

7

The Muscular System

Tips for Success as You Begin

Read Chapter 7 from your textbook before attending the class. Listen when you attend the lecture and fill in the blanks in this notebook. You may choose to complete the blanks before attending the class as a way to prepare for the day's topics. The same day you attend the lecture, read the material again, and complete the exercises after each section in this notebook. Start studying early and study this material often—you are now encountering some more complex physiology as well as numerous skeletal muscles you may have to learn.

Introduction

LEARNING OBJECTIVE 1. Indicate the primary function of muscles.

Recall from Chapter 4 the three types of muscle tissue:

1. Smooth muscle
2. Cardiac muscle
3. Skeletal muscle

Which of the three tissue types is the major component of the roughly 600 muscles in the human body?

Skeletal

Skeletal muscle tissue contracts (shortens) to move the bones to which it is attached. The three major functions of the muscular system are:

1. **Movement**: Movement relies on the integration of bones, nerves, joints, and nearby muscles to produce a movement.
2. **Support**: Rigid connections hold the body in an upright posture and strengthen the frame.
3. **Heat production**: Movement produces heat that helps to maintain body temperature.

CONCEPT 1

Muscle Structure

Concept: A muscle is an organ bound by several layers of connective tissue and mainly consists of skeletal muscle tissue. Each skeletal muscle cell is a long filamentous fiber containing contractile proteins in a highly ordered arrangement.

LEARNING OBJECTIVE 2. Describe the connective tissues associated with muscles.

Muscles usually extend from one bone to another. Muscles are a combination of skeletal muscle tissue, connective tissue, nerves, and a blood supply.

Connective Tissues of Muscle

The most abundant connective tissue associated with muscle is **fascia**.

- **Superficial fascia** exists between skin and muscles or it may surround muscles.
- **Deep fascia** is part of the muscle, the organ. Deep fascia internally divides the muscle and is composed of connective tissue rich in **collagen** fibers.

Layers of Deep Fascia in Muscle

The following three layers are deep fascia. Each layer brings blood vessels and nerves to the deep compartments of muscle and provides support to the muscle.

1. **Epimysium** surrounds the entire muscle, covering it like a sheath.
2. **Perimysium** divides the muscle into compartments, known as **fascicles**. Fascicles are bundles of skeletal muscle cells.
3. **Endomysium** is the thinnest, innermost fascia that surrounds each individual muscle cell.

Connecting Muscle to Bone and Muscle to Muscle

- **Tendons** are narrow bands formed from the union of the three layers of deep fascia found in the muscle. Tendons attach the muscle to the bone. Do you recall the type of connective tissue that forms tendons? **dense regular connective tissue**
- **Aponeuroses** are broad sheets of dense connective tissue that anchor muscles to bone or muscles to other muscles.

Other tissues associated with muscle include loose connective tissue (areolar tissue) and adipose tissue.

TIP! Build your own muscle, complete with connective tissue layers.

What you'll need: A handful of straws (with paper wrappers), one paper plate, several napkins, or paper towels.

How to build your muscle: Each straw is a muscle cell. The paper covering on the straw is deep fascia known as the endomysium. Take a bundle of straws in your hand. You now hold a fascicle (bundle) of muscle cells; each muscle cell is individually wrapped by its own endomysium. Use the napkin or paper towel to wrap this bundle. The napkin serves as the perimysium. Do the same to create more fascicles of straws with a paper towel perimysium. Finally, take the paper plate and wrap all of your bundles. The paper plate is the muscle's epimysium.

Microscopic Structure of Muscle

LEARNING OBJECTIVE 3. Identify and describe the microscopic components of skeletal muscle tissue.

Muscle cells are also known as muscle fiber. Muscle cells are unique in that they are multinucleate.

- The plasma membrane of a muscle cell is called the sarcolemma and the cytoplasm is termed sarcoplasm.
- Muscle cells contract and return to their original strength. To accommodate this function, many mitochondria work to produce ATP for contractions.
- **Sarcoplasmic reticulum (SR)** is a membranous sac that stores calcium for muscle contractions.
- **Transverse (T) tubules** are tubes situated between the SR; they unite with the sarcolemma. T tubules form channels to enable the quick flow of ions between the sarcoplasm and the SR.
- **Myofibrils** are cylindrical cords of protein deep to the SR that lay parallel to one another. Myofibrils have two kinds of proteins: **thick filaments** and **thin filaments**.
 1. What protein forms the thick filaments? myosin
 2. What proteins form the thin filaments? actin, troponin, tropomyosin
- The myosin filaments composing of the thick filaments have swellings known as **heads** (cross bridges) while actin, troponin, and tropomyosin form a thin filament.

Patterns of Filaments

Thick and thin filaments create a light–dark striation pattern that is identical in muscle fibers. The arrangement is discussed next.

- **A band:** A *dark* region where thick and thin filaments overlap. “A” comes from **anisotropic**.
- **H zone:** A region within the A band where only thick filaments are found.
- **I band:** A *light* region where only thin filaments are found. “I” comes from **isotropic**.
- **Z lines:** A strand of proteins with a zig-zag appearance that intersects the thin filaments at regular intervals.
- **Sarcomere:** Distance between two adjacent Z lines. Each sarcomere contains half of two I bands on either side of an A band. The sarcomere is the primary structural and functional unit of a muscle fiber.

TIP! Remember that the “I” in light bands reminds us that I bands are the light bands. Likewise, the “A” in dark bands reminds us that A bands are dark bands.

Review Time!

- I. Using the terms in the list below, write the appropriate muscle anatomy in each blank. You may use a term more than once.

Myofibril

Sarcolemma

Sarcoplasm

Sarcoplasmic reticulum

Thick filaments

Thin filaments

Transverse (T) tubules

1. Type of protein filament composed of myosin
2. Enables the flow of ions between the sarcoplasm and the sarcoplasmic reticulum
3. Another name for the cytoplasm of a muscle fiber

Thick filament

Transverse (T) tubules

Sarcoplasm

4. Stores calcium ions for muscle contractions
5. Type of protein filament composed of actin, troponin, and tropomyosin
6. Another name for the plasma membrane of the muscle fiber
7. Has swellings known as heads (cross bridges)
8. May be composed of thick or thin filaments
9. Connected to the sarcoplasmic reticulum and the sarcoplasm
10. Membranous sac similar to the endoplasmic reticulum in other cells

Sarcoplasmic reticulum

Thin filaments

Sarcolemma

Thick filaments

Myofibril

Transverse tubules

Sarcoplasmic reticulum

II. Using the terms in the list below, write the appropriate part of the sarcomere in each blank. You may use a term more than once.

A band

H zone

I band

Sarcomere

Z line

1. Region where only thin filaments are found
2. Isotropic
3. Structural and functional unit of the muscle fiber
4. Zig-zag appearance to a strand of proteins
5. Light region
6. Segment between two adjacent Z lines
7. Protein strands that intersect the thin filaments at regular intervals
8. Dark region
9. Region within the A band where only thin filaments are found
10. Region where thin and thick filaments overlap

I band

I band

Sarcomere

Z lines

I band

Sarcomere

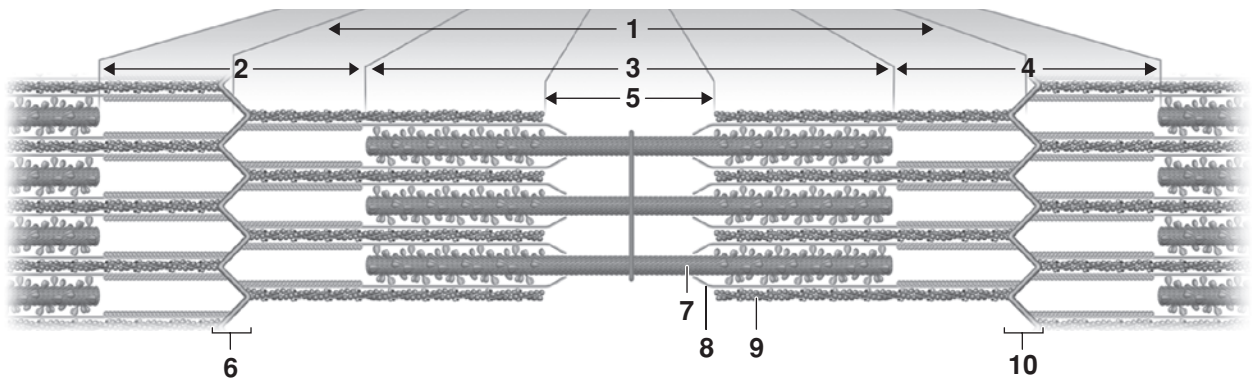
Z line

A band

H zone

A band

III. Using the terms in the list below, label this sarcomere of skeletal muscle. You may use a term more than once.



1. Sarcomere

2. I band

3. A band

4. I band

5. H zone

6. Z lines

7. Thick filament

8. Elastic filament

9. Thin filament

10. Z line

A band

Elastic filament

H zone

I band

Sarcomere

Thick filament

Thin filament

Z line

IV. Provide a brief answer for each of the following questions.

- Place the following layers of fascia in order from superficial to deep: endomysium, epimysium, perimysium. Epimysium
Perimysium
Endomysium
- Under the microscope, you see alternating light and dark bands when viewing a section of skeletal muscle tissue. Explain what forms those light and dark bands. The thin and thick filaments of the sarcomere overlap each other and form the banding pattern of the myofibril.
- Describe the function of the transverse (T) tubules. The transverse (T) tubules form channels between the sarcoplasm and sarcoplasmic reticulum so ions can flow freely.
- What does the distance between two adjacent Z lines create? sarcomere
- Why does a muscle fiber need hundreds of mitochondria? Mitochondria create ATP. ATP is energy needed for muscle contraction.
- Complete this sentence with an appropriate directional term: The sarcolemma is deep to the endomysium.
- Describe the two types of filaments that form the myofibril. Thick filaments are made of the protein myosin. Thin filaments contain either actin, tropomyosin, or troponin.
- Compare and contrast the function of tendons and aponeuroses. They are both made of dense connective tissue and are usually made to connect muscle to bone. Tendons are a narrow band of dense regular connective tissue that undergo a lot of stress. Aponeuroses are broad flat sheets used to connect muscle to bone and sometimes to muscle.
- Complete this sentence with an appropriate directional term: The sarcoplasm is deep to the sarcolemma.
- What is a fascicle? a bundle of skeletal muscles (myofibrils)
What type of fascia wraps fascicles? perimysium

Nerve Supply

Since a muscle fiber is unable to contract on its own, it must rely on stimulation from nerve impulses to contract.

- Motor neuron** is the nerve cell that originates in the brain or spinal cord and travels to the muscle.
- Synaptic knobs** (bulbs) are the branched distal ends of the motor neuron. The synaptic knobs are slightly enlarged. *Each* synaptic knob forms a junction with *one* muscle fiber.
- Motor unit** is the functional unit consisting of a single motor neuron, its branches, and the numerous muscle fibers innervated by the neuron. An impulse carried by the single motor neuron will stimulate all the muscle cells in the motor unit to contract.
- Motor end plate** is a highly folded region of the sarcolemma (muscle cell's plasma membrane) that has many receptors embedded within the phospholipid bilayer.
- Synaptic cleft** is a fluid-filled gap between the synaptic knob of a motor neuron and the motor end plate of a muscle fiber.

- **Neuromuscular junction** includes the synaptic knob of a motor neuron, the synaptic cleft, and the sarcolemma of a muscle fiber.
- **Synaptic vesicles** are located in the cytoplasm of the synaptic knob of a motor neuron. These vesicles contain a chemical called a **neurotransmitter**. Neurotransmitters transmit nerve signals from one neuron to a **motor neuron** or **a muscle**. The specific type of neurotransmitter housed in the vesicle is **acetylcholine**, or **ACh**.

Nerve Impulse Transmission

1. Nerve impulse arrives at the terminal end of a motor neuron. Acetylcholine (ACh) is stimulated to be released from synaptic vesicles.
2. Once released, ACh diffuses across the **synaptic cleft** and binds with receptors in the motor end plate of the muscle fiber.
3. Binding of ACh to receptors triggers muscle contraction (our next topic).

Review Time!

I. Provide a brief answer for each of the following questions.

1. Explain how the motor unit and neuromuscular junction differ. **The motor unit is the motor neuron, all of its branches, and the muscle fibers it stimulates. The neuromuscular junction is the place where the motor neuron knob, end plate, and synaptic cleft come together.**
2. What is a neurotransmitter? What is its function? **A neurotransmitter is a chemical that transmits information from one neuron to another or to a muscle.**
3. Are the motor neuron and the motor unit the same? Explain. **The motor neuron is a part of the motor unit. The motor unit also contains all of the terminal branches of the motor neuron and the fibers stimulated.**
4. Where is the synaptic cleft located? Be specific. **The synaptic cleft is located between the cell membrane of the motor neuron and the sarcolemma (motor end plate) of the myofibril.**
5. What chemical is housed within synaptic vesicles? **acetylcholine (ACh)**
6. What is the function of ACh? **ACh transmits information from one neuron to another or to a muscle.**
7. What chemical promotes the contraction of a muscle cell? **acetylcholine (ACh)**
8. Where is the motor end plate located? **in the sarcolemma of the myofibril**
9. Can a skeletal muscle fiber contract on its own without stimulation? Explain. **No. The muscle fiber's contraction is stimulated by the release of ACh.**
10. To what type of cell—the nerve cell or the muscle cell—do synaptic knobs belong? **Synaptic knobs belong to the motor neuron (the nerve).**

CONCEPT 2

Physiology of Muscle Contraction

Concept: Muscle contraction is achieved when the sarcomeres of muscle fibers shorten in length. This movement requires a stimulus, calcium ions, and energy in the form of ATP.

LEARNING OBJECTIVE 4. Identify the parts of the neuromuscular junction.

LEARNING OBJECTIVE 5. Explain the sliding filament mechanism of muscle contraction.

LEARNING OBJECTIVE 6. Describe in their proper order of occurrence the events leading to muscle contraction.

In a motor unit, muscle fibers contract simultaneously to produce a smooth contraction. Upon stimulation, the contraction of a single muscle fiber is accomplished by the sliding action of the thin filaments inward toward the **H** _____ zones, causing **the sarcomere** _____ to shorten. The shortening of myofibrils produces muscle contractions, a concept known as the **sliding filament mechanism**.

The Muscle Fiber at Rest

- Calcium ions are stored within the sarcoplasmic reticulum.
- ATP is bound to thick filaments made of the protein **myosin** _____.
- Thin filaments are intact with all three proteins (actin, **troponin** _____, and **tropomyosin** _____).

Role of the Stimulus

- ACh is released into the synaptic cleft. ACh provides the stimulus that is needed for muscle contraction to start.
- ACh binds to receptors on the motor end plate of the **muscle** _____ fiber.
- An impulse is generated through the **sarcolemma** _____, down T tubule membranes, and to the sarcoplasmic reticulum.
- The SR releases calcium into the sarcoplasm. Calcium diffuses to the **myofibrils** _____.

Muscle Contraction

- Calcium binds to troponin on the thin filaments. Troponin and actin undergo a shape change, revealing actin-binding sites on the **thin** _____ filaments.
- Once the actin-binding sites are exposed, myosin heads on the **thick** _____ filaments bind. The connection, or *coupling*, between thick and thin filaments occurs by a chemical bond.
- Coupling requires calcium ions from the SR, but does not need energy input.
- Calcium ions activate the breakdown of ATP that is bound to the **thick** _____ filaments.
- Myosin catalyzes the breakdown of ATP into ADP, a phosphate group, and energy. The energy is stored in the myosin head momentarily and then it is released. The release of the energy pivots the myosin head, producing a *power stroke*.
- The pivot of the myosin head causes the **thin** _____ filament to slide toward the center of the sarcomere. Once the pivot action is complete, another ATP molecule binds to the **myosin** _____ head and is broken down to produce energy, causing the head to release from the thin filament.

- Since the binding site is now exposed, another myosin head can bind. What happens next?
The myosin head reforms its attachment to a binding site on the thin filament closer to the sarcomere's center and repeats the process.
- The process repeats: coupling, power stroke, detachment. The thin filaments slide toward the center of the sarcomere. Z lines move closer together and the sarcomere shortens. Sarcomere shortening also shortens the myofibril, leading to contraction of the muscle fiber.
- **Rigor mortis** occurs after death because no ATP is available for the release of myosin heads from the actin-binding sites. This condition of muscular rigidity is not permanent as muscle decomposition occurs.

Return to Rest

- Although ACh release stops once the nerve impulse no longer travels down the motor neuron, the stimulus does not end until all ACh is inactivated. What enzyme is responsible for the inactivation of ACh molecules? acetylcholinesterase (AChE)
- Calcium ions are returned to the sarcoplasmic reticulum by enzymes through active transport (requires ATP).
- What happens to the actin-binding sites if calcium is no longer present? The original shape of the thin filaments are restored, which covers the binding sites.
- The lack of binding sites breaks attachments to myosin heads.
- Thin filaments slide back to their original position in the sarcomere.

Review Time!

- Place a number from 1 to 6 in the blank before each statement to indicate the correct order of the steps of muscle contraction.
 - 2 Myosin heads bind to exposed actin-binding sites on the thin filaments.
 - 5 After the myosin head detaches from the actin-binding site, it can attach to a binding site on another thin filament closer to the sarcomere's center.
 - 4 The breakdown of a second ATP powers the release of the myosin head from the thin filament.
 - 1 Calcium binds to troponin molecules in the thin filaments causing a change in the shape of actin and troponin.
 - 6 The sarcomere shortens as Z lines are drawn together.
 - 3 The breakdown of a first ATP promotes a power stroke of a myosin head.
- Provide a brief answer for each of the following questions.
 - Since the thick and thin filaments do not shorten during muscle contraction, how is muscle shortening accomplished? The thin filaments slide over and under the thick filaments using spaces within the I bands and H zones.
 - Describe the events of the sliding filament mechanism of muscle contraction.
Calcium binds with troponin, which changes actin binding sites. Myosin heads attach to actin binding sites. Myosin heads pivot, pulling the thin filaments. ATP forces release of actin binding sites. Myosin heads reattach and pivot again, shortening sarcomeres.
 - Explain the role of ACh in stimulating a muscle to contract. The ACh, when released, stimulates a change in the SR and allows for an increase in calcium ions. This binds to troponin and exposes actin binding sites.

4. List and discuss two events during muscle contraction and relaxation that require the use of ATP.
 1. **ATP is bound to the myosin heads. Calcium breaks this bond, releasing the energy for the muscle contraction.**
 2. **The release of ATP causes the myosin head to pivot or power strike. The head will rebind to actin, and if ATP is available, will pivot again.**
5. How does the sarcomere shorten during muscle contraction? **When the myosin head pivots, the thin filaments are pulled toward the sarcomere center. This pulls the Z lines closer, shortening the sarcomere.**
6. What is the role of acetylcholinesterase in returning the muscle to rest? **The AChE deactivates the ACh so the stimulation to contract stops.**
7. Where is calcium stored when the muscle is not contracting? **sarcoplasmic reticulum**
8. Discuss two roles of calcium during muscle contraction.
 1. **Calcium binds to troponin, which changes the thin filaments and exposes actin-binding sites.**
 2. **Calcium ions break the bond between ATP and myosin heads to allow for actin/myosin binding.**
9. Why does rigor mortis occur after death? Explain this condition. **ATP is no longer available to release the actin from the myosin heads.**
10. What happens during “coupling”? Explain. **“Coupling” is when the actin-binding sites attach with myosin heads.**

LEARNING OBJECTIVE 7. Indicate the roles of ATP in muscle contraction and how this energy is supplied.

LEARNING OBJECTIVE 8. Describe the oxygen debt and muscle fatigue.

Energy for Contraction

List three times during muscle contraction and relaxation when energy (ATP) is required.

1. **Power stroke**
2. **Detachment (uncoupling) of myosin heads from thick filaments**
3. **Enzymatic return of calcium ions in the sarcoplasmic reticulum**

Discuss the three methods of producing ATP.

1. **Cellular respiration:** Energy is made available when ATP is broken down to yield **ADP** + phosphate (PO_4^{2-}) + energy. Do you recall from Chapter 3 where ATP is made in the cell? **mitochondria**. ATP is made during cellular respiration when sugar molecules are degraded to release energy. That energy is stored temporarily in ATP in muscle fibers, but used up within seconds once muscle contractions begin.
2. **Creatine phosphate:** Once muscle contractions begin, ATP made by cellular respiration is used up quickly, so another source of energy is necessary. Creatine phosphate (phosphocreatine) is a high-energy molecule that includes a phosphate group (PO_4^{2-}) that can be transferred to ADP to form **creatine phosphate**. What are the advantages of creatine phosphate over ATP?
 - Creatine phosphate can be stored for longer periods than ATP in muscle fibers.
 - Creatine phosphate is four to six times more abundant than ATP in muscle.

3. **Other Sources:** Together, stored ATP and creatine phosphate only power muscle contractions for 15 seconds. Once ATP and creatine phosphate are depleted, free molecules of *glucose* are metabolized to make ATP, then *glycogen* is broken down into **glucose** and used to generate ATP. Finally, strenuous or prolonged exercise promotes the use of **lipids**, which store the most energy.

Metabolism and Fitness

Cellular respiration is a form of catabolism that involves the breakdown of **glucose** molecules by mitochondria to form ATP.

- If oxygen is available during cellular respiration, the maximum number of ATP molecules can be generated (36) from each molecule of glucose. The process is called **aerobic cellular respiration**.
- If oxygen is *not* available during cellular respiration, glucose is only partially broken down through a process that yields only 2 ATP molecules and a byproduct called lactic acid. The process is less efficient than aerobic respiration and known as **anaerobic respiration** (fermentation).

Myoglobin is a protein in muscle tissue that binds to **oxygen** and stores it until it is needed. After several minutes of strenuous exercise, myoglobin will become depleted and the respiratory and cardiovascular systems won't be able to bring in enough oxygen. Cells now enter **anaerobic** respiration and lactic acid will be produced until oxygen is restored. The individual with greater cardiovascular fitness will produce lactic acid at a rate about half that for untrained individuals during heavy exercise.

Oxygen debt is the amount of oxygen needed to **restore all systems to their normal states following strenuous exercise**

Muscle fatigue is the inability of a muscle to contract that can be caused by unavailability of **ATP**, and accumulation of lactic acid and a decrease in pH.

Cramps may follow muscle fatigue when a muscle contracts spasmodically without relaxing. What is typically the cause of cramping? **insufficient ATP to properly return calcium ions to the sarcoplasmic reticulum, preventing the muscle from relaxing**

Comparing Muscle Tissues

Cardiac Muscle Cells

Cardiac muscle cells have:

- A single **nucleus**
- A rectangular shape
- Branches that contact adjacent cells
- **Intercalated discs**—thickenings of the cell membrane where neighboring cells contact each other. What is the function of intercalated discs? **facilitate the flow of ions between cardiac cells.**

- Thick and thin filaments arranged into sarcomeres that produce striations
- Large amounts of myoglobin and a large blood supply volume
- Autorhythmic contractions (no external stimulus needed to start contractions)

Cardiac muscle cells do not:

- Produce contractions as forceful as skeletal muscle
- Develop oxygen debt or muscle fatigue

Smooth Muscle Cells

Smooth muscle cells have:

- A single nucleus
- A small, spindle shape
- The greatest ability of all three muscle types to sustain contraction

Smooth muscle cells do not:

- Have troponin fibers and have few actin fibers in the thin filaments
- Have sarcomeres
- Possess striations
- House many sarcoplasmic reticula
- Produce fast, forceful contractions
- Develop oxygen debt or muscle fatigue

Review Time!

I. Using the terms in the list below, write the correct method of ATP production in each blank. You may use a term more than once.

Aerobic cellular respiration

Anaerobic cellular respiration

Creatine phosphate

1. Produces the most ATP per glucose molecule
2. Besides aerobic cellular respiration, ATP production that only lasts about 15 seconds
3. Produces lactic acid
4. Utilizes oxygen to generate ATP
5. Upon depletion of myoglobin, this form of respiration is used
6. Also known as fermentation
7. Stored in the muscles
8. Utilized during strenuous activity
9. Yields only 2 ATP per glucose
10. Form of cellular respiration in which no oxygen is used to make ATP

Aerobic cellular respiration

Creatine phosphate

Anaerobic cellular respiration

Aerobic cellular respiration

Anaerobic cellular respiration

Anaerobic cellular respiration

Creatine phosphate

Anaerobic cellular respiration

Anaerobic cellular respiration

Anaerobic cellular respiration

II. Using the terms in the list below, write the correct type of muscle tissue in each blank. You may use a term more than once.

Cardiac muscle tissue

Skeletal muscle tissue

Smooth muscle tissue

1. Lacks striations
2. Autorhythmic contractions
3. Most forceful contractions of all three types
4. Lacks sarcomeres
5. Experiences oxygen debt and muscle fatigue
6. Lacks troponin fibers
7. Intercalated discs
8. Spindle-shaped cells with a single nucleus
9. Rectangular cells that have a single nucleus
10. Cells are branched

Smooth muscle tissue

Cardiac muscle tissue

Skeletal muscle tissue

Smooth muscle tissue

Skeletal muscle tissue

Smooth muscle tissue

Cardiac muscle tissue

Smooth muscle tissue

Cardiac muscle tissue

Cardiac muscle tissue

III. Provide a brief answer for each of the following questions.

1. Rank these energy sources in order of their use by the body to produce ATP: glycogen, lipids, glucose.
1. Glucose
2. Glycogen
3. Lipids
2. Identify the process that produces the most ATP from a single glucose molecule.
aerobic cellular respiration
3. An hour into his first hike of the season, David complains of being “out of breath” and is breathing heavily. What is he experiencing? Why?
He is experiencing oxygen debt because he has used all of the stored oxygen that his muscles and body needs and he needs to replenish his supplies.
4. A day after starting a new exercise program, Keisha has sore muscles in her legs. Explain to her why her leg muscles are sore and why the soreness won’t be as bad if she continues to exercise.
“Out of shape” people tend to go into anaerobic cellular respiration earlier than people who are “in shape.” This creates lactic acid which makes muscles sore. Aerobic exercise will increase oxygen to the muscles, which will remove lactic acid.
5. How long could you exercise if you relied solely on cellular respiration and creatine phosphate to provide your ATP? Explain.
Stored ATP is used up in seconds; ATP from creatine phosphate is used in 15 seconds.
6. List some causes of muscle fatigue.
decreased supply of ATP; accumulation of lactic acid; decrease in pH
7. What role does myoglobin play in cellular respiration? What happens once it is depleted?
Myoglobin is a protein that binds to oxygen and stores it. When it is depleted the body begins to use anaerobic cellular respiration for its energy needs.
8. Why is ATP needed during muscle contraction? List three times when ATP is necessary.
ATP is needed during the “power stroke”-myosin head pivot, the uncoupling of myosin heads from actin-binding sites, and the enzymatic return of calcium ions to the sarcoplasmic reticulum.
9. Compare cardiac muscle cells to skeletal muscle cells. How are these tissues similar?
Both of these muscles are striated due to sarcomeres in their tissues.
10. What unique features do cardiac muscle cells have that allow them to work collectively as a unit?
Intercalated discs allow the flow of ions between cardiac cells.

CONCEPT 3

Muscle Mechanics

Concept: A muscle fiber responds to a stimulus of sufficient strength by contracting. The nature of contraction of the muscle may vary according to the number of motor units responding, the frequency of stimuli received, and how tension is applied.

LEARNING OBJECTIVE 9. Define threshold stimulus, and relate it to the concept of the all-or-none response.

LEARNING OBJECTIVE 10. Compare twitch, tetanic, isotonic, and isometric contractions.

All-or-None Response

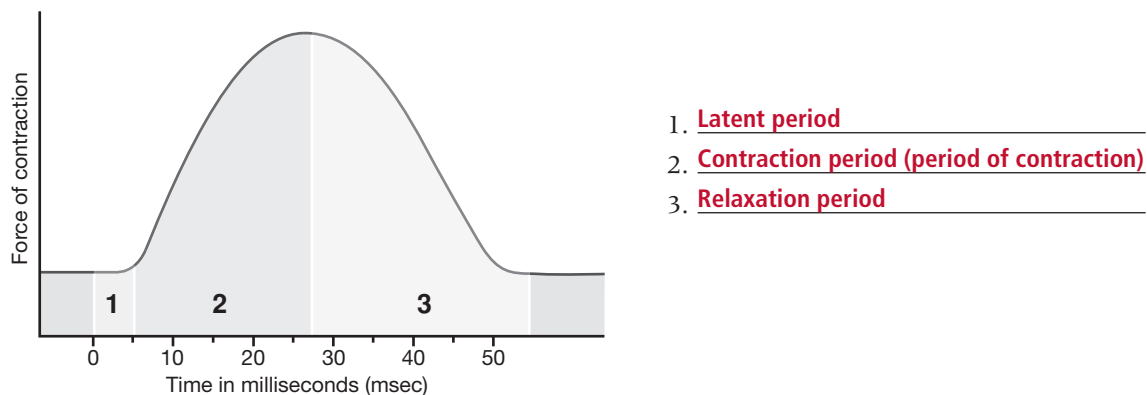
Threshold stimulus is the weakest stimulus that can initiate a muscle to contract to its complete capacity. How does the muscle respond if the stimulus is less than threshold? The muscle will not respond at all.

All-or-none response means the muscle will either contract all the way, or not at all.

Each motor neuron stimulates motor units with their own unique threshold stimulus. Contractions increase in force as the intensity of stimulation increases and more motor units are activated (called **recruitment**). The greater the number of motor units stimulated, the greater the strength of contraction.

Measuring Muscle Contraction

Twitch contraction is a rapid response to a single stimulus that is slightly over threshold and experienced by a single muscle fiber. The measurement of a twitch is known as a **myogram**.



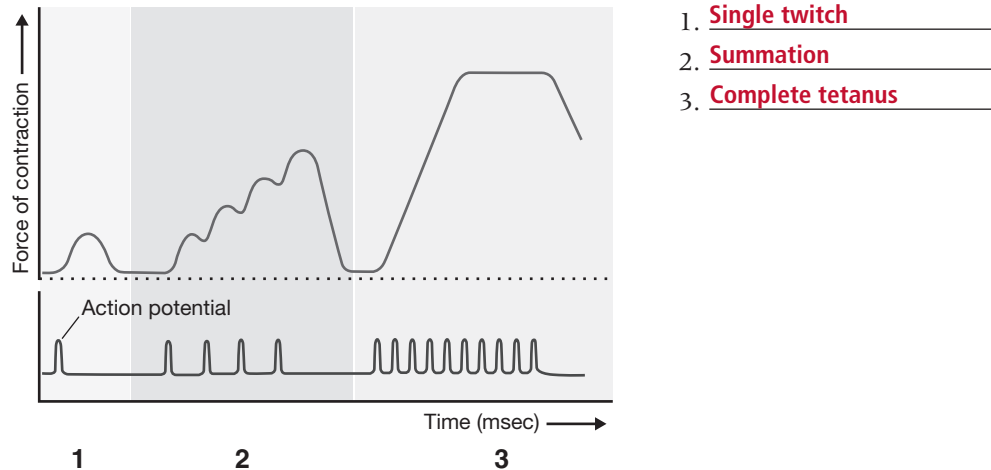
As you consider the events of the twitch, label the myogram above with the following three periods.

- **Latent period:** Contraction is delayed after the stimulus. This is the time required for calcium ions to be released, the activation of myosin, and cross bridge attachment to occur.
- **Period of contraction:** Tension increases in the muscle fiber as the sarcomere shortens.

- **Period of relaxation:** Muscle fiber returns to its original length. Calcium ions return to the SR and myosin heads detach from thin filaments.

Sustained Muscle Contraction

If a muscle fiber receives a series of stimuli, the muscle will respond as shown in the myogram below.



As you study the myogram above, label the single twitch, summation, and complete tetanus.

- **Summation:** The time between stimuli is shortened to prevent the muscle fiber from **relaxing**. The twitches combine by summation. How is the force of contraction affected? **The total force of the contraction increases.**
- **Tetanic contraction:** The time between stimuli is shortened further; this type of contraction will reach maximal force. **Complete tetanus** represents a fusion of twitches from many stimuli. The contraction is forceful and sustained. Your body movements, such as walking and moving your arms, are accomplished by muscles that reach complete tetanus. Complete tetanus also maintains **muscle tone**. What is muscle tone? **Muscle tone is a series of maintained/sustained contractions by a small number of fibers.**

Muscle tone keeps a muscle in a ready state so it can respond when a stimulus arrives. It helps with posture, for instance.

Isotonic and Isometric Contractions

Tension is the **force** exerted by muscle contraction. Isotonic and isometric contractions are two types of tetanic contractions.

- **Isotonic contractions** produce movement as a muscle pulls bone(s). Exercise through isotonic contractions increases **muscle mass** and **endurance**.
- **Isometric contractions** produce muscle tension, but no shortening of the muscle, and no movement of the muscle. If you push against an immovable object, such as a wall, your muscles contract isometrically. Isometric contractions strengthen **joints** and burn energy.

Review Time!

I. Place a number from 1 to 5 in the blank before each statement to indicate the correct order of the periods of muscle contraction.

- 1 During the latent period, calcium ions must be released from the SR.
- 5 The muscle fiber returns to its original length during the period of relaxation.
- 3 The binding of myosin heads to thin filaments promotes cross bridge formation.
- 4 The period of contraction occurs as the sarcomere shortens when the muscle fiber increases tension.
- 2 Once the calcium ions are released from the SR, myosin heads can attach to actin-binding sites on thin filaments.

II. Provide a brief answer for each of the following questions.

1. Describe the all-or-none response. The muscle has a minimum stimulus (threshold stimulus) that must be met or the muscle will not contract at all. There are no partial contractions.
2. A muscle fiber receives a subthreshold stimulus. How does the muscle respond? Explain. The muscle does not respond or contract at all. Muscle contraction is an "all or none" response. The threshold must be met for a contraction to occur.
3. Discuss the location of calcium ions during the latent period and during the period of relaxation. Calcium ions are stored in the sarcoplasmic reticulum during the latent period and are released. They return to the sarcoplasmic reticulum when relaxation occurs.
4. April needs to move a 40 pound box. Explain how muscle recruitment will benefit her task. As additional strength is needed, additional motor units are stimulated until maximal or desired contraction is reached.
5. What is the significance of muscle tone? Explain. Muscle tone is important in maintaining posture and keeping muscles in a "ready to respond" state.
6. Why do you think we lose muscle tone after death? There is no way to maintain complete tetanus after death. No stimulus can be sent.
7. Differentiate between summation of twitches and complete tetanus. Summation of twitches occurs when multiple stimuli make the muscle contract without relaxing. Complete tetanus results in a smoother, more forceful contraction that is sustained.
8. In gym class, Ken has run in place, completed a set of jumping jacks, and carried a weight in each hand from the storage room to the gymnasium. Which of these activities can be classified as isometric exercises? Explain your choice. Carrying the weight is isometric. The weight is not being lifted by the body. The weight is being held in the same position. (The walking, however, is isotonic.)

9. Do isometric or isotonic contractions bulk a muscle and increase its mass? Explain your choice. **Isometric contractions bulk muscle and increase its mass. You can add weights to increase the work the muscle is doing and increase muscle mass.**
10. Chris wants to increase his endurance so that he can run a 10-kilometer race. Which type of exercise do you recommend to help him achieve his goal: isotonic or isometric exercises? **isotonic**. Discuss your choice. **Isotonic movements increase muscle mass and endurance. The more the muscle is moved the better the endurance will be.**

CONCEPT 4

Production of Movement

Concept: Movement occurs when a muscle contracts, pulling a movable bone toward a more stationary bone. For most movements, many muscles are involved and each plays one of several possible roles.

LEARNING OBJECTIVE 11. Define origin and insertion, and describe the role of group actions in producing movement.

We will now explore the nature of muscle movement, including how the muscle is attached, the structure of the joint, and interactions of nearby muscles.

Origin and Insertion

Muscles produce movement by pulling on their attachments (tendons attached to bones). Most muscles cross a joint between two opposing bones. One end of the muscle is relatively *immovable* while the other end of the muscle is *movable*. During contraction, the insertion is pulled toward the origin. In the muscles of the limbs, the origins are proximal and the insertions are **distal**.

- **Origin:** Point of attachment to the *more stationary* bone
- **Insertion:** Point of attachment to the *more movable* bone

Group Actions

Group action is the coordinated response of a group of muscles to bring about a body movement. Muscles within the group have specific roles:

- **Agonists** are prime movers because they cause the desired action by contracting.
- **Antagonists** **relax** during the action.
- **Synergists** assist the **agonists** in performing the action.
- **Fixators** **stabilize** the origin of the prime mover.

CONCEPT 5

Major Muscles of the Body

Concept: The muscles provide for movement of all movable bones of the body. Their names correspond to their appearance, location, action, or relationship to other structures.

LEARNING OBJECTIVE 12. Identify the primary muscles on the basis of their locations, origins, insertions, and actions.

For the remainder of this chapter, we cover the origin, insertion, and primary action of primary muscles.

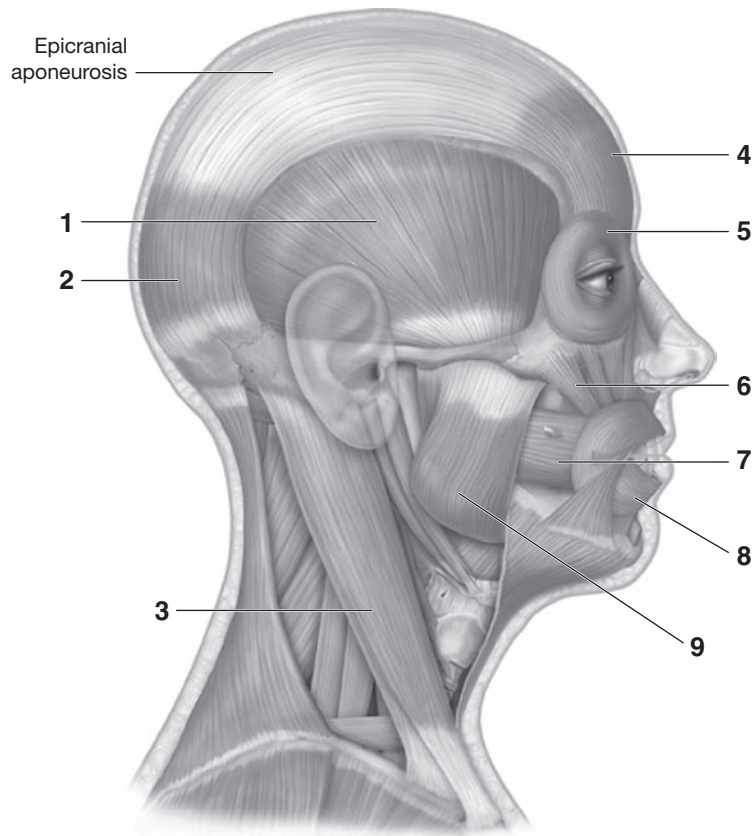
Muscles of the Head and Neck, Muscles of Mastication, and Muscles Moving the Head

Complete the table below by supplying the primary action for each muscle listed.

Muscles of Facial Expression, Mastication, and Head Movement

Muscle	Origin	Insertion	Action
Frontalis	Occipital bone	Skin around the eye	Raises the eyebrows
Occipitalis	Occipital bone	Skin around the eye	Pulls the scalp posteriorly
Orbicularis oculi	Maxillary and frontal bones around the orbit	The eyelid	Closes eyelids and squinches eyes
Orbicularis oris	Muscles surrounding the mouth	Skin at the corner of the mouth	Pucker the mouth
Buccinator	Maxilla and mandible	Orbicularis oris	Raises the corners of the mouth
Zygomaticus	Zygomatic bone	Skin and muscle at the corner of the mouth	Raises the corners of the mouth
Masseter	Zygomatic process of the temporal bone and zygomatic arch	Mandible	Closes the mouth by elevating the mandible
Temporalis	Temporal bone	Mandible	Closes the mouth by elevating the mandible
Sternocleidomastoid	Manubrium of the sternum and the clavicle	Mastoid process of the temporal bone	Moves the head; flexes and rotates

As we discuss the muscles of the head and neck, add labels to the illustration below. When you are done, you should be able to identify the muscles of the head and neck listed below.



1. Temporalis
2. Occipitalis
3. Sternocleidomastoid

4. Frontalis
5. Orbicularis oculi
6. Zygomaticus

7. Buccinator
8. Orbicularis oris
9. Masseter

Buccinator

Frontalis

Masseter

Occipitalis

Orbicularis oculi

Orbicularis oris

Sternocleidomastoid

Temporalis

Zygomaticus

Muscles Moving the Pectoral Girdle and Trunk

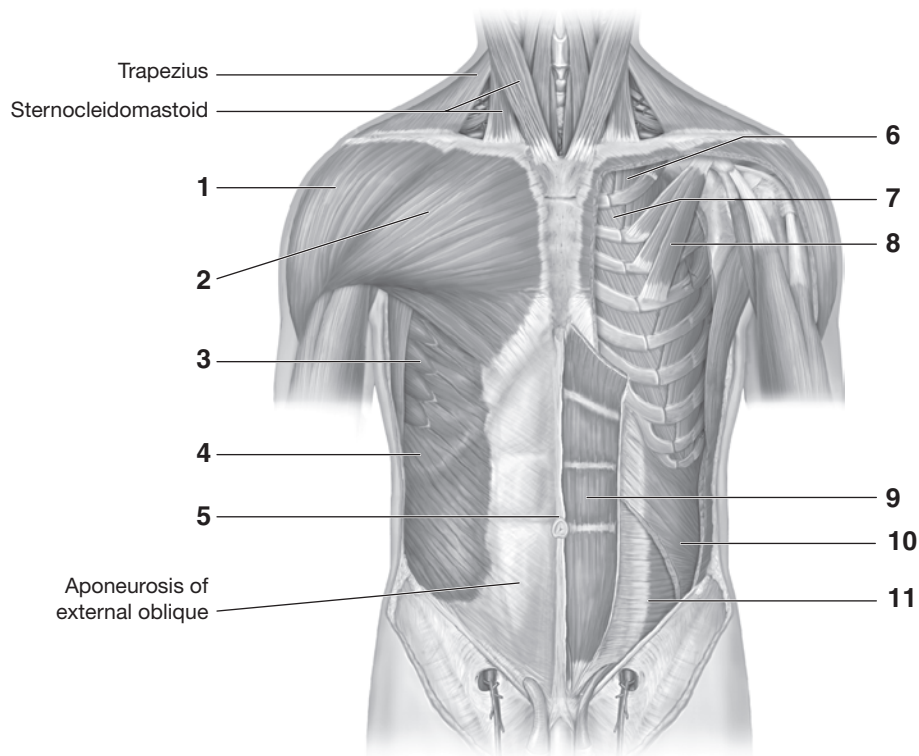
Anterior Muscles of the Pectoral Girdle and Trunk

Complete the table below by supplying the primary action for each muscle listed.

Anterior Muscles of the Pectoral Girdle and Trunk

Muscle	Origin	Insertion	Action
Pectoralis major	Clavicle, sternum, and costal cartilages of the first 6 ribs	Greater tubercle of the humerus	Flex, adduct, and medially rotate the arm
Pectoralis minor	Ribs 3–5	Coracoid process of the scapula	Draws the scapula forward and downward
Deltoid	Acromion and spine of the scapula, and the clavicle	Deltoid tuberosity of the humerus	Abducts the arm; aids in extending and flexing humerus
Serratus anterior	The first 8 ribs	Scapula	Adducts scapula and rotates it.
Subscapularis	Anterior surface of the scapula	Lesser tubercle of the humerus	Rotates arm medially
Rectus abdominis	Pubic bone and symphysis pubis	Xiphoid process of the sternum and the costal cartilages of fifth to seventh rib	Flexes the vertebral column, which compresses the abdomen
External oblique	Lower 8 ribs	Iliac crest and the linea alba	When both sides contract, aids the rectus abdominis in flexing vertebral column; when one side contracts, aids muscles of the trunk in rotation and flexion of the vertebral column
Internal oblique	A large aponeurosis of the lower back, the iliac crest, and the costal cartilages of the lower ribs	Linea alba and the pubic bone	Same as external oblique
Transverse abdominis	A large aponeurosis of the lower back, the iliac crest, and the costal cartilages of the lower ribs	Linea alba and the pubic bone	Same as external oblique
External intercostals	Ribs	Rib inferior to the rib of origin	Elevate the ribs during inhalation
Internal intercostals	Ribs	Rib superior to the rib of origin	Depress the ribs during forceful exhalation

As we discuss the muscles of the pectoral girdle and anterior trunk, add labels to the illustration below. When you are done, you should be able to identify the muscles of the pectoral girdle and anterior trunk listed below.



1. Deltoid
2. Pectoralis major
3. Serratus anterior
4. External oblique

5. Linea alba
6. External intercostals
7. Internal intercostals
8. Pectoralis minor

9. Rectus abdominus
10. Internal oblique
11. Transverse abdominus

Deltoid
External intercostals
External oblique
Internal intercostals

Internal oblique
Linea alba
Pectoralis major
Pectoralis minor

Rectus abdominis
Serratus anterior
Transverse abdominis

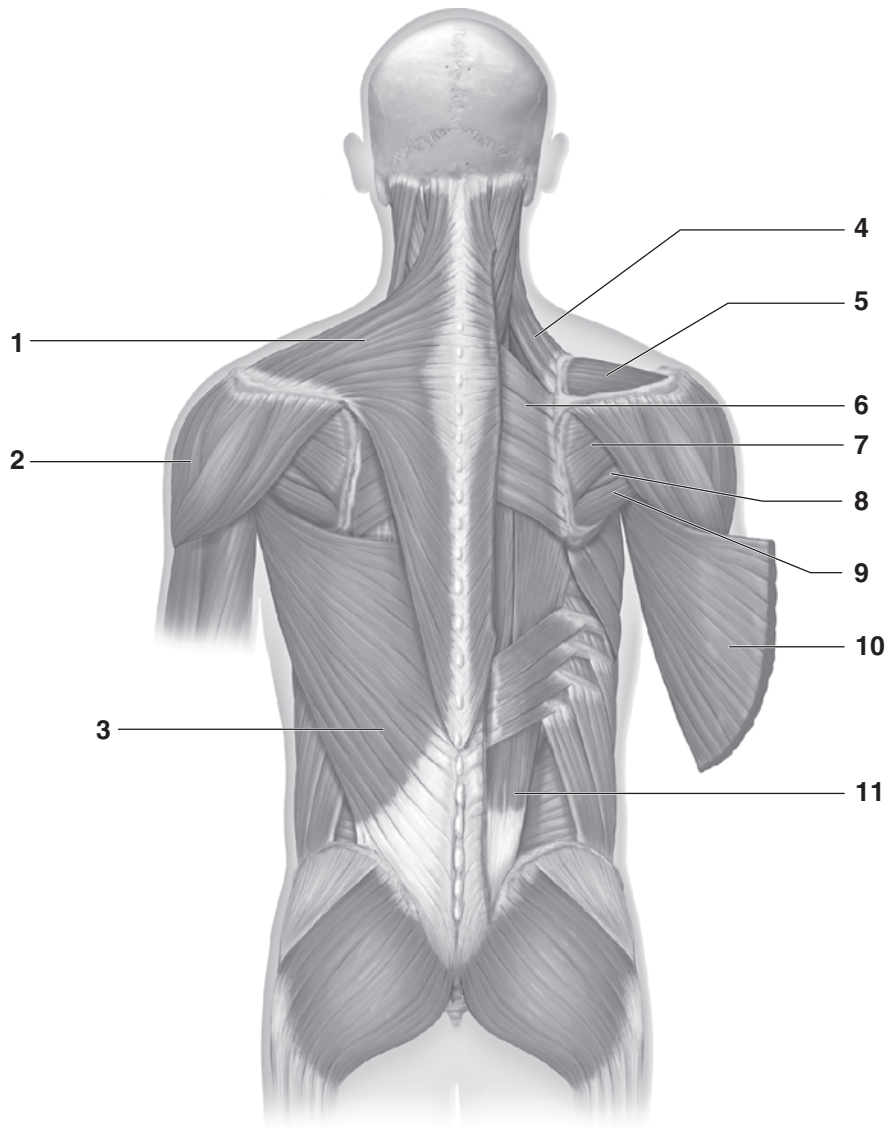
Posterior Muscles of the Pectoral Girdle and Trunk

Complete the table below by supplying the primary action for each muscle listed.

Posterior Muscles of the Pectoral Girdle and Trunk

Muscle	Origin	Insertion	Action
Trapezius	Occipital bone and spines of the cervical and thoracic vertebrae	Acromion and spine of the scapula	Elevates and rotates scapula; adducts the scapula; depresses the shoulder; extends the hand
Levator scapulae	First four cervical vertebrae	Scapula	Elevates and adducts the scapula; flexes the head to either side
Rhomboids	Seventh cervical and first five thoracic vertebrae	Scapula	Adducts scapula to "square the shoulders"; rotates the scapula as in paddling a canoe
Latissimus dorsi	Spines of lower six thoracic vertebrae, lumbar vertebrae, lower ribs, and iliac crest	Intertubercular groove of the humerus	Extends the arm; adducts and medially rotates the arm; pulls shoulder downward and back
Supraspinatus	Posterior surface of the scapula superior to the spine	Greater tubercle of the humerus	Abducts the arm
Infraspinatus	Posterior surface of the scapula inferior to the spine	Greater tubercle of the humerus	Rotates the arm laterally
Teres major	Scapula	Lesser tubercle of the humerus	Extends, adducts, medially rotates the arm
Teres minor	Scapula	Greater tubercle of the humerus	Rotates the arm laterally with the infraspinatus
Erector spinae	Vertebrae, pelvis	Superior vertebrae and ribs	Extends the vertebral column

As we discuss the muscles of the pectoral girdle and posterior trunk, add labels to the illustration below. When you are done, you should be able to identify the muscles of the pectoral girdle and posterior trunk listed below. You may use one term more than once.



- | | | |
|----------------------------|-------------------------|-----------------------------|
| 1. <u>Trapezius</u> | 5. <u>Supraspinatus</u> | 9. <u>Teres major</u> |
| 2. <u>Deltoid</u> | 6. <u>Rhomboids</u> | 10. <u>Latissimus dorsi</u> |
| 3. <u>Latissimus dorsi</u> | 7. <u>Infraspinatus</u> | 11. <u>Erector spinae</u> |
| 4. <u>Levator scapulae</u> | 8. <u>Teres minor</u> | |

Deltoid
Erector spinae
Infraspinatus
Latissimus dorsi

Levator scapulae
Rhomboids
Supraspinatus

Teres major
Teres minor
Trapezius

Muscles of the Upper Limb

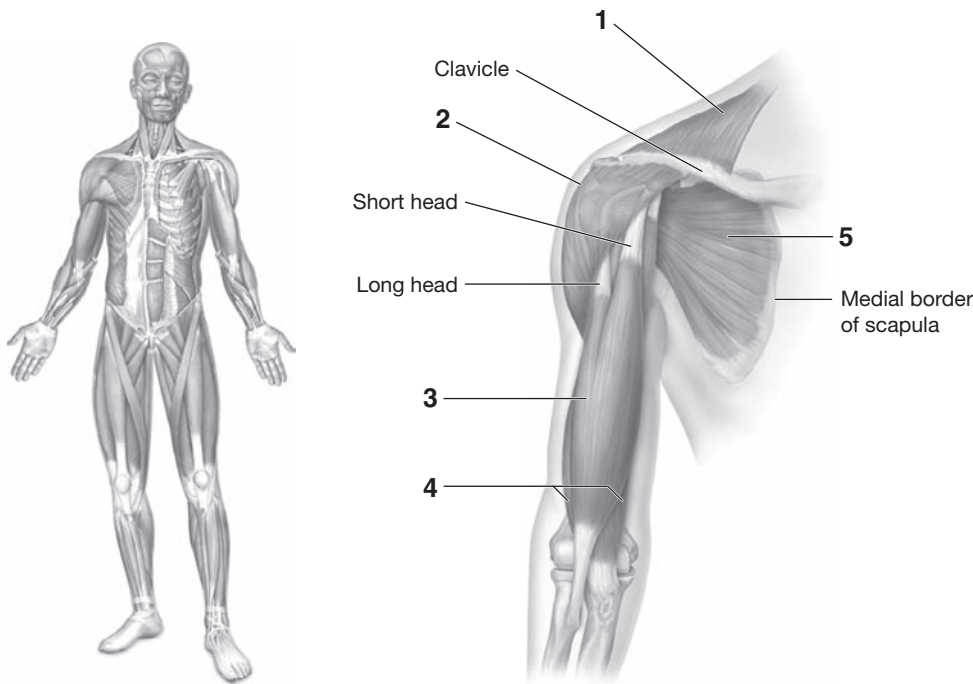
Muscles that Move the Forearm

Complete the table below by supplying the primary action for each muscle listed.

Muscles that Move the Forearm

Muscle	Origin	Insertion	Action
Biceps brachii	Two heads of origin on the scapula	Radial tuberosity of the radius	Flexes the forearm at the elbow; supinates the hand
Brachialis	Shaft of the humerus	Coronoid process of the ulna	Flexes the forearm
Brachioradialis	Distal end of the humerus	Base of the styloid process of the radius	Flexes the forearm
Triceps brachii	Three heads of origin on the scapula and humerus	Olecranon process of the ulna	Extends the forearm
Supinator	Distal end of the humerus and proximal end of the ulna	Proximal end of the radius	Supinates the forearm
Pronator teres	Distal end of the humerus and coronoid process of the ulna	Shaft of the radius	Pronates the forearm

As we discuss the muscles of the anterior arm, add labels to the illustration below. When you are done, you should be able to identify the muscles of the anterior arm listed below.



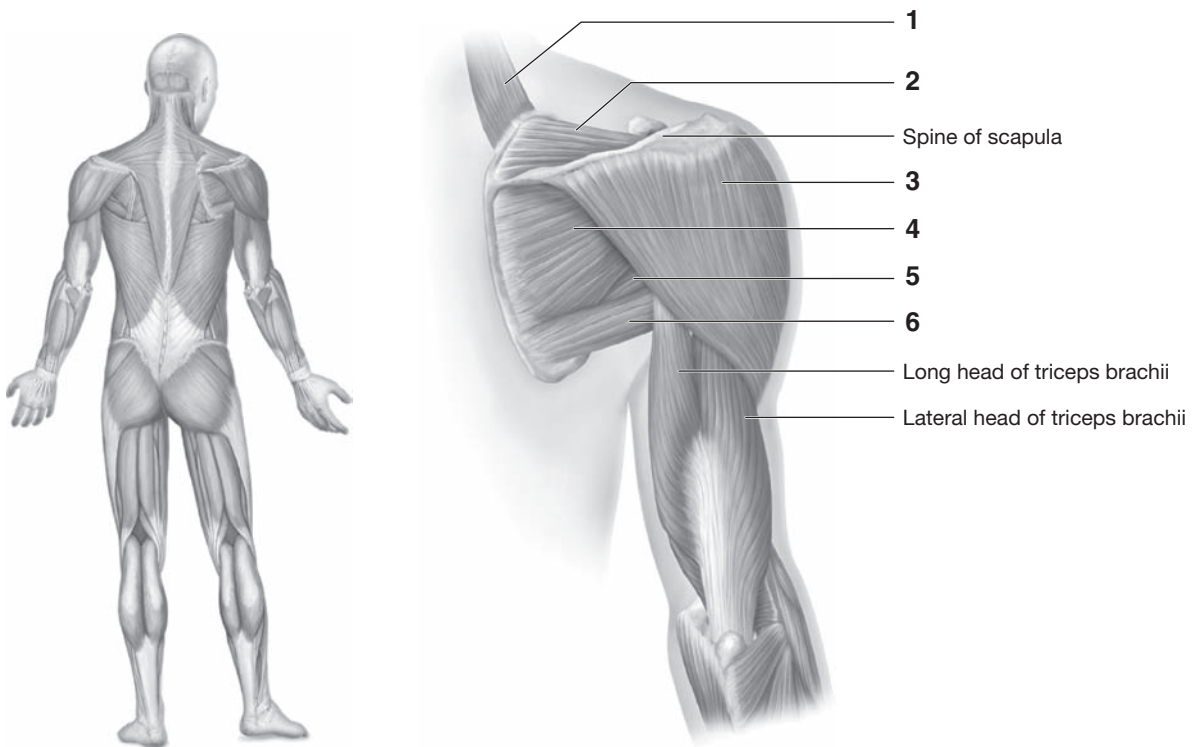
1. **Trapezius** _____ 3. **Biceps brachii** _____ 5. **Subscapularis** _____
 2. **Deltoid** _____ 4. **Brachialis** _____

Biceps brachii
Brachialis

Deltoid
Subscapularis

Trapezius

As we discuss the muscles of the posterior arm, add labels to the illustration below. When you are done, you should be able to identify the muscles of the posterior arm listed below.



- | | | |
|---------------------------|-------------------------|-----------------------|
| 1. <u>Levator scapula</u> | 3. <u>Deltoid</u> | 5. <u>Teres minor</u> |
| 2. <u>Supraspinatus</u> | 4. <u>Infraspinatus</u> | 6. <u>Teres major</u> |

Deltoid
Infraspinatus

Levator scapulae
Supraspinatus

Teres major
Teres minor

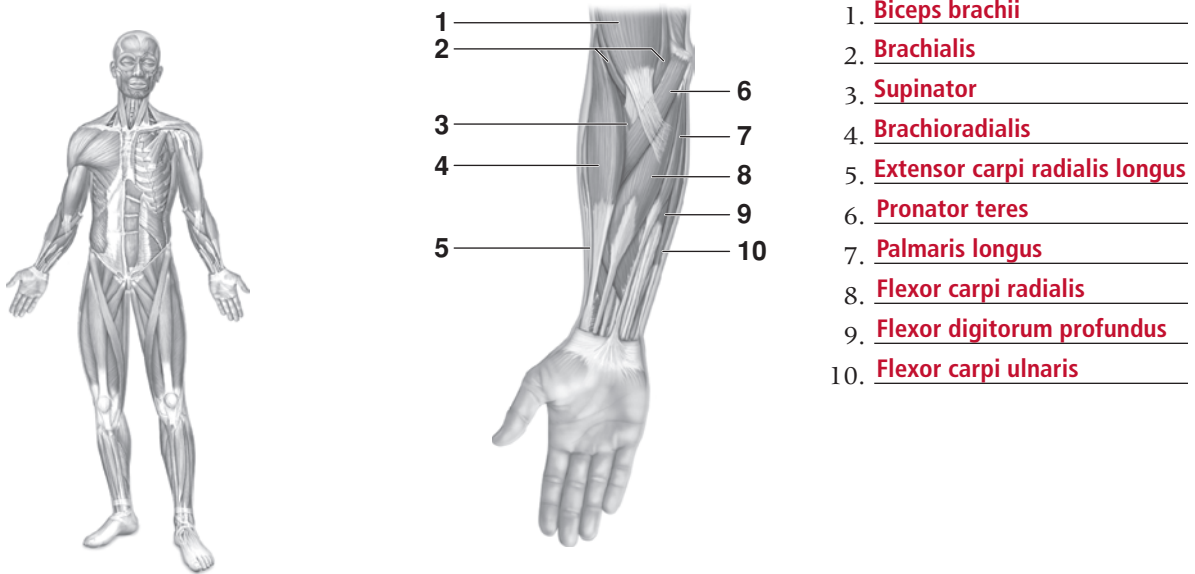
Muscles that Move the Hand and Fingers

Complete the table below by supplying the primary action for each muscle listed.

Muscles that Move the Hand and Fingers

Muscle	Origin	Insertion	Action
Flexor carpi radialis	Distal end of the humerus	Second and third metacarpals	Flexes and abducts the hand at the wrist
Flexor carpi ulnaris	Distal end of the humerus and the olecranon process of the ulna	Carpal and metacarpal bones	Flexes and adducts the hand at the wrist
Palmaris longus	Distal end of the humerus	Fascia of the palm	Flexes the hand at the wrist
Flexor digitorum profundus	Anterior surface of the ulna	Distal phalanges of digits 2–5	Flexes the distal phalanges of digits 2–5
Extensor carpi radialis longus	Distal end of the humerus	Second metacarpal	Extends and abducts the hand at the wrist
Extensor carpi ulnaris	Distal end of the humerus	Fifth metacarpal	Extends and adducts the hand at the wrist
Extensor digitorum	Distal end of the humerus	Middle and distal phalanges in digits 2–5	Extends the digits 2–5

As we discuss the muscles of the anterior forearm, add labels to the illustration below. When you are done, you should be able to identify the muscles of the anterior forearm listed below.



Biceps brachii

Brachialis

Brachioradialis

Extensor carpi radialis longus

Flexor carpi radialis

Flexor carpi ulnaris

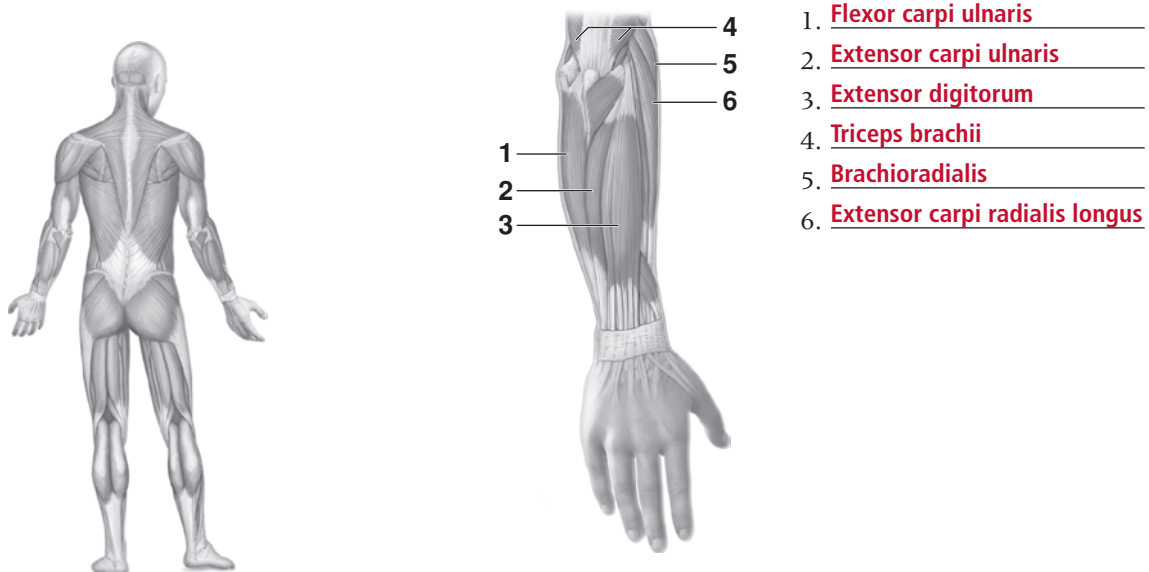
Flexor digitorum profundus

Palmaris longus

Pronator teres

Supinator

As we discuss the muscles of the posterior forearm, add labels to the illustration below. When you are done, you should be able to identify the muscles of the posterior forearm listed below.



Brachioradialis

Extensor carpi radialis longus

Extensor carpi ulnaris

Extensor digitorum

Flexor carpi ulnaris

Triceps brachii

Muscles of the Lower Limbs

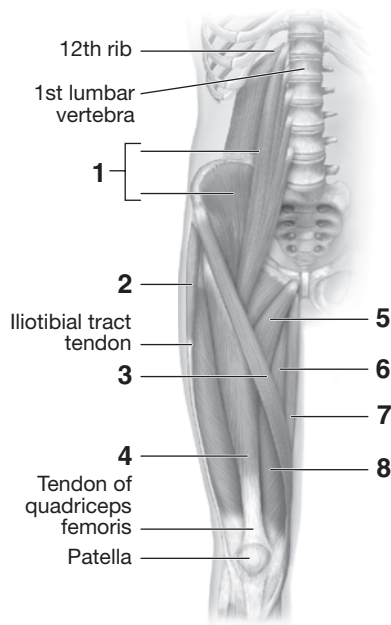
Muscles that Move the Leg

Complete the table below by supplying the primary action for each muscle listed.

Muscles that Move the Thigh and Leg

Muscle	Origin	Insertion	Action
Iliopsoas	Iliac fossa and lumbar vertebrae	Lesser trochanter of the femur	Flexes and medially rotates the thigh at the hip
Tensor fascia latae	Iliac crest of the ilium	Tibia by way of fascia of the thigh	Abducts, flexes, and medially rotates the thigh at the hip
Adductor longus	Pubic bone and symphysis pubis	Posterior surface of the femur	Adducts, flexes, and laterally-rotates the thigh at the hip
Adductor magnus	Ischial tuberosity	Posterior surface of the femur	Adducts the thigh; anterior part flexes the thigh and posterior part extends the thigh.
Gracilis	Pubic bone	Medial surface of the tibia	Adducts the thigh; flexes and medially rotates the leg
Quadriceps femoris group:			
Rectus femoris	Ilium and margin of the acetabulum	Patella and tibial tuberosity by way of the quadriceps tendon	Extends the leg at the knee and flexes the thigh at the hip
Vastus lateralis	Greater trochanter and posterior surface of the femur	Same as the rectus femoris	Extends the leg at the knee
Vastus medialis	Medial surface of the femur	Same as the rectus femoris	Extends the leg at the knee
Vastus intermedius	Anterior and lateral surface of the femur	Same as the rectus femoris	Extends the leg at the knee
Gluteus maximus	Ilium, sacrum, and coccyx	Posterior surface of the femur and fascia of the thigh	Extends the thigh at the hip
Gluteus medius	Ilium	Greater trochanter of the femur	Abducts and medially rotates the thigh
Biceps femoris	Two heads of origin: At the ischium and along the linea aspera of the femur	Proximal ends of the fibula and tibia by way of a common tendon	Flexes and rotates the leg at the knee laterally; extends the thigh at the hip
Semitendinosus	Ischium	Medial surface of the tibia	Extends the thigh at the hip and flexes the leg at the knee
Semimembranosus	Ischium	Proximal end of the tibia	Extends the thigh at the hip and flexes the leg at the knee

*As we discuss the muscles of the anterior thigh, add labels to the illustration below. When you are done, you should be able to identify the muscles of the anterior thigh listed below.



1. Iliopsoas
2. Tensor fasciae latae
3. Sartorius
4. Rectus femoris
5. Adductor longus
6. Adductor magnus
7. Gracilis
8. Vastus medialis

Adductor longus

Iliopsoas

Sartorius

Adductor magnus

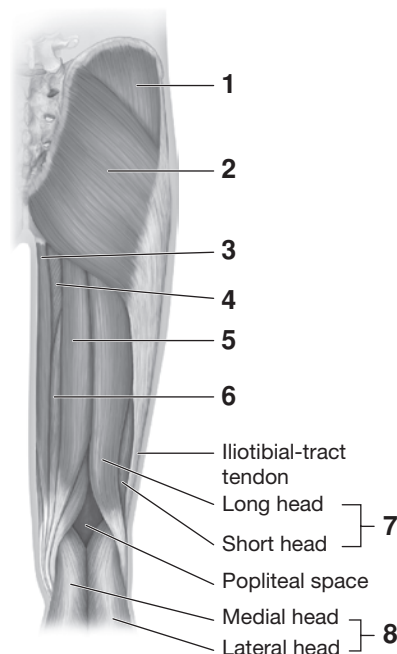
Rectus femoris

Vastus medialis

Gracilis

Tensor fasciae latae

As we discuss the muscles of the posterior thigh, add labels to the illustration below. When you are done, you should be able to identify the muscles of the posterior thigh listed below.



1. Gluteus medius
2. Gluteus maximus
3. Gracilis
4. Adductor magnus
5. Semitendinosus
6. Semimembranosus
7. Biceps femoris
8. Gastrocnemius

Adductor magnus

Gluteus maximus

Semimembranosus

Biceps femoris

Gluteus medius

Semitendinosus

Gastrocnemius

Gracilis

*Note: This exercise has been modified from the printed text.

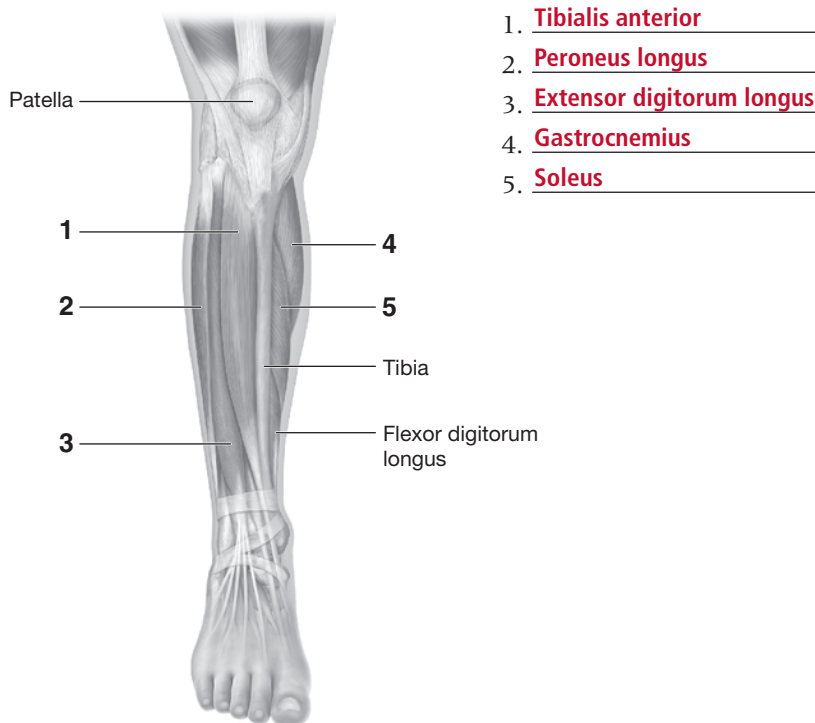
Muscles that Move the Foot and Toes

Complete the table below by supplying the primary action for each muscle listed.

Muscles that Move the Foot and Toes

Muscle	Origin	Insertion	Action
Tibialis anterior	Proximal two-thirds of the tibia	Tarsal bone (cuneiform) and the first metatarsal	Dorsiflexion; inverts the foot at the ankle
Extensor digitorum longus	Proximal end of the tibia, anterior surface of the fibula	Second and third phalanges of digits 2–5	Dorsiflexion; everts the foot at the ankle
Gastrocnemius	Two heads, both at the distal end of the femur	Calcaneus by way of the calcaneal tendon	Plantar flexion; flexes the leg at the knee
Soleus	Proximal ends of the tibia and fibula	Calcaneus by way of the calcaneal tendon	Plantar flexion
Peroneus longus	Proximal ends of the tibia and fibula	Tarsal and metatarsal bones	Plantar flexion; everts the foot at the ankle
Peroneus tertius	Distal surface of the fibula	Fifth metatarsal	Dorsiflexion; everts the foot at the ankle

As we discuss the muscles of the anterior leg and foot, add labels to the illustration below. When you are done, you should be able to identify the muscles of the anterior leg and foot listed below.

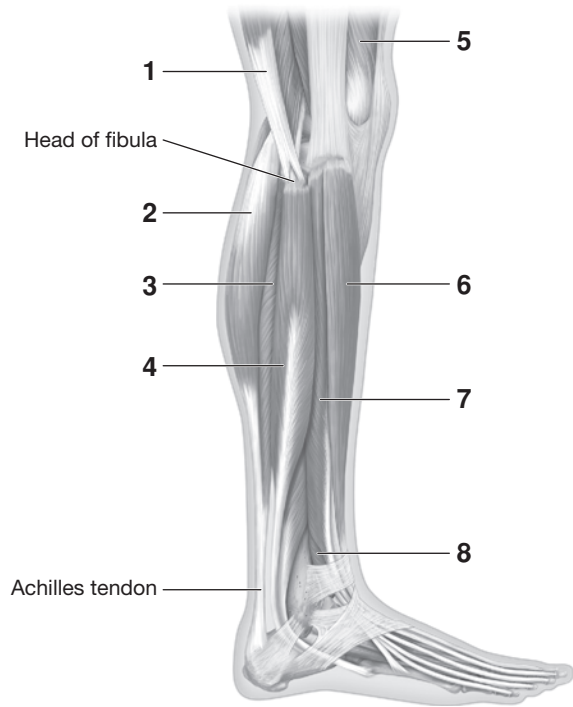


Extensor digitorum longus
Gastrocnemius

Peroneus longus
Soleus

Tibialis anterior

As we discuss the muscles of the lateral and posterior leg and foot, add labels to the illustration below. When you are done, you should be able to identify the muscles of the lateral and posterior leg and foot listed below.



1. Biceps femoris
2. Gastrocnemius
3. Soleus
4. Peroneus longus
5. Vastus lateralis
6. Tibialis anterior
7. Extensor digitorum longus
8. Peroneus tertius

Biceps femoris
Extensor digitorum longus
Gastrocnemius

Peroneus longus
Peroneus tertius
Soleus

Tibialis anterior
Vastus lateralis