



**Biological
Sciences
Initiative**



Muscle Contraction

SUMMARY

In this activity, students will play the role of different proteins involved in muscle contraction and act out the process. The activity also covers information on sarcomere structure and the proteins involved in muscle contraction.

LEARNING OBJECTIVES

- Understand the structure of muscle fibers.
- Explore the process of muscle contraction.
- Understand the roles that different proteins play in this process.

INTENDED GRADE LEVEL(S)

High school biology

Could easily be simplified for middle school biology.

COLORADO STATE STANDARDS ADDRESSED

- **STANDARD 3: Life Science:** Students know and understand the characteristics and structure of living things, the processes of life, and how living things interact with each other and their environment.

MATERIALS INCLUDED IN THIS ACTIVITY PACKET

- Background Information/Lecture Notes
- Overhead Masters
- Student Activity Worksheet(s)
- Teacher Worksheet Answers
- Teacher Prep Instructions
- Recommended Resources



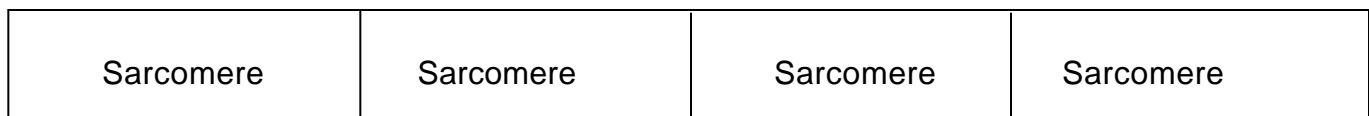
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Muscle Contraction Background Information/Lecture Notes

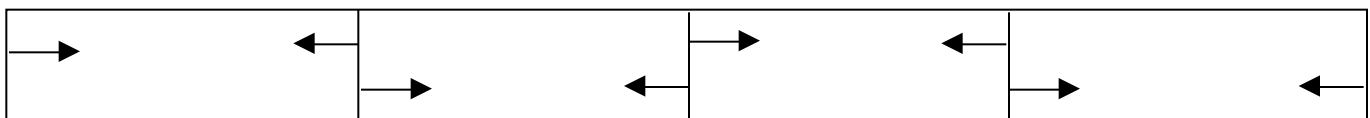
Sarcomeres

Muscles are made up of muscle fibers. Within each muscle fiber, subunits of muscle (called sarcomeres) line up end to end in a long chain, as shown below.



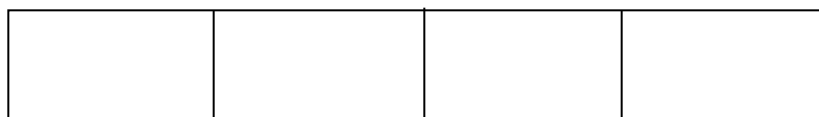
The ends of each sarcomere pull towards each other during contraction such that the sarcomere gets shorter during the contraction process. Thus, the alignment of sarcomeres end to end allows the muscle to contract in a coordinated fashion in a specific direction as shown below.

Before Contraction



arrows depict the ends of the sarcomeres pulling towards each other

After Contraction

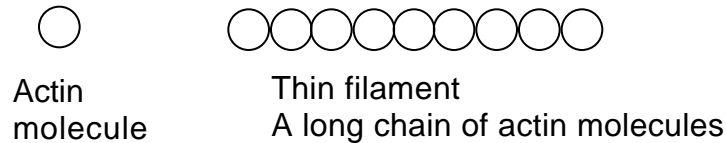


Note how each sarcomere is shorter following contraction, and how the length of the muscle fiber is shorter.

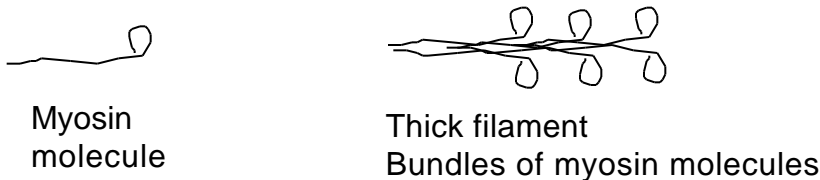
Actin and Myosin

Actin and myosin are the major proteins found in muscle. The interaction of these two proteins, within each sarcomere causes the sarcomere to shorten.

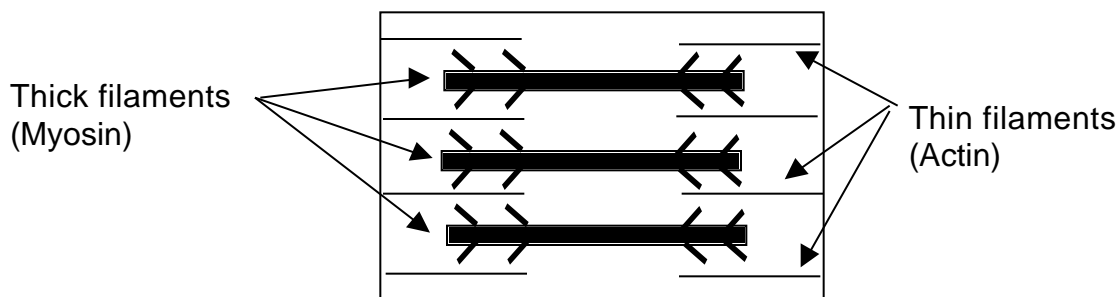
Actin is a round protein shaped roughly like a ball. In the sarcomere, many of these actin molecules are linked together in a long chain to form a filament, called thin filament.



Myosin is a long thin protein with a head on it. Many of these myosin proteins are linked together in a bundle, also forming a filament, with the heads pointing out.



Thick and thin filaments of myosin and actin are arranged next to each other within the sarcomere such that they can interact in an organized fashion resulting in muscle contraction. This arrangement is shown below.

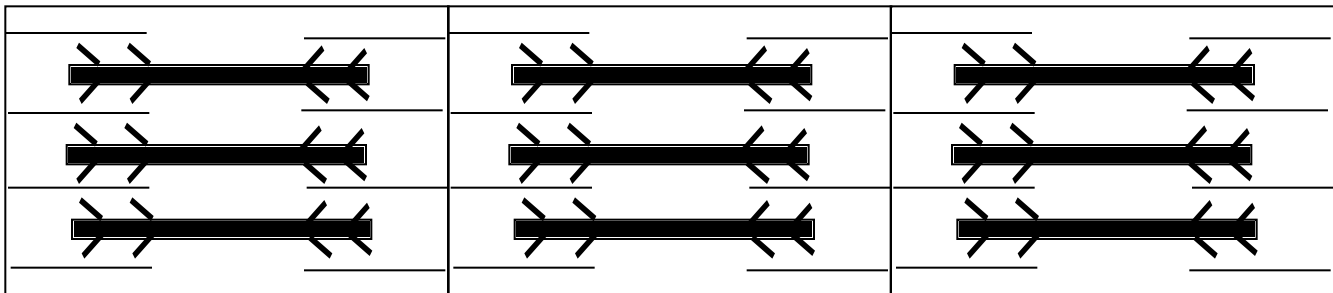


- Thin filaments are composed of primarily of actin. These filaments are attached to the end walls of the sarcomere. Note that the thin filaments do not extend the entire way across the sarcomere. Instead they run towards the center from each side of the sarcomere, leaving a gap in the middle.
- Thick filaments are made of myosin. Note that thick filaments also do not run the entire length of the sarcomere. They traverse the center of the sarcomere but do not either end.

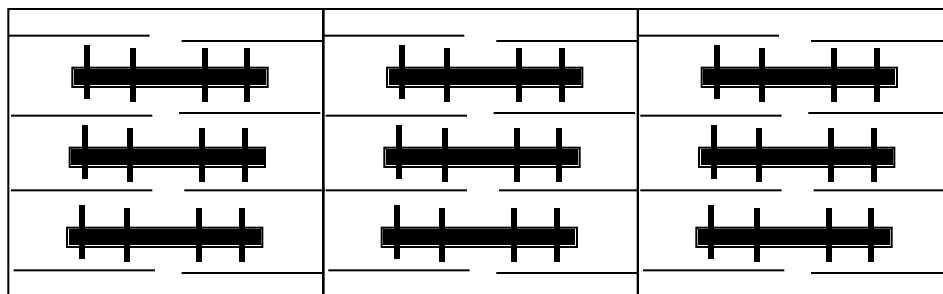
During contraction, myosin heads in the thick filaments (which stick out towards the thin filaments) bind actin in the thin filaments and pull the thin filaments in towards the center. There are many sites at which myosin binds actin, running the entire length of the thin filament/thick filament overlap. This process is similar to pulling on a rope, with each pull (or stroke of the myosin heads), the rope (or thin filament) is pulled inward more.

Note that during contraction, the ends of the sarcomeres are pulled closer together, thus shortening the length of the muscle fiber.

Before Contraction



After contraction



Tropomyosin and Troponin

Tropomyosin and troponin are two other proteins found in small quantities in muscle. They help regulate muscle contraction.

Troponin is associated with the thin filaments and can bind to the actin molecules. There is usually one troponin per 6-8 actin molecules.

Tropomyosin is a long thin protein that extends between, and binds to, the troponin molecules. When troponin is bound to actin, the tropomyosin is positioned so it prevents the myosin heads from contacting actin, thus preventing contraction.

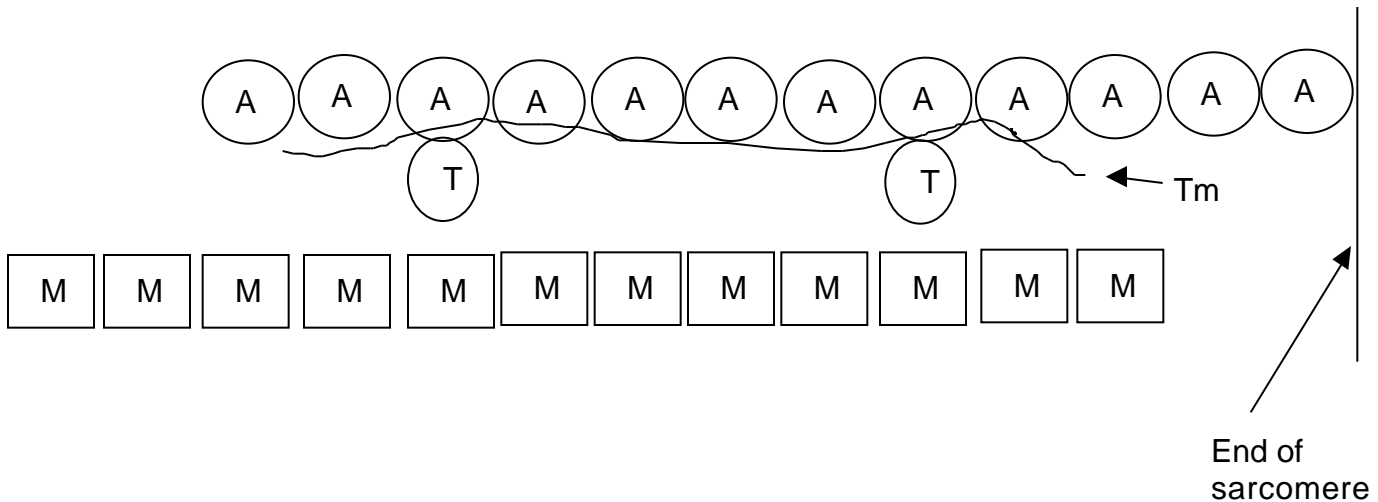
Location of Troponin and Tropomyosin in Thin Filaments

A = actin

T = troponin

Tm = tropomyosin

M = myosin



The Contraction Process

- Electrical signal arrives at the cell.
- Electrical signal causes Ca^{2+} release into the cell.
- Ca^{2+} binds to troponin.
- Troponin/ Ca^{2+} no longer binds actin.
- Tropomyosin is no longer blocking the myosin binding sites on actin.
- Myosin binds actin.
- ATP is hydrolyzed supplying the energy for the myosin heads to move with respect to the rod portion, causing the actin filaments to be drawn towards the center of the sarcomere.
- This process is repeated many times; with each movement of a myosin head, the thin filament pulled further inward.

Animation – The Process in Action

A very good animation of the process of contraction at the molecular level is available on line. You can view this process frame by frame, or as a continual moving picture.

http://www.sci.sdsu.edu/movies/actin_myosin_gif.html



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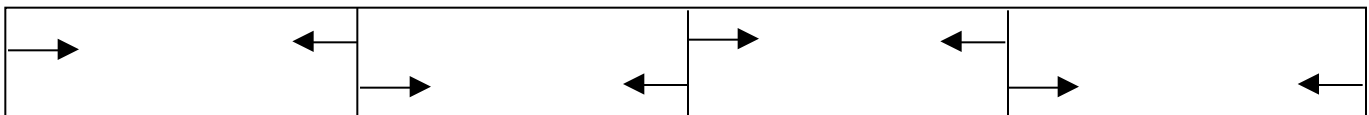
**Title of Activity Packet
Overhead Masters**

Sarcomeres

Muscles are made up of muscle fibers.

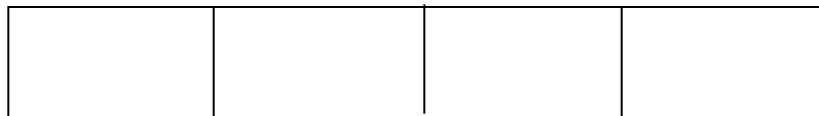
Within each muscle fiber, subunits of muscle (called sarcomeres) line up end to end in a long chain, as shown below.

Before Contraction



arrows depict the ends of the sarcomeres pulling towards each other

After Contraction



Note how each sarcomere is shorter following contraction, and how the length of the muscle fiber is shorter.

Actin and Myosin



Actin molecule



Thin filament
A long chain of actin molecules



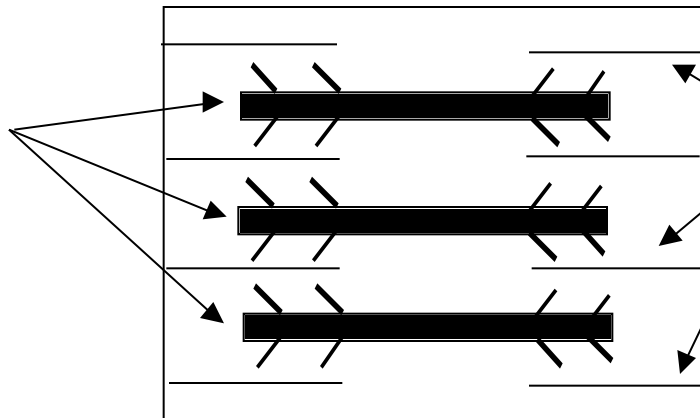
Myosin molecule



Thick filament
Bundles of myosin molecules

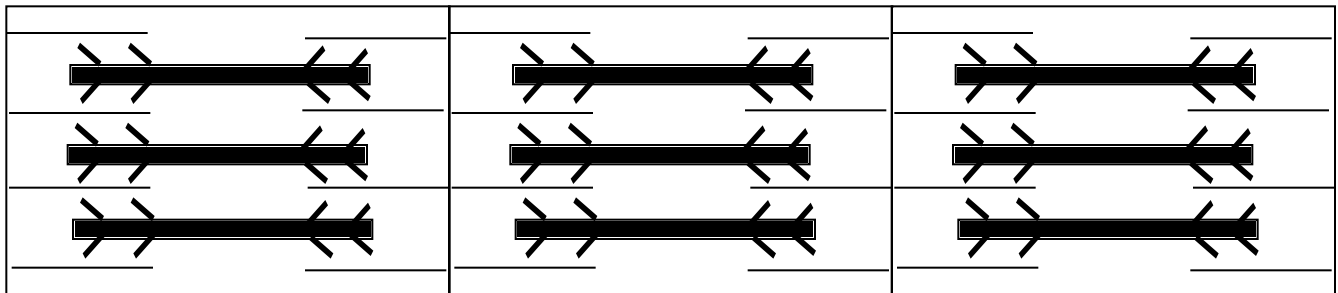
Arrangement of Actin and Myosin in Sarcomeres

Thick filaments (Myosin)

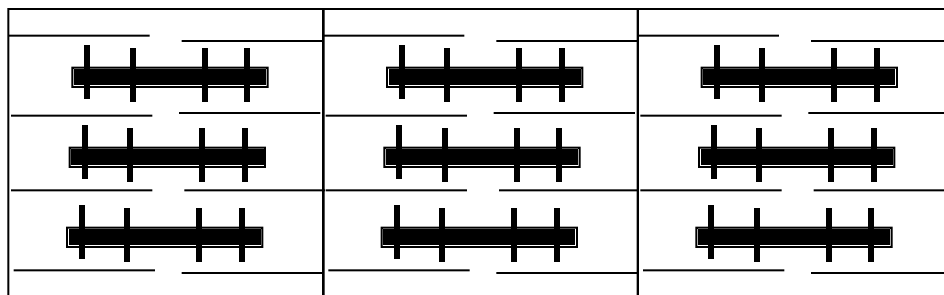


Thin filaments (Actin)

Before Contraction



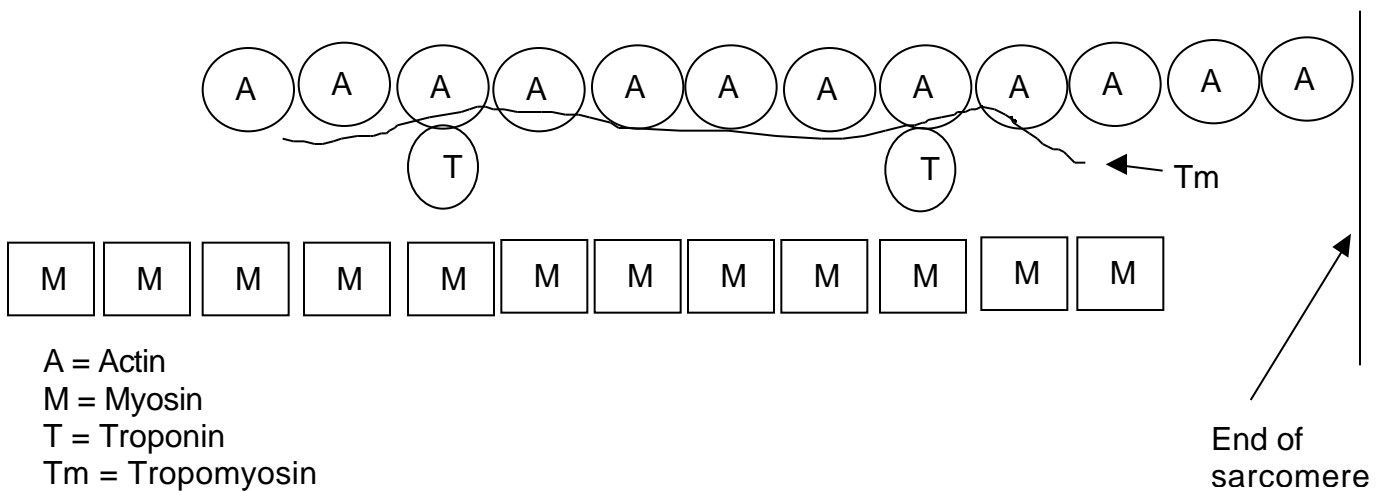
After contraction



Tropomyosin and Troponin

Troponin can bind to the actin molecules.
There is usually one troponin per 6-8 actin molecules.

Tropomyosin is a long thin protein that extends between, and binds to, the troponin molecules.
When troponin is bound to actin, the tropomyosin is positioned so it prevents the myosin heads from contacting actin, thus preventing contraction.



4. Line up to form a representative portion of a sarcomere.

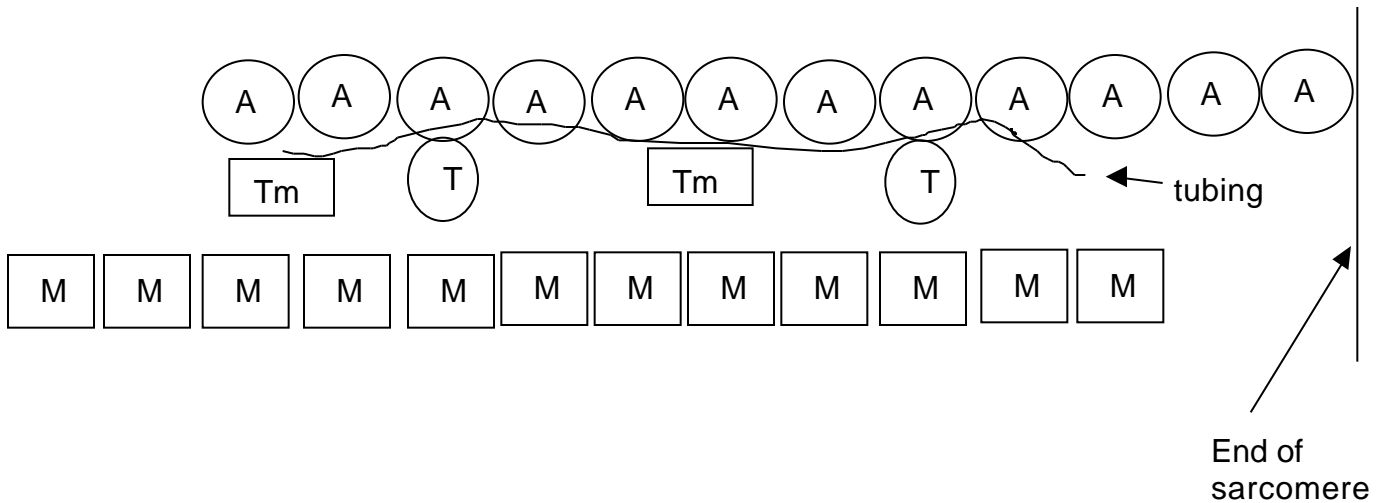
Note: The exact actin unit to which troponin and tropomyosin bind is not important.

A = actin

T = troponin

Tm = tropomyosin

M = myosin





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Muscle Contraction Student Worksheet

LEARNING OBJECTIVES

- Understand the structure of muscle fibers.
- Explore the process of muscle contraction.
- Understand the roles that different proteins play in this process.

MATERIALS

- “Name tags” to identify students as different proteins.
- Active site and binding site tags.
- Tubing
- Myosin heads

QUESTIONS

Review the proteins involved in muscle contraction described in the background information. In particular, note that the proteins involved interact with one another. This interaction takes place at binding sites located on the proteins. A protein that interacts with another protein will have a binding site for that protein. For instance, myosin binds to actin to cause contraction. Thus, actin has a myosin binding site, and myosin has an actin binding site. These two sites bind to each other during contraction. Proteins can also have binding sites for ions such as Ca^{2+} .

Below, list the binding sites found on each of the following proteins

Troponin -

Tropomyosin -

Actin -

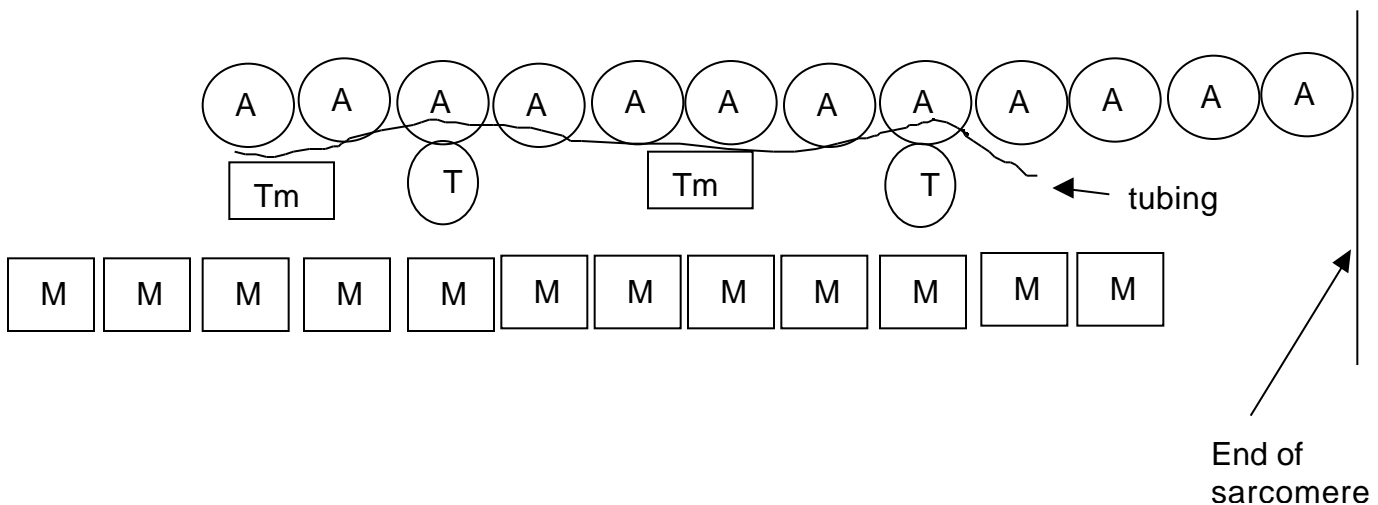
Myosin -

INSTRUCTIONS

- Decide who will play which protein – for a class of 30 a good distribution would be:
 - 12 myosin
 - 12 actin
 - 2 troponin
 - 2 tropomyosin
 - 2 Ca²⁺
 - there are usually 6 – 8 actins per troponin
- Attach appropriate name tags and binding sites to your clothing.
- Students playing tropomyosin will receive a long thin tube to stretch between them since this will simulate the structure of tropomyosin. This will be used in place of the actin binding site and will bind to the tropomyosin binding sites on actin.
- Students playing myosin will receive myosin heads which will bind to the active site on actin. Remember that myosin is composed of rods and heads and that it is the heads that bind actin.
- Line up to form a representative portion of a sarcomere.

Note: The exact actin unit to which troponin and tropomyosin bind is not important.

A = actin
 T = troponin
 Tm = tropomyosin
 M = myosin



Questions

When muscle contraction occurs, which protein(s) will move?

Which protein(s) will stay in place?

Mark the direction of movement of the proteins on the sketch on the previous page using an arrow.

5. Act out muscle contraction

- Electrical signal arrives at cell
- Electrical signal causes Ca^{2+} release into the cell
- Ca^{2+} binds to troponin
- Troponin/ Ca^{2+} no longer binds actin
- Tropomyosin is no longer blocking the myosin binding sites on actin
- Myosin binds actin
- ATP is hydrolyzed supplying the energy for the myosin heads to move with respect to the rod portion, causing the actin filaments to be drawn towards the center of the sarcomere.
- This process is repeated many times - with each movement of a myosin head, the thin filament pulled further inward.



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Muscle Contraction Teacher Worksheet Key

QUESTIONS - pg 10

Review the proteins involved in muscle contraction described in the background information. In particular, note that the proteins involved interact with one another. This interaction takes place at binding sites located on the proteins. A protein that interacts with another protein will have a binding site for that protein. For instance, myosin binds to actin to cause contraction. Thus, actin has a myosin binding site, and myosin has an actin binding site. These two sites bind to each other during contraction. Proteins can also have binding sites for ions such as Ca^{2+} .

Below, list the binding sites found on each of the following proteins

Troponin -

Calcium binding site
Actin binding site

Tropomyosin -

Actin binding site

Actin -

Tropomyosin binding site
Troponin binding site
Myosin binding site

Myosin -

Actin binding site

Questions - pg 12

When muscle contraction occurs, which protein(s) will move?

*Actin, troponin, tropomyosin will move to the left
Tropomyosin will move away from actin*

Which protein(s) will stay in place?

Myosin

Mark the direction of movement of the proteins on the sketch on the previous page using an arrow.

Described above



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**Title of Activity Packet
Teacher Prep Instructions**

Labels for the different proteins and binding sites are attached.

The following proteins (and calcium) contain the following binding sites:

Actin - Ca^{2+} binding site, troponin binding site, tropomyosin binding site

Calcium - troponin binding site

Troponin - Ca^{2+} binding site, actin binding site

Myosin - heads of myosin will contain actin binding sites.

Tropomyosin will have tubing that extends between them. This tubing serves as the actin binding site and binds to actin.

For a class of 30 a good distribution would be:

- 12 myosin
- 12 actin
- 2 troponin
- 2 tropomyosin
- 2 Ca^{2+}
- there are usually 6 – 8 actins per troponin



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**Muscle Contraction
Recommended Resources**

Internet Sites

A very good animation of the process of contraction at the molecular level is available on line. You can view this process frame by frame, or as a continual moving picture.

http://www.sci.sdsu.edu/movies/actin_myosin_gif.html