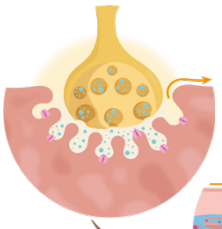
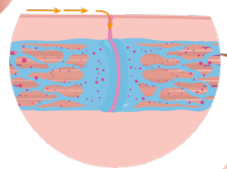
**TOPIC:** STEPS OF MUSCLE CONTRACTION

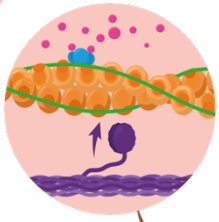
**Overview of Muscle Contraction**

- Muscle contraction involves the **transmission of a nervous** _____ and the **contraction of the** _____.



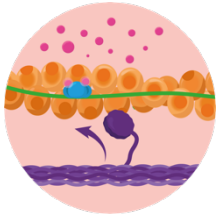
**A.** At **neuro-muscular junction**, muscle cell is stimulated by the _____ system, initiating an **action potential.**





**B. Excitation-Contraction Coupling**:

- Action potential _____ (propagates) along the sarcolemma and enters the ____ tubules.
- Sarcoplasmic reticulum releases ____.
- _____ binding sites are exposed.



**C.** Myosin binds to _____ forming a **crossbridge** and performs the **power stroke**.

**EXAMPLE:** Below is a list of structures that are found in the muscle fiber.

- Mark the structure with a **T** if its primary role is involved in **transferring** a signal through the cell.
- Mark the structure with an **R** if it is directly involved in **regulating** whether the sarcomere contracts.
- Mark the structure with a **C** if it is directly active in the mechanics of **contraction**.

| | | | |
|---|---|---|---|
| 1. Actin | | 5. Sarcoplasmic reticulum | |
| 2. Calcium ions | | 6. Troponin | |
| 3. Myosin | | 7. Tropomyosin | |
| 4. Sarcolemma | | 8. T tubule | |

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**PRACTICE:** True or False: if false, choose the answer that best corrects the statement.

The events of excitation-contraction coupling involve converting the electrochemical signal to the mechanical movement of contraction.

a) True.

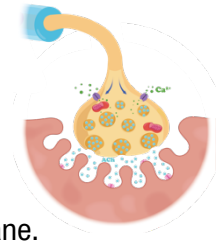
b) False, excitation-contraction coupling involves the reception of the nerve signal at the neuromuscular junction.

c) False, excitation-contraction coupling involves the movement of actin by the myosin power stroke.

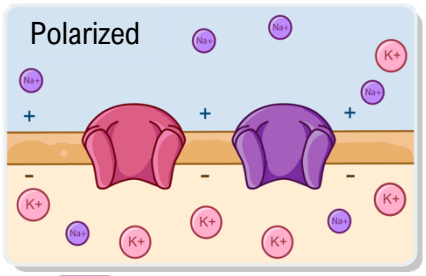
d) False, excitation-contraction coupling involves propagation of the signal through the sarcolemma and T tubules.

**TOPIC:** STEPS OF MUSCLE CONTRACTION

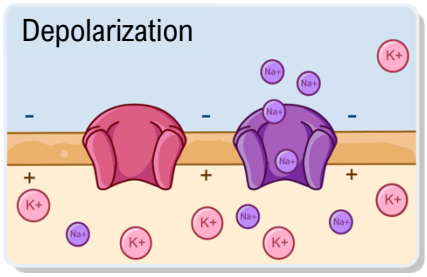
**Neurotransmitters & Action Potentials**



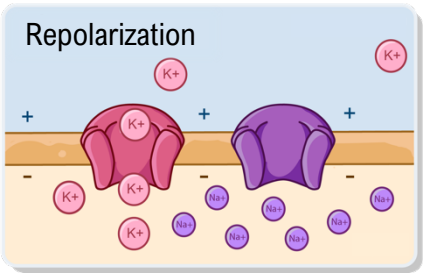
- **Neurotransmitters**: chemical messengers used at _____.
  - **Synapse**: _____ between the axon and the muscle.
  - **Acetylcholine**: neurotransmitter of the neuromuscular junction.
- **Action potential**: _____ of electric signal that moves along a membrane.
  - Muscle fibers are **polarized:** _____ charged inside; _____ charged outside.
  - _____ change of polarization caused by movement of $Na^+$ and $K^+$ _____.




- $Na^+$ outside cell.
- $K^+$ inside cell.

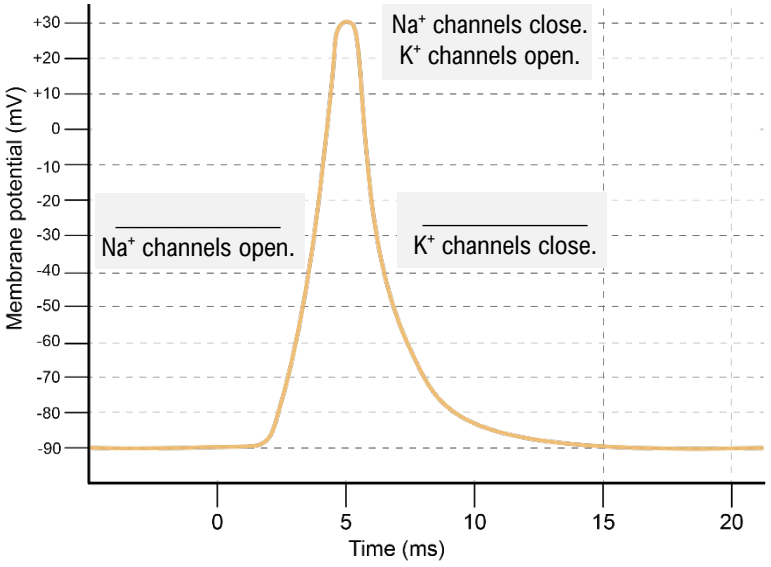


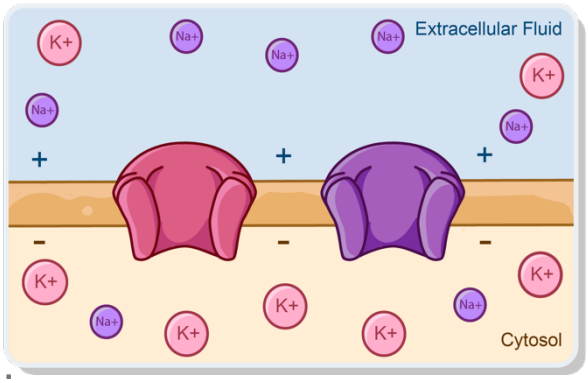

- _____ moves inside.
- Inside cell more positive.




- _____ moves outside.
- Charge is restored.

**EXAMPLE**: The membrane potential inside a cell during an action potential is graphed below. Identify which part of the graph refers to depolarization and which refers to repolarization.




**PRACTICE:** During an action potential, the phase where _____ moves into the cell results in depolarization while the phase where _____ exits the cell results in repolarization.

a) $Na^+$, $K^+$. b) $Ca^{+2}$, $Na^+$. c) $Na^+$, $Ca^{+2}$. d) $K^+$, $Ca^{+2}$.

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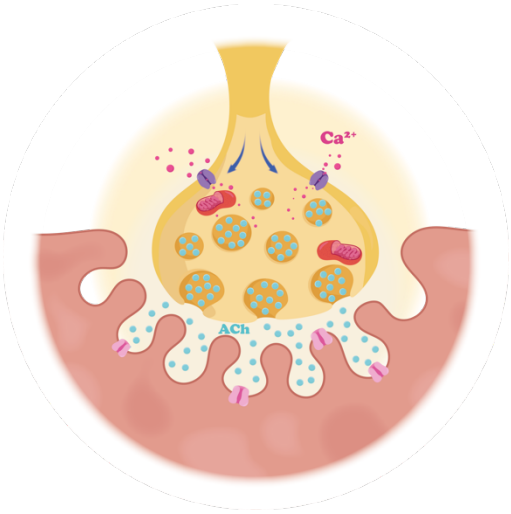
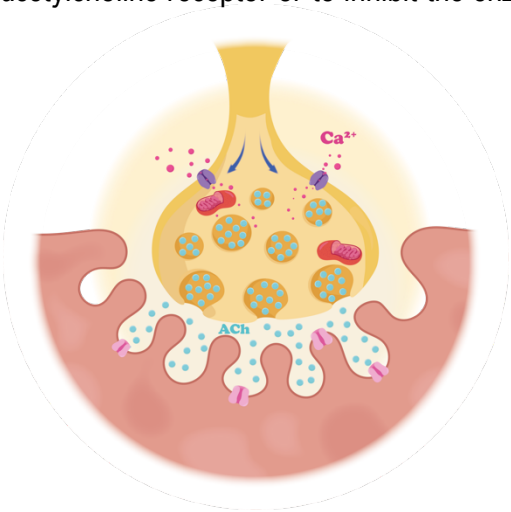
## A. Events at the Neuromuscular Junction

- **Neuromuscular junction**: connection between the _____ system and **motor end plate** of the muscle fiber.
  - **Acetylcholine (_____)**: neurotransmitter used at neuromuscular junction.




| |
|---|
| **1**. Action potential arrives at the axon _____. |
| **2.** Voltage gated $Ca^{+2}$ channels _____. |
| **3.** $Ca^{+2}$ enters, axon releases _____ into the synapse. |
| **4**. ACh diffuses across the synaptic cleft and binds to the receptors in the _____. |
| **5**. $Na^{+}$ ion channels open in the sarcolemma—starting an _____ potential in the muscle fiber. |
| **6**. ACh is broken down by the enzyme ***Acetylcholinesterase***, signal _____. |

**EXAMPLE**: Interfering with the function of acetylcholine at the neuromuscular junction will interfere with muscle function and can even lead to death. Two ways to interfere with acetylcholine function are to block the acetylcholine receptor or to inhibit the enzyme acetylcholinesterase. Predict how each will affect muscle function?




- Effect of blocking the acetylcholine receptor:

  _____

- Effect of inhibiting acetylcholinesterase:

  _____

**TOPIC:** STEPS OF MUSCLE CONTRACTION

**PRACTICE**: What is the role of the calcium ion in the signaling of an action potential at the neuromuscular junction?

a) Calcium moves across the synaptic cleft to relay the signal to the muscle tissue.

b) Calcium causes the muscle cell to depolarize propagating the action potential.

c) Calcium is important for contraction in the sarcomere; it does not play a role at the axon terminal.

d) Calcium entering the axon terminal triggers the release of Acetylcholine into the synaptic cleft.

**PRACTICE:** True or false: if false, choose the answer that best corrects the statement:

The motor neuron is in contact with the sarcolemma in order to efficiently pass the electrical signal to the muscle fiber.

a) True.

b) False: the axon terminal touches the endomysium.

c) False: the motor neuron forms a synapse with the muscle fiber at the neuromuscular junction.

d) False: the axon terminal touches the sarcolemma passing on a chemical signal.

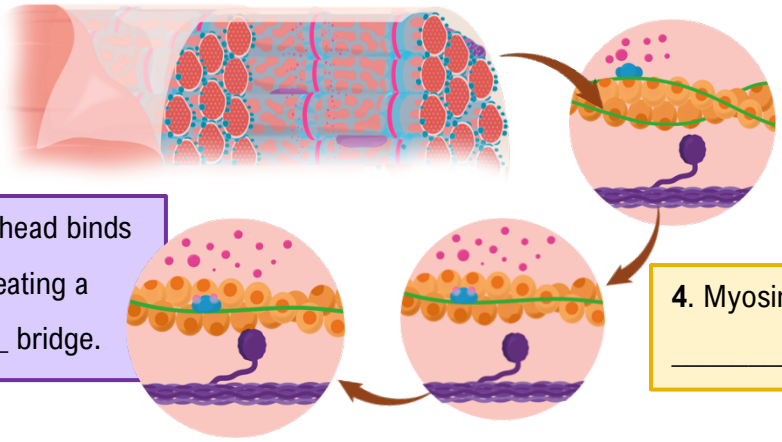
**TOPIC:** STEPS OF MUSCLE CONTRACTION

**B. Excitation-Contraction Coupling**

● **Excitation-Contraction Coupling**: transmission from _____ _____ (AP) → muscle contraction.

**1.** AP spreads down the sarcolemma into the ___ tubules.

**2**. Voltage gated channels of the sarcoplasmic reticulum release _____ into the sarcomere.



**3**. Calcium binds to _____ moving tropomyosin.

**4**. Myosin binding sites on _____ are exposed.

**5**. Myosin head binds to actin creating a _____ bridge.

● When $Ca^{+2}$ exits sarcomere/re-enters sarcoplasmic reticulum; binding sites _____.

**EXAMPLE:** The term excitation-contraction coupling refers to the events that turn the action potential into a muscle contraction. Put the steps in order.

a) Calcium binds to troponin.
b) Myosin binding sites on actin are exposed.
c) Action potential travels down the sarcolemma and T tubules.
d) Voltage gated channels open releasing $Ca^{+2}$ into the sarcomere.
e) Troponin changes conformation, moving tropomyosin.

**Action potential propagates through the muscle fiber.** → _____ → _____ → _____ → _____ → _____ → **Cross bridges form and muscle contracts.**

**PRACTICE**: Voltage gated channels respond to the depolarization of an action potential by releasing $Ca^{+2}$. Where are these channels located?

a) Sarcolemma.
b) Sarcoplasmic Reticulum.
c) Sarcomere.
d) T-Tubule.

**TOPIC:** STEPS OF MUSCLE CONTRACTION

**PRACTICE**: How does tropomyosin regulate muscle contraction?

a) Tropomyosin binds calcium, changing the confirmation of troponin.

b) Tropomyosin prevents myosin heads from binding to actin in the absence of calcium.

c) Tropomyosin wraps myosin preventing actin from binding in the absence of calcium.

d) Tropomyosin releases calcium during an action potential.

**PRACTICE**: In a skeletal muscle fiber, which structure would you expect to have the greatest total surface area?

a) Sarcolemma.

b) Sarcoplasmic Reticulum.

c) Sarcomere.

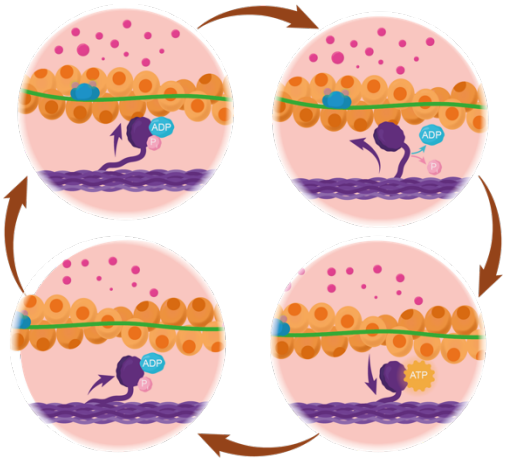
d) T-Tubule.

**TOPIC:** STEPS OF MUSCLE CONTRACTION

**C. Cross Bridge Cycle**

- **Cross Bridge Cycle**: interaction of actin and myosin that leads to the _____ shortening.

**1**. Myosin head binds to exposed _____.




**2.** Myosin performs the **power stroke,** moving actin and releasing _____ + $P_i$.

**4.** ATP is _____, the myosin head moves into cocked position—ready to start

**3.** _____ binds to the myosin head, releasing the actin.

- During contraction, _____ of cross bridges contribute to the shortening of the sarcomere.

**EXAMPLE**: The events of the cross-bridge cycle as they relate to actin and myosin are numbered in order below. Separately, the events as they relate to ATP are labeled a, b, c (but are not necessarily in the correct order). Match the steps as they relate to actin and myosin to the steps as they relate to ATP by matching each letter to the correct numbered step. Note that not all numbered steps correspond to a step as it relates to ATP.

**1.** Myosin head binds to actin. _____
**2.** Power Stroke. _____
**3.** Myosin head releases to actin. _____
**4.** Myosin head moves to cocked position. _____

a) ATP binds to myosin head.
b) ATP is hydrolyzed.
c) ADP and $P_i$ are released from myosin.

**TOPIC:** STEPS OF MUSCLE CONTRACTION

**PRACTICE**: Which part of the cross-bridge cycle is called the power stroke?

a) Cocking of the myosin head.

b) ATP hydrolysis.

c) Myosin pulling the actin.

d) Binding of myosin heads to actin.

**PRACTICE**: What would happen if a muscle completely ran out of ATP *during* a muscle contraction.

a) The myosin head would not move into the cocked position.

b) After the power stroke, the myosin would remain bound to the actin.

c) The myosin would bind to the actin, but the power stroke would not occur.

d) The sarcoplasmic reticulum would be unable to release calcium.