NOTES:
The Muscular System (Ch 6, part 1)
The muscular system consists of three types of muscle tissue:

- **Skeletal**
- **Smooth**
- **Cardiac**
STRUCTURE OF A SKELETAL MUSCLE:

*Individual muscles are the organs of the muscular system. They contain skeletal muscle tissue, nervous tissue, blood, and connective tissues.
Connective Tissue Coverings:

• **FASCIA:**
  - covers skeletal muscles
  - separates individual skeletal muscles from adjacent muscles
  - hold muscles in position
  - may project beyond muscle to form a cordlike **TENDON**
  - fibers in tendon may intertwine with fibers in a bone’s periosteum, attaching muscle to bone!
• OTHER CONNECTIVE TISSUES:
  - attach muscles to bones or to other muscles
  - a network of connective tissue extends throughout the muscular system
  - include these tissues:
    • **epimysium**: closely surrounds a skeletal muscle (underneath the fascia)
    • **perimysium**: extends inward from the epimysium and separates the muscle tissue into small compartments called **FASCICLES**
    • **endomysium**: surrounds each individual muscle fiber within a fascicle
Skeletal Muscle Fibers:

- each muscle fiber is a single muscle cell, which is the unit of contraction

- just beneath the cell membrane (SARCOLEMMA), the cytoplasm (SARCOPLASM) contains:
  
  - many small, oval nuclei
  
  - mitochondria
  
  - SARCOPLASMIC RETICULUM (a modified endoplasmic reticulum)
  
  - MYOFIBRILS (of actin and myosin)
Skeletal Muscle Fibers:

**the organization of actin and myosin filaments produces STRIATIONS (bands)**

**the thick (myosin) and thin (actin) filaments are organized into structural units called SARCOMERES**
Transverse sections

Actin (thin filaments)
Myosin (thick filament)
Actin + myosin

Z line
H zone
A band
Sarcomere

I line
Z line
Also part of a muscle fiber...

**TRANSVERSE TUBULES** (T tubules) extend inward from the cell membrane and associate with the SARCOPLASMIC RETICULUM (whose membranes surround each myofibril)
Neuromuscular Junction:

- **MOTOR NEURONS** stimulate muscle fibers to contract

- In response to a nerve impulse, the end of a motor neuron axon secretes a **NEUROTRANSMITTER**, which stimulates the muscle fiber to contract
Neuromuscular Junction:

- one **MOTOR NEURON** and the **MUSCLE FIBERS** associated with it constitute a **MOTOR UNIT**

- all muscle fibers of a motor unit contract together!
SKELETAL MUSCLE CONTRACTION

*Muscle fiber contraction results from a sliding movement of actin and myosin filaments.

(known as the SLIDING FILAMENT MODEL in which individual sarcomeres shorten)
Role of MYOSIN and ACTIN:

- **cross-bridges** of myosin filaments form linkages with actin filaments

- the reaction between actin and myosin filaments generates the force of contraction
ATTACHED—At the start of the cycle shown in this figure, a myosin head lacking a bound nucleotide is locked tightly onto an actin filament in a rigor configuration (so named because it is responsible for rigor mortis, the rigidity of death). In an actively contracting muscle this state is very short-lived, being rapidly terminated by the binding of a molecule of ATP.

RELEASED—A molecule of ATP binds to the large cleft on the “back” of the head (that is, on the side farthest from the actin filament) and immediately causes a slight change in the conformation of the domains that make up the actin-binding site. This reduces the affinity of the head for actin and allows it to move along the filament. (The space drawn here between the head and actin emphasizes this change, although in reality the head probably remains very close to the actin.)

COCKED—The cleft closes like a clam shell around the ATP molecule, triggering a large shape change that causes the head to be displaced along the filament by a distance of about 5 nm. Hydrolysis of ATP occurs, but the ADP and P_i produced remain tightly bound to the protein.
FORCE-GENERATING—The weak binding of the myosin head to a new site on the actin filament causes release of the inorganic phosphate produced by ATP hydrolysis, concomitantly with the tight binding of the head to actin. This release triggers the power stroke—the force-generating change in shape during which the head regains its original conformation. In the course of the power stroke, the head loses its bound ADP, thereby returning to the start of a new cycle.

ATTACHED—At the end of the cycle, the myosin head is again locked tightly to the actin filament in a rigor configuration. Note that the head has moved to a new position on the actin filament.
OTHER PROTEINS INVOLVED:

- TROPONIN and TROPOMYOSIN: together form a complex that covers the myosin-binding sites on actin; by covering these binding sites, myosin cannot bind to actin and a contraction cannot occur.
Role of Calcium in Muscle Contraction

- Myosin head
- Tropomyosin
- Actin
- Binding sites for cross-bridges blocked

- Ca++
- Binding sites for cross-bridges exposed
Stimulus for and Steps of...a CONTRACTION:

> **ACETYLCHELINE** (a neurotransmitter) is released from the distal end of a motor neuron axon and stimulates a skeletal muscle fiber

> acetylcholine causes the muscle fiber to conduct an impulse over the surface of the fiber that reaches deep within the fiber through the **TRANSVERSE TUBULES**

> a muscle impulse signals the sarcoplasmic reticulum to release **CALCIUM IONS**
Steps of a Muscle Contraction…

> calcium ions bind to troponin protein &
  tropomyosin is pulled aside, uncovering
  the myosin-binding sites on actin

> linkages form between actin and myosin

> the myosin cross-bridges pull on actin
  filaments, shortening the fiber
Tropomyosin

Actin filament

Troponin

Myosin binding site

+ Ca^{2+}

Ca^{2+}
1. Action potential causes depolarization and release of $\text{Ca}^{2+}$

2. $\text{Ca}^{2+}$ exposes myosin binding sites; myosin heads bind to actin
3. Power stroke; filaments slide past one another

4. ATP binds to myosin, causing it to release actin
5. ATP is hydrolyzed and myosin heads return to resting position

6. If Ca\(^{2+}\) is returned to sarcoplasmic reticulum, muscle relaxes

7. If Ca\(^{2+}\) remains available, the cycle repeats and muscle contraction continues
The end of a contraction...

- The muscle fiber relaxes (and the contraction ends) when cross-bridges release from actin and when calcium ions are actively transported back into the sarcoplasmic reticulum (without calcium present, the troponin-tropomyosin complex re-covers the myosin-binding sites on actin).

- Acetylcholine is broken down by the enzyme ACETYLCHOLINESTERASE.
Energy Sources for Contraction

- ATP supplies the energy for muscle fiber contraction

- for sustained muscle contractions, a molecule called creatine phosphate is used to make more ATP
Oxygen Supply and Cellular Respiration

- **aerobic respiration** requires oxygen

- **red blood cells** carry oxygen to body cells (oxygen binds to **HEMOGLOBIN** in the RBCs)

- **MYOGLOBIN** in muscle cells temporarily stores oxygen
Oxygen Debt

- during rest or moderate exercise, muscles receive enough oxygen to respire aerobically

- during strenuous exercise, oxygen deficiency may cause **lactic acid** to accumulate

- **Oxygen Debt** is the amount of oxygen required to convert accumulated lactic acid to glucose and to restore supplies of ATP

**the metabolic capacity of a muscle may change with training!**
Muscle Fatigue:

- a fatigued muscle loses its ability to contract

- muscle fatigue is usually due to **accumulated lactic acid**
Heat Production

**muscle action is an important source of body heat!**