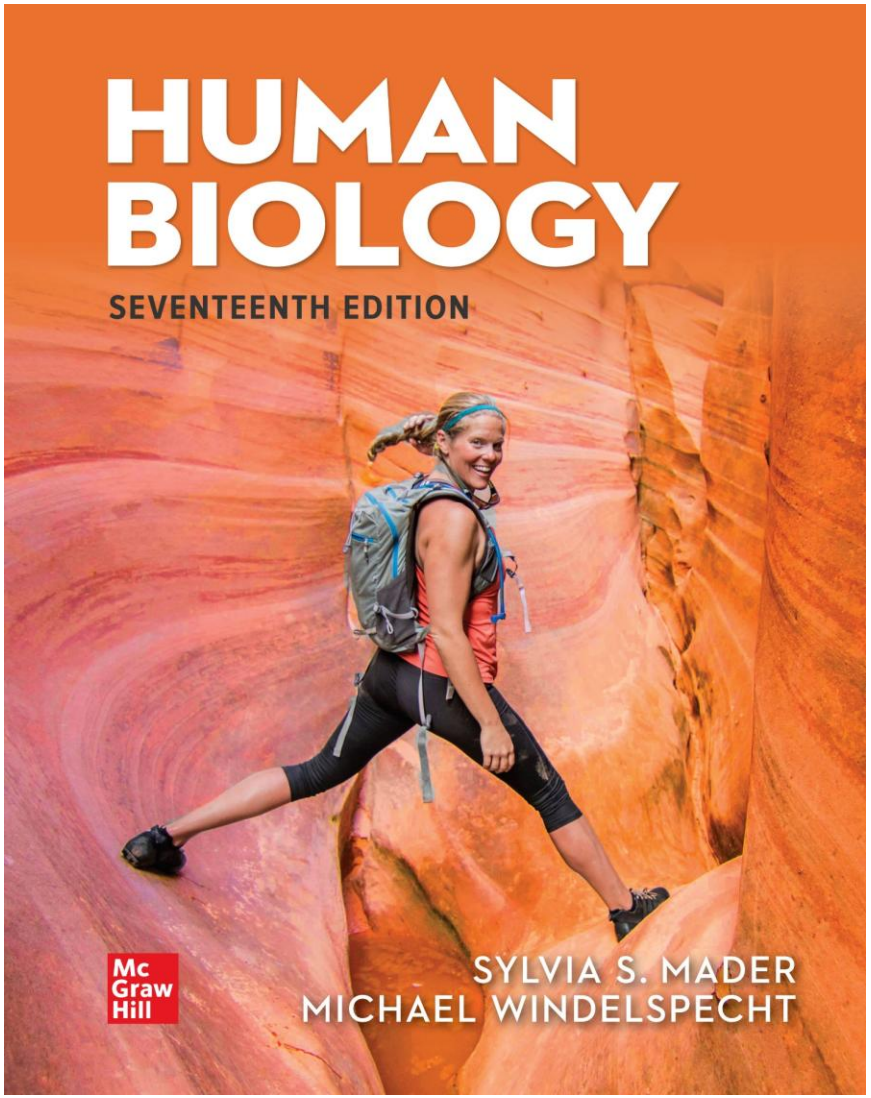
Mc Graw Hill

Because learning changes everything.®



HUMAN BIOLOGY

Seventeenth Edition

Sylvia S. Mader
Michael Windelspecht

Chapter 13
Muscular System

13.1 Overview of the Muscular System [1]

Learning Outcomes:

- List the three types of muscle tissue and provide a function for each.
- Describe the general structure of a skeletal muscle.
- Recognize how skeletal muscles are named.

13.1 Overview of the Muscular System 2

Muscular system.

Functions in:

- Movement of the entire organism.
  - That is, walking, running.
- Movement of materials within the organism.
  - That is, blood, food.

Types of Muscle 1

Three types of muscle tissue: **smooth, cardiac,** and **skeletal.**

- The cells are called **muscle fibers.**

Types of Muscle 2

Smooth muscle.

Fibers are:

- Shaped like cylinders with pointed ends.
- Uninucleated.
- Arranged in parallel lines, forming sheets.
- Not striated.

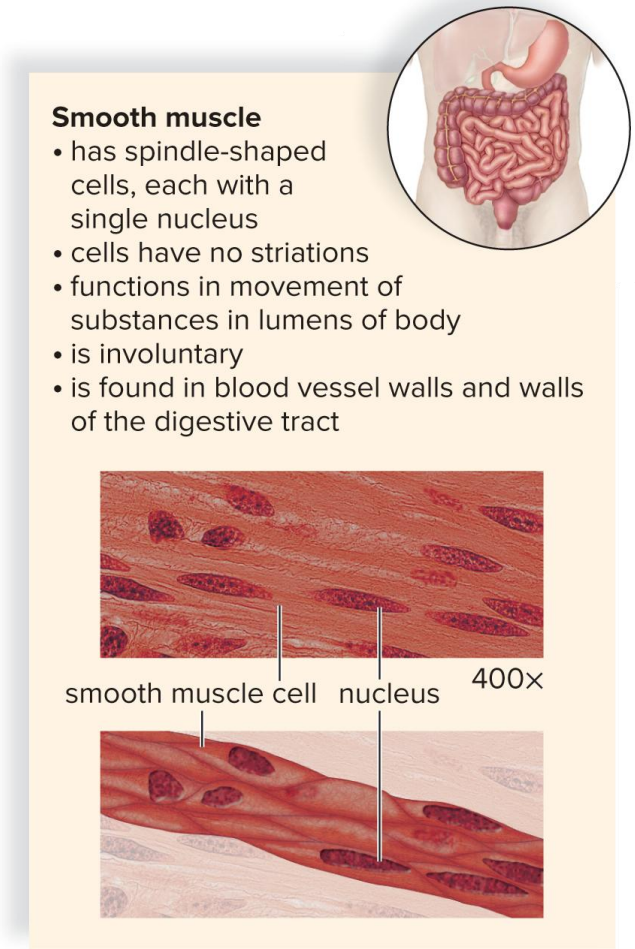
Located in the walls of hollow internal organs and blood vessels and causes these walls to contract.

Types of Muscle 3

Smooth muscle, continued.

- Contraction is involuntary.
- Although smooth muscle is slower to contract than skeletal muscle, it can sustain prolonged contractions and does not fatigue easily.

The Three Classes of Muscles in Humans (Figure 13.1b) 1



b.

Access the text alternative for slide images.

Types of Muscle 4

Cardiac muscle.

Forms the heart wall.

Fibers are:

- Uninucleated, striated, and tubular.
- Branched; interlock at **intercalated disks.**
  - Contain gap junctions that permit contractions to spread through the heart wall.

Types of Muscle 5

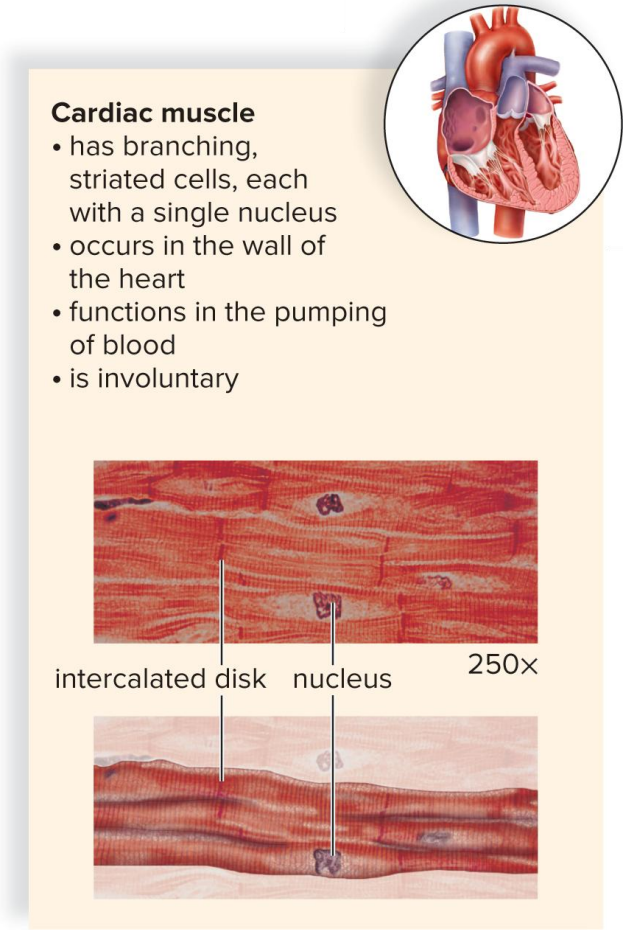
Cardiac muscle, continued.

Relaxes completely between contractions, which prevents fatigue.

Contraction:

- Is rhythmic.
- Occurs without nervous stimulation.
- Is involuntary.

The Three Classes of Muscles in Humans (Figure 13.1c) 2



c.

Access the text alternative for slide images.

Types of Muscle 6

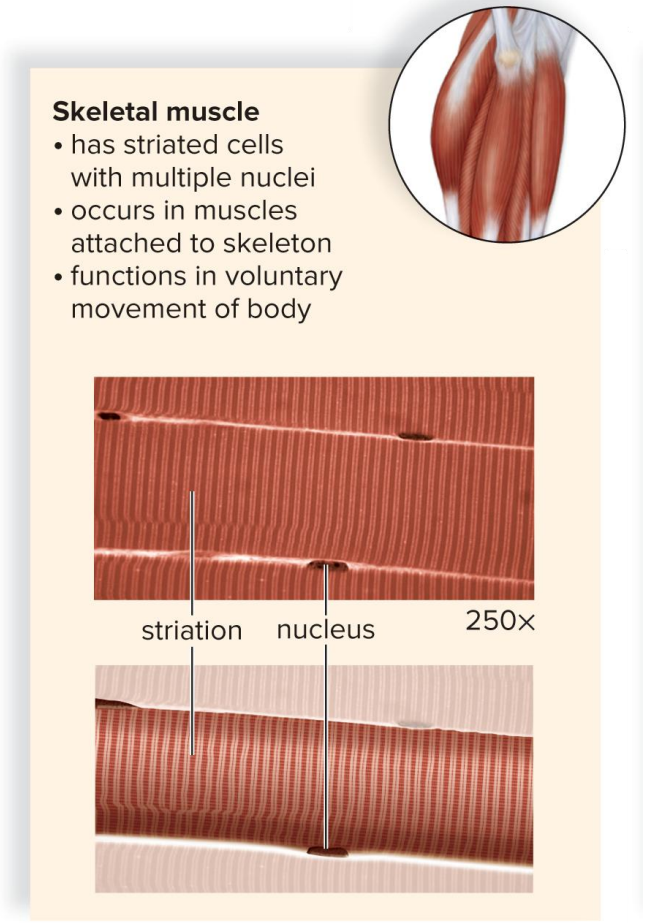
Skeletal muscle.

Fibers are:

- Tubular, multinucleated, and striated.
- Make up skeletal muscles, which are attached to the skeleton.
- Very long; run the length of the muscle.

Is voluntarily controlled.

The Three Classes of Muscles in Humans (Figure 13.1a) 3



a.

Access the text alternative for slide images.

Skeletal Muscles of the Body 1

Humans belong to a class of animals called the **vertebrates.**

- Possess an internal vertebral column, a skeleton, and jointed appendages.

Skeletal muscles are attached to the skeleton, and their contraction causes the movement of bones at joints.

Skeletal Muscles of the Body 2

Functions of skeletal muscles:

Support—muscle contraction opposes gravity and allows us to remain upright.

Movements of bones and other body structures.

- Arms, legs, eyes, facial expressions, and breathing.

Maintenance of a constant body temperature.

- Contraction causes ATP to break down, releasing heat, which helps maintain temperature homeostasis in the body.

Skeletal Muscles of the Body 3

Functions of skeletal muscles, continued:

Movement of fluids in the cardiovascular and lymphatic systems.

- Keeps blood moving in cardiovascular veins and lymph moving in lymphatic vessels.

Protection of the internal organs and the stabilization of joints.

- Muscles pad the bones, and the muscular wall of the abdomen protects internal organs.
- Muscle tendons hold bones together at joints.

Skeletal Muscles of the Body 4

Basic Structure of Skeletal Muscles.

Fascicle—bundle of skeletal muscle fibers.

- Within a fascicle, each fiber is surrounded by connective tissue; the fascicle is also surrounded by connective tissue.
- **Fascia**—connective tissue that covers muscles and extends to become its **tendon.**
- Small, fluid-filled sacs called **bursae** (*sing.*, bursa) can often be found between tendons and bones.
  - The bursae act as cushions, lubrication.

Skeletal Muscles of the Body 5

Skeletal muscles work in pairs.

For a given movement, the **origin** of a muscle is the attachment site to the stationary bone, and the **insertion** is the attachment on the bone that moves.

- When a muscle contracts, it pulls on the tendons at its insertion and the bone moves.
  - That is, when the biceps brachii contracts, it raises the forearm.

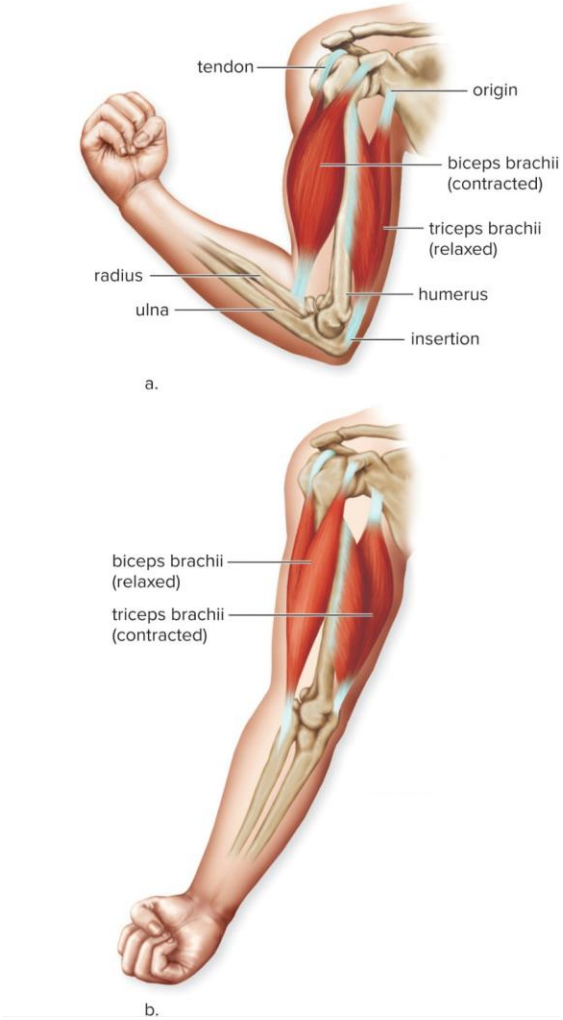
Skeletal Muscles of the Body 6

Skeletal muscles work in pairs, continued.

Skeletal muscles usually function in groups.

- **Agonist (prime mover)**—the muscle that does most of the work.
- **Synergist**—assists the agonist.
- **Antagonist**—the muscle that acts opposite to a prime mover.
  - That is, the biceps brachii and the triceps brachii are antagonists; biceps flexes the forearm, and the triceps extends the forearm.
    - If both contract at once, there would be no movement.

Skeletal Muscles Often Work in Pairs (Figure 13.3)



Access the text alternative for slide images.

Skeletal Muscles of the Body 7

Names and actions of skeletal muscles.

The names of skeletal muscles often use the following terms to characterize them:

- **Size**: gluteus **maximus,** gluteus **minimus.**
  - Other terms used to indicate size: **vastus** (huge), **longus** (long), and **brevis** (short).
- **Shape**: **deltoid** (shaped like the Greek letter delta).
  - **Trapezius** is shaped like a trapezoid.
  - Other terms used to indicate shape are **latissimus** (wide) and **teres** (round).

Skeletal Muscles of the Body 8

Names and actions of skeletal muscles, continued.

Location: external obliques, **internal** obliques.

- **Frontalis** muscle overlies the frontal bone.
- Other terms used to indicate location are **pectoralis** (chest), **gluteus** (buttock), **brachii** (arm), and **sub** (beneath).

Skeletal Muscles of the Body 9

Names and actions of skeletal muscles, continued.

Direction of muscle fibers: rectus abdominis (**rectus** = “straight”).

- **Orbicularis** oculi—circular muscle around the eye.
- Other terms used to indicate direction are **transverse** (across) and **oblique** (diagonal).

Skeletal Muscles of the Body 10

Names and actions of skeletal muscles, continued.

Attachment: **sternocleidomastoid** is attached to the sternum, clavicle, and mastoid process.

- **Brachioradialis**—attached to the brachium (arm) and the radius (forearm).

Number of attachments: biceps brachii has two attachments.

- **Quadriceps** femoris has four origins.

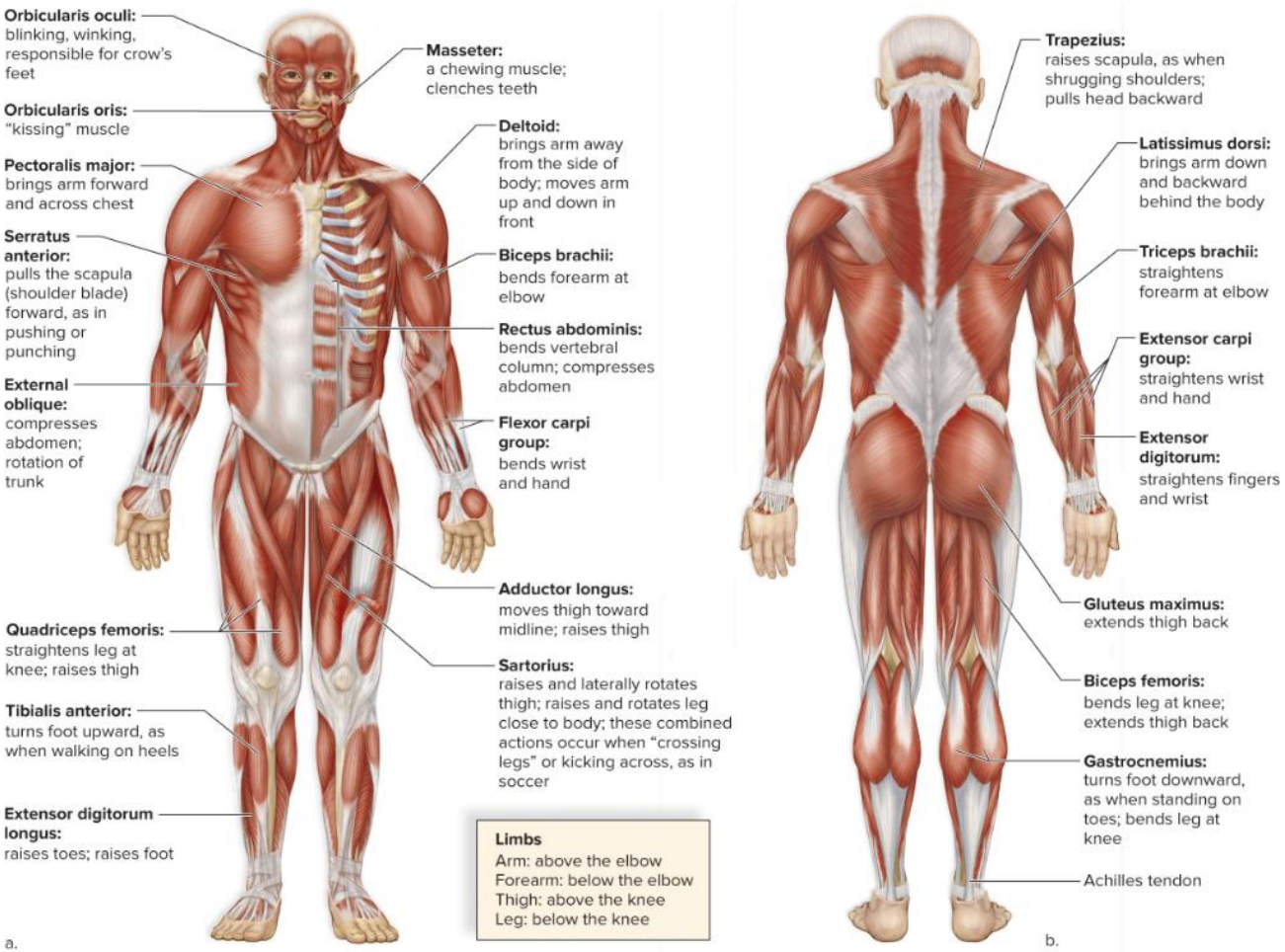
Skeletal Muscles of the Body 11

Names and actions of skeletal muscles, concluded.

Action: extensor digitorum extends the fingers (digits).

- **Adductor** longus adducts the thigh.
- Other terms used to indicate action are **flexor** (to bend), **masseter** (to chew), and **levator** (to lift).

The Major Skeletal Muscles of the Human Body (Figure 13.5)



Access the text alternative for slide images.

Check Your Progress 13.1

- State the three types of muscles in the human body and explain where each is found in the body.
- Summarize the functions of skeletal muscles.
- Explain how skeletal muscles work together to cause bones to move.

13.2 Skeletal Muscle Fiber Contraction

Learning Outcomes:

- Identify the structures of a muscle fiber.
- Explain how the sliding filament model is responsible for muscle contraction.
- Summarize how activities within the neuromuscular junction control muscle fiber contraction.

Muscle Fibers and How They Move 1

Cellular components of a muscle fiber:

Sarcolemma—plasma membrane.

Sarcoplasm—cytoplasm.

Sarcoplasmic reticulum—endoplasmic reticulum.

- Calcium storage site.

T (transverse) tubules—penetrate the cells; come close to portions of the sarcoplasmic reticulum.

Anatomy of a Muscle Fiber (Table 13.1)

Table 13.1 Anatomy of a Muscle Fiber

Name	Function
Sarcolemma	The plasma membrane of a muscle fiber that forms T tubules
Sarcoplasm	The cytoplasm of a muscle fiber that contains the organelles, including myofibrils
Myoglobin	A red pigment that stores oxygen for muscle contraction
T tubule	An extension of the sarcolemma that extends into the muscle fiber and conveys impulses that cause Ca^{2+} to be released from the sarcoplasmic reticulum
Sarcoplasmic reticulum	The smooth endoplasmic reticulum (ER) of a muscle fiber that stores Ca^{2+}
Myofibril	A bundle of myofilaments that contracts
Myofilament	Actin filaments and myosin filaments whose structure accounts for the muscle striations and functions in muscle contraction.

Muscle Fibers and How They Move 2

Cellular components of a muscle fiber, continued:

- The sarcolemma contains many **myofibrils**, the contractile parts of muscle fibers.
- The sarcoplasm also contains glycogen, which provides energy for muscle contraction.
- The sarcoplasm includes the red pigment **myoglobin**, which binds oxygen.

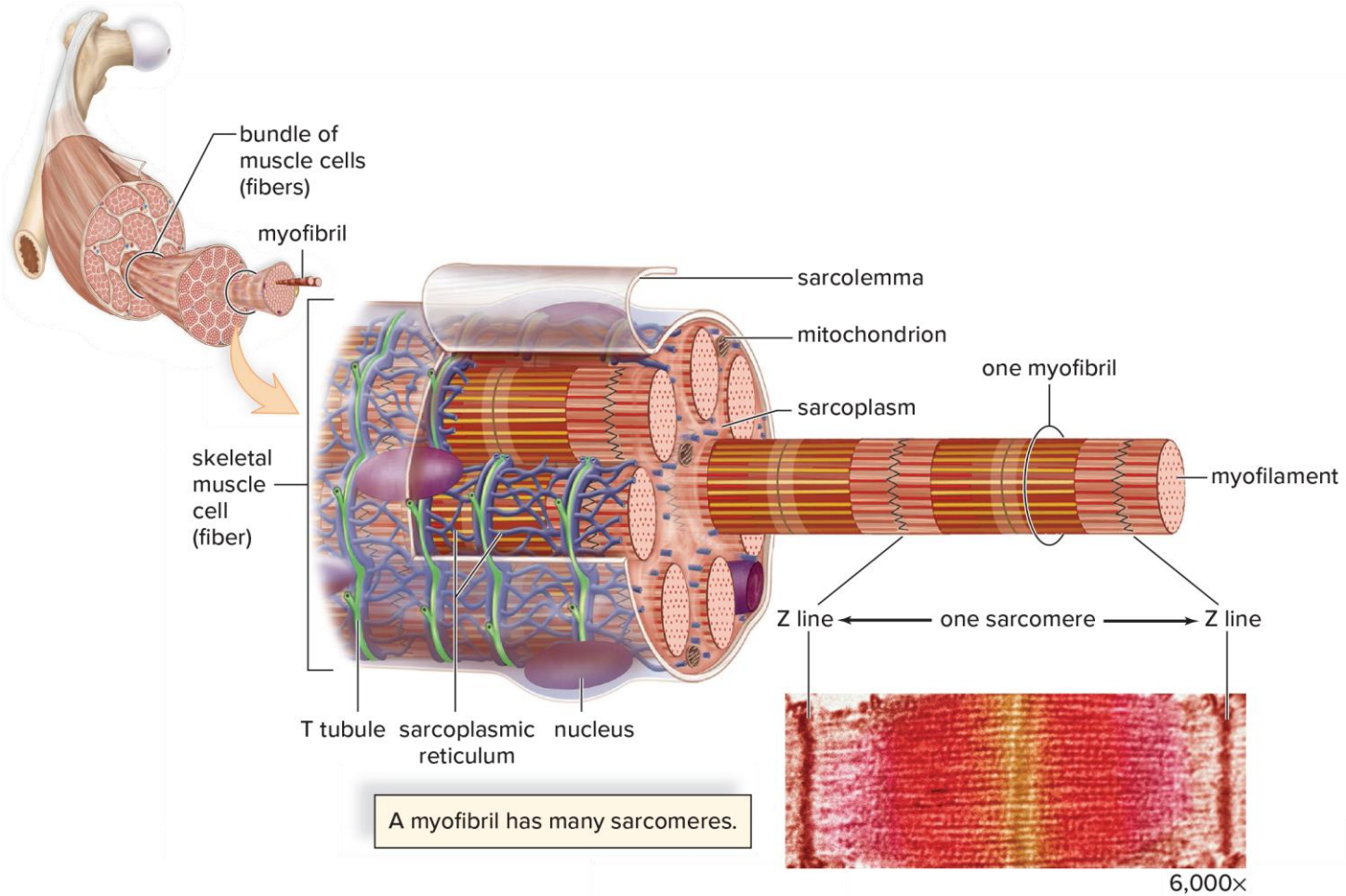
Muscle Fibers and How They Move 3

Myofibrils and sarcomeres.

Muscle fiber.

- Cylindrical in shape.
- Grouped inside this larger cylinder are smaller cylinders called **myofibrils.**
  - Myofibrils run the entire length of the muscle fiber.
  - Made of smaller cylinders called **myofilaments.**
  - Thus, the muscle cell is a set of small cylinders (myofilaments) assembled into larger cylinders (myofibrils) clustered within the largest cylinder (the muscle fiber).

The Structure of a Skeletal Muscle Fiber (Figure 13.6 top) 1



Access the text alternative for slide images.

(photo): Biology Pics/Science Source

Muscle Fibers and How They Move 4

Myofibrils and sarcomeres, continued.

Muscle fiber, continued.

- **Striations**—stripes formed by the placement of myofilaments within myofibrils.
- Two types of myofilaments:
  - Thick myofilaments are made up of **myosin.**
  - Thin myofilaments are composed of **actin.**

Muscle Fibers and How They Move 5

Myofibrils and sarcomeres, continued.

Muscle fiber, concluded.

- Myofibrils are further divided into **sarcomeres.**
  - Sarcomeres extend between two dark vertical lines called **Z lines.**
  - **I band**—light colored; made of only thin myofilaments.
  - **A band**—made of overlapping thin and thick myofilaments.
    - Centered within the A band is a vertical **H band**, which contains only thick myofilaments.

Muscle Fibers and How They Move 6

Myofibrils and sarcomeres, concluded.

Thick filaments.

- Composed of the protein **myosin.**
  - Each myosin molecule is shaped like a golf club, with the straight portion of the molecule ending in a globular head, or **cross-bridge**.

Thin filaments.

- Made of two intertwining strands of the protein **actin**, with **tropomyosin,** and **troponin.**

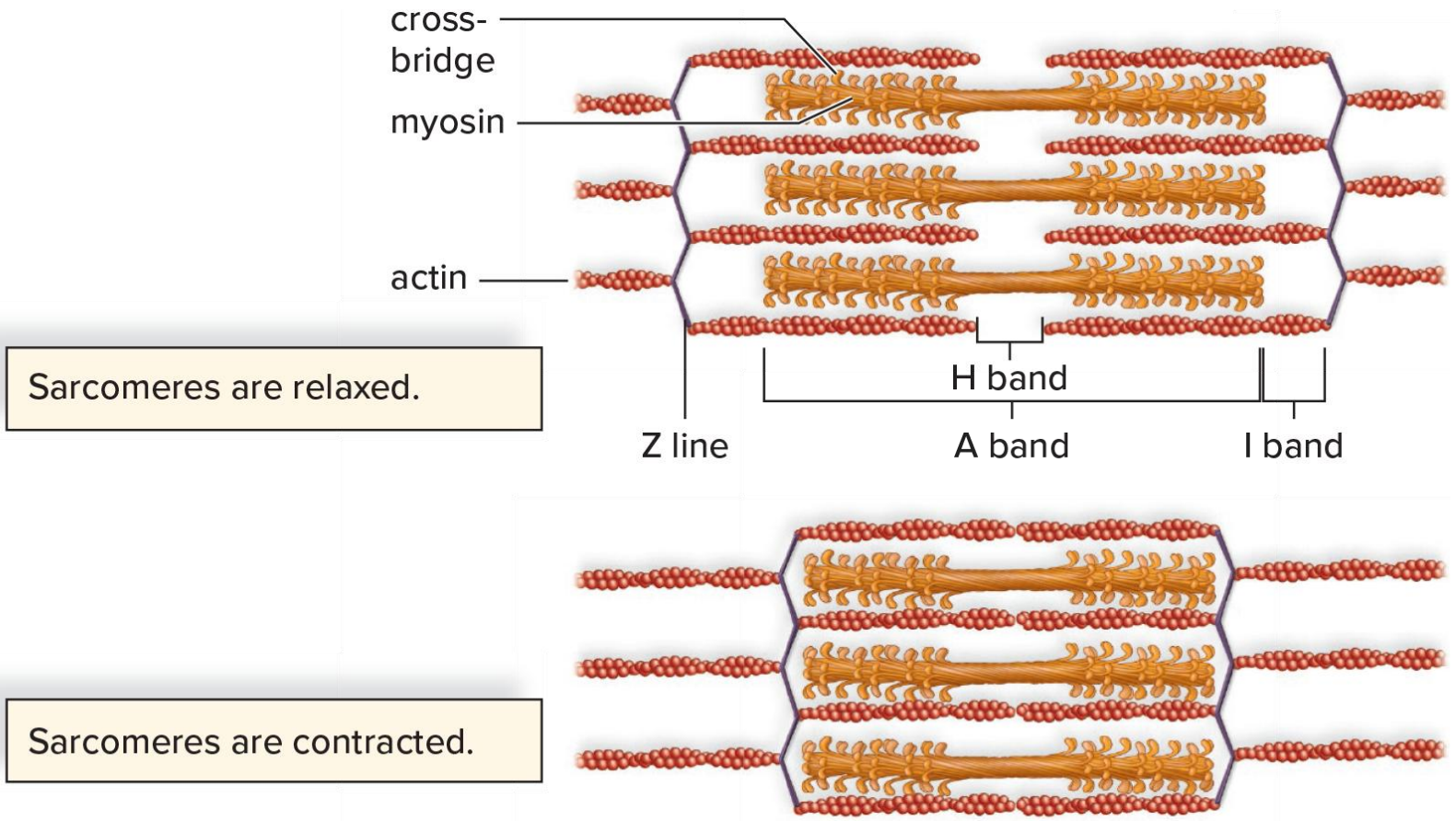
Muscle Fibers and How They Move 7

The sliding filament model.

The muscle fiber contracts as the sarcomeres shorten.

- Note that when the sarcomere contracts, the filaments themselves remain the same length.
  - The thin filaments slide past the thick filaments.
  - The I band shortens, the Z lines move inward, and the H band almost disappears.

The Structure of a Skeletal Muscle Fiber (Figure 13.6 bottom) 2



Access the text alternative for slide images.

Muscle Fibers and How They Move 8

The sliding filament model, continued.

ATP supplies the energy for muscle contraction.

- Myosin filaments break down ATP, and their cross-bridges pull the actin filament toward the center of the sarcomere.

Muscle Fiber Contraction 1

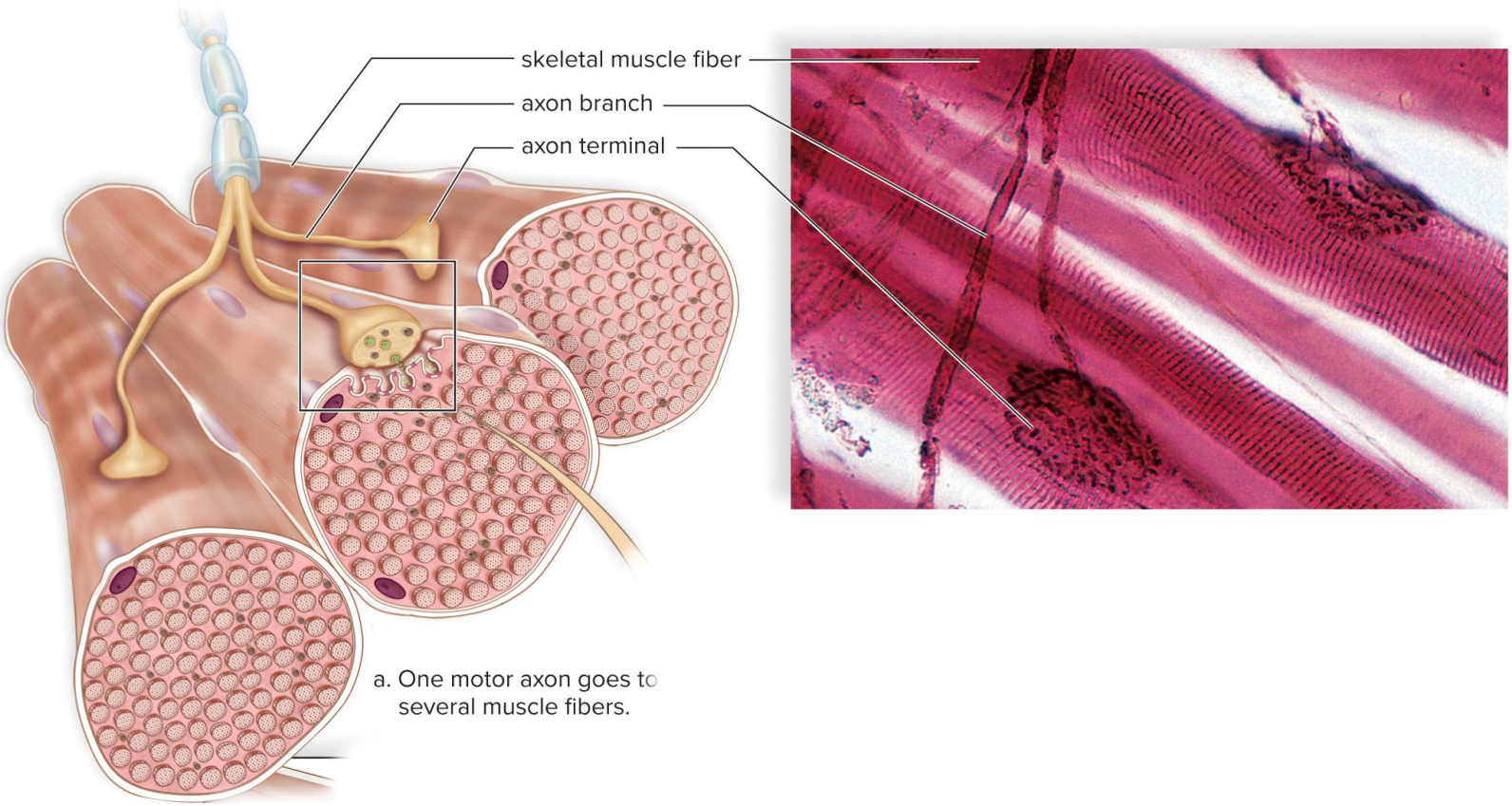
Motor neuron—a type of nervous system cell that stimulates muscle fibers to contract.

Nerve—group of neurons.

Axon—the part of a neuron that stimulates a muscle fiber.

- Branches, so can stimulate several muscle fibers.

Neuromuscular Junctions (Figure 13.7a) 1



(photo): Ed Reschke/Stone/Getty Images

Muscle Fiber Contraction 2

Neuromuscular junction.

Where an **axon terminal** (end of an axon) comes near the sarcolemma.

- **Synaptic cleft**—the space that separates the two.

Axon terminals contain **synaptic vesicles** filled with the neurotransmitter **acetylcholine (ACh).**

- When nerve signals traveling down the axon arrive at an axon terminal, synaptic vesicles release ACh into the synaptic cleft.

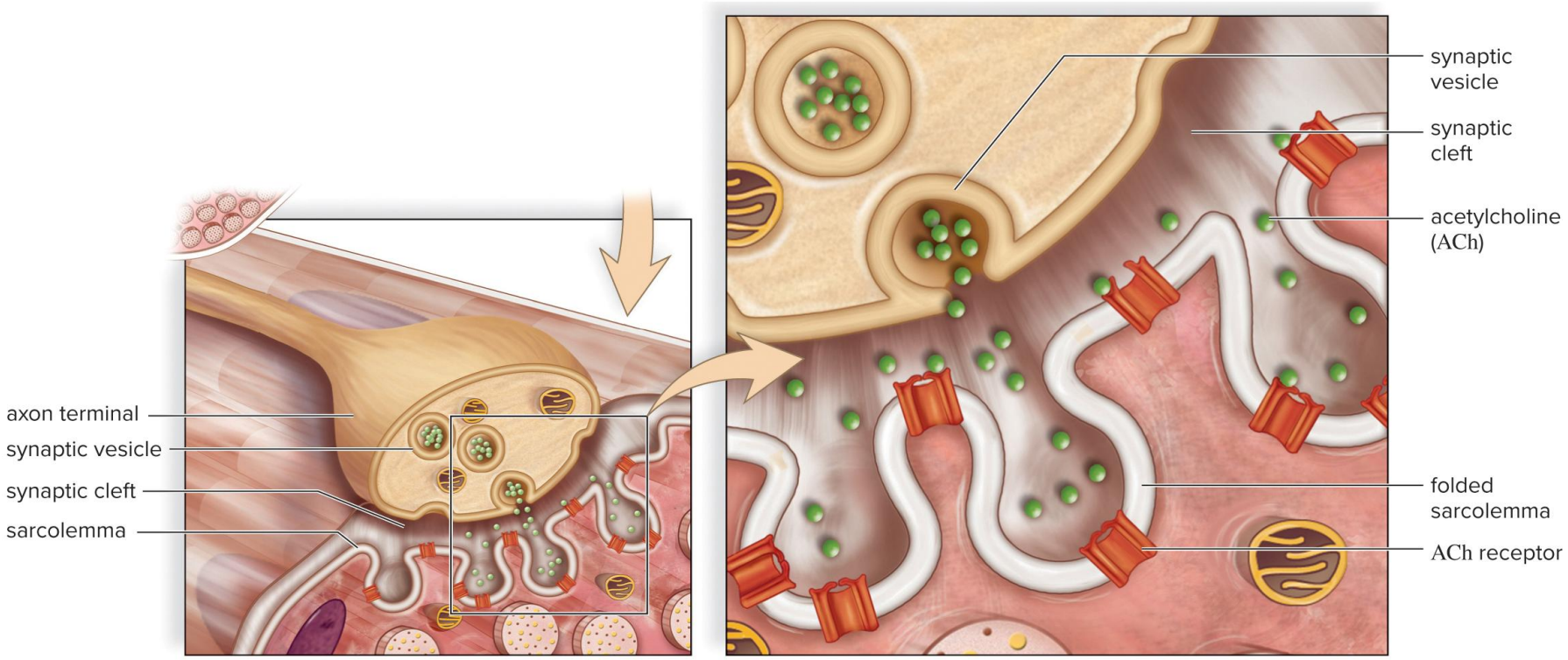
Muscle Fiber Contraction 3

Neuromuscular junction, concluded.

ACh diffuses across the cleft and binds to receptors in the sarcolemma.

- This generates electrical signals that spread across the sarcolemma and down the T tubules.
- This causes calcium to be released from the sarcoplasmic reticulum.

Neuromuscular Junctions (Figure 13.7b,c) 2



b. A synaptic cleft exists between an axon terminal and a muscle fiber.

c. Neurotransmitter (ACh) diffuses across synaptic cleft and binds to receptors in sarcolemma.

Access the text alternative for slide images.

Muscle Fiber Contraction 4

Two other proteins are in thin filaments:

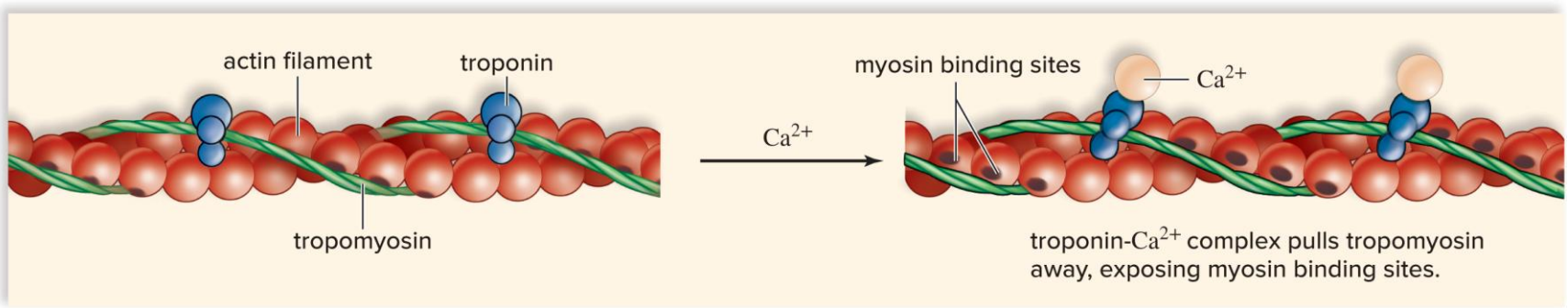
Threads of **tropomyosin** wind around the strands of actin, covering binding sites for myosin.

Troponin occurs at intervals along the threads.

When Ca^{2+} is released from the sarcoplasmic reticulum, it binds to troponin.

- The tropomyosin threads move, exposing myosin-binding sites.

The Role of Calcium Ions and ATP During Muscular Contraction (Figure 13.8a)



a. Function of Ca^{2+} ions in muscle contraction

Access the text alternative for slide images.

Muscle Fiber Contraction 5

Steps of a muscle contraction.

The myosin heads have ATP-binding sites.

- At this site, ATP is split to form ADP and P.

Myosin heads attach to actin.

- Form temporary bonds called **cross-bridges.**

ADP and P are then released and the myosin heads bend.

- This is the power stroke that pulls the actin filament toward the center of the sarcomere.

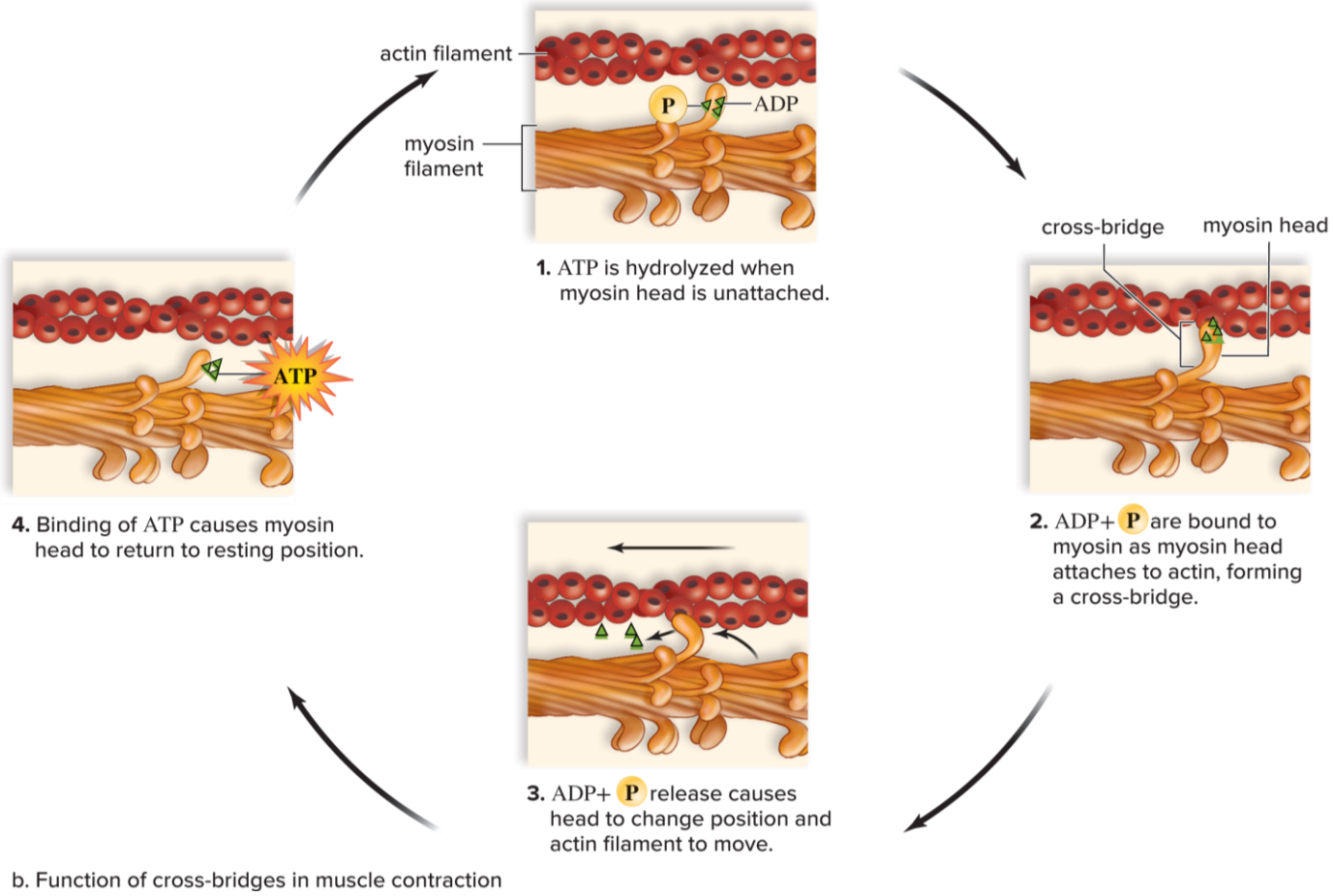
Muscle Fiber Contraction 6

Steps of a muscle contraction, continued.

The binding of ATP to myosin heads breaks the cross-bridges.

- Myosin detaches from actin.
- The cycle begins again and myosin reattaches farther along the actin filament.
- The cycle recurs over and over, shortening the sarcomere (and therefore the muscle).
- **Rigor mortis**—relaxing the muscle is impossible, because ATP is needed to break the cross-bridges.

The Role of Calcium Ions and ATP During Muscular Contraction (Figure 13.8b) 2



Access the text alternative for slide images.

Check Your Progress 13.2

- Explain the role of the myofibril, myofilament, and sarcomere in a muscle fiber.
- Explain how the thin and thick filaments interact in the sliding filament model.
- Describe the role of both ATP and calcium ions in muscle contraction.

13.3 Whole Muscle Contraction

Learning Outcomes:

- List the stages of a muscle twitch and explain what is occurring in each stage.
- Explain how summation and tetanus increase the strength of whole muscle contraction.
- Summarize how muscle cells produce ATP for muscle contraction.
- Distinguish between fast-twitch and slow-twitch muscle fibers.

Muscles Have Motor Units 1

Motor unit—a nerve fiber and all the muscle fibers it innervates.

All muscle fibers in a motor unit are stimulated at once; they all either contract or don't.

The number of muscle fibers within a motor unit varies.

- Some motor units, like the ones that require fine control, contain only a few fibers.
- Motor units responsible for strength contain many fibers.

Muscles Have Motor Units 2

Muscle twitch—a single contraction of a muscle fiber; lasts only a fraction of a second.

Divided into three stages:

- **Latent period**—the time between stimulation and initiation of contraction.
  - The events that begin muscle contraction are occurring: ACh diffuses across the synaptic cleft, causing an electrical signal to spread across the sarcolemma and down the T tubules.

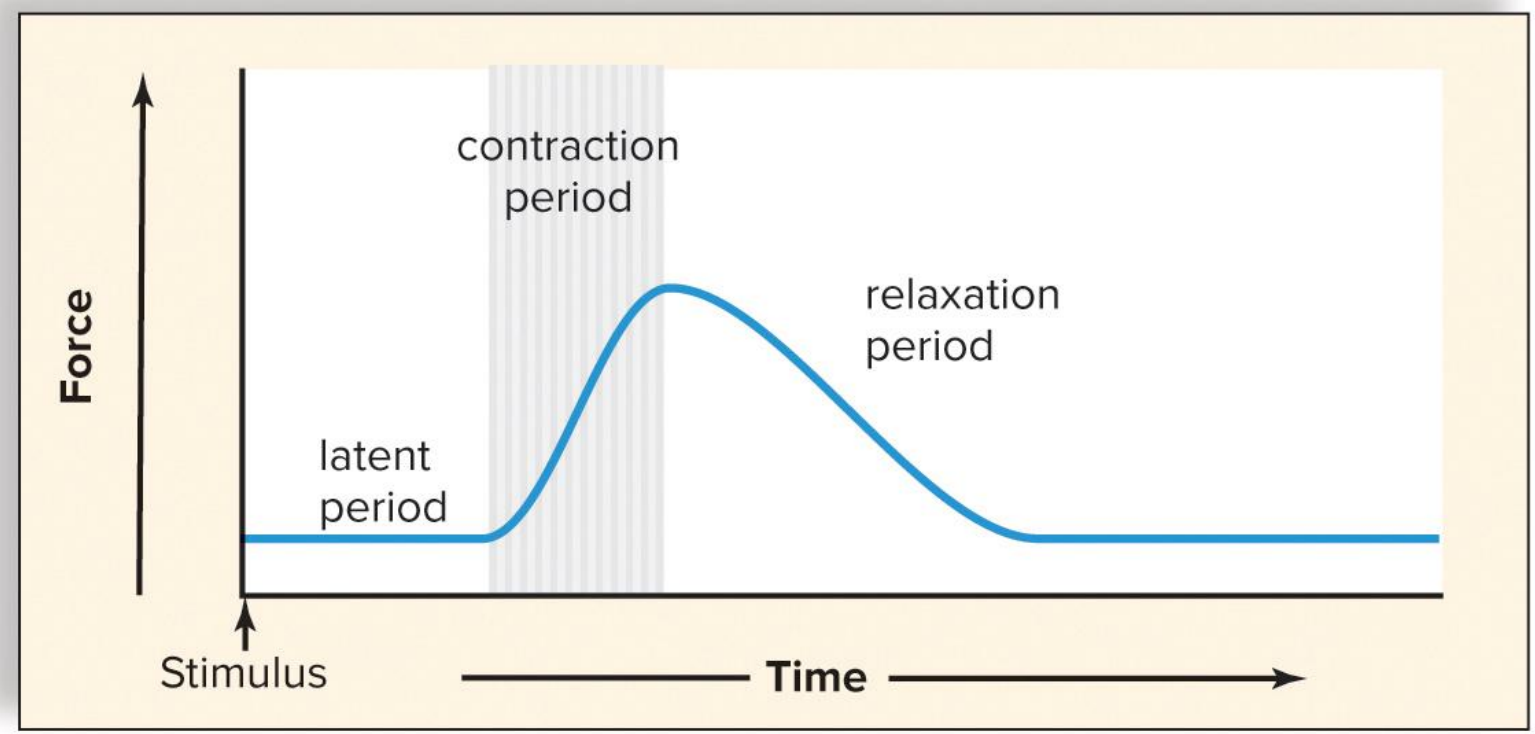
Muscles Have Motor Units 3

Muscle twitch, continued.

Three stages of a muscle twitch, continued.

- **Contraction period**—calcium leaves the sarcoplasmic reticulum; cross-bridges form.
- **Relaxation period**—cross-bridges are broken; calcium returns to the sarcoplasmic reticulum.
  - Force diminishes as the muscle returns to its former length.

The Three Phases of a Single Muscle Twitch (Figure 13.9a) 1



a.

Access the text alternative for slide images.

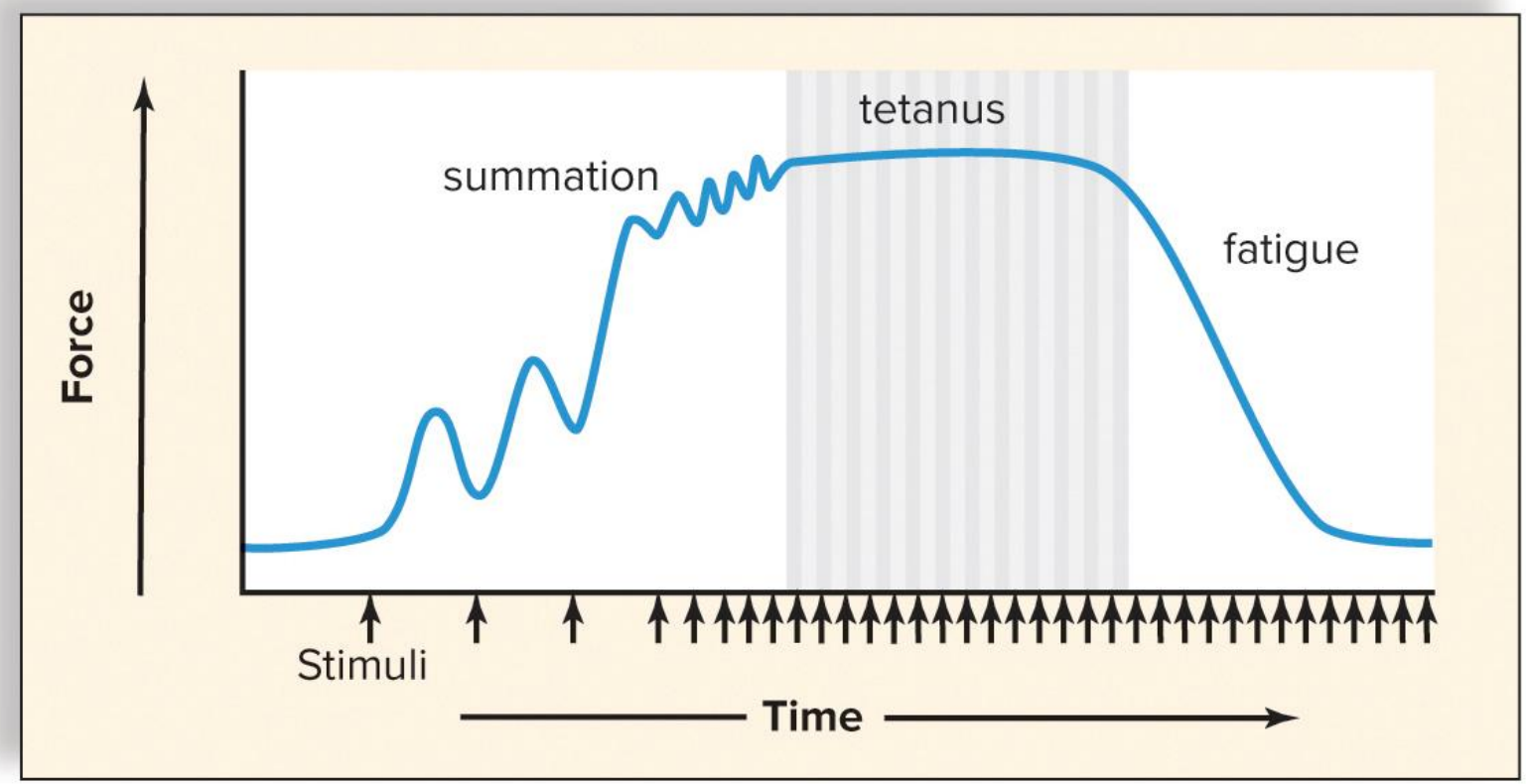
Muscles Have Motor Units 4

Summation—increased muscle contraction.

Can occur until maximal sustained contraction, called **tetanus**, is achieved.

- Tetanus continues until the muscle fatigues due to depletion of energy reserves.
  - Fatigue—when a muscle relaxes, even though stimulation continues.
- Not the same as the infection called tetanus.

The Three Phases of a Single Muscle Twitch (Figure 13.9b) 2



b.

Access the text alternative for slide images.

Muscles Have Motor Units 5

Recruitment—as the intensity of nervous stimulation increases, more motor units in a muscle are activated.

Maximum contraction of a muscle requires that all motor units be in tetanus.

- This rarely happens, because they would all fatigue at the same time.
- Instead, some motor units contract maximally while others rest.

Muscles Have Motor Units 6

Muscle tone.

Muscle tone = muscle firmness.

- The amount is dependent on muscle contraction.
- Some motor units are always contracted, but not enough to cause movement.

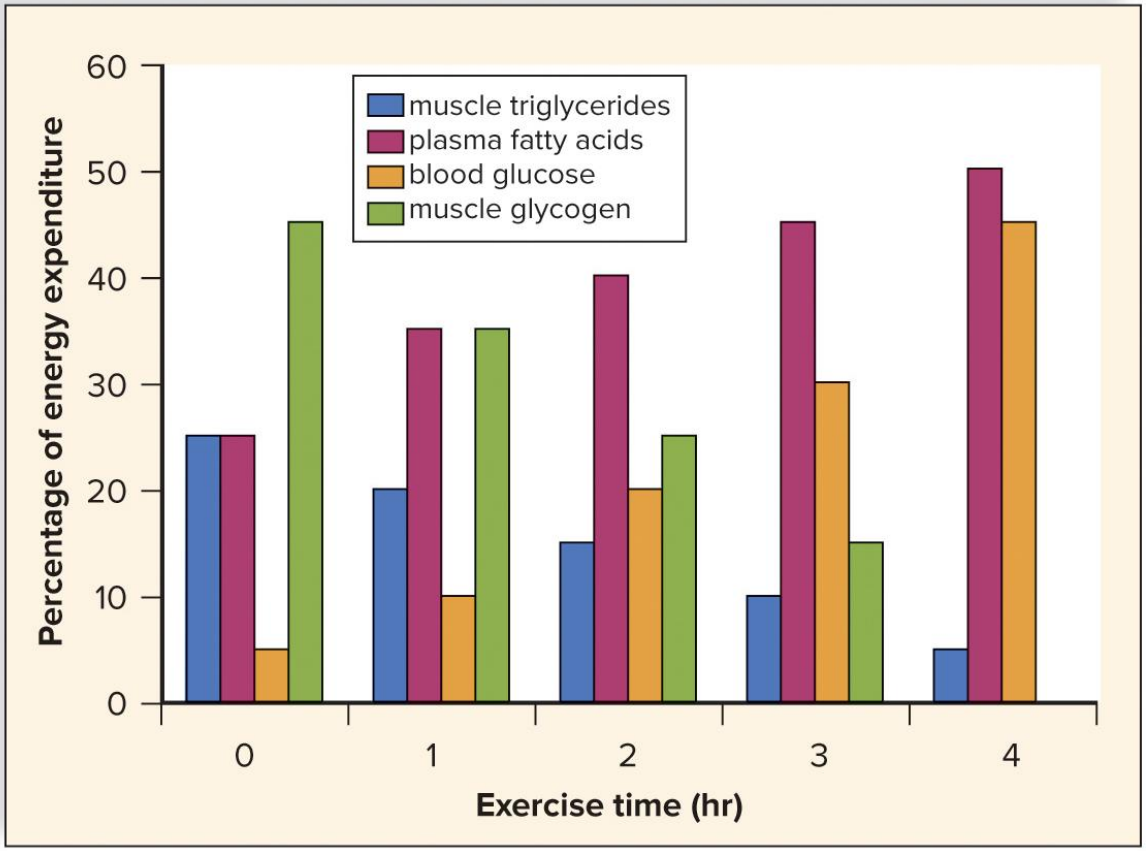
Energy for Muscle Contraction 1

Fuel sources for exercise.

Muscles have four different sources of energy:

- Two are stored in muscle (glycogen, triglycerides) and two are acquired from blood (glucose, fatty acids).
  - Which of these are used depends on exercise intensity and duration.
- As time of exercise increases, use of muscle energy stores decreases and use of energy sources from the blood increases.

The Sources of Energy for Muscle Contraction (Figure 13.10)



Access the text alternative for slide images.

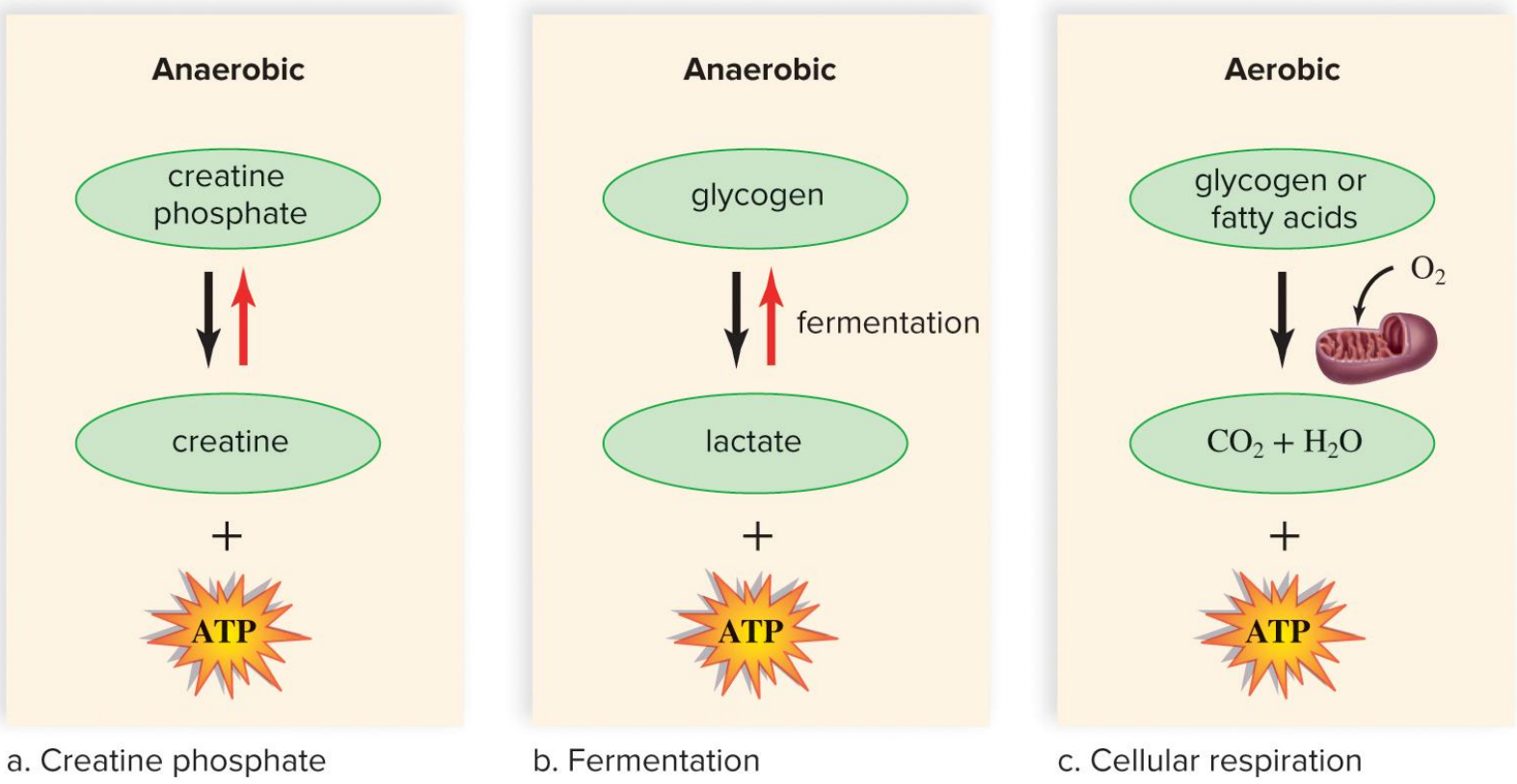
Energy for Muscle Contraction 2

Sources of ATP for muscle contraction.

Muscle cells store limited amounts of ATP.

- Once it is used up, they have three ways to produce more ATP:
  - The creatine phosphate (CP) pathway.
  - Fermentation.
  - Cellular respiration.
    - Mitochondria uses oxygen, so is **aerobic**; neither the CP pathway nor fermentation requires oxygen (are **anaerobic**).

The Three Pathways by Which Muscle Cells Produce the ATP Energy Needed for Contraction (Figure 13.11)



a. Creatine phosphate

b. Fermentation

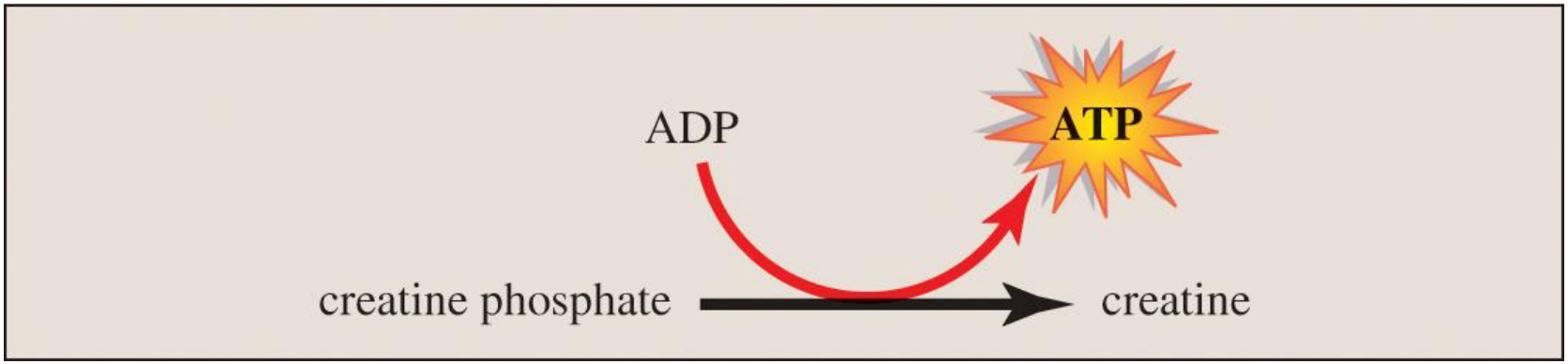
c. Cellular respiration

Access the text alternative for slide images.

Energy for Muscle Contraction 3

The creatine phosphate pathway.

- The simplest and fastest way for muscle to make ATP; it consists of only one reaction:



Energy for Muscle Contraction 4

The creatine phosphate pathway, continued:

Creatine phosphate is formed only when a muscle cell is resting, and only a limited amount is stored.

The CP pathway is used at the beginning of exercise.

- That is, the energy to complete a play in a football game comes principally from the CP system.

Intense activities lasting longer than 5 seconds also make use of fermentation.

Energy for Muscle Contraction 5

Fermentation.

The anaerobic processes of glycolysis and **fermentation** produce two ATPs from the breakdown of glucose to lactate.

- Hormones signal cells to break down glycogen, making glucose available as an energy source.
- Fermentation, like the CP pathway, is fast-acting, but results in the buildup of lactate.
  - Lactate produces short-term muscle aches and fatigue.

Energy for Muscle Contraction 6

Fermentation, continued.

Oxygen debt—heavy breathing following strenuous exercise is required to complete the metabolism of lactate and restore cells to their original energy state.

- People who train have more mitochondria in their muscles.

Energy for Muscle Contraction 7

Cellular respiration.

The slowest of all three mechanisms used to produce ATP, but the most efficient.

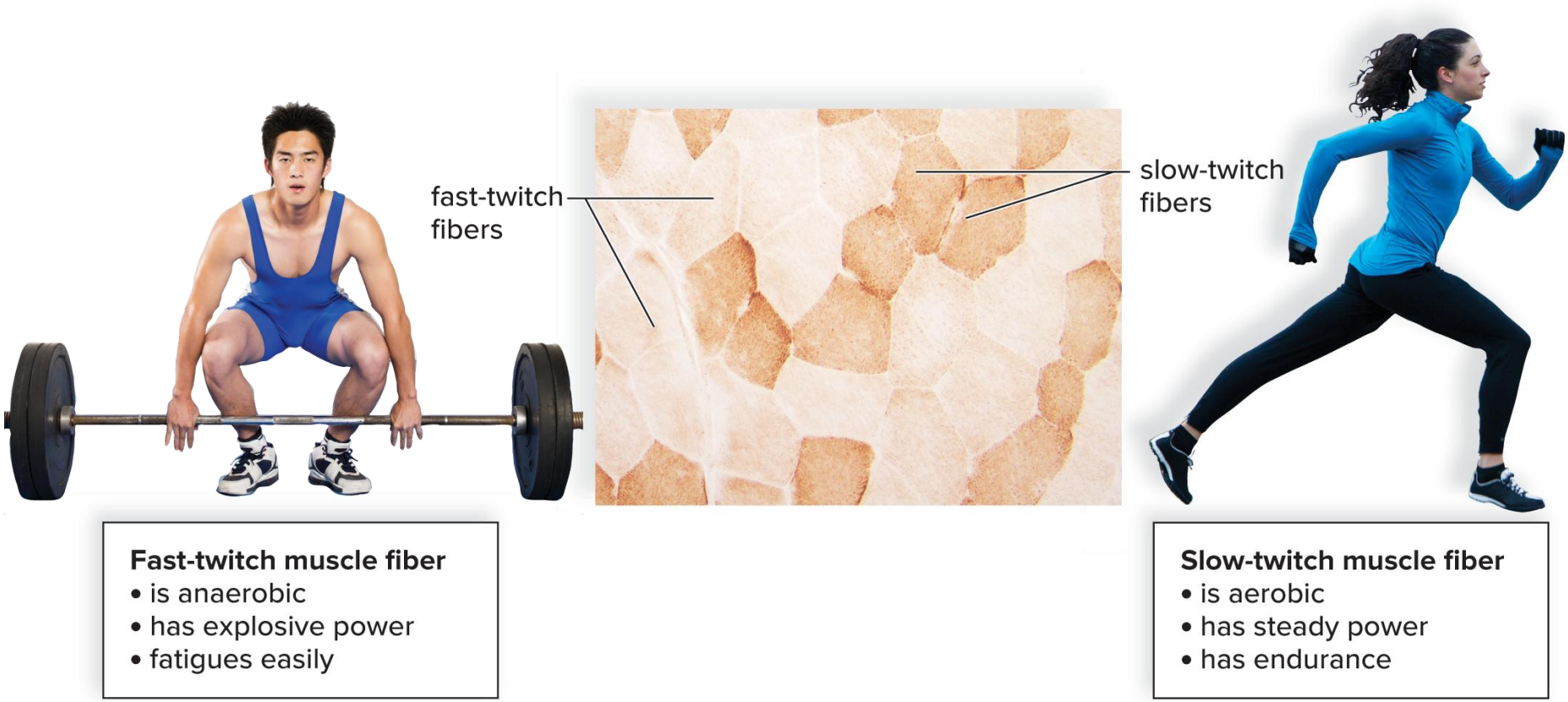
- Occurs in the mitochondria.
- **Myoglobin**—a protein in muscle cells that delivers oxygen directly to the mitochondria.
- Can use glucose from stored glycogen, glucose in the blood, and fatty acids.

Fast-Twitch and Slow-Twitch Muscle Fibers 1

Fast-twitch fibers rely on the creatine phosphate pathway and fermentation (are anaerobic).

Slow-twitch fibers tend to prefer cellular respiration, which is aerobic.

Fast-Twitch and Slow-Twitch Muscle Fibers Differ in Structure (Figure 13.12)



Access the text alternative for slide images.

(weightlifter): Isadora Getty Buyou/Image Source; (twitch fibers): Cultura Creative Ltd/Alamy Stock Photo; (runner): John Giustina/Purestock/Getty Images

Fast-Twitch and Slow-Twitch Muscle Fibers 2

Fast-twitch fibers.

- Designed for strength; their motor units contain many fibers.
- Provide explosions of energy.
- Are most helpful in sports such as sprinting and weightlifting.

Fast-Twitch and Slow-Twitch Muscle Fibers 3

Fast-twitch fibers, continued.

- Are light in color because they have fewer mitochondria, little myoglobin, and fewer blood vessels than slow-twitch fibers.
- Develop maximum tension faster than slow-twitch fibers.
- Maximum tension is greater.
- Their dependence on anaerobic energy leaves them vulnerable to an accumulation of lactate, which causes them to fatigue quickly.

Fast-Twitch and Slow-Twitch Muscle Fibers 4

Slow-twitch fibers.

Motor units have fewer muscle fibers.

Have more stamina.

- Most helpful in endurance sports: long-distance running, biking, jogging, and swimming.

Produce most of their energy aerobically; they tire only when their fuel supply is gone.

Have many mitochondria and are dark in color because they contain myoglobin.

Fast-Twitch and Slow-Twitch Muscle Fibers 5

Slow-twitch fibers, continued.

- Surrounded by dense capillary beds; draw more blood and oxygen than fast-twitch fibers.
- Tension develops slowly.
- Highly resistant to fatigue.
- Have a reserve of glycogen and fat so their mitochondria can maintain a steady, prolonged production of ATP when oxygen is available.

Check Your Progress 13.3

- List the stages of a muscle twitch.
- Contrast the activities of a single muscle twitch with the action of summation and tetanus.
- Summarize how the CP pathway, fermentation, and cellular respiration produce ATP for muscle contraction.
- Explain why weightlifters are not well adapted for distance running.

13.4 Muscular Disorders

Learning Outcomes:

- Distinguish between common muscle conditions, such as strains and sprains.
- Summarize the causes of fibromyalgia, muscular dystrophy, myasthenia gravis, and muscle cancer.

Common Muscular Conditions 1

Common muscular conditions.

Spasms—sudden, involuntary muscle contractions, accompanied by pain.

- Can occur in smooth and skeletal muscles.
- **Convulsion**—multiple spasms of skeletal muscles.

Cramps—strong, painful spasms due to strenuous activity.

Facial tics—spasms in the face that can be controlled voluntarily, but only with great effort.

Common Muscular Conditions 2

Common muscular conditions, continued.

Strain—stretching or tearing of a muscle.

Sprain—twisting of a joint, leading to swelling and injury of muscles, ligaments, tendons, blood vessels, and nerves.

Tendinitis—inflammation of a tendon.

- May irritate the bursae underlying the tendon, causing **bursitis.**