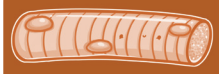

NOTES
MUSCLES

MUSCULAR SYSTEM ANATOMY & PHYSIOLOGY

osms.it/muscle-anatomy-physiology

- Three types of muscle cell/tissue
  - Skeletal, cardiac, smooth
- Differ in location, innervation, cell structure
  - All cells excitable, extensible, elastic

SKELETAL MUSCLE

- Attaches to bone/skin; mostly voluntary; maintains posture, stabilizes joints, generates heat
- Most muscles consist of belly (contracts), tendons

Connective tissue

- Layers of connective tissue separate muscle belly
  - *Epimysium:* wrapped around muscle
  - *Perimysium:* wrapped around fascicles in muscle
  - *Endomysium:* wrapped around muscle fibers/cells (e.g. myocytes in fascicles)

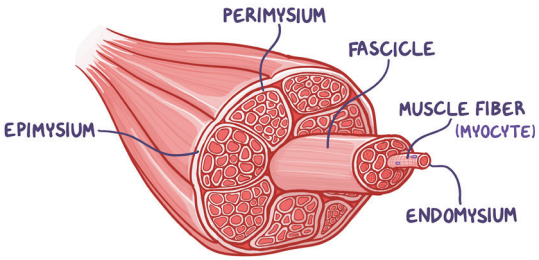

Figure 49.1 Cross section of skeletal muscle illustrating connective tissue layers, fascicles, muscle fibers.

- Combine at end to form tendons
  - Origin attaches to stationary bone; insertion attaches to moving bone

Myocytes

- Long cylindrical cells with multiple nuclei
- Cell membrane → sarcolemma
- Cytoplasm → sarcoplasm
  - Contains smooth endoplasmic reticulum → sarcoplasmic reticulum (stores calcium)
- Transverse tubules (T tubules) project from sarcolemma to center of muscle
- Long filaments called myofibrils fill sarcoplasm, contain thin actin filaments, thick myosin filaments (arranged into sarcomeres)

Motor signals

- Brain's motor signals control skeletal system
- Motor neurons release acetylcholine receptors onto sarcolemma → rapid ion shifts across sarcolemma, down T tubules → calcium enters myocyte → sarcoplasmic reticulum releases calcium into sarcoplasm → actin, myosin bind → sarcomeres contract → myocyte contracts → sarcoplasmic reticulum grabs calcium → muscle relaxes

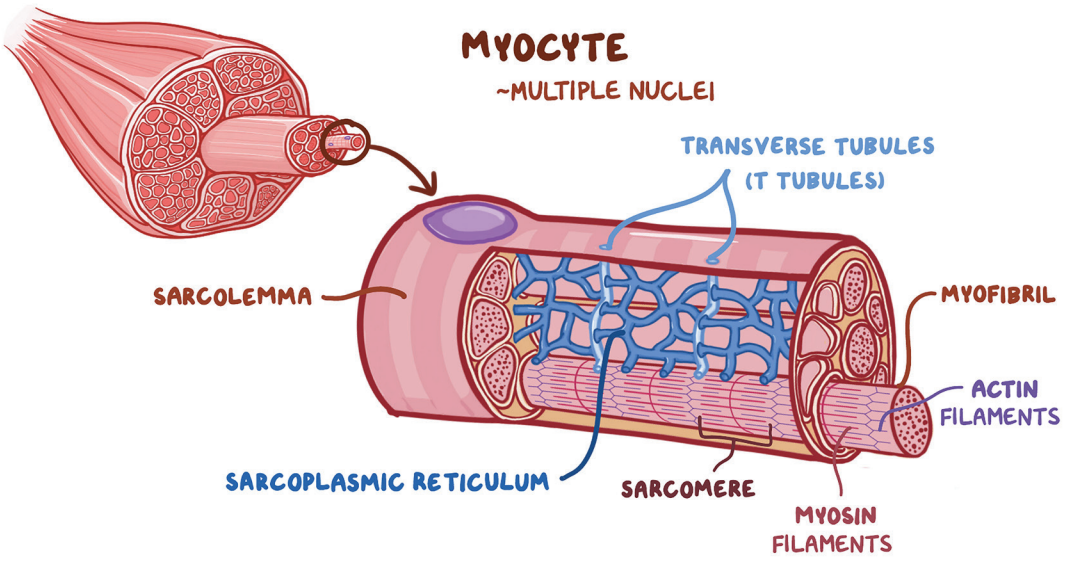

Figure 49.2 Composition of a myocyte.

CARDIAC MUSCLE

- Involuntary, striated muscle; found only in heart walls
- Shorter than skeletal muscle; branched and interconnected
- 1–2 central nuclei per fiber
- Numerous mitochondria provide resistance to fatigue
- Pacemaker cells demonstrate automaticity; generate action potentials

Intercalated discs

- Composed of gap junctions and desmosomes
  - *Gap junctions:* areas of low resistance, allows fast signal propagation between cardiomyocytes (coordinated contraction of cells)
  - *Desmosomes:* anchor the cells together; keeps cells from pulling apart during contraction
  - Allows heart to work as a unit (functional syncytium; syn = together, citos = cell)

T tubules/transverse tubules

- Invaginate from sarcolemma
- Also serve faster propagation
  - Help conduct signal deeper into cell, enabling more synchronized contraction
  - Run along Z bands, communicate with sarcoplasmic reticulum (Ca^{2+} storage)

Thick and thin filaments

- Like skeletal muscle, cardiac myofibrils contain sarcomeres bounded by Z bands
  - *Z bands:* perpendicular to myofibril, attached to thin filaments
  - Thick filaments lie between Z bands
  - All proteins involved are globular
- Thick, thin filaments slide over each other → contraction

Thick filaments

- *Myosin:* tail with two heads
  - Each head has ATPase, actin binding sites

Thin filaments

- *Actin:* globular/G-actin polymerizes into a strand of filamentous/F-actin
  - Two F-actins twist into strand with myosin binding site
- *Tropomyosin:* site blocker, prevents contraction by disabling attachment of myosin to actin
- *Troponin:* molecule composed of three subunits:
  - *C:* Ca^{2+} binding → stops troponin inhibition of actin
  - *I:* Inhibitory → inhibits ATPase
  - *T:* → relaxed state attachment of troponin complex to actin; myocardial infarction marker in blood

Endomysium (intercellular connective tissue)

- Contains capillaries, nerves
- Provides support, elasticity; separates cells
- Maintained by fibroblasts

SMOOTH MUSCLE

- Often found in hollow organs (e.g. intestines, bladder, uterus, blood vessels); involuntary muscle
- Smooth muscle cells fusiform, only one nucleus
- No T tubules; invaginations called caveolae
- Thin, thick myofilaments; no sarcomeres → "smooth" appearance

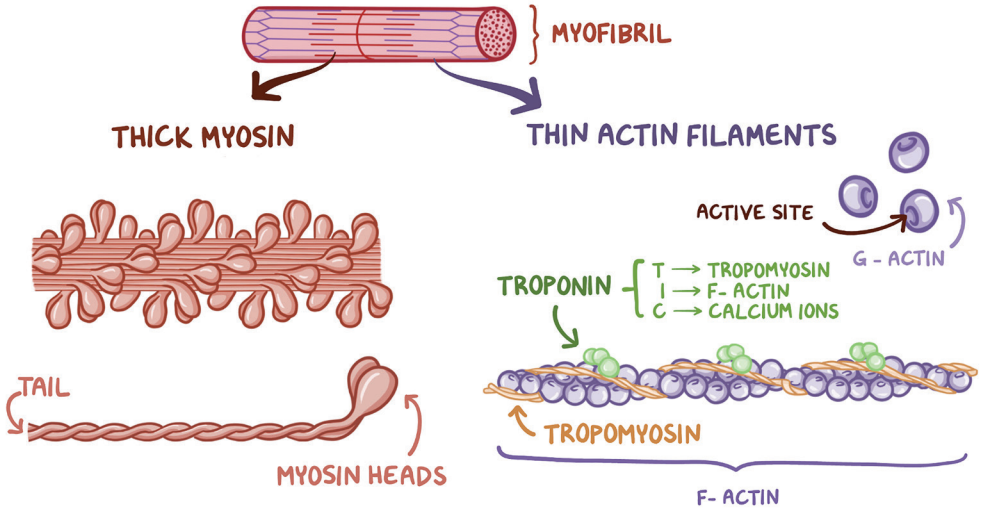

Figure 49.3 Appearance of myosin and actin filaments.

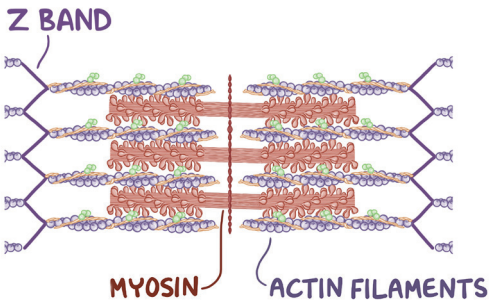

Figure 49.4 Z bands are the boundaries between sarcomeres in skeletal and cardiac muscles.

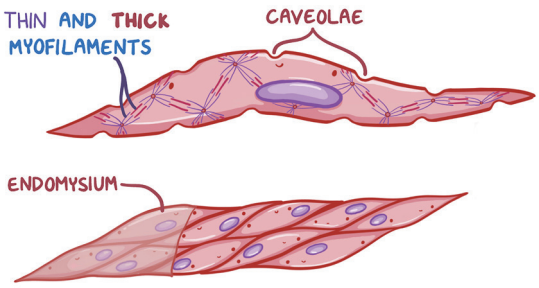

Figure 49.5 Features of smooth muscle cells.

TYPES OF MUSCLE

	SKELETAL	SMOOTH	CARDIAC
LOCATION	Attached to bones	Forms walls of hollow organs Lines blood vessels, glands	Heart
NEUROLOGICAL CONTROL	Voluntary Involuntary (reflexes, shivering) Innervation: somatic nervous system Neurotransmitter: ACh	Involuntary Innervation: autonomic nervous system Neurotransmitter: ACh, NE Also regulated by hormones (e.g. oxytocin), locally-produced substances (e.g. histamine) Autorhythmicity (e.g. visceral smooth muscle in digestive tract) Contracts in response to being stretched	Involuntary Innervation: autonomic nervous system Neurotransmitter: ACh Autorhythmicity: pacemaker cells
FUNCTIONS	Movement, posture, stabilization of body Shivering thermogenesis Voluntary control of micturition (external sphincter)	Wide distribution Digestive tract: movement of food Urinary: bladder emptying Vascular: vessel diameter Sensory: pupil size changes Endocrine: contraction of glands	Propulsion of blood
CELL CHARACTERISTICS	Long, cylindrical, striated	Spindle-shaped	Cylindrical, striated, branched
NUCLEUS	Multiple	One, centrally located	One, centrally located
SPECIAL CELL-TO-CELL CHARACTERISTICS	None	Gap junctions in some visceral cells	Intercalated discs Desmosomes Gap junctions

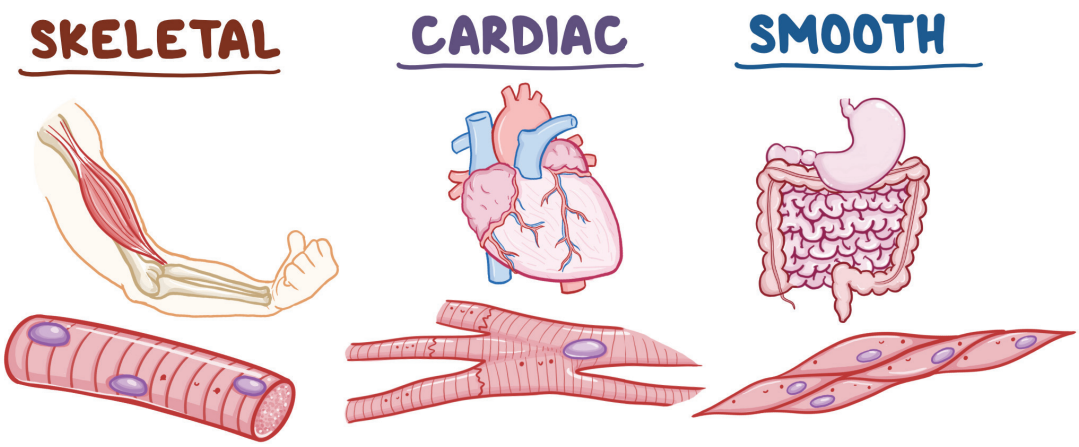

Figure 49.6 An illustration of the three types of muscle: skeletal, cardiac, and smooth.

SLOW TWITCH & FAST TWITCH MUSCLE FIBERS

osms.it/slow-fast-twitch-muscle-fibers

- Each action potential generates brief muscle contraction (AKA twitch)
- Twitches overlap to create longer, smooth muscle contractions

Skeletal muscle fibers

- Slow twitch (AKA slow oxidative)
- Fast twitch (AKA fast oxidative, fast glycolytic)
- Slow twitch fibers → slow-functioning ATPases → slower individual twitches
- Fast twitch fibers → fast-functioning ATPases → longer individual twitches

SLOW OXIDATIVE FIBERS

- AKA Type I fibers
- Have aerobic respiration pathway for metabolizing glucose
- Relatively small → weakest contractions
- ↑ blood vessels, ↑ myoglobin → red color
  - AKA "slow red muscle fibers"
- ↑↑ mitochondria supports aerobic respiration
- Generate lots of ATP, use little; ↓ glycogen storage
- Sustain muscle ability for long time

FAST OXIDATIVE FIBERS

- AKA Type IIa fibers
- Have aerobic respiration pathway for metabolizing glucose
- Larger than slow fibers → stronger contractions
- ↑ blood vessels, ↑ myoglobin → red color
  - AKA "fast red muscle fibers"
- ↑↑ mitochondria supports aerobic respiration
- Generate lots of ATP, use more; ↑ glycogen storage
- Fatigue quickly

FAST GLYCOLYTIC FIBERS

- AKA Type IIx fibers
- Have anaerobic respiration pathway for metabolizing glucose
- Largest fibers → stronger contractions
- ↓ blood vessels, ↓ myoglobin → white color
  - AKA "white muscle fibers"
- ↓ mitochondria
- Generate little ATP, use lots; ↑↑ glycogen storage
- Fatigue fastest

SLIDING FILAMENT MODEL OF MUSCLE CONTRACTION

osms.it/sliding-filament-model

MECHANISM OF MUSCLE CONTRACTION AFTER POWER STROKE

- Thick myosin filaments pull thin actin filaments towards M-line → sarcomere shortens; A-band of the muscle does not change, but H-, I-bands shorten
- At max contraction, almost complete overlap of thick, thin filaments; H-, I- bands almost completely gone

FACTORS DETERMINING CONTRACTION FORCE

Size of muscle fibers

- Larger muscle fibers → ↑ filaments → ↑ cross-bridges → stronger contraction

Number of active muscle fibers

- ↑ muscle fibers → stronger contraction

Frequency of stimulation (force-frequency relationship)

- ↑ frequency of stimulation → ↑ calcium ions flow from sarcoplasmic reticulum into sarcoplasm → ↑ bind to troponin regulatory proteins on actin filaments → ↑ myosin binding → stronger contraction

Length of sarcomere

- AKA length-tension relationship
- Longer sarcomere → stronger contraction; directly proportional

Velocity of muscle shortening

- AKA force-velocity relationship
- Slower contraction → stronger contraction

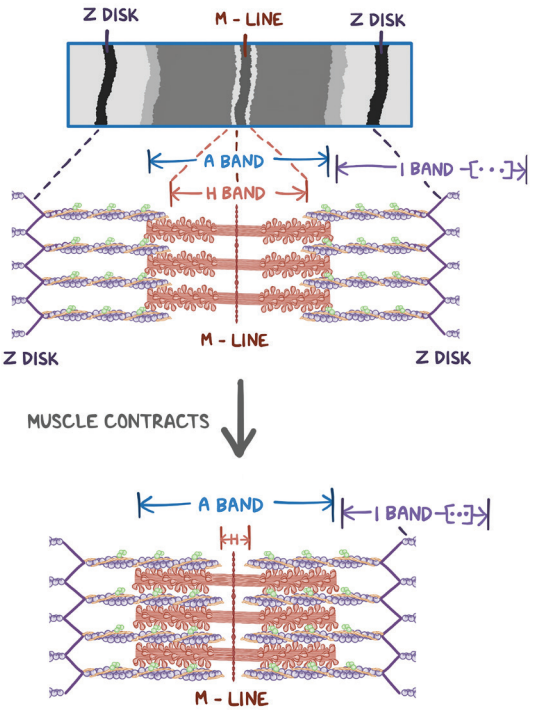

Figure 49.7 The changes that occur when muscle contracts.

ATP & MUSCLE CONTRACTION

osms.it/ATP-and-muscle-contraction

MUSCLE TONE

- Force applied to muscles at rest

MUSCLE TENSION

- Pulling force when muscles act

MUSCLE CONTRACTION

- Action potential travels along sarcolemma, reaches T-tubule, stimulating dihydropyridine (DHP) receptors
- DHP receptor stimulation opens ryanodine receptors
  - AKA calcium channels
- Calcium from sarcoplasmic reticulum flows into sarcoplasm, binds to C-subunits of troponin regulatory proteins
- Troponin changes shape, moving tropomyosin out of the way, allowing actin to be bound by myosin head's cross-bridge formation
- Energy cocks myosin head backwards → high-energy position
- Myosin head can then launch towards M-line, pulling actin filament with it
  - AKA power stroke
- Action potential ends → calcium ions pumped back into sarcoplasmic reticulum → C-subunit of troponin no longer bound → troponin, tropomyosin cover back up actin's active sites → no myosin binding (cross-bridge detaches) → muscle relaxes

ISOTONIC VS. ISOMETRIC CONTRACTIONS

- *Isotonic:* muscle length changes but tension stays same
- *Isometric:* muscle length stays same but tension increases

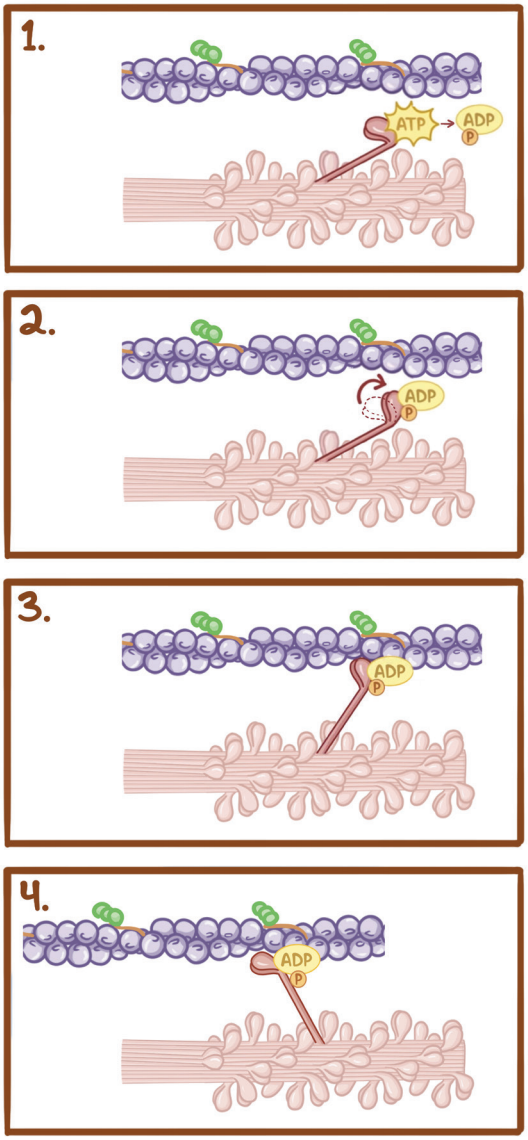

Figure 49.8 Muscle contraction.
1: Part of myosin head is an ATPase; it cleaves ATP into ADP and phosphate ion.
2: Myosin head uses this energy to tip back into its high-energy position.
3: Myosin head binds to active site on actin, triggering release of stored energy in myosin head.
4: Power stroke (myosin head launches, pulling actin with it).

NEUROMUSCULAR JUNCTION & MOTOR UNIT

osms.it/neuromuscular-junction-motor-unit

NEUROMUSCULAR JUNCTION

- Where axon terminal meets muscle fiber
- Presynaptic membrane
  - Membrane of axon terminal
- Postsynaptic membrane
  - AKA motor end plate
  - Membrane of skeletal muscle fiber
- Synaptic cleft
  - Gap between membranes

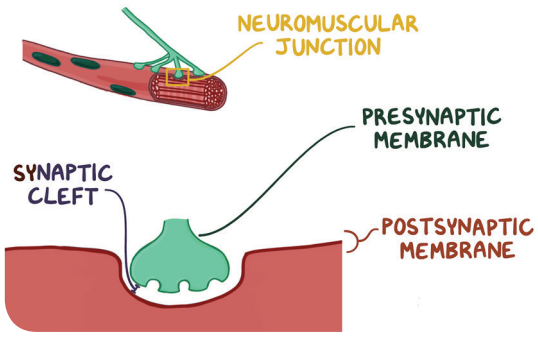

Figure 49.9 Illustration of the neuromuscular junction.

ACTION POTENTIAL GENERATION IN MUSCLE FIBER

- Action potentials in axon terminal stimulate voltage-gated calcium channels in presynaptic membrane → extracellular calcium ions flow into the axon terminal
- Calcium binds to acetylcholine-containing vesicles in axon terminal → vesicles fuse with presynaptic membrane, acetylcholine released into synaptic cleft
- Two acetylcholine molecules bind to one ligand gated ion channel
  - AKA nicotinic receptor
  - On motor end plate → sodium ions flow into muscle
- Positive charge builds up inside muscle fiber → creates end plate potential
  - AKA depolarization
- *Resting potential of membrane:* -100mV → -60mV
- Voltage-gated sodium channels open up → more sodium ions flow in, generating action potential in muscle fiber

ACTION POTENTIAL CESSATION IN MUSCLE FIBER

- Action potential in axon stops → voltage-gated calcium channels close → influx of calcium ions to axon terminal stops → synaptic vesicles stop fusing with membrane
- Remaining acetylcholine in cleft degraded by acetylcholinesterase into choline, acetate → choline taken back into axon terminal → acetylcholine transferase makes new acetylcholine → acetate diffuses away

MOTOR UNITS

- One lower motor neuron, fibers it innervates form single motor unit
- On average, one lower motor neuron innervates 150 skeletal muscle fibers
- More precise muscles → smaller motor units; e.g. 10–15 muscle fibers per neuron in eye
- Less precise muscles → larger motor units (e.g. ≤ 2000 muscle fibers per neuron in bicep)

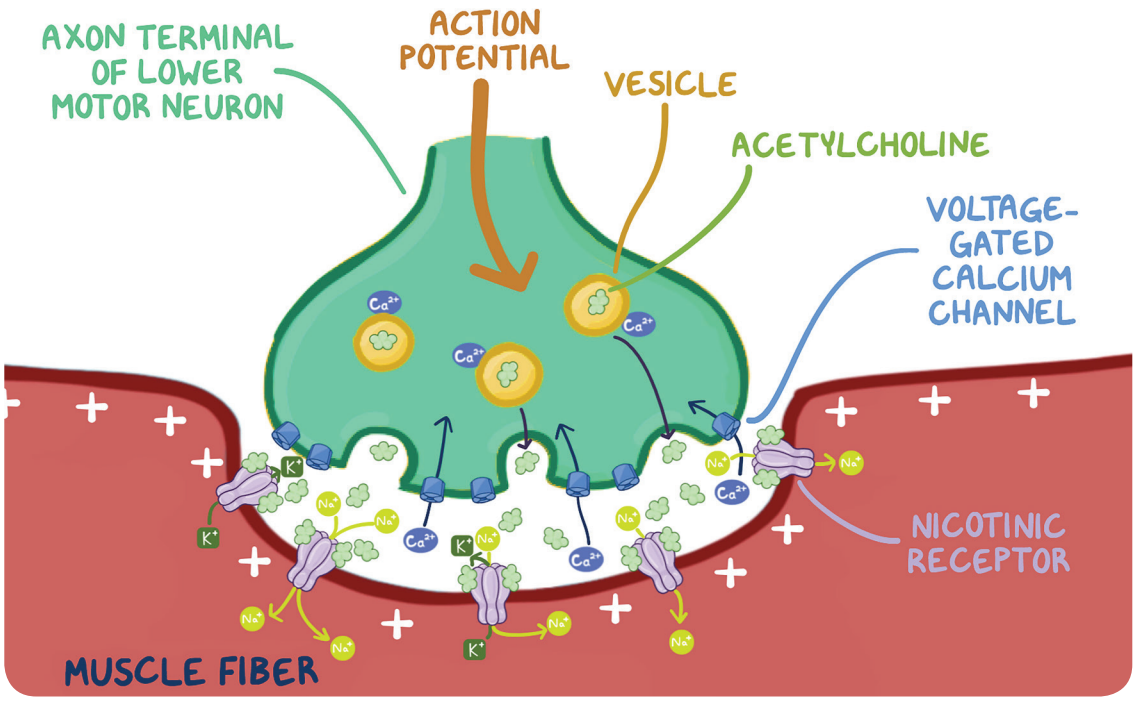

Figure 49.10 Action potential generation in muscle fiber. Influx of sodium ions leads to buildup of positive charge inside muscle fiber. Action potential generated → muscle fiber contracts.

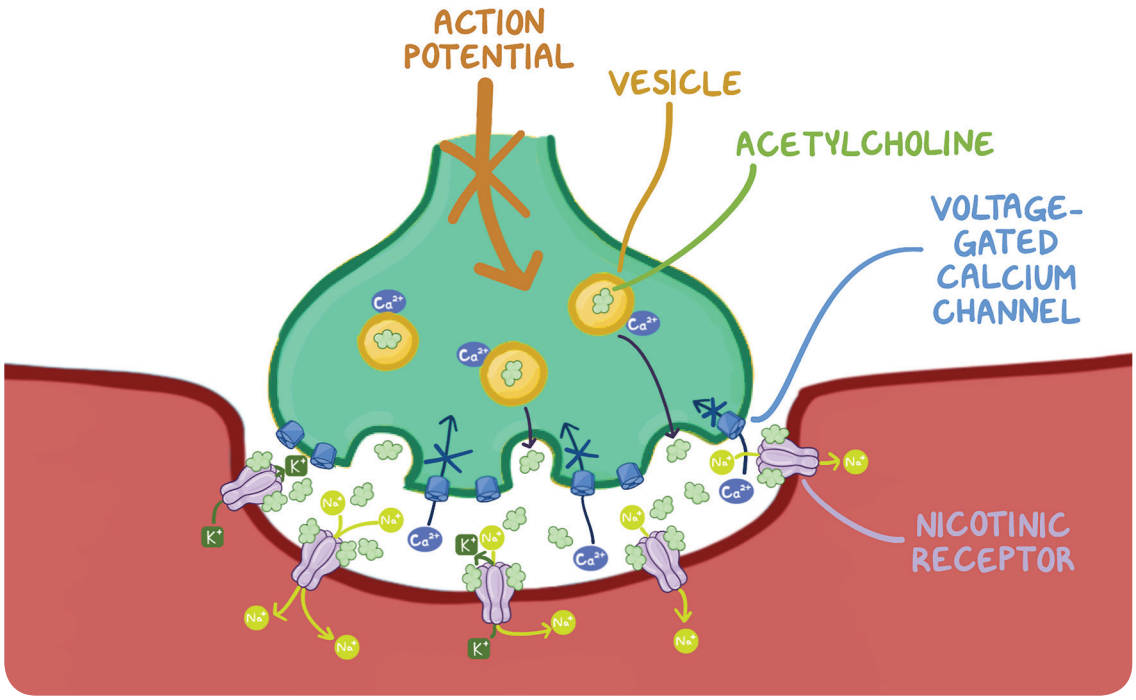

Figure 49.11 Action potential cessation in muscle fiber. Action potential in axons stops → voltage-gated calcium channels close → influx of calcium stops → synaptic vesicles stop fusing with membrane.