Hole's Human Anatomy and Physiology

Twelfth Edition

Shier ◆ Butler ◆ Lewis

Chapter 9 Muscular System

9.1: Introduction

Animals use muscles to convert the chemical energy of ATP into mechanical work.

***Myo-*: muscle**

Muscle Actions:

Our muscles are responsible for:

- generating our heat
- all of the movement in our bodies:
  - Walking
  - Talking
  - Breathing
  - Digesting
  - Moving bodily fluids and heat around

Three different kinds of muscles are found in vertebrate animals…

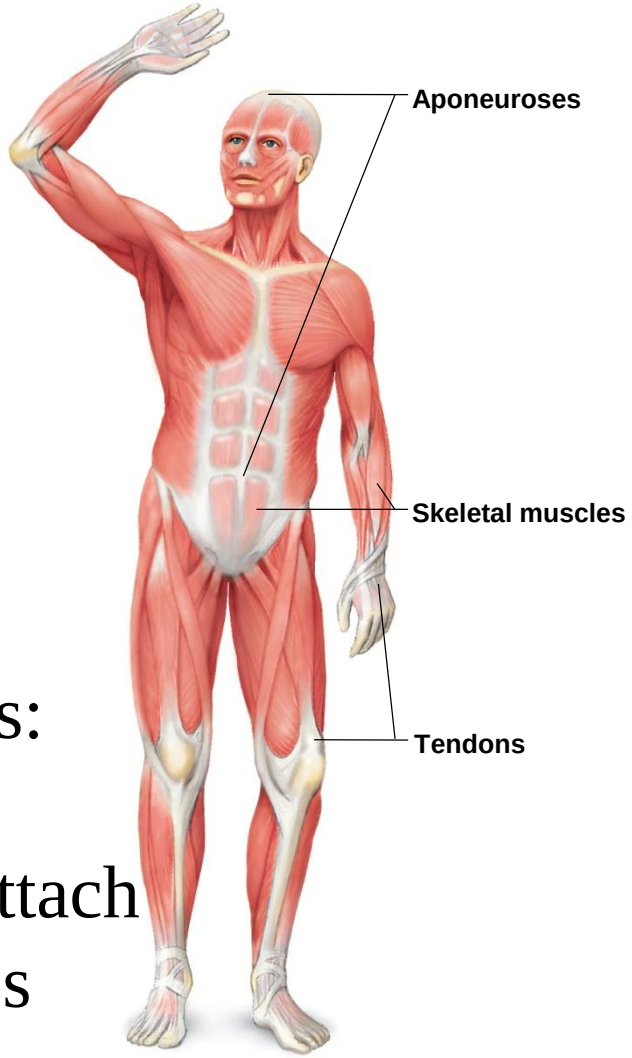
9.1: Introduction

Three (3) Types of Muscle Tissues:

- Skeletal Muscle
  - usually attached to bones via tendons; facial expression
  - voluntary
  - striated
  - multinucleate
- Cardiac Muscle
  - wall of heart
  - involuntary
  - autonomic
  - striated
  - single nucleus
- Smooth Muscle
  - walls of most viscera, blood vessels and dermis
  - involuntary
  - not striated
  - single nucleus

9.2: Structure of Skeletal Muscle

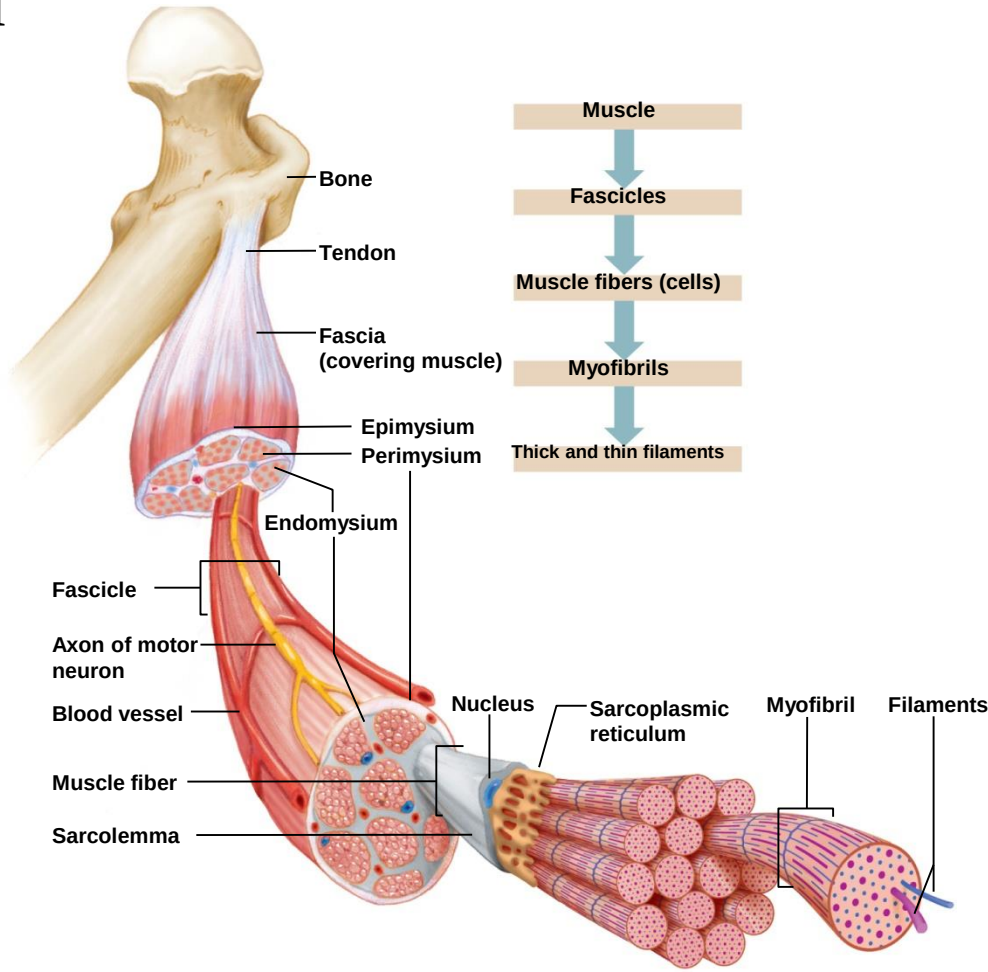
- Skeletal Muscle
  - muscles are organs
  - consists of:
    - skeletal muscle tissue
    - nervous tissue
    - blood
    - connective tissues
  - fascia –dense connective tissue that covers each skeletal muscle and forms:
    - tendons – attach muscle to bone
    - aponeuroses – attach to bone or attach to covering of neighboring muscles



Skeletal Muscle Structure

- **Connective tissues**:
  - epimysium-deep to fascia
  - perimysium: separates muscle cells into fascicles: bundles of muscle cells/fibers
  - endomysium: separates individual muscle cells/fibers within a fascicle

*blood vessels and nerves run through these connective tissues



Skeletal Muscle Structure

Skeletal muscle is made up of thousands of cylindrical **muscle fibers** often running all the way from origin to insertion.

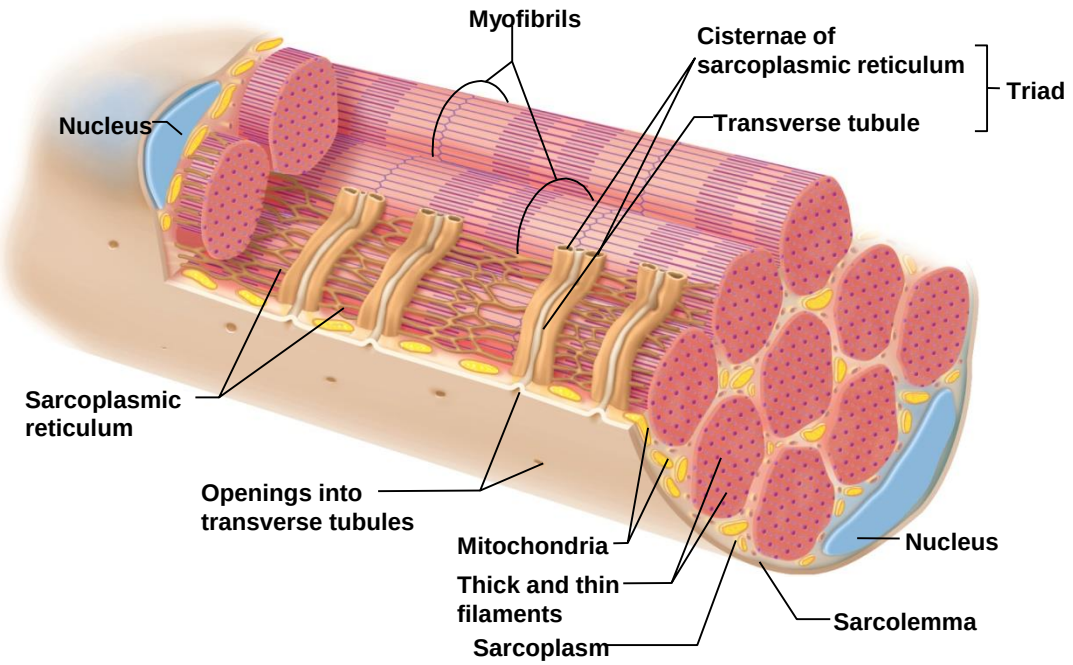
Each skeletal muscle fiber contains:

- an array of myofibrils, parallel threads of proteins filaments (actin and myosin), that run the entire length of the muscle fiber; these cause contraction at the micro-level
- Mitochondria : make a lot of ATP
- Sarcoplasmic reticulum (SR): a type of smooth ER that releases Ca^{2+} when signaled from the nervous system
- Many nuclei: provide instructions to build protein

Skeletal Muscle Structure

- Sarcolemma: cell membrane of muscle fiber
- Sarcoplasm: cytoplasm

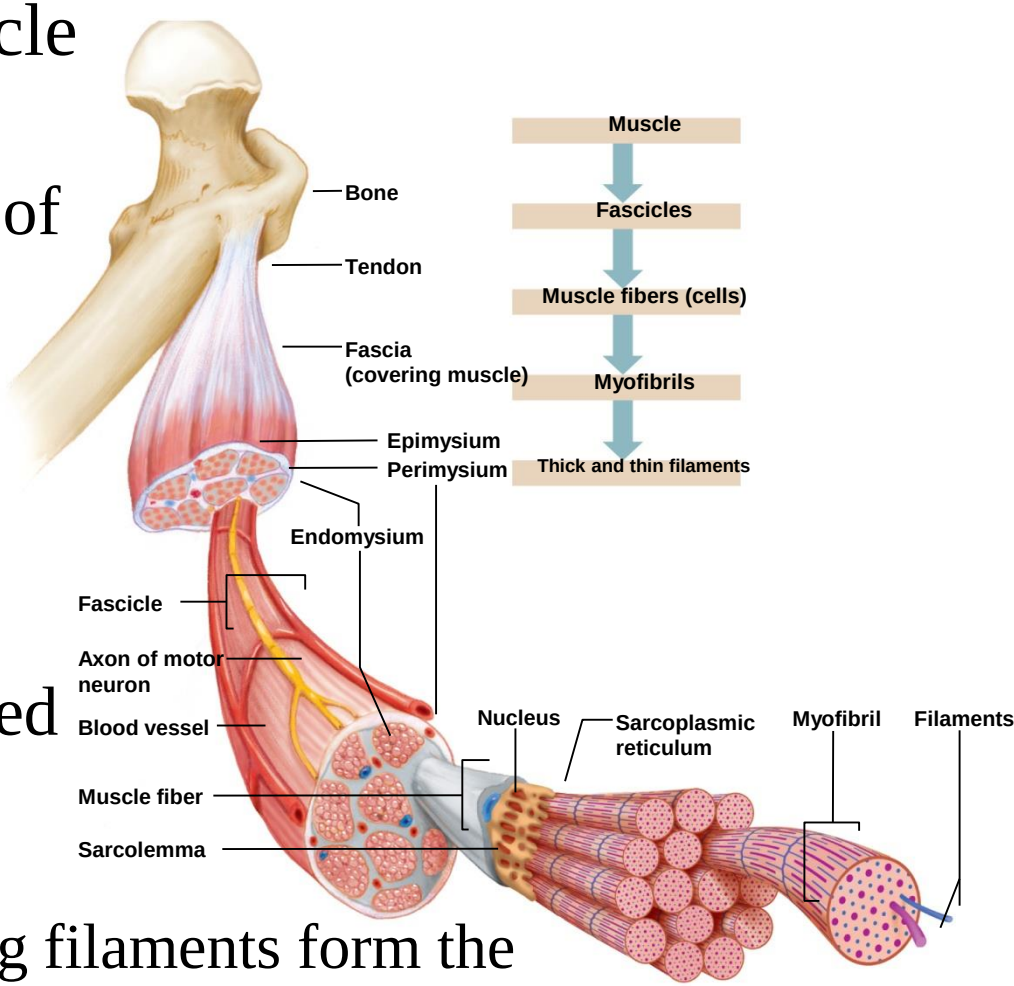
*The myofibrils consist of repeating patterns of myofilaments (thick and thin).



The repeating pattern is called a sarcomere; IOW: Myofibrils consist of sarcomeres joined end-to-end. When sarcomeres contract: the muscle fiber contracts, the fascicle contracts, and the muscle contracts (Ca^{2+} is the "go signal" that allows it to happen!)

Myofibrils, Again!

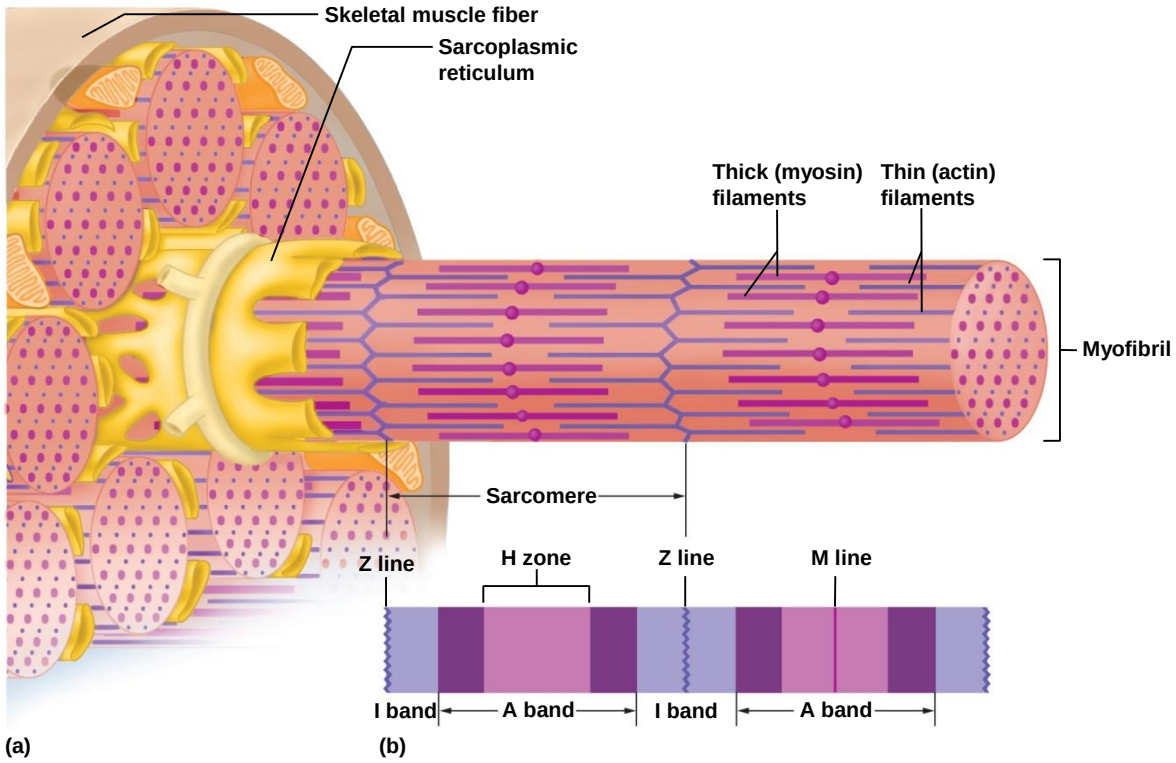
- Myofibrils – organelles, parallel threads inside of muscle cells/fibers
  - consist of two major types of protein filaments ("myofilaments"):
    - thick filaments (composed mainly of myosin)
    - thin filaments (composed of actin)



- The arrangement of alternating filaments form the striations in muscle (skeletal and cardiac); smooth muscle has less "arrangement"

9.3: Skeletal Muscle Contraction

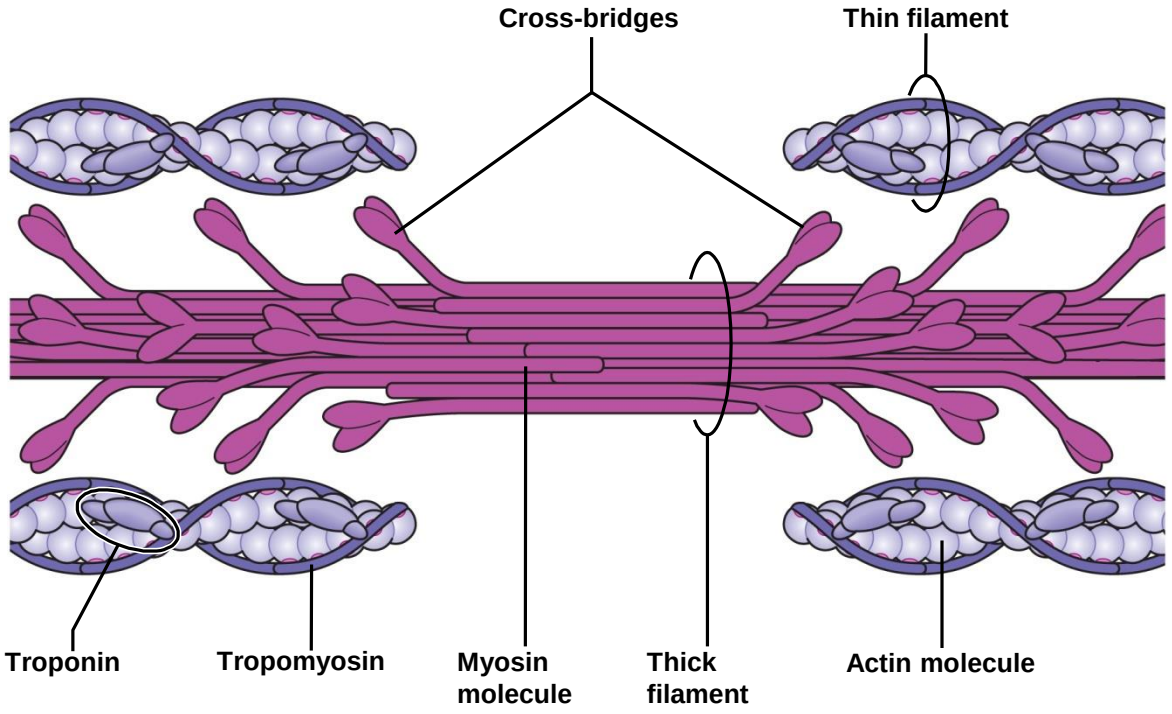
- happens when there is movement within the myofilaments
- The myosin (thick filament) grabs the actin (thin filament) and pulls it, shortening the sarcomeres (units of muscle cell) and ultimately the whole muscle!



Here's how the process works…

Myofilaments

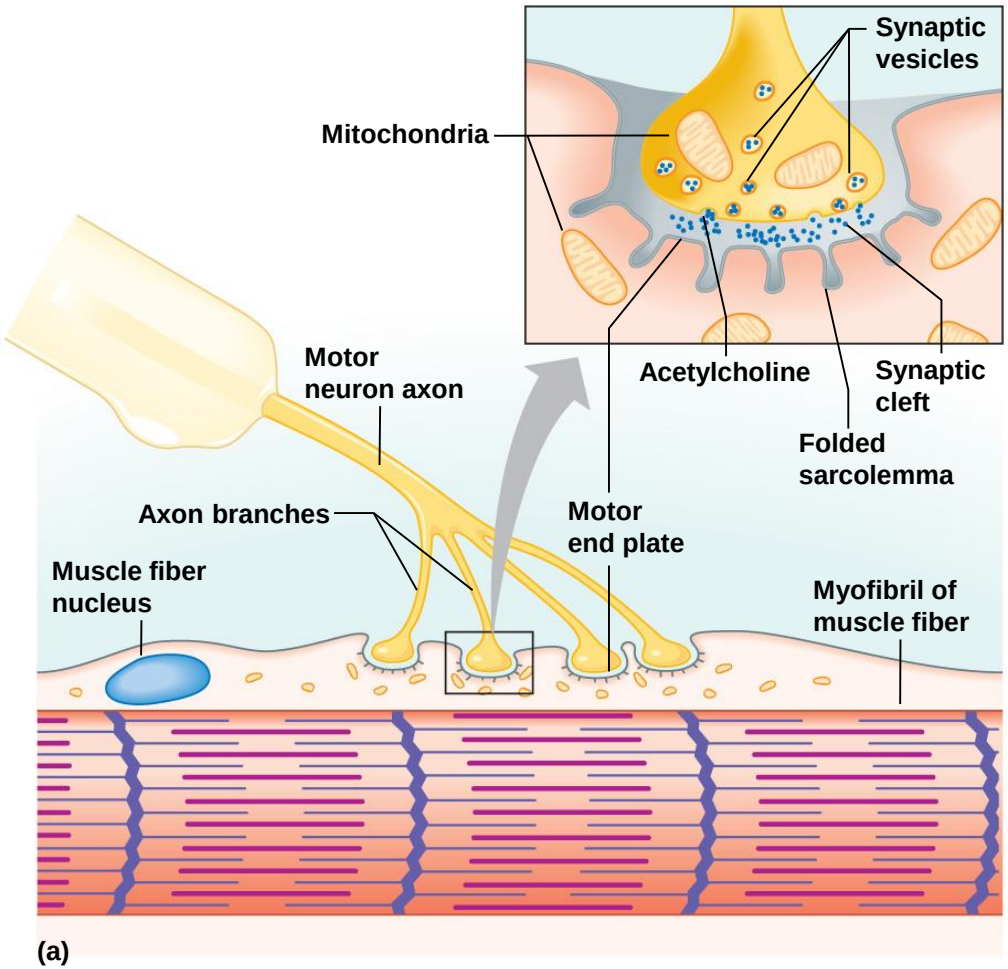
- Thick myofilaments:
  - composed of myosin protein
  - form the cross-bridges
- Thin myofilaments:
  - composed mainly of actin protein
  - associated with troponin and tropomyosin proteins



Keep in mind that nerve impulses/hormones can control muscular action…

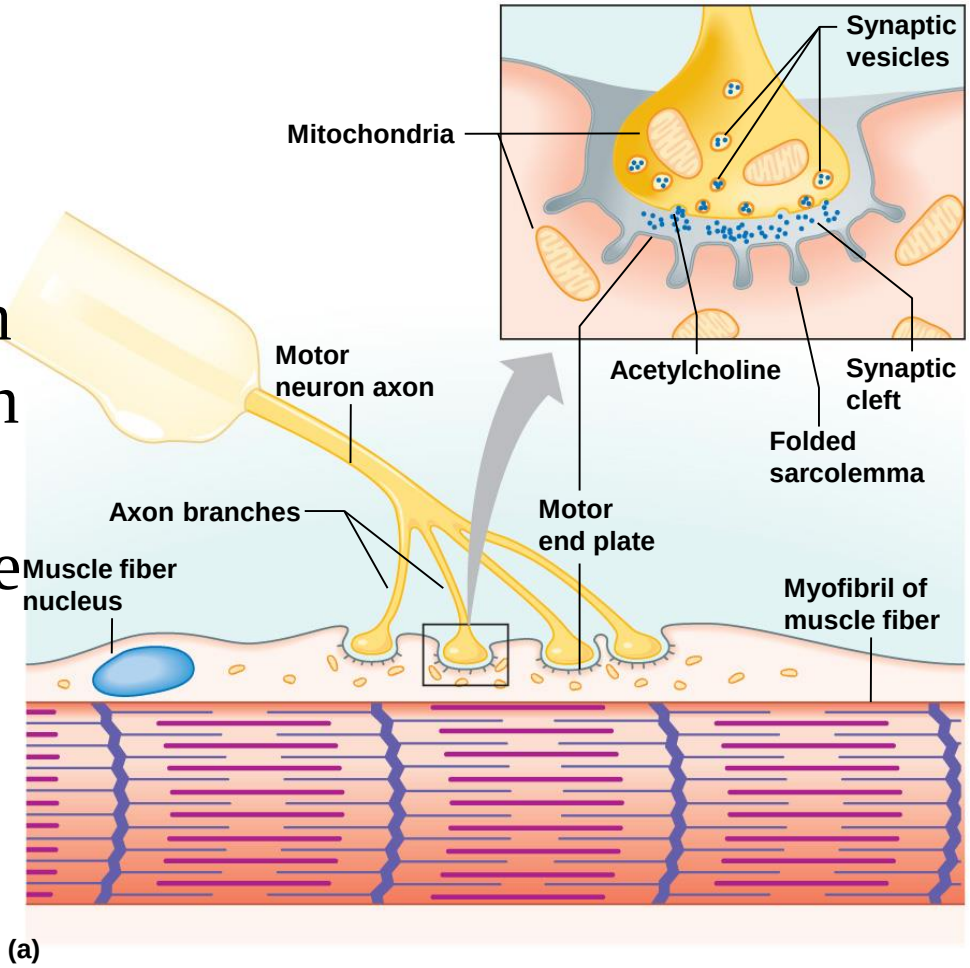
Neuromuscular Junction

- AKA "NMJ": site where an axon (extension of a neuron) and muscle fiber meet
- **Key Parts**
  - •Synapse: where a neuron (nerve cell) meets the muscle
  - •Neurotransmitters: chemical released by the neuron (b/c of nerve impulse) that signals the muscle to contract



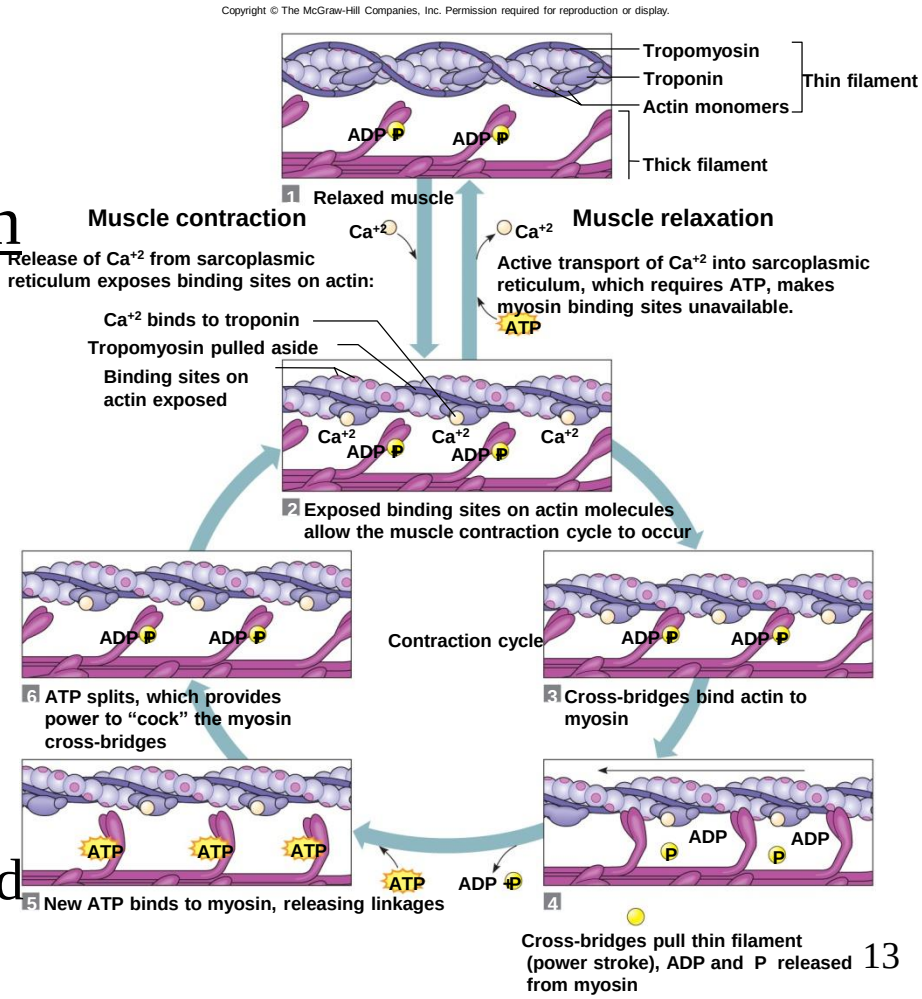
Stimulus for Contraction

- Acetylcholine (ACh) is the neurotransmitter for muscle contration.
- Nerve impulse causes release of ACh from synaptic vesicles (pouches in the neuron)
- ACh binds to ACh receptors on the motor end plate (receptors on the muscle cell/fiber)
- this generates a muscle impulse
- Muscle impulse eventually reaches the SR (sarcoplasmic reticulum)



Steps to muscle contraction

- The muscle impulses cause SR to release calcium ions into the muscle cell/fiber cytosol
- Calcium (Ca^{2+}) binds to troponin (on actin) to change its shape
- The position of tropomyosin (also on actin) is altered
- Binding sites on actin are now exposed ("hey, come bind with me")
- Actin and myosin molecules bind via myosin cross bridges (little hockey stick heads on myosin bind with actin)

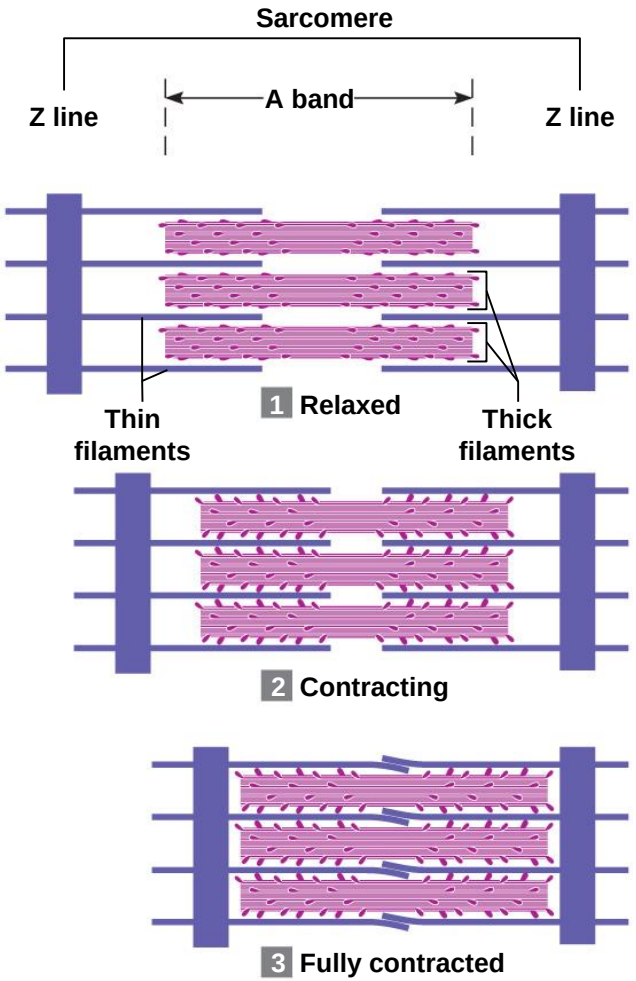


- Sarcomeres shorten as the myosin pulls the actin in: muscle contracts

The Sliding Filament Model of Muscle Contraction

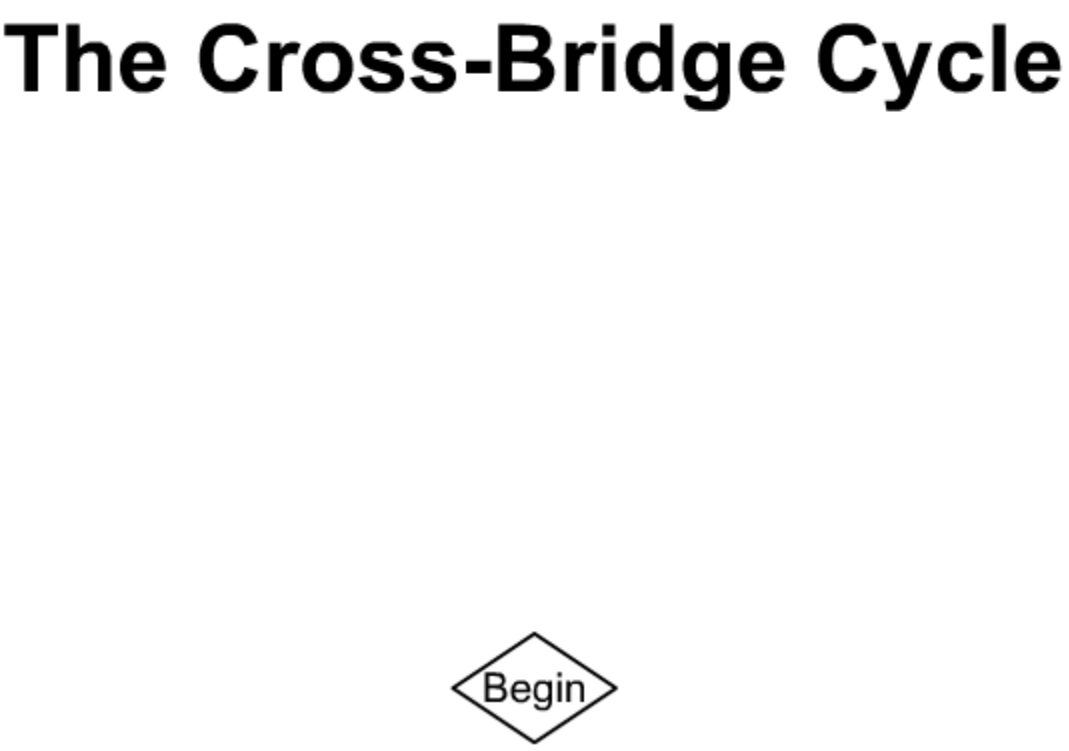
- When sarcomeres shorten, thick (myosin) and thin (actin) filaments slide past one another

- To relax: ATP is needed to break the cross bridges between thick and thin filaments



(a)

Animation: The Cross-Bridge Cycle



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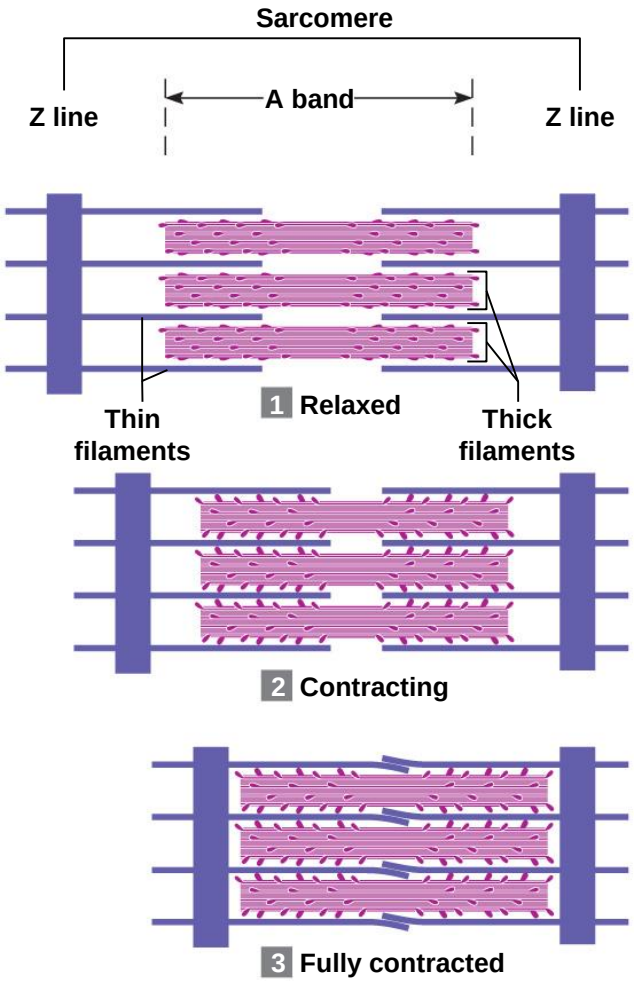
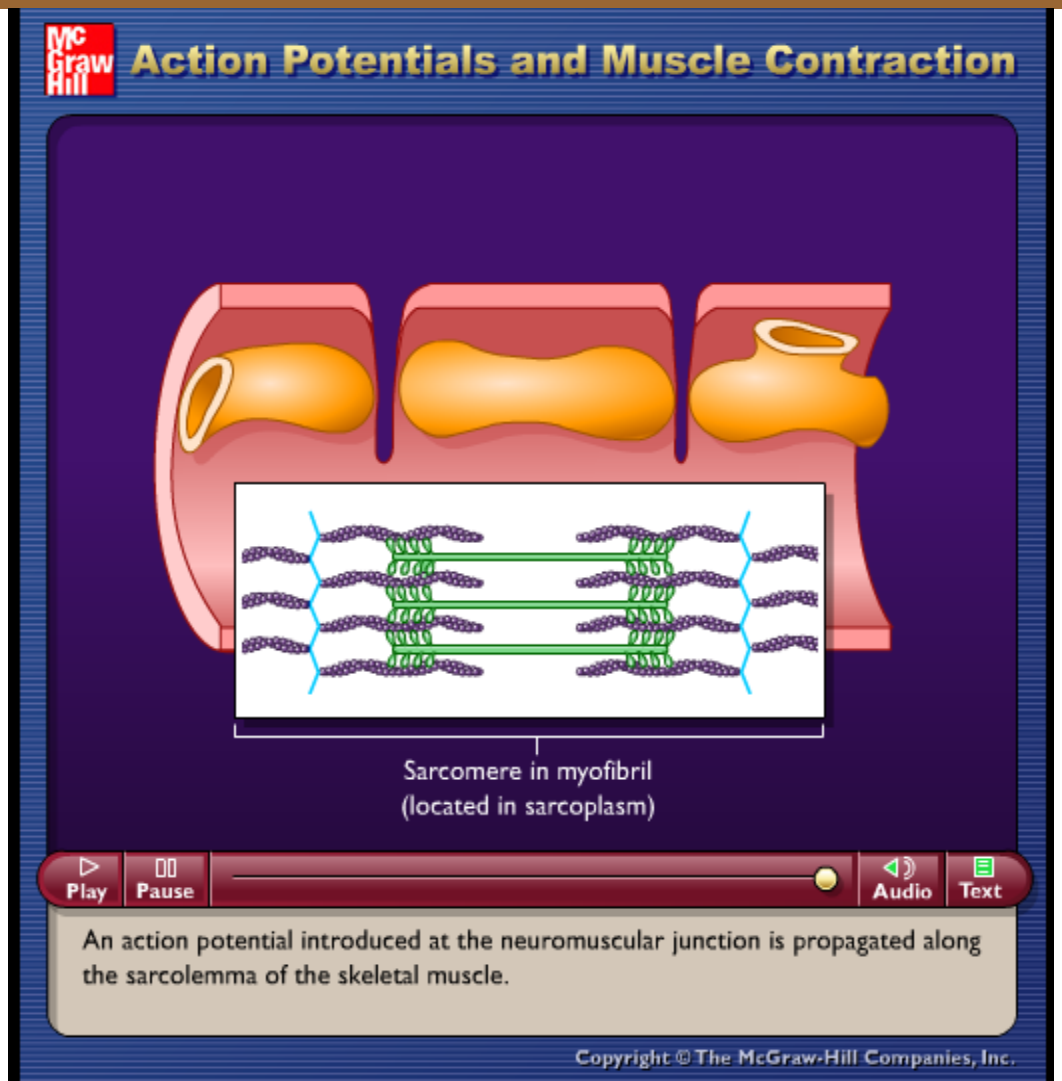


(a)

"Take home" SUMMARY of muscle contraction:

- neurotransmitter (ACh) from nerve cell signal the release of Ca^{2+} (Ca^{2+} is the final "GO SIGNAL" for contraction)
- Ca^{2+} binds to actin and causes the troponin to change its shape and the position of tropomyosin to be altered (both of these proteins are on actin) exposing the "binding sites" on actin
- Myosin (thick filament) attaches to actin and pulls it in to shorten sarcomeres of the myofibrils (organelles) in the muscle fibers (which shorten the muscle)
- ATP is necessary to break the connection between actin and myosin, to relax the contraction and for the filaments to go back to "ready stage"

Animation: Action Potentials and Muscle Contraction



Ultimate Relaxation?

- ATP is needed for relaxation of the muscle contraction; when ATP binds to the myosin cross bridge (the hockey stick thing) the myosin releases the actin causing the filaments to move apart and slide back to "starting position". (NOTE: the remaining energy in ADP is used to aid the steps of the next contraction…so ATP energy is used for relaxation, ADP energy is used for contraction)
- When a person dies, they cannot produce ATP so that is why their bodies are temporarily stiff, as the muscles can not relax right away; this is called rigor mortis. (eventually the cells die and they will "relax")

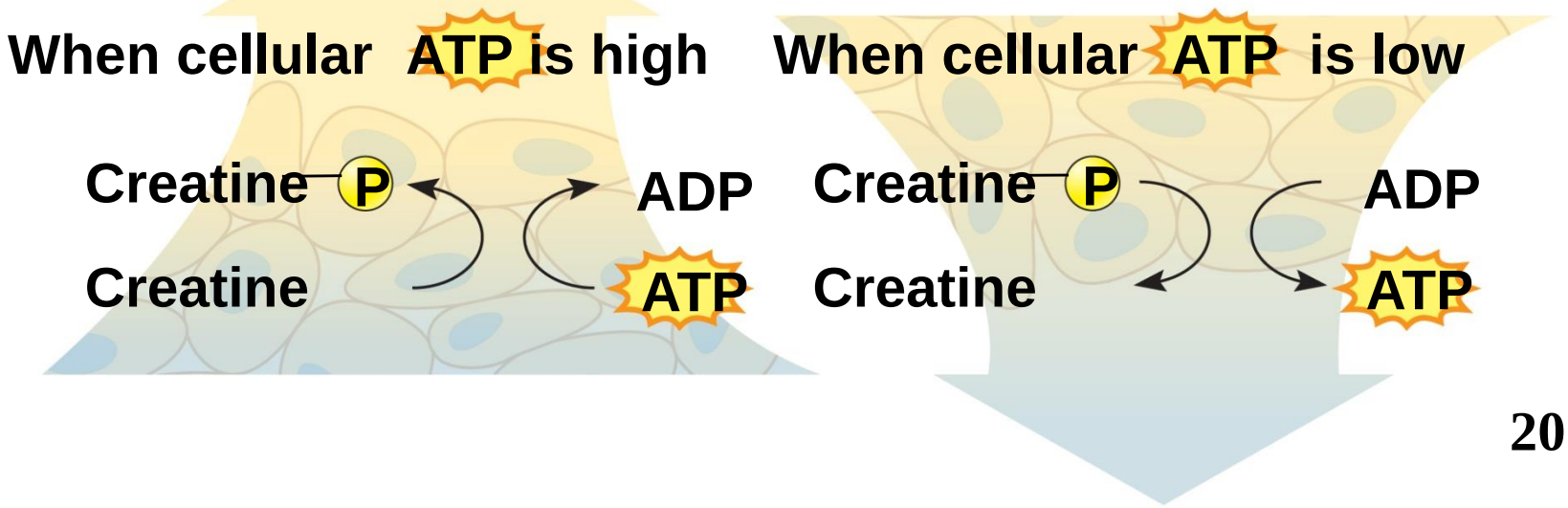
Energy Sources for Contraction

What is the source of cellular energy for muscle contraction?

Creatine phosphate and **Cellular respiration**

- *Creatine phosphate stores energy that quickly converts ADP to ATP*

***Our bodies make it from amino acids in meat and fish**



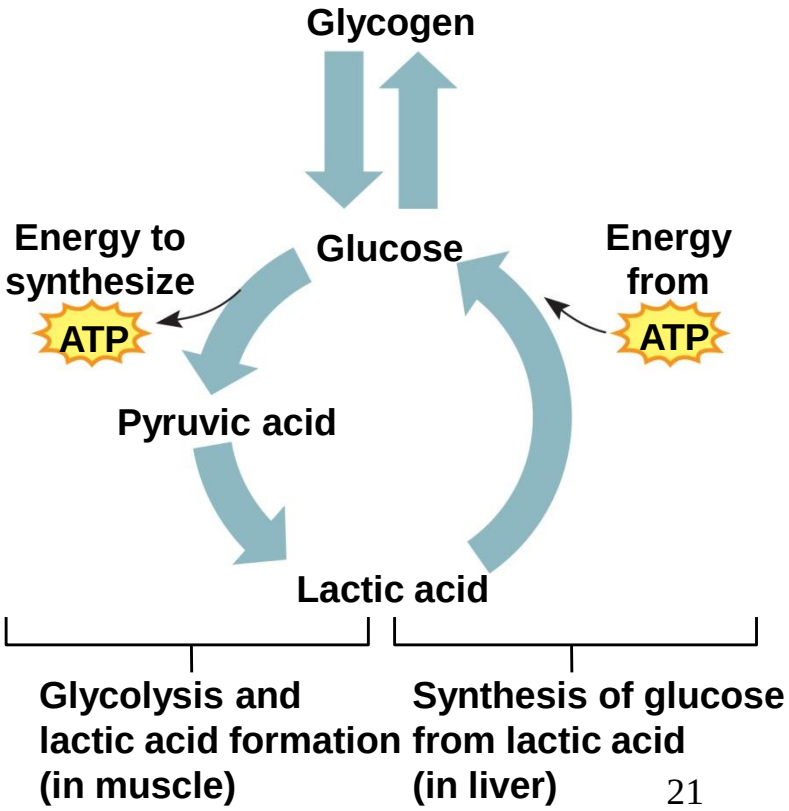
Oxygen Debt

•Oxygen debt – the additional oxygen that must be taken into the body after vigorous exercise to restore all systems to their normal states

•oxygen is necessary to reconvert lactic acid to glucose and decomposed ATP and creatine phosphate to their original states.

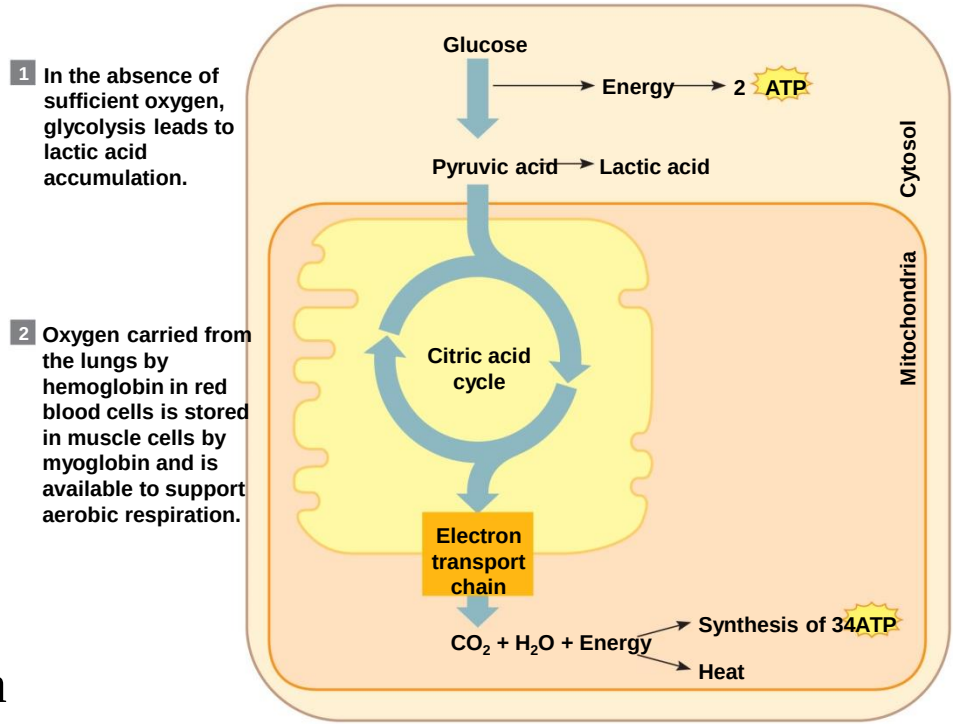
•Generated as our muscles develop lactic acid build up from fermentation

- when enough oxygen is not available the bodies switch to lactic acid fermentation,
- breathe heavily to repay after strenuous exercise…



Oxygen Supply and Cellular Respiration

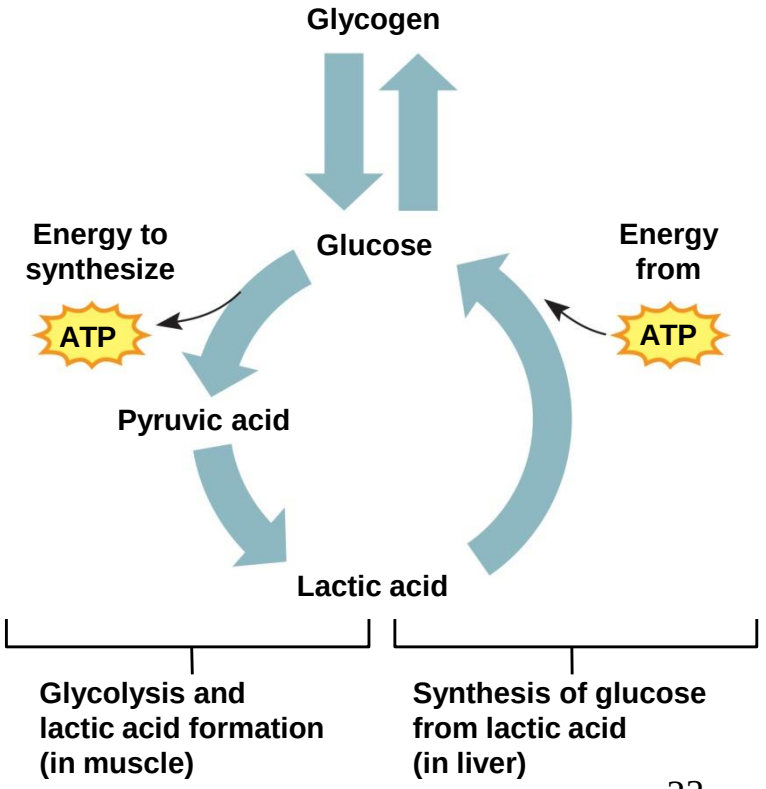
- Cellular respiration:
  - Anaerobic Phase
    - Glycolysis
    - Occurs in cytoplasm
    - Produces little ATP
  - Aerobic Phase
    - Citric acid cycle
    - Electron transport system
    - Occurs in the mitochondria
    - Produces most ATP
    - Myoglobin stores extra oxygen



Oxygen Debt (Again!)

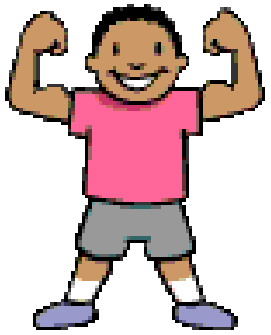
• Oxygen debt – amount of oxygen needed by liver cells to use the accumulated lactic acid to produce glucose

- Oxygen not available
- Glycolysis continues
- Pyruvic acid converted to lactic acid
- Liver converts lactic acid to glucose



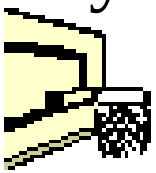
Muscle Fatigue

- Inability to contract muscle
- Commonly caused from:
  - decreased blood flow
  - ion imbalances across the sarcolemma
  - accumulation of lactic acid (product of fermentation!)
- Cramp – sustained, involuntary muscle contraction

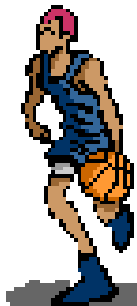


Oxygen Debt and Athletes

Highly trained athletes can have maximal oxygen uptakes that are *twice* that of average people, probably owing to a combination of genetics and training. As a result, they are capable of greater muscular activity without increasing their lactic acid production, and their oxygen debts are less. It is for these reasons that they do not become short of breath as readily as untrained individuals.



•anaerobic threshold - the amount of work done before lactic acid begins to accumulate in the blood.



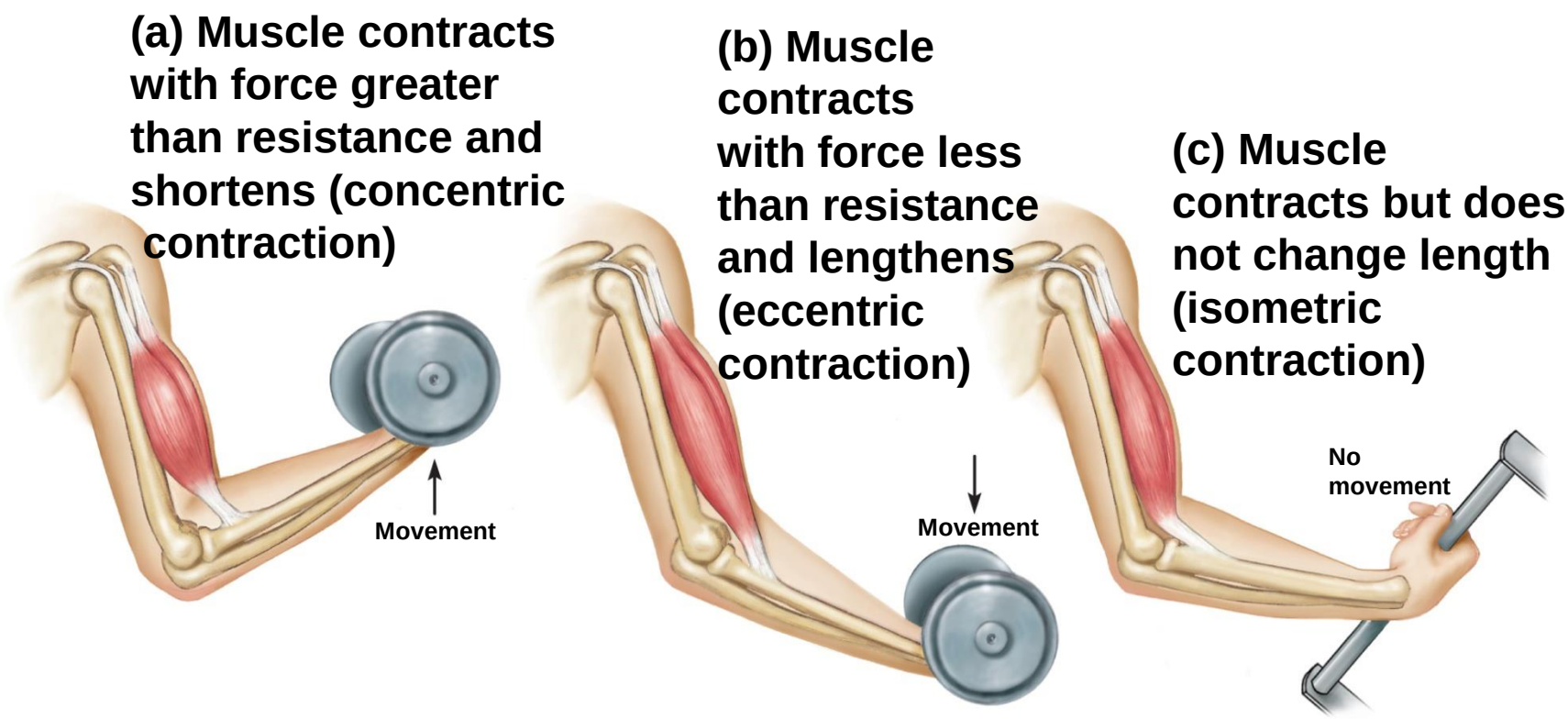
Aerobic v. Anaerobic Exercise

- **Anaerobic exercise** (no oxygen, using glycolyis, lactic acid fermentation to break down glucose to make ATP) comprises brief, strength-based activities, such as sprinting or bodybuilding, whereas **aerobic exercise** (using oxygen to break down glucose to make ATP) is centered around endurance activities, such as marathon running or long-distance cycling.
  - However, the earliest stage of all exercise is anaerobic.
  - anaerobic exercise examples include: weight lifting, sprinting, and jumping; any exercise that consists of short exertion, high-intensity movement, is an anaerobic exercise.

Types of Contractions

- Isotonic: muscle contracts *and* changes length
  - Concentric: shortening contraction
  - Eccentric: lengthening contraction

- Isometric: muscle contracts but *does not* change length



"Slow Twitch" and "Fast Twitch" Muscle Fibers

Slow-twitch fibers (Type I)

- "Red fibers"
  - Most myoglobin and mitochondria
  - Good blood supply (Have all the "machinery" to generate enough ATP for extended amt. of time)
  - AKA "Oxidative fibers": highest aerobic capacity – can perform aerobic for a long time w/o tiring
  - Resistant to fatigue

* Marathon runners have more of these

Fast-twitch fibers (Type IIb)

- "White fibers" (less myoglobin, mitochondria)
- AKA "Glycolytic fibers": perform glycolysis/anaerobic after CP used up
- Contract rapidly
- Fatigue easier (than slow twitch fibers) from lactic acid build-up

*Sprinters have more of these

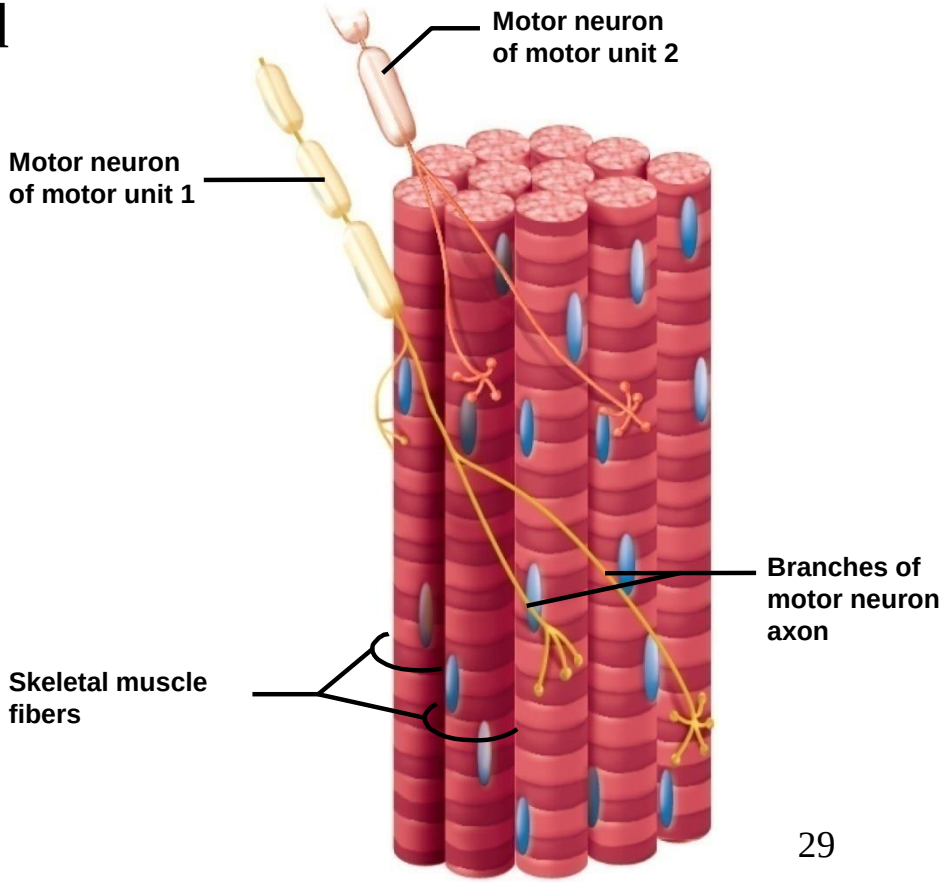
*make up majority of fibers in hand and eye muscles…

Fast-twitch, fatigue-resistant fibers (Type IIa)

- "Intermediate fibers"
- Fast-twitch speed with w/more oxidative capacity

Motor Unit

- Single motor neuron
- All muscle fibers controlled by motor neuron
- As few as four fibers
- As many as 1000's of muscle fibers



Relaxation

- Acetylcholinesterase – rapidly decomposes Ach remaining in the synapse
- Muscle impulse stops
- Stimulus to sarcolemma and muscle fiber membrane ceases
- Calcium moves back into sarcoplasmic reticulum (SR)
- Myosin and actin binding prevented
- Muscle fiber relaxes

Recruitment of Motor Units

- Recruitment - increase in the number of motor units activated

- Whole muscle composed of many motor units
- More precise movements are produced with fewer muscle fibers within a motor unit
- As intensity of stimulation increases, recruitment of motor units continues until all motor units are activated

Sustained Contractions

- Smaller motor units (smaller diameter axons) - recruited first
- Larger motor units (larger diameter axons) - recruited later
- Produce smooth movements
- Muscle tone – continuous state of partial contraction