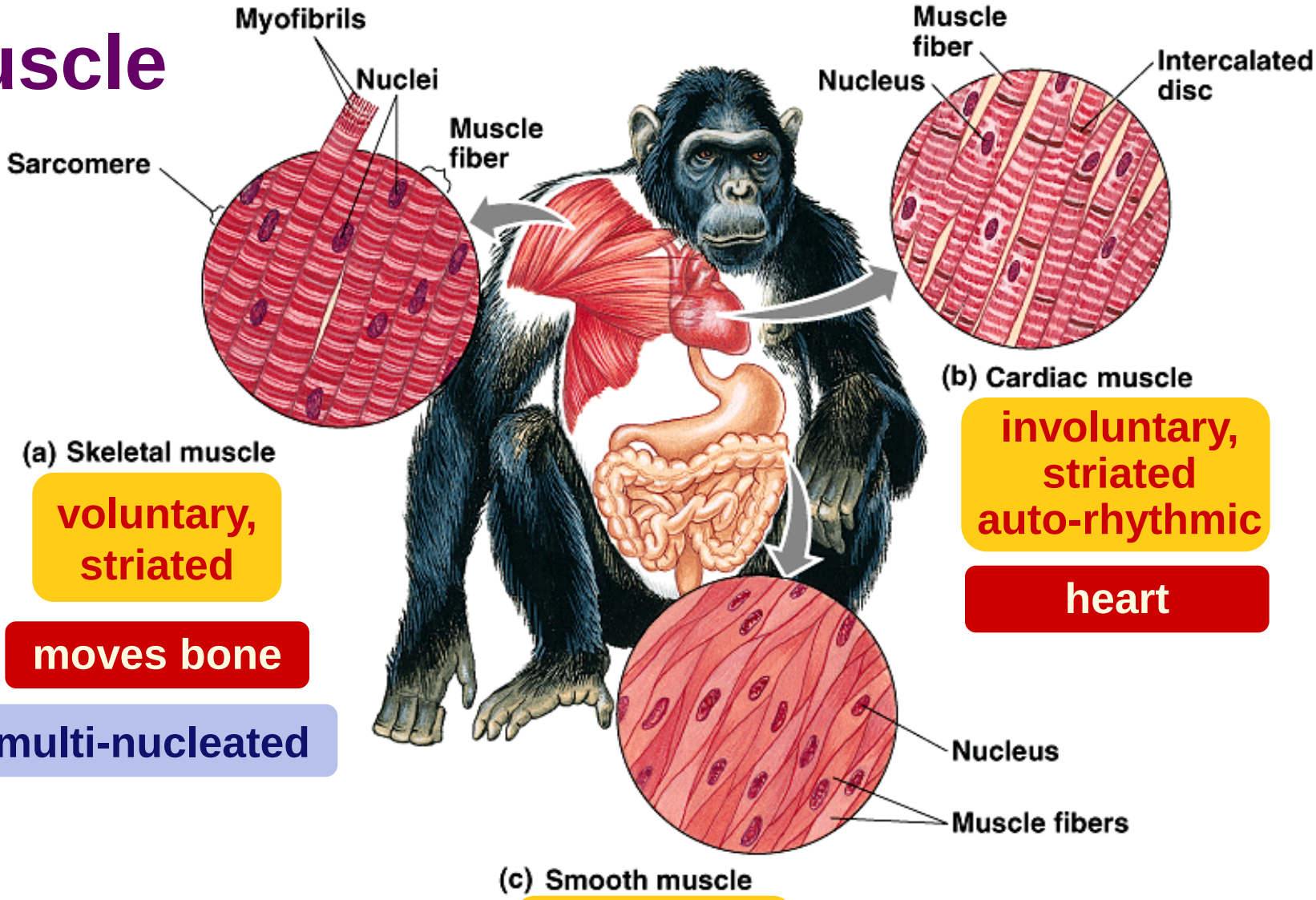
motile

Lots of ways to get around…

Lots of ways to get around…

Lots of ways to get around…

Muscle



voluntary, striated

moves bone

multi-nucleated

involuntary, striated auto-rhythmic

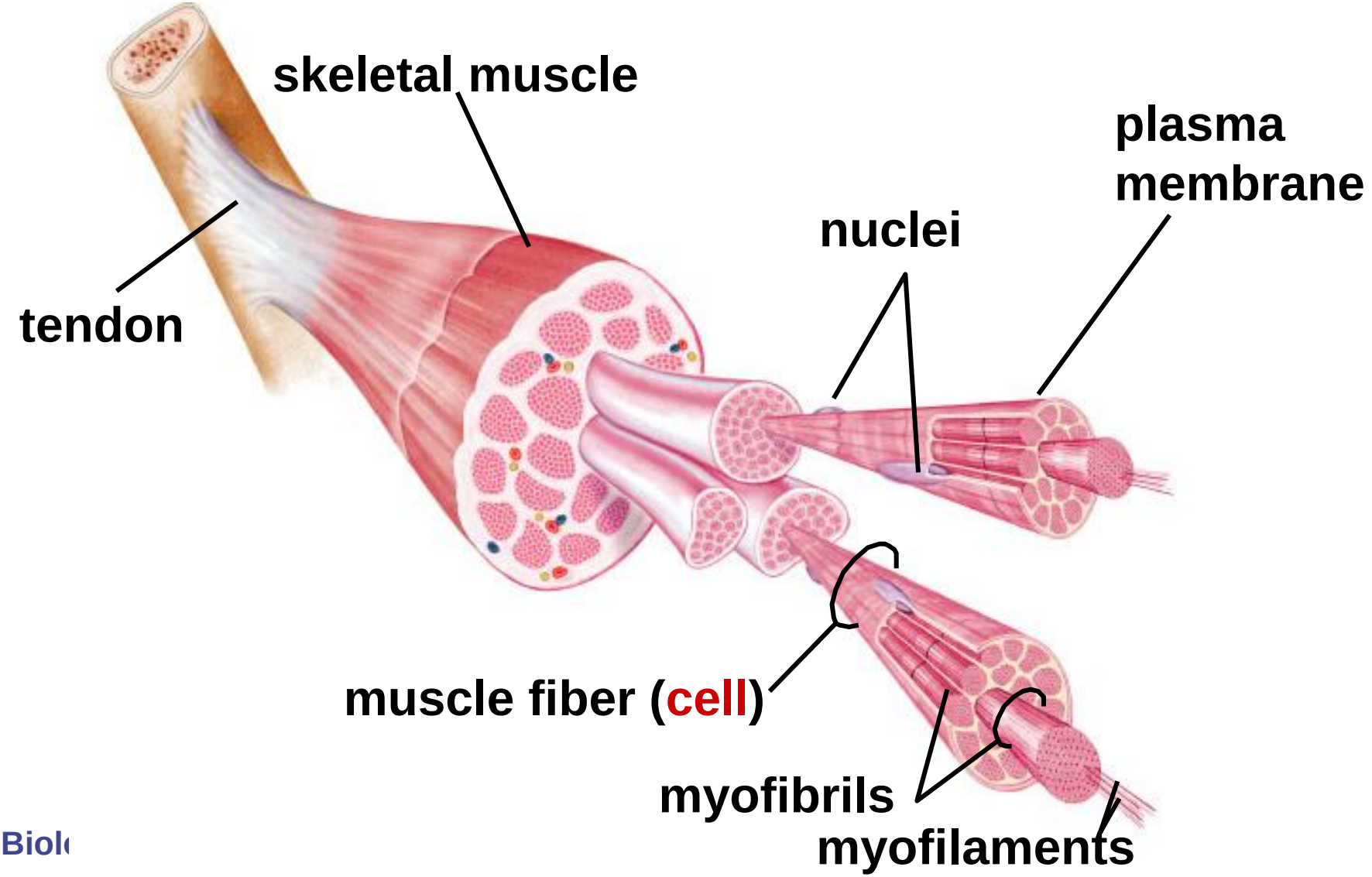
heart

evolved first

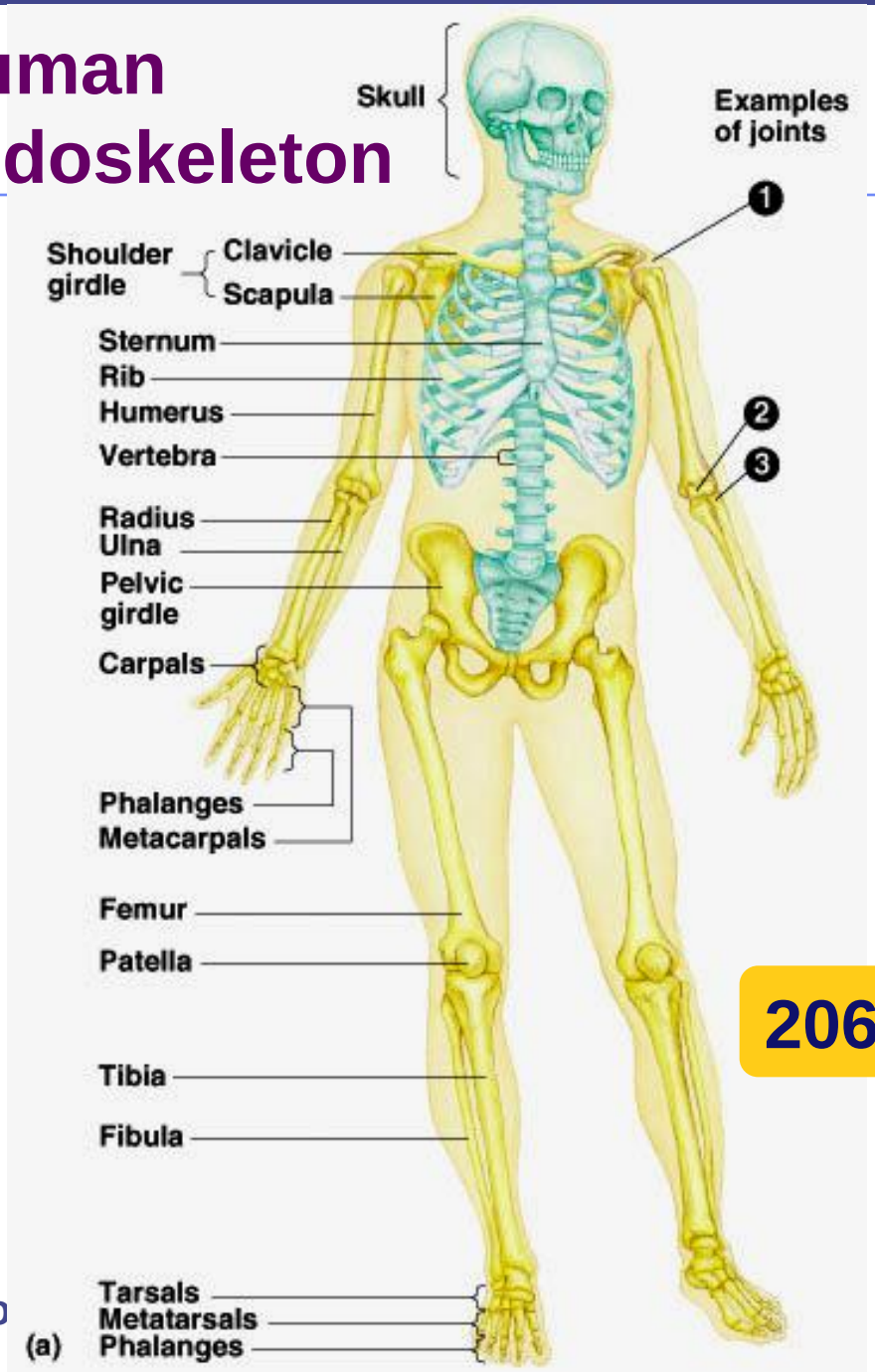
involuntary, non-striated

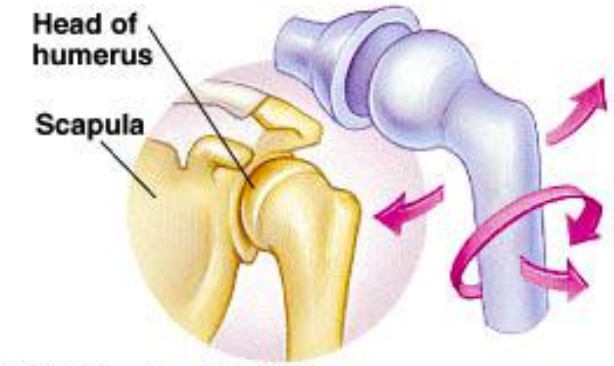
digestive system arteries, veins

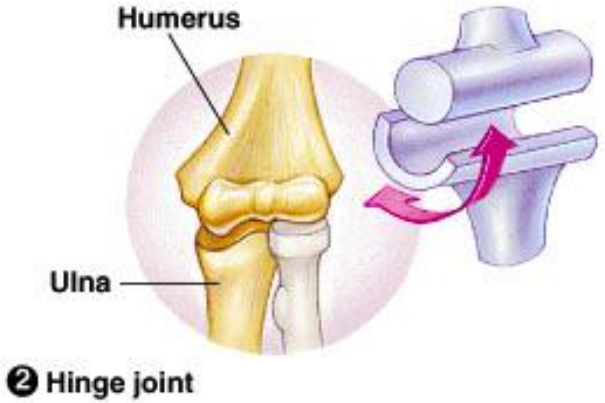
Organization of Skeletal muscle



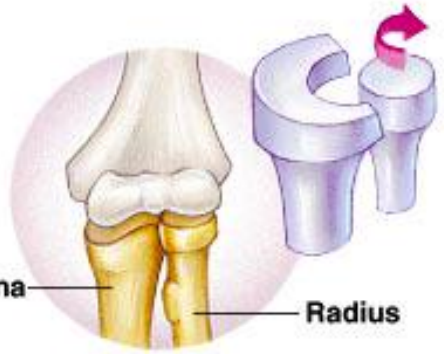
Human endoskeleton







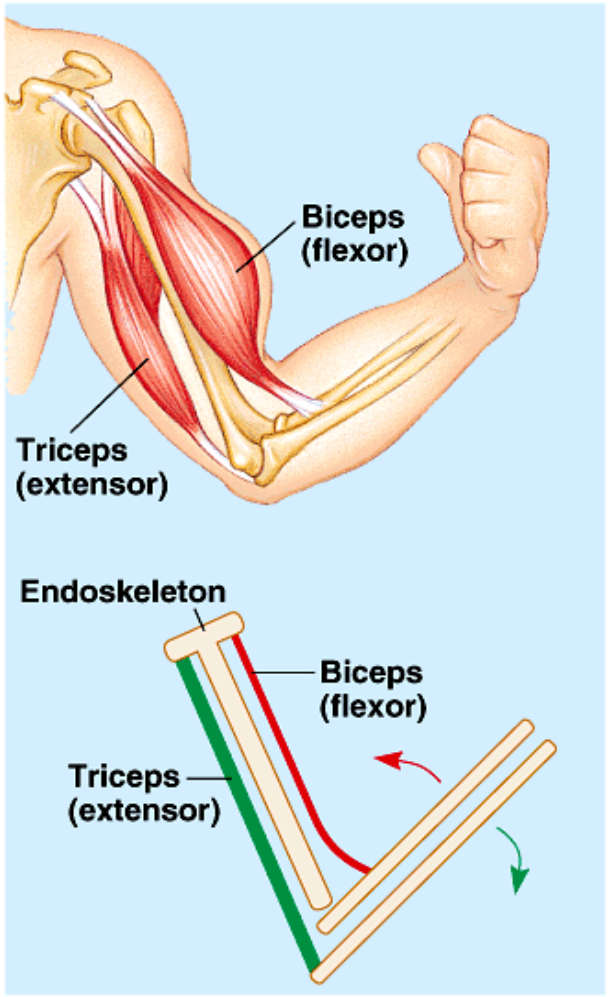
206 bones

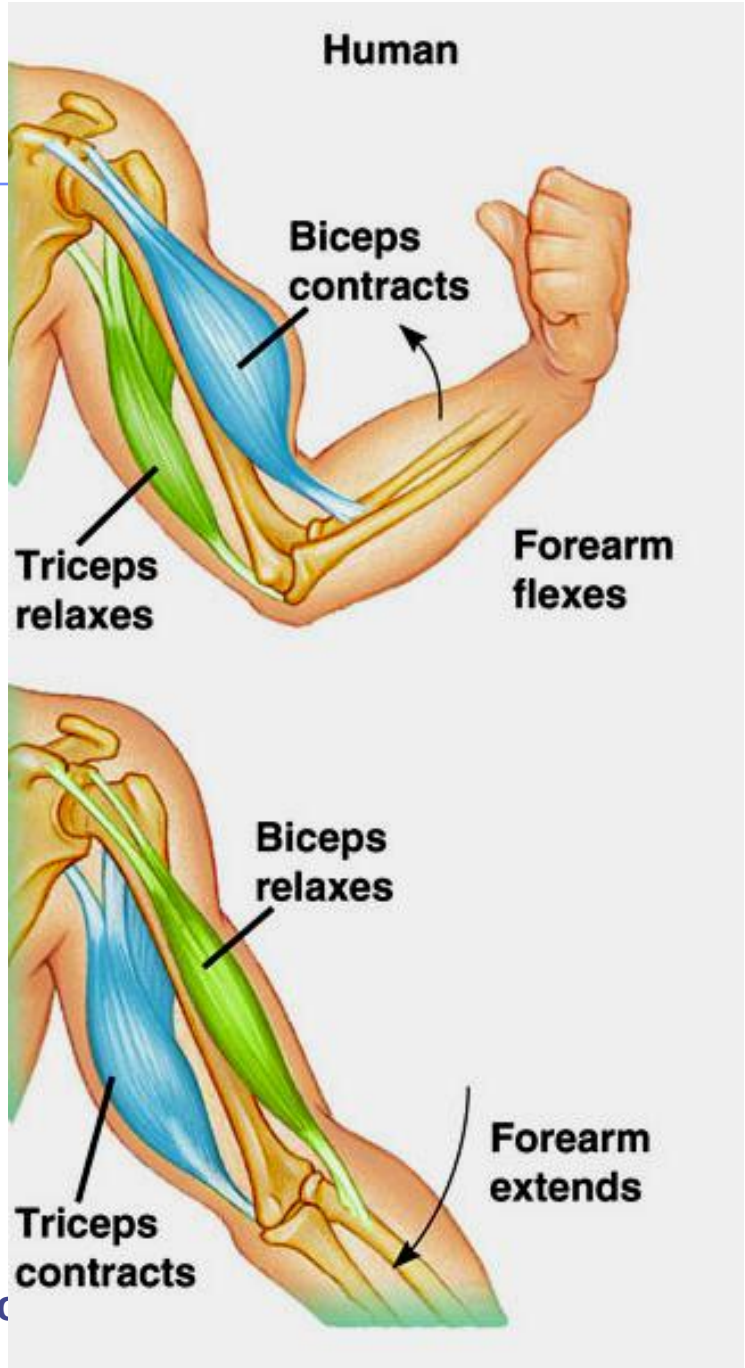


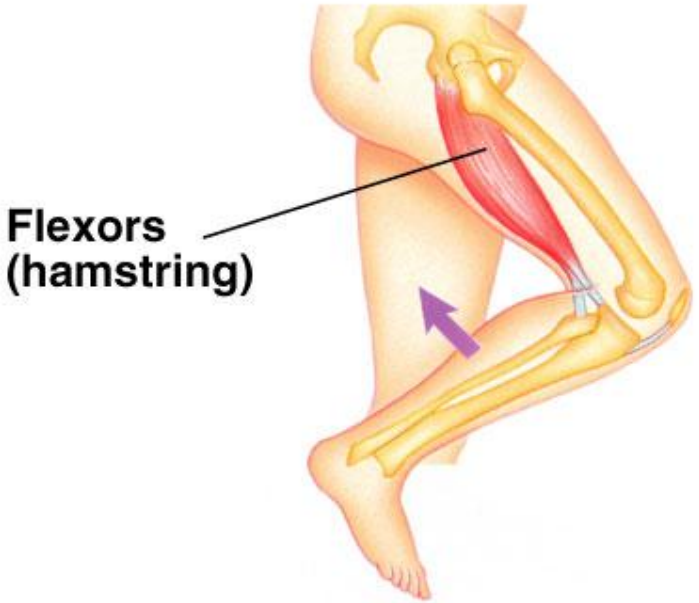
(b)

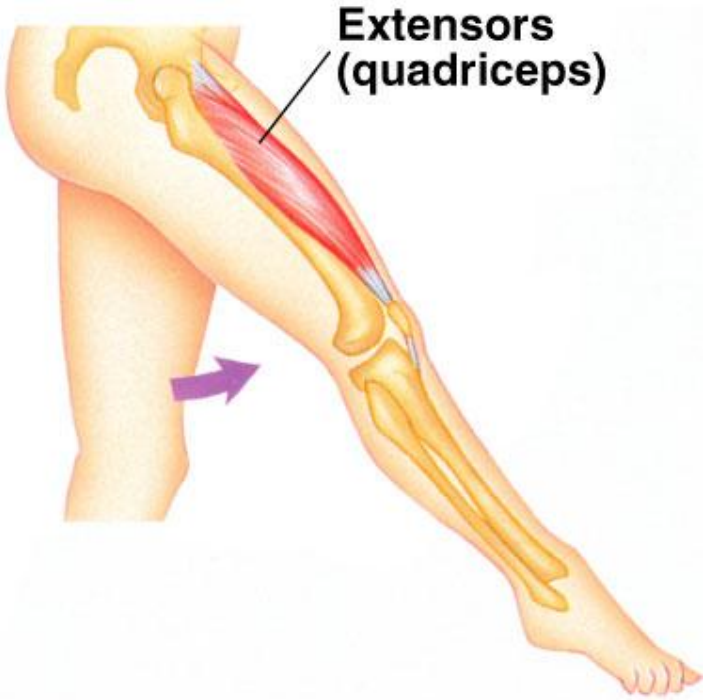
Muscles movement

- **Muscles do work by contracting**
  - skeletal muscles come in antagonistic pairs
    - flexor vs. extensor
  - contracting = shortening
    - move skeletal parts
  - tendons
    - connect bone to muscle
  - ligaments
    - connect bone to bone



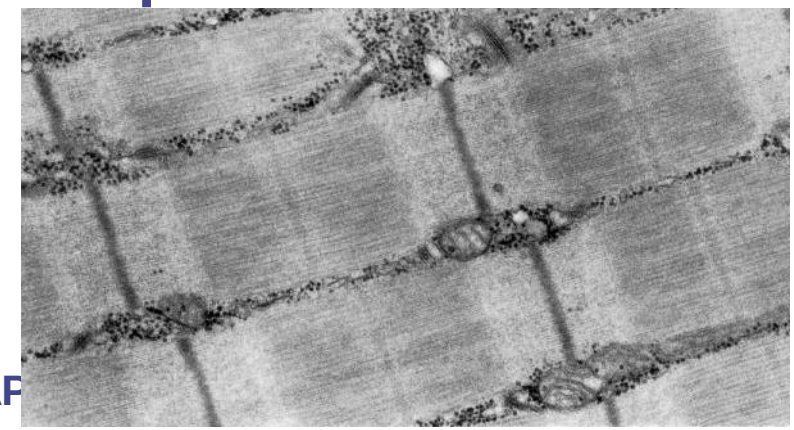

Human
Biceps contracts
Triceps relaxes
Forearm flexes
Biceps relaxes
Triceps contracts
Forearm extends

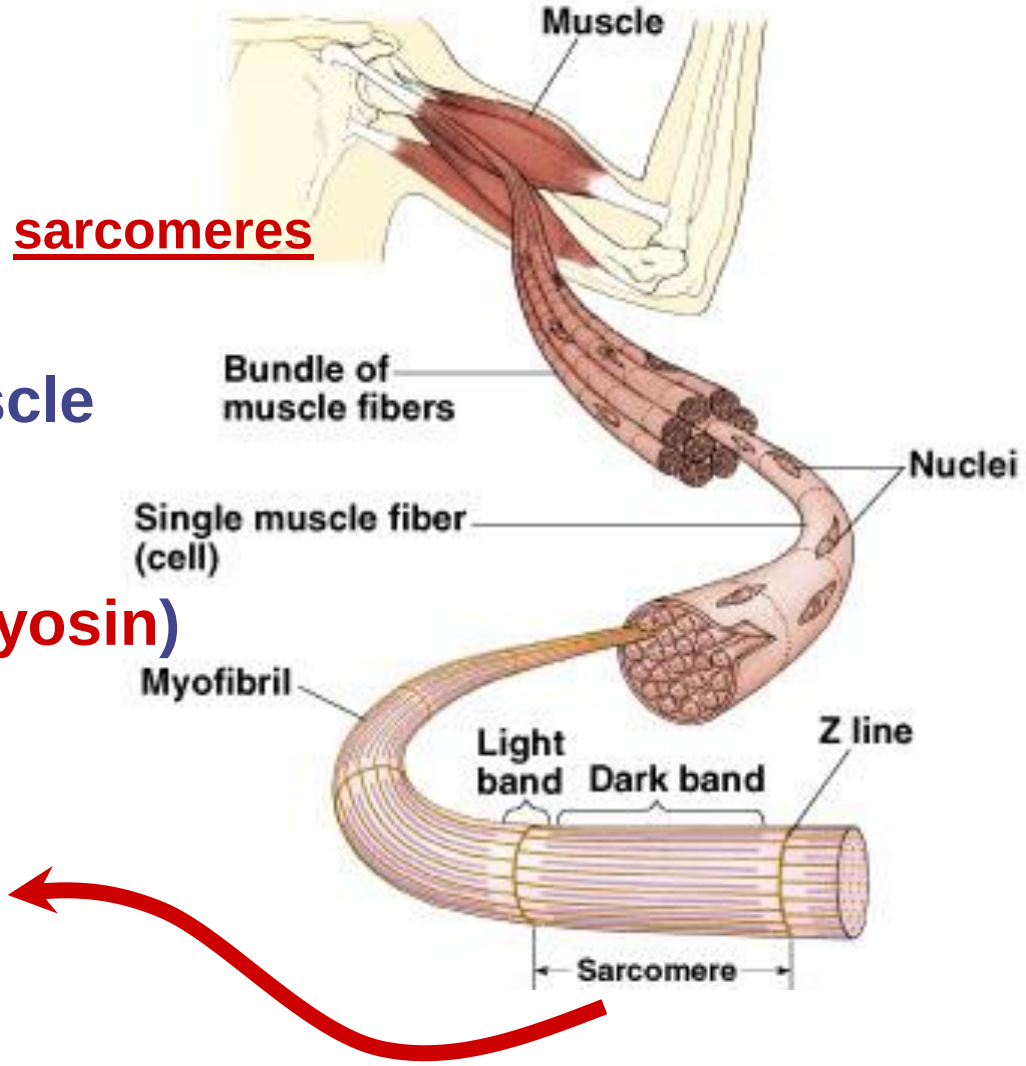

Flexors (hamstring)


Extensors (quadriceps)

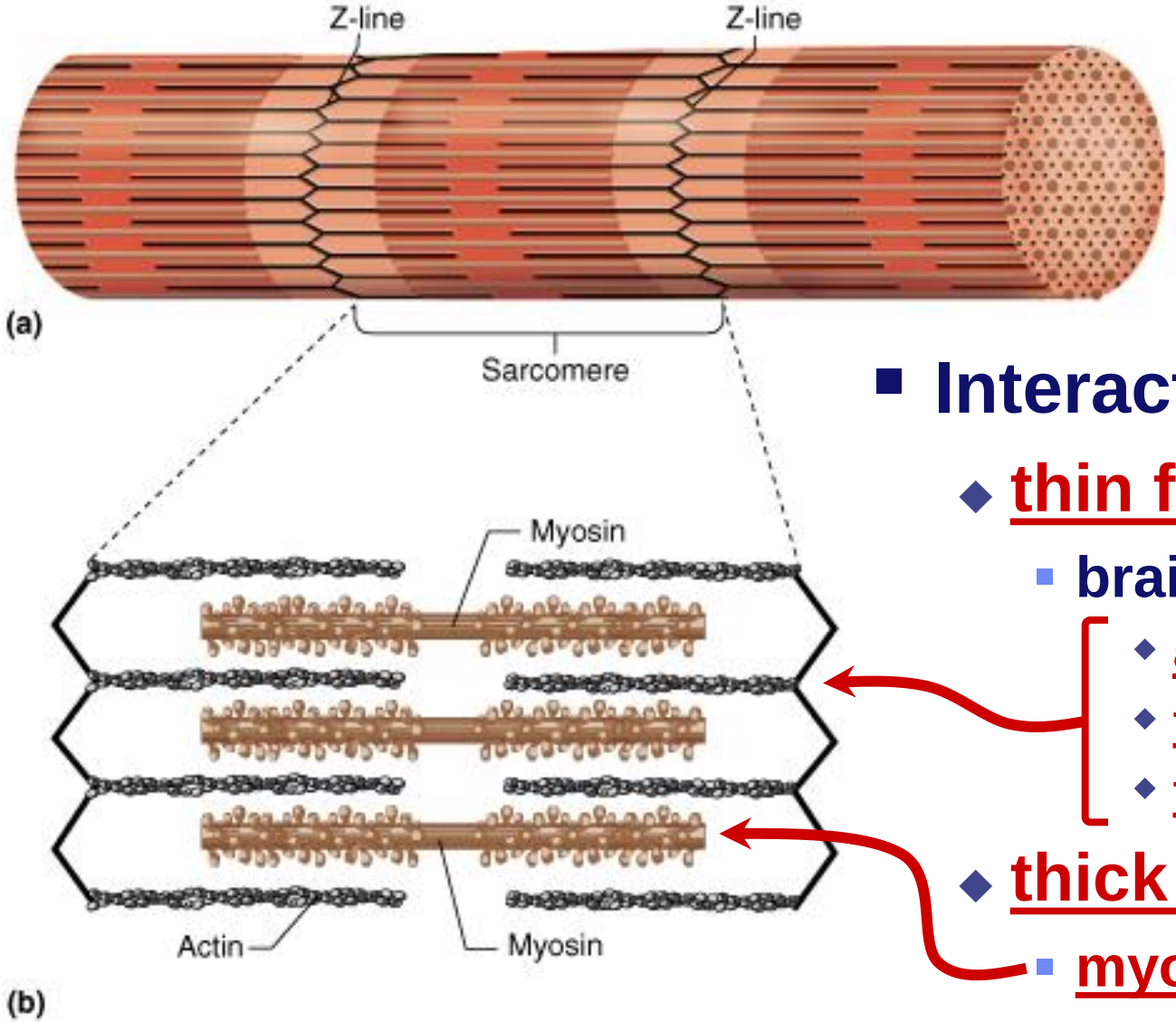
Structure of striated skeletal muscle

- **Muscle Fiber**
  - **muscle cell**
    - divided into sections = **sarcomeres**
- **Sarcomere**
  - functional unit of muscle contraction
  - alternating bands of thin (actin) & thick (myosin) protein filaments





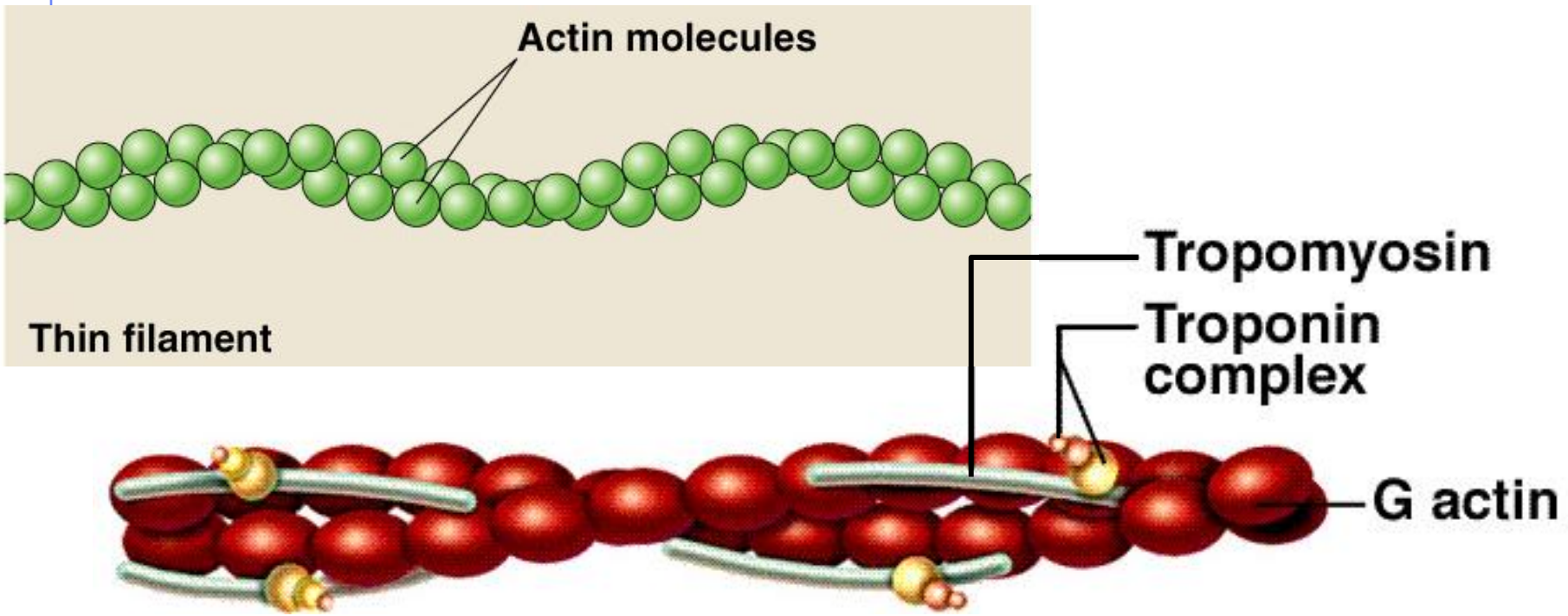
Muscle filaments & Sarcomere



- Interacting proteins
  - thin filaments
    - braided strands
      - actin
      - tropomyosin
      - troponin
  - thick filaments
    - myosin

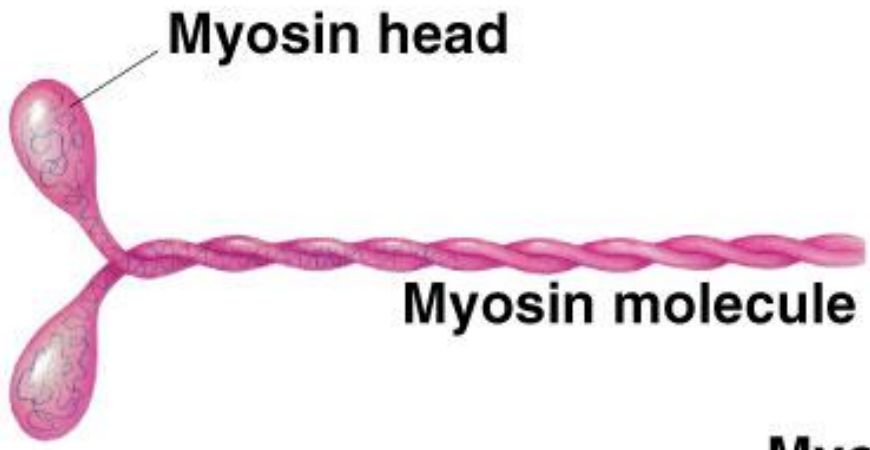
Thin filaments: actin

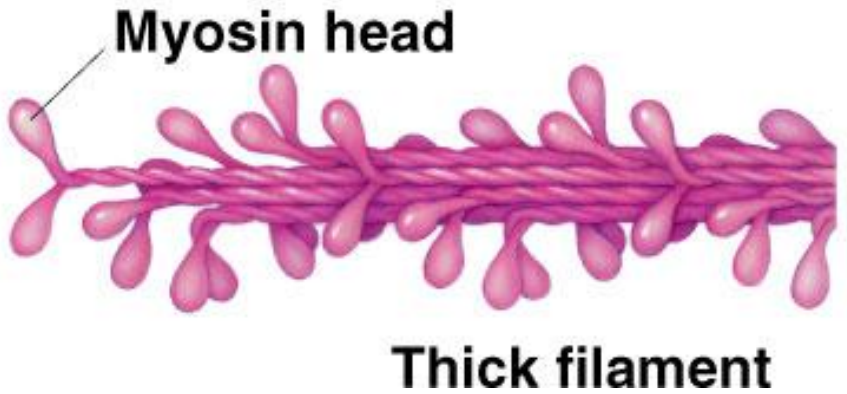
- **Complex of proteins**
  - **braid of actin molecules & tropomyosin fibers**
    - **tropomyosin fibers secured with troponin molecules**



Thick filaments: myosin

- **Single protein**
  - **myosin molecule**
    - **long protein with globular head**

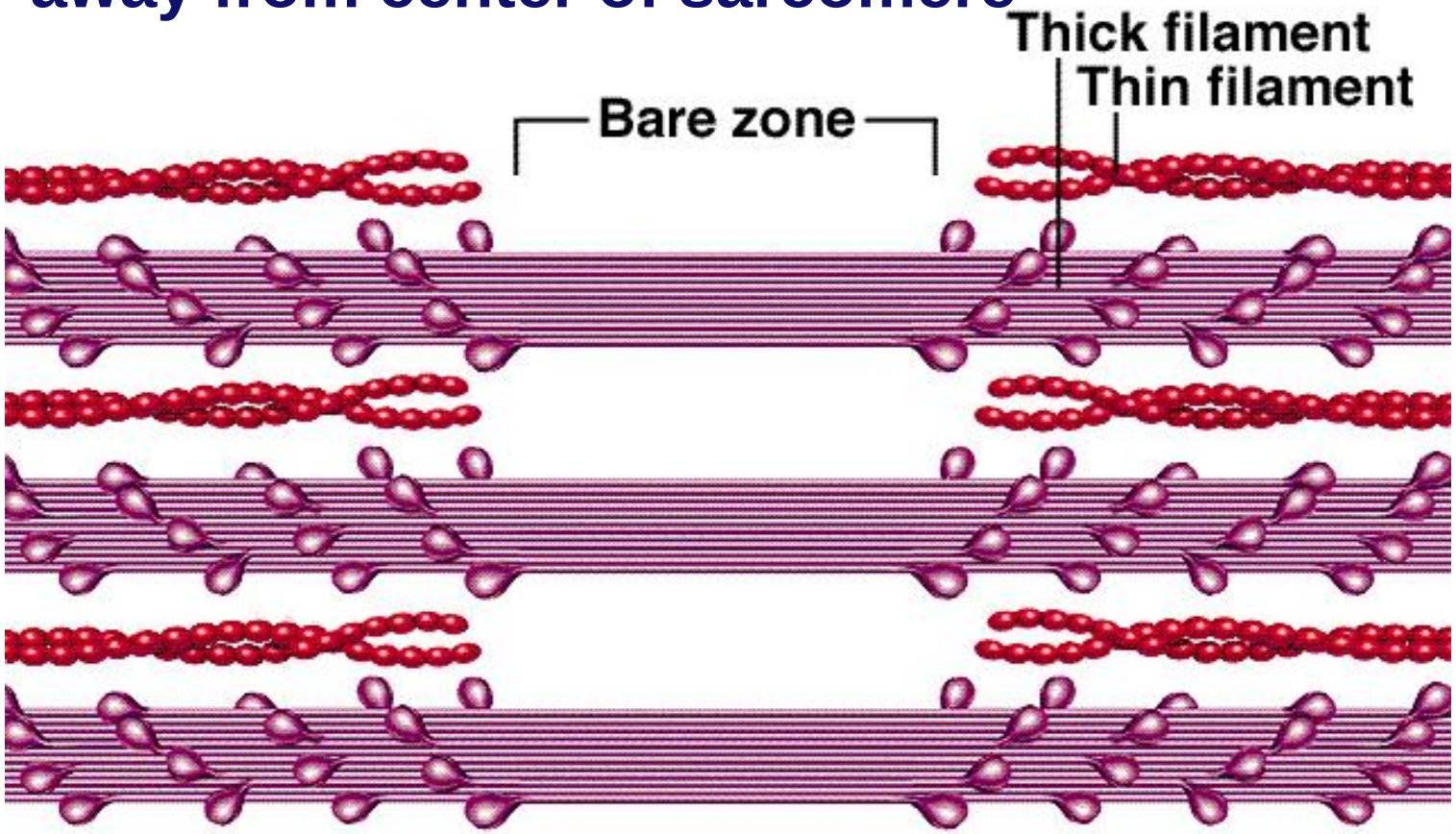




bundle of myosin proteins: globular heads aligned

Thick & thin filaments

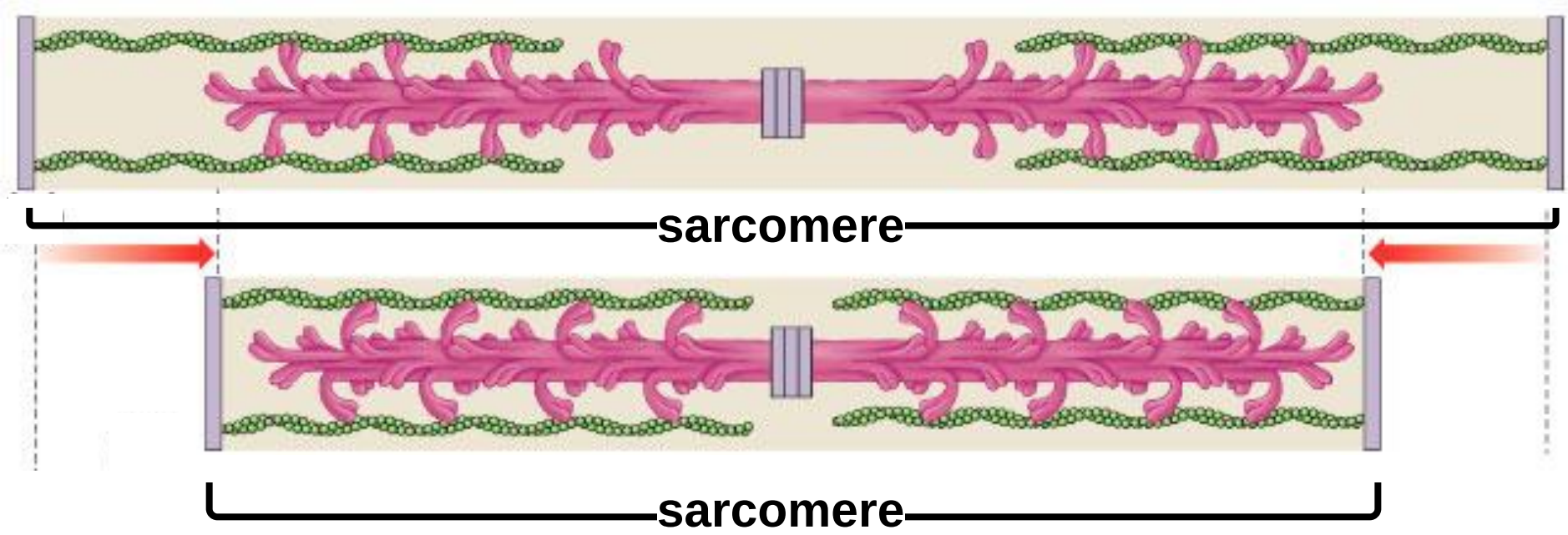
- **Myosin tails aligned together & heads pointed away from center of sarcomere**



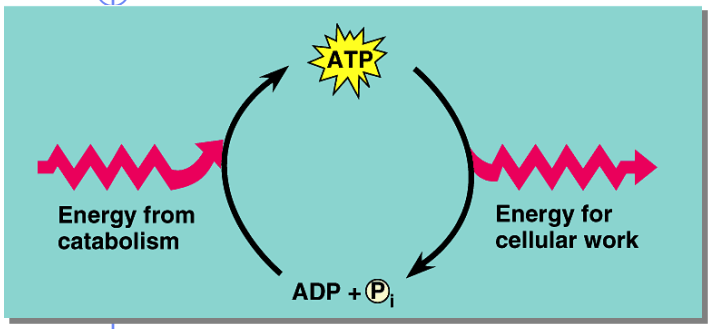
Portion of a sarcomere showing the overlap of thick and thin filaments

Interaction of thick & thin filaments

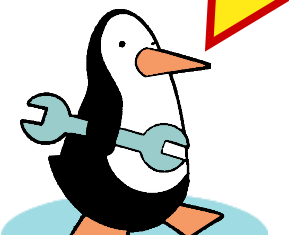
- **Cross bridges**
  - connections formed between **myosin heads** (thick filaments) & **actin** (thin filaments)
  - cause the muscle to shorten (contract)

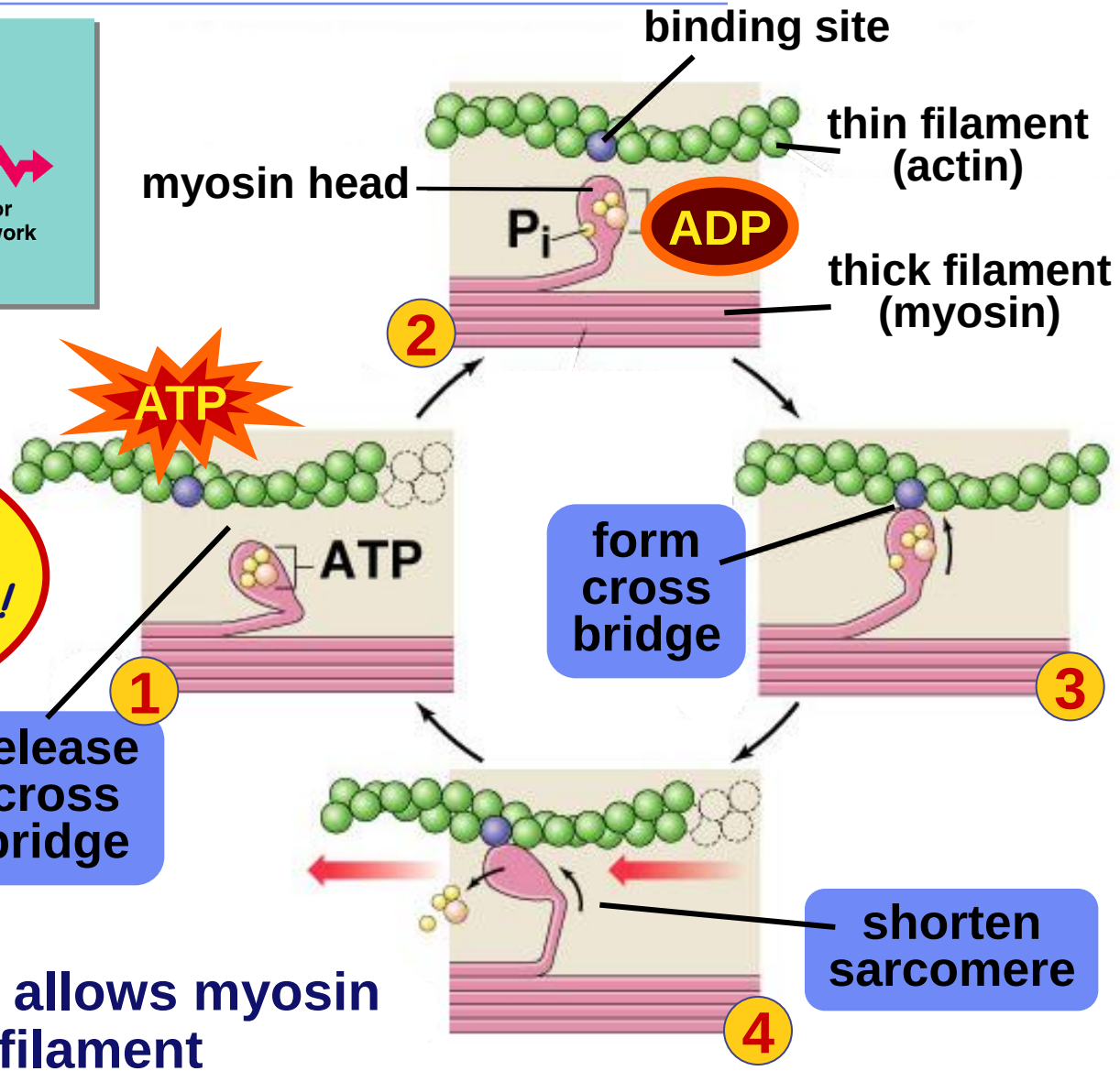


Where is ATP needed?



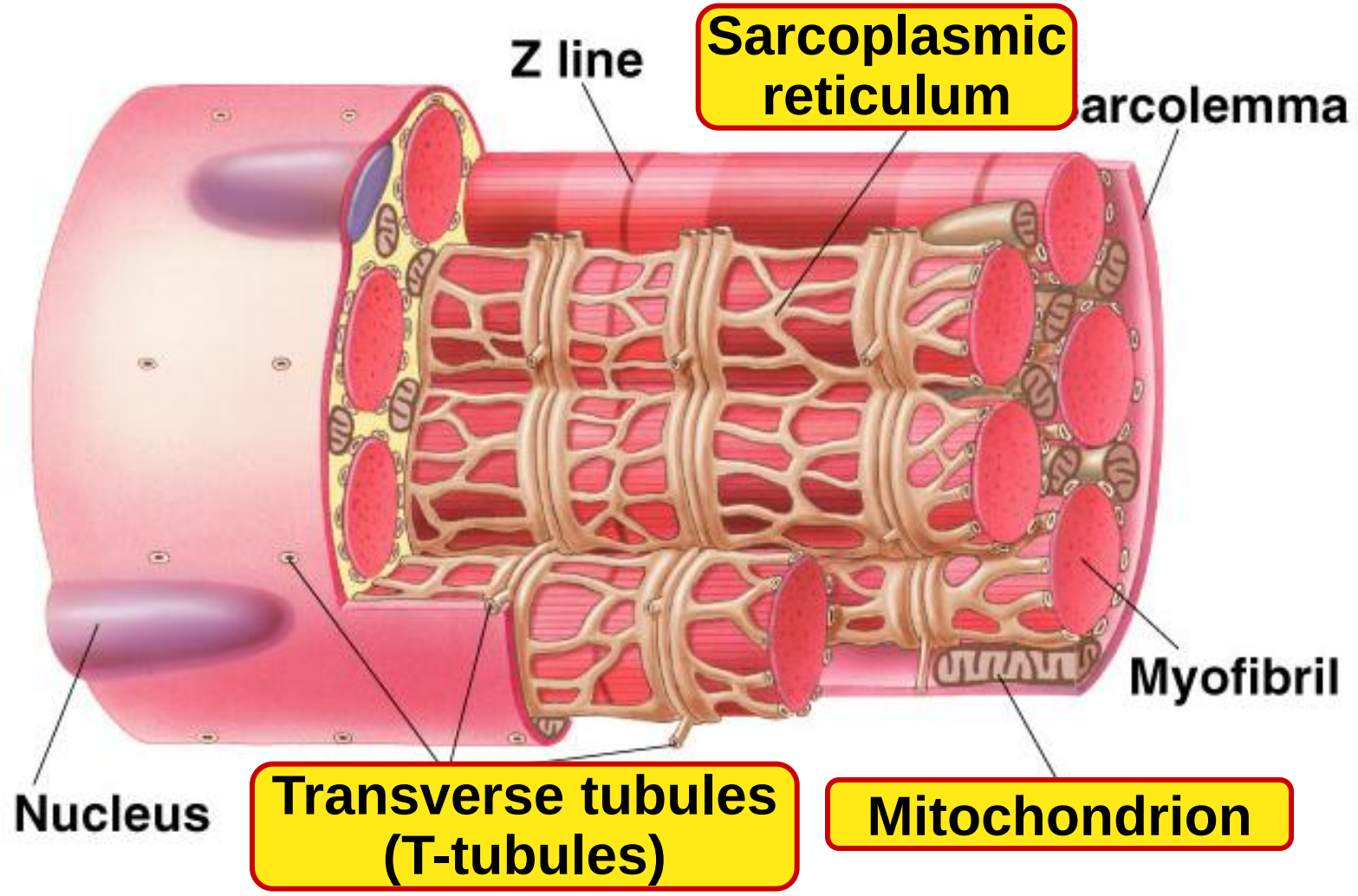
So that's where those 10,000,000 ATPs go! Well, not all of it!





Cleaving ATP → ADP allows myosin head to bind to actin filament

Closer look at muscle cell

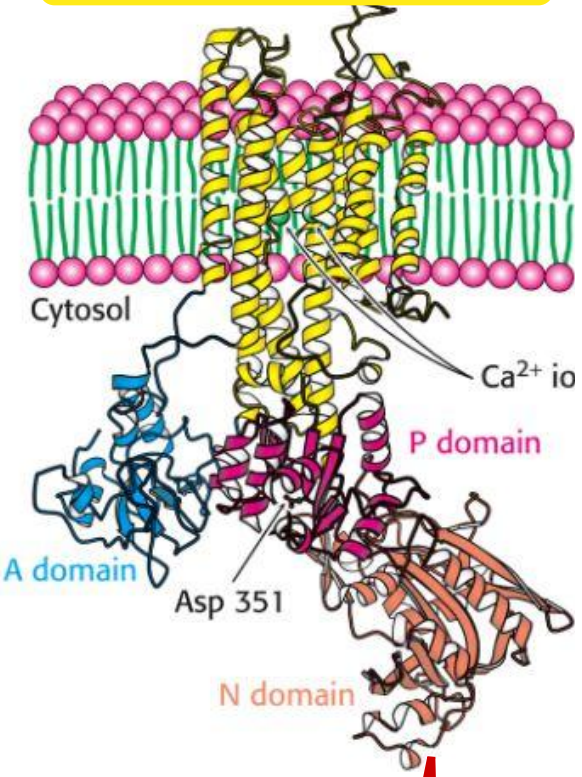


multi-nucleated

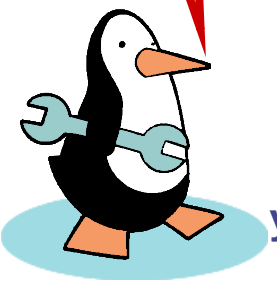
Muscle cell organelles

- **Sarcoplasm**
  - muscle cell cytoplasm
  - contains many mitochondria
- **Sarcoplasmic reticulum (SR)**
  - organelle similar to ER
    - network of tubes
  - **stores Ca^{2+}**
    - Ca^{2+} released from SR through channels
    - Ca^{2+} restored to SR by Ca^{2+} pumps
      - pump Ca^{2+} from cytosol
      - pumps use ATP

Ca^{2+} ATPase of SR



There's the rest of the ATPs!



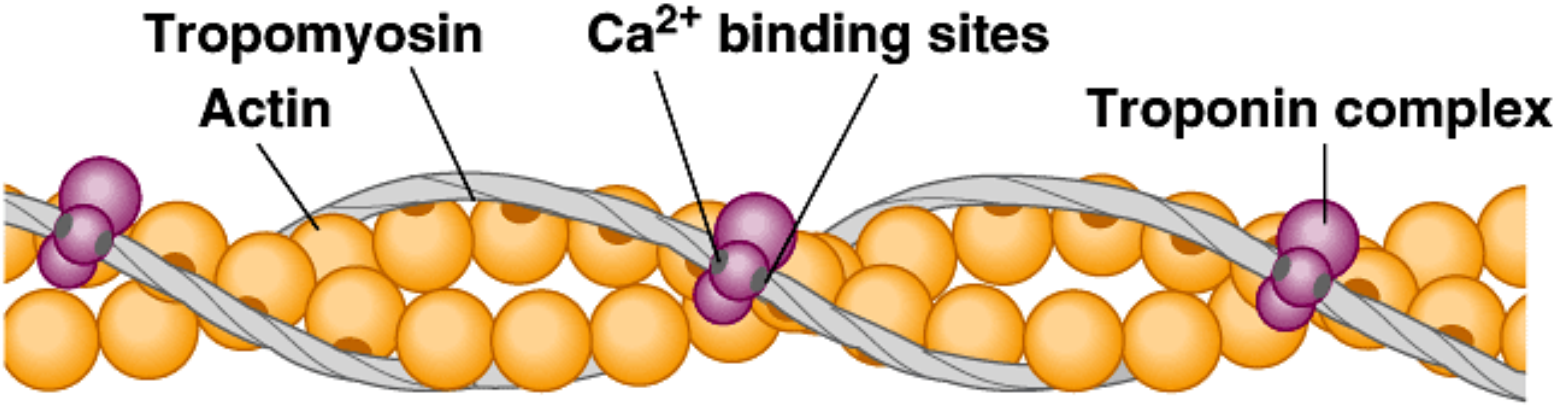
y

ATP

But what does the Ca^{2+} do?

Muscle at rest

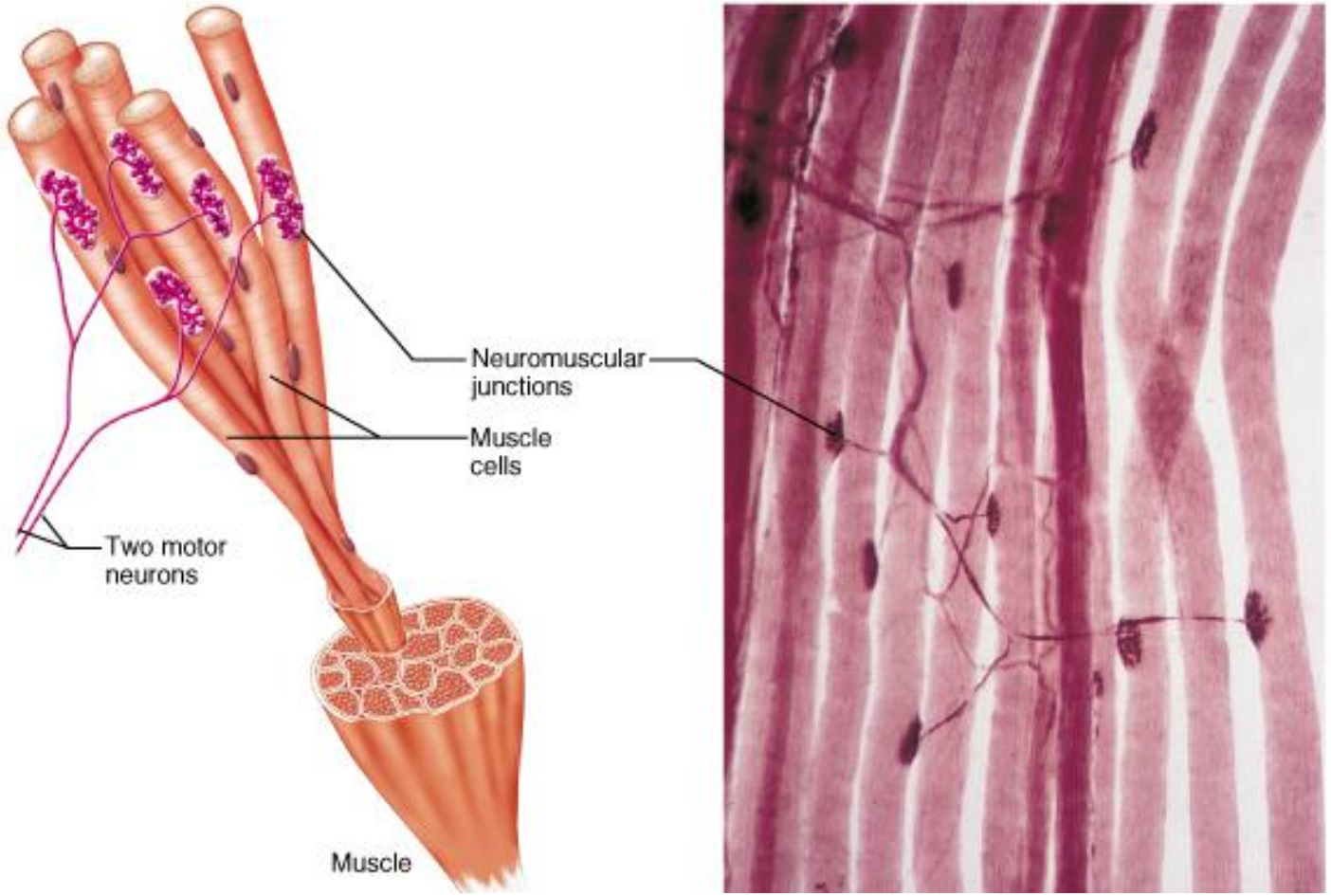
- **Interacting proteins**
  - at rest, troponin molecules hold tropomyosin fibers so that they cover the myosin-binding sites on actin
    - troponin has Ca^{2+} binding sites



(a) Myosin binding sites blocked; muscle cannot contract

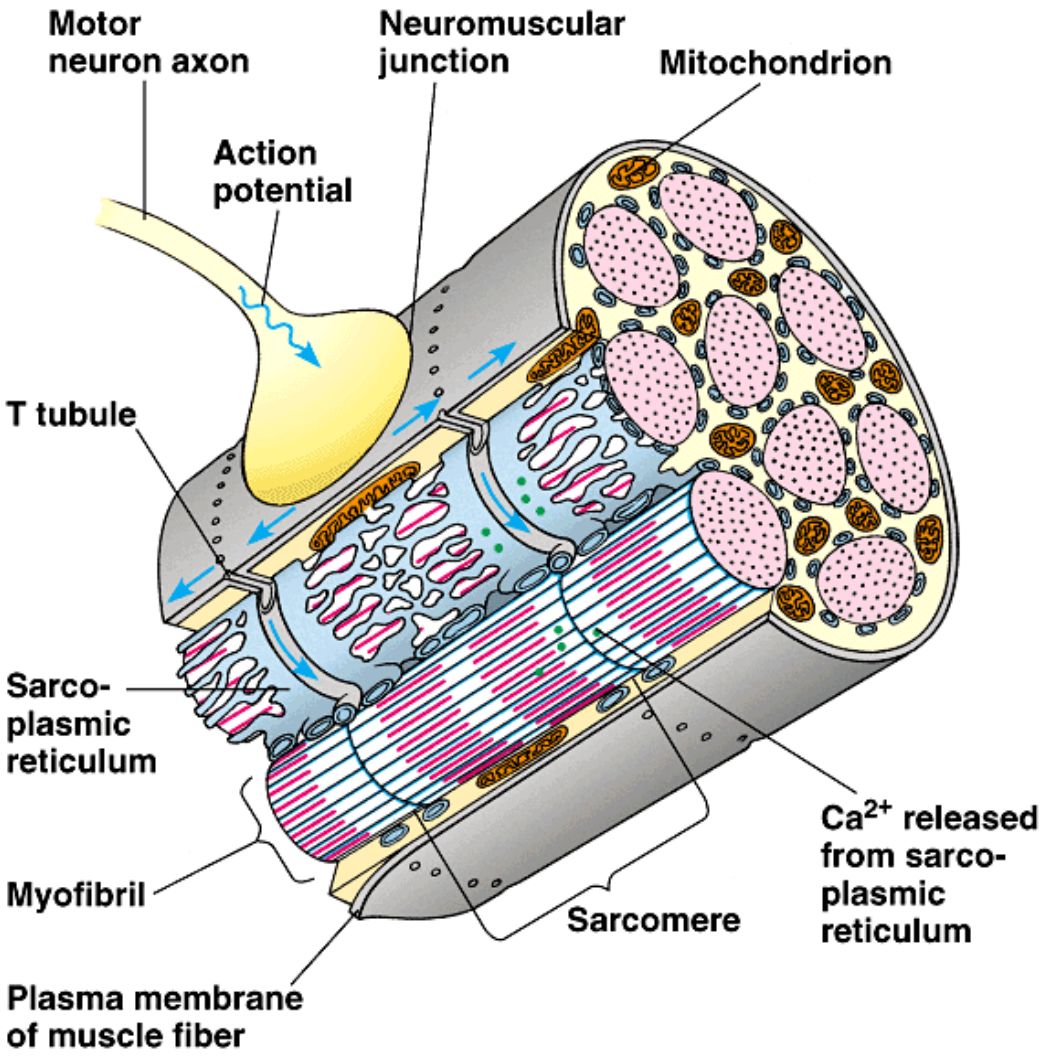
The Trigger: motor neurons

- **Motor neuron triggers muscle contraction**
  - **release acetylcholine (Ach) neurotransmitter**



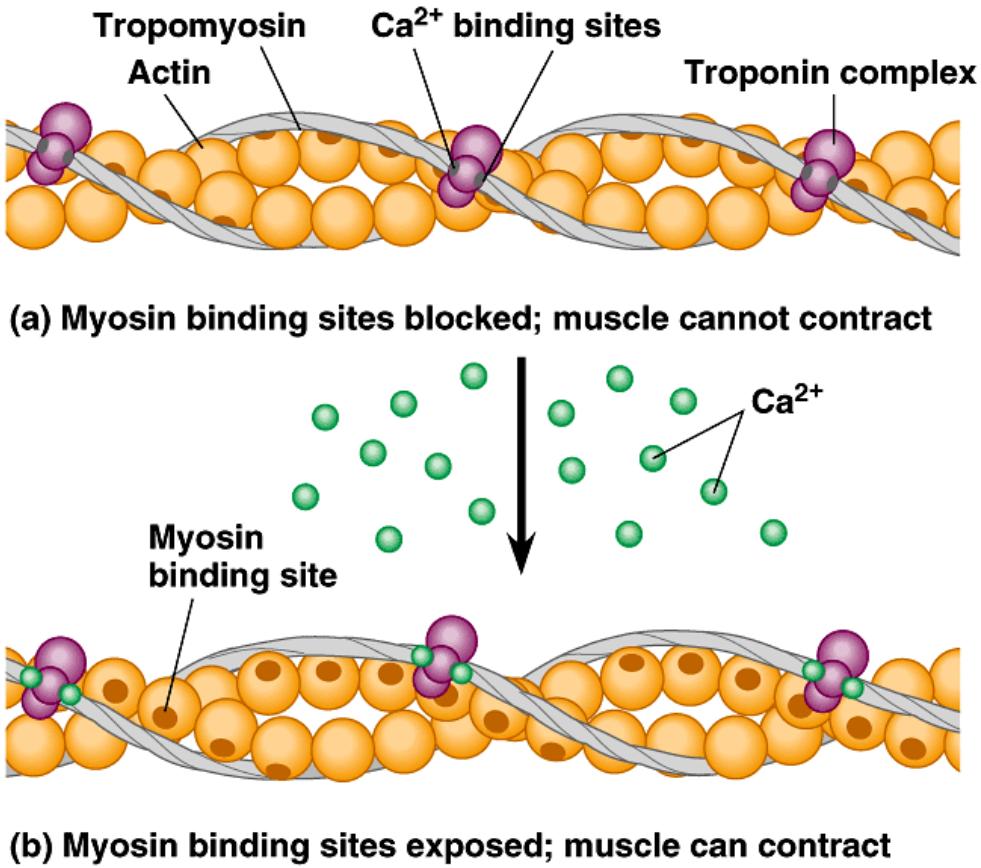
Nerve trigger of muscle action

- **Nerve signal travels down T-tubule**
  - **stimulates sarcoplasmic reticulum (SR) of muscle cell to release stored Ca^{2+}**
  - **flooding muscle fibers with Ca^{2+}**



Ca^{2+} triggers muscle action

- At rest, tropomyosin blocks myosin-binding sites on actin
  - secured by troponin
- Ca^{2+} binds to troponin
  - shape change causes movement of troponin
  - releasing tropomyosin
  - exposes myosin-binding sites on actin

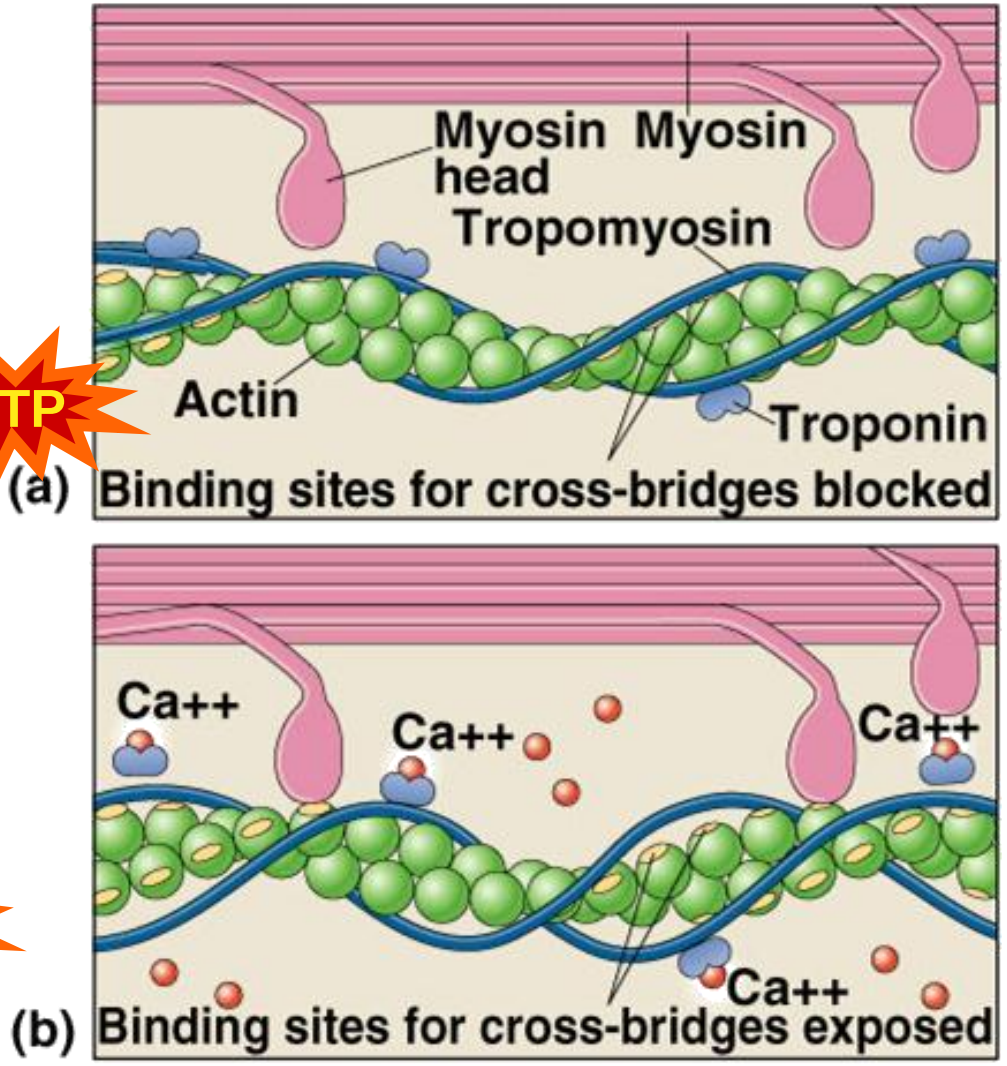


How Ca^{2+} controls muscle

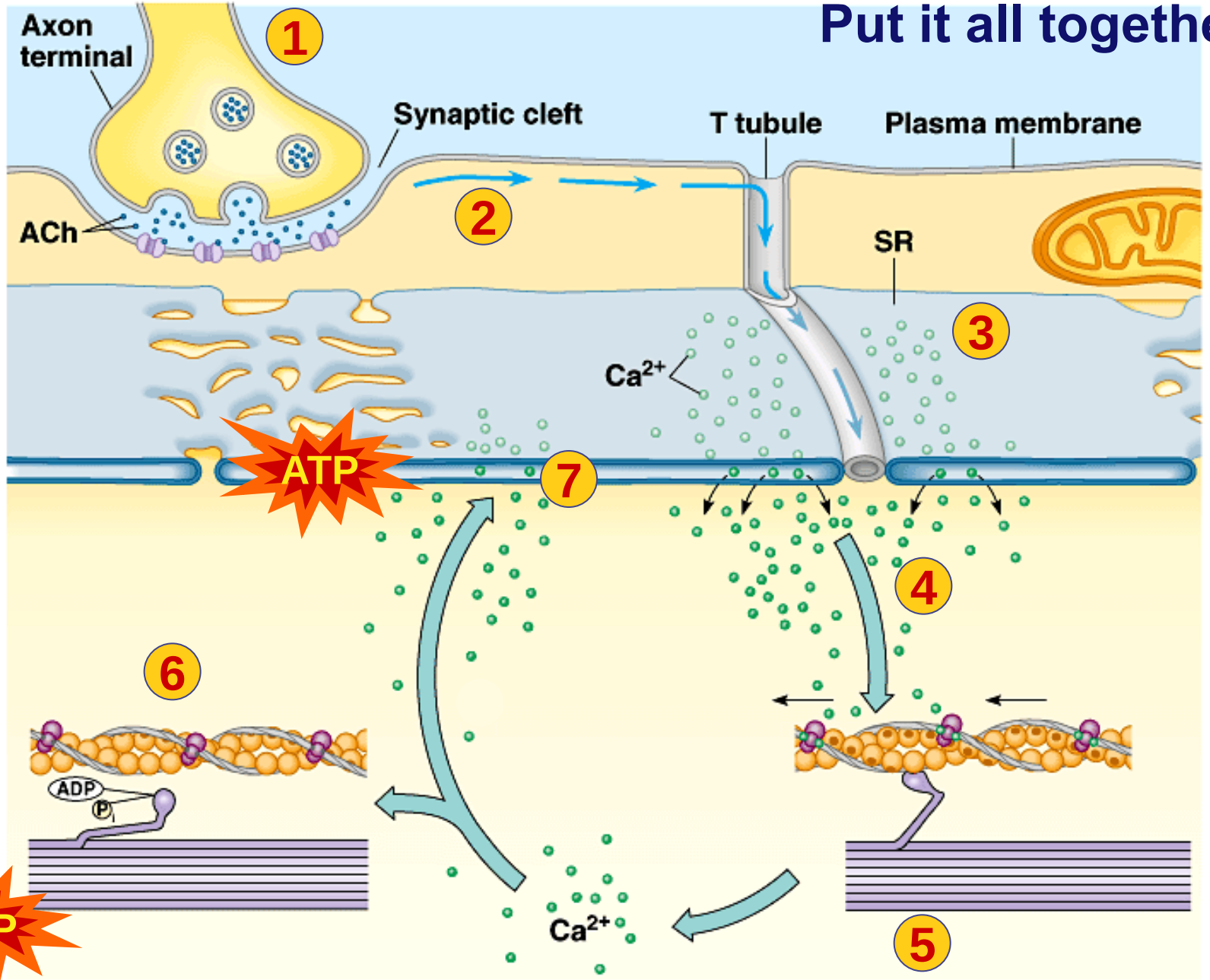
- **Sliding filament model**
  - exposed actin binds to myosin
  - fibers slide past each other
    - ratchet system
  - shorten muscle cell
    - muscle contraction
  - muscle doesn't relax until Ca^{2+} is pumped back into SR
    - requires ATP

ATP

ATP



Put it all together…



How it all works…

- Action potential causes Ca^{2+} release from SR
  - Ca^{2+} binds to troponin
- Troponin moves tropomyosin uncovering myosin binding site on actin
- Myosin binds actin

  - uses ATP to "ratchet" each time
  - releases, "unratchets" & binds to next actin
- Myosin pulls actin chain along
- Sarcomere shortens
  - Z discs move closer together
- Whole fiber shortens → contraction!
- Ca^{2+} pumps restore Ca^{2+} to SR → relaxation!
  - pumps use ATP

Fast twitch & slow twitch muscles

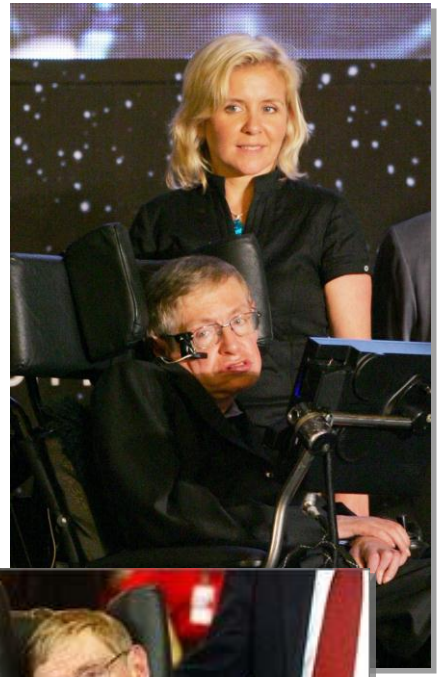
- **Slow twitch muscle fibers**
  - **contract slowly**, but keep going for a long time
    - more mitochondria for aerobic respiration
    - less SR → Ca^{2+} remains in cytosol longer
  - **long distance runner**
  - "dark" meat = more blood vessels
- **Fast twitch muscle fibers**
  - **contract quickly**, but get tired rapidly
    - store more glycogen for anaerobic respiration
  - **sprinter**
  - "white" meat

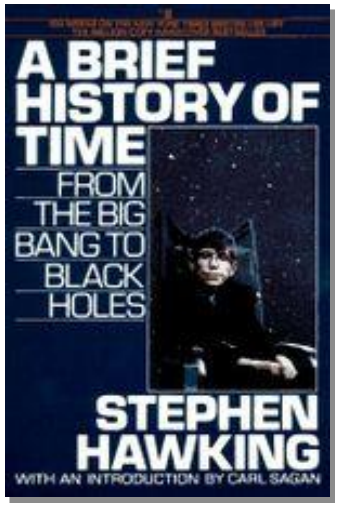
Muscle limits

- **Muscle fatigue**
  - lack of sugar
    - lack of ATP to restore Ca^{2+} gradient
  - low O_2
    - lactic acid drops pH which interferes with protein function
  - synaptic fatigue
    - loss of acetylcholine
- **Muscle cramps**
  - build up of lactic acid
  - ATP depletion
  - ion imbalance
    - massage or stretching increases circulation

Diseases of Muscle tissue

- **ALS**
  - amyotrophic lateral sclerosis
  - Lou Gehrig's disease
  - motor neurons degenerate
- **Myasthenia gravis**
  - auto-immune
  - antibodies to acetylcholine receptors

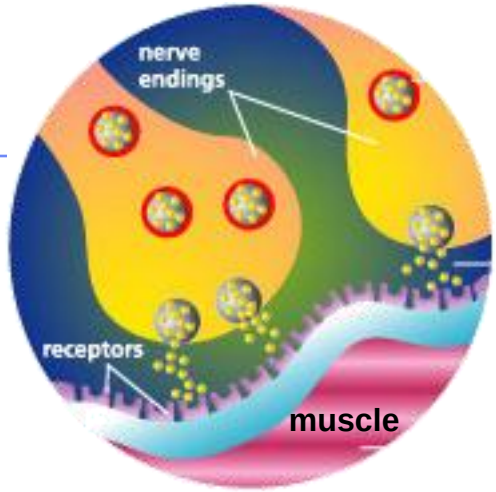


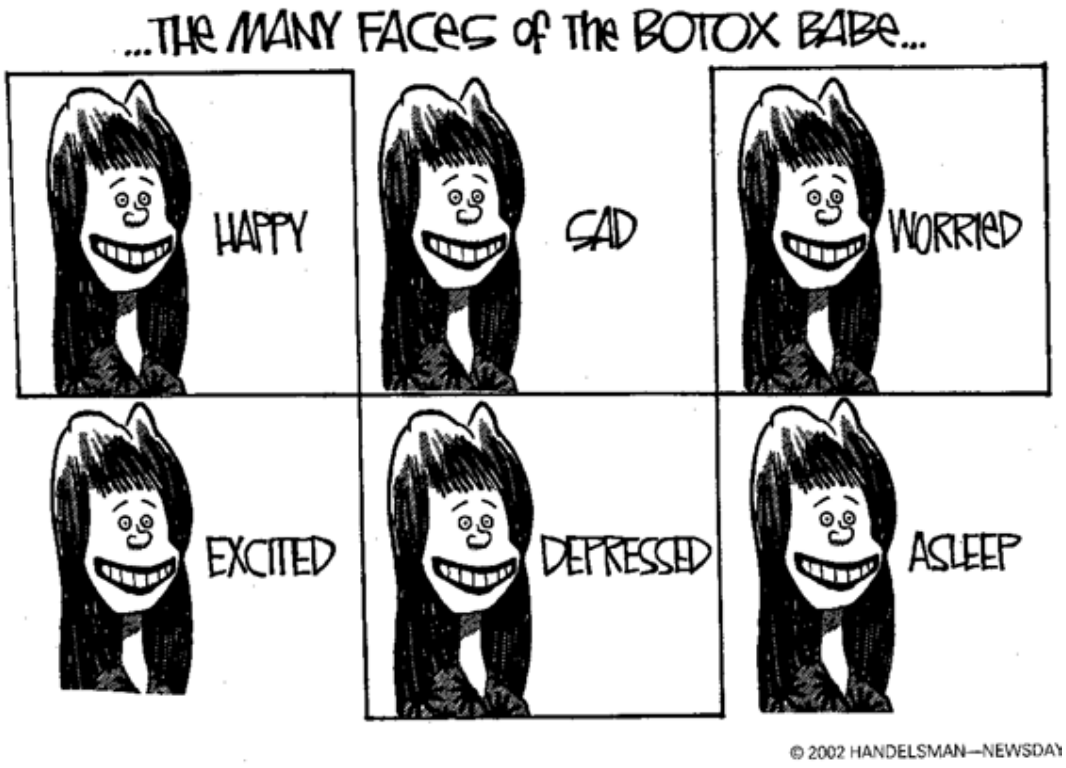


Stephen Hawking

Botox

- Bacteria *Clostridium botulinum* toxin
  - blocks release of acetylcholine
  - botulism can be fatal





Rigor mortis

- **So why are dead people "stiffs"?**
  - no life, no breathing
  - no breathing, no O_2
  - no O_2, no aerobic respiration
  - no aerobic respiration, no ATP
  - no ATP, no Ca^{2+} pumps
  - Ca^{2+} stays in muscle cytoplasm
  - muscle fibers continually contract
    - tetany or rigor mortis
  - eventually tissues breakdown & relax
    - measure of time of death

So don't be a stiff*!*
Ask Questions*!!*

Ghosts of Lectures Past (storage)

Shortening sarcomere

- Myosin pulls actin chain along toward center of sarcomere
- Sarcomere shortens (Z lines move closer together)
- Muscle contracts
  - energy from:
    - ATP
    - glycogen