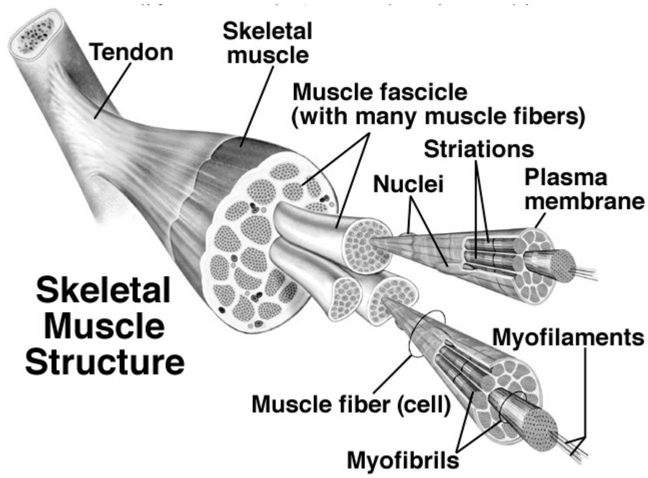
Muscles

How muscles contract - **The Sliding Filament Theory**

- A muscle contains many muscle fibers
- A muscle fiber is a series of fused cells
- Each fiber contains a bundle of 4-20 myofibrils
- Myofibrils are composed of thin and thick myofilaments
- Each fibril is striated

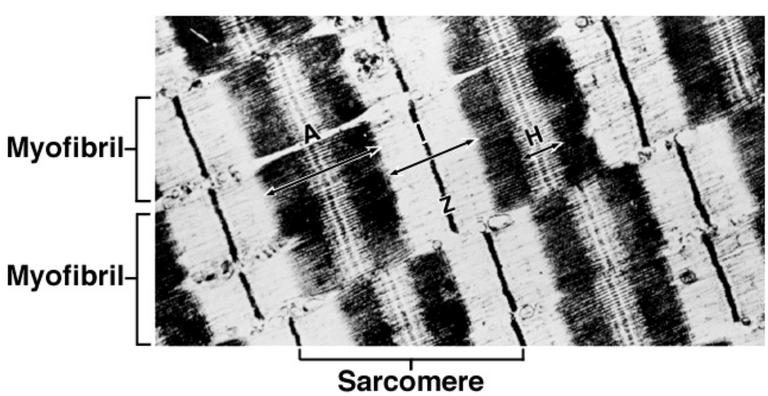


Striations are produced by the arrangement of thick and thin filaments

Striations - the alternation of dark and light bands within a myofibril

Thick and thin filaments overlap to form dark **A bands**

Thin filaments alone form light **I bands**



The **H band**, within the A band, is where there is no overlap

The **Z-line** is a dark line within the I bands

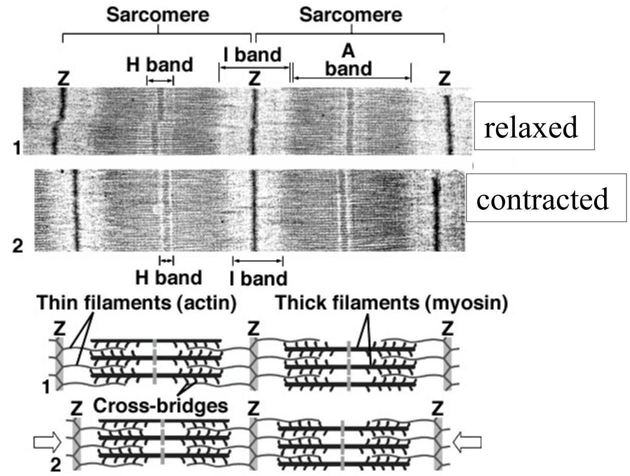
Two Z-lines delimit the unit of muscle contraction - the **Sarcomere**

During muscle contraction, sarcomeres shorten, the distance between Z-lines decreases - the width of the H and I-bands also decreases

Thick filaments are composed of the protein myosin

Thin filaments are composed of the protein actin

During contraction the amount of overlap between actin and myosin increases



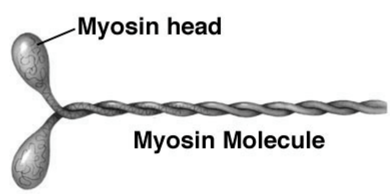
Contraction is produced by an interaction between actin and myosin
Through the formation of cross bridges, the actin is pulled into the space between the myosin filaments

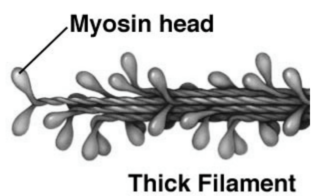
Cross-bridges extend from thick to thin filaments

Each myosin molecule has a protruding head

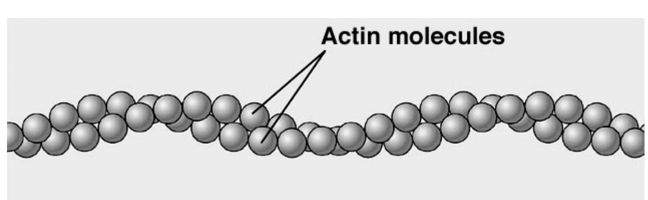
Heads form cross-bridges by interacting with actin

Thick filaments are composed of many myosin molecules



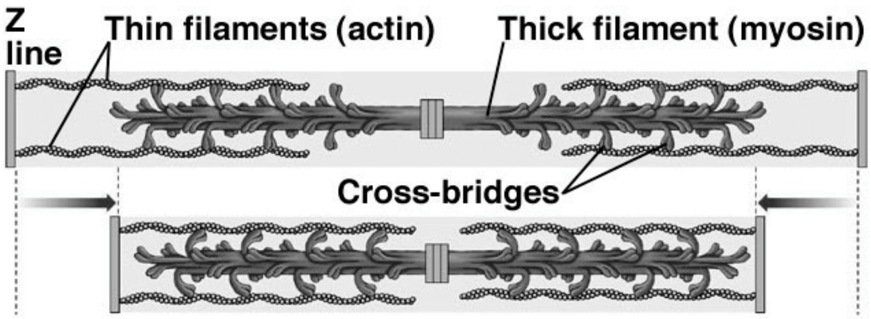


Thin filaments are composed of a double helix of globular actin molecules



During contraction, myosin heads bind to actin molecules of the thin filaments

Flexing of the myosin heads pulls the thin filaments over the thick filaments - shortening the sarcomere

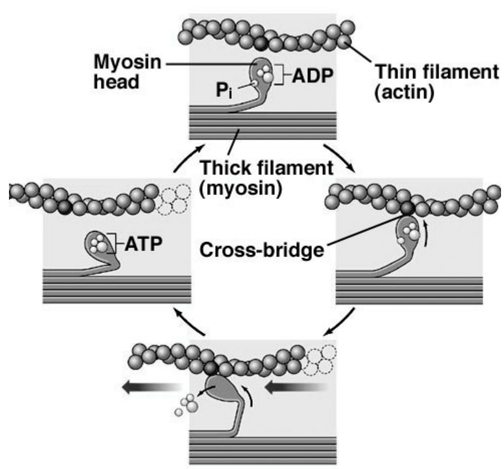


Muscle contraction requires ATP

Cleavage of ATP activates the myosin head

When activated, the myosin head can form a cross-bridge to actin

After binding to actin, ADP is released from myosin head - head flexes, pulling the actin filament over myosin



ATP is required to detach myosin from actin and repeat cycle

Multiple rounds of the cycle at many myosin heads results in shortening of the sarcomere

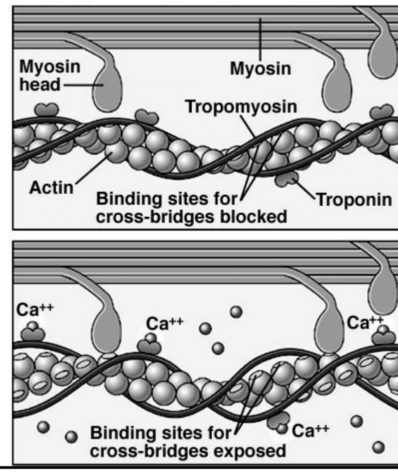
ATP is normally present in live muscle at all times - the depletion of ATP in dying muscle causes formation of permanent cross-bridges the dying muscle becomes rigid - "*rigor mortis*"

Muscle contraction requires Ca^{++} - Ca^{++} presence exposes the actin binding sites through an interaction between Ca and troponin

Tropomyosin associates with actin and blocks binding sites on actin when Ca^{++} is absent

Troponin associates with tropomyosin and causes conformational change in tropomyosin when Ca^{++} associates with troponin

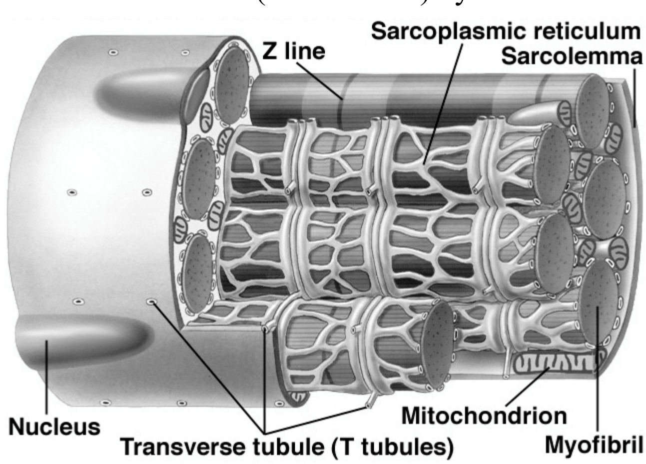
When muscles are relaxed Ca^{++} is stored in sarcoplasmic reticulum - release causes contraction cycle to begin



The sarcoplasmic reticulum (SR) surrounds each myofibril, and is connected to the muscle cell membrane (sarcolemma) by T-tubules

Skeletal muscle fiber contraction is the result of nervous stimulation

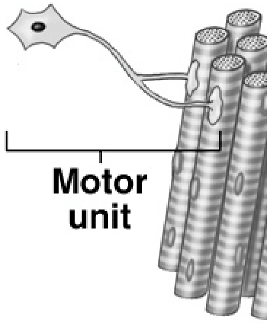
Nerve stimulation results in change in permeability of the sarcolemma and SR



The stimulated SR membrane becomes permeable to Ca^{++} - releasing stored Ca^{++} - and the contraction cycle can begin

Nerves connect to muscles at **neuromuscular junctions** - a single nerve may connect with more than one muscle fiber

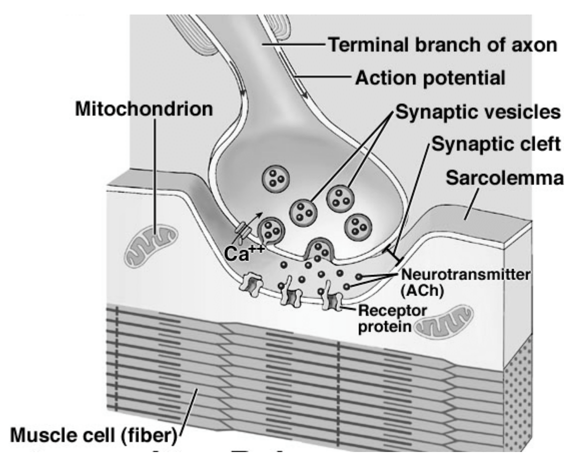
The nerve and the muscle fibers it innervates is a **“motor unit”**



Nerve stimulation involves the release of a **neurotransmitter** from the axon terminus at the neuromuscular junction - **“excitation-contraction coupling”**

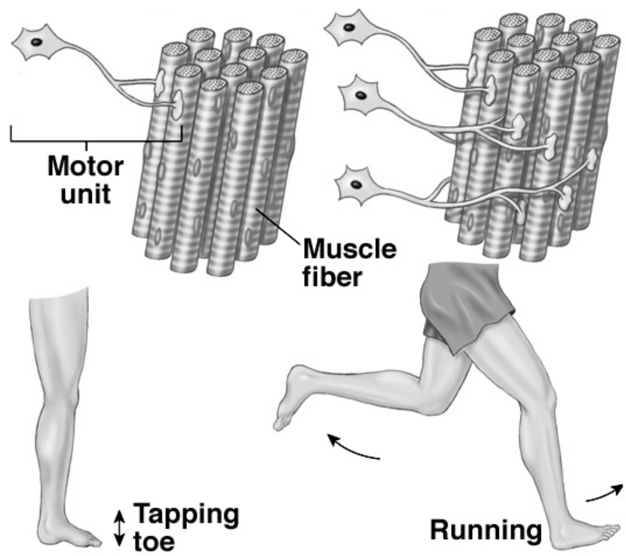
The neurotransmitter is Acetylcholine (ACh)

ACh binds to receptor proteins on the sarcolemma and changes membrane permeability - change is transmitted along membranes of the T-tubules to the SR



Relaxation of muscle fibers involves the uptake of Ca^{++} from the cytoplasm of the muscle fiber by the SR

Recruitment: Small force muscle contractions involve few motor units - Higher force contractions involve an increased number of motor units

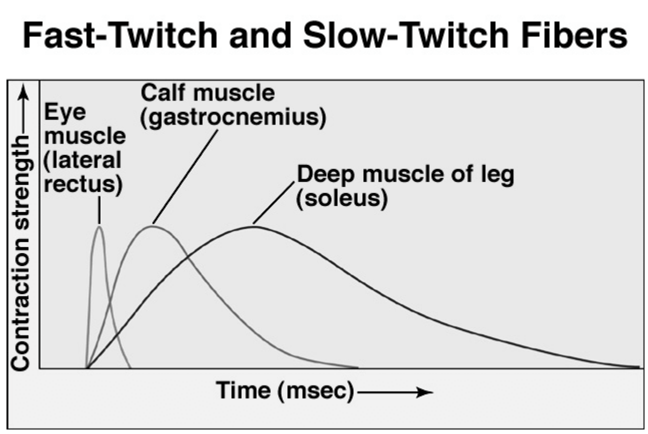


Types of Muscle Fibers

Fast-twitch fibers (type II fibers) - common in muscles that move eyes - reach maximum tension in 7.3 msec

Slow-twitch fibers (type I fibers) - common in leg muscle - reach maximum tension in 100 msec

Many muscles have a mixture of slow and fast-twitch fibers



Slow-twitch fibers are able to sustain contractions over long periods without fatigue

use aerobic respiration, have rich vascular supply, many mitochondria, high concentration of myoglobin gives them a red color, “red fibers”

Fast-twitch fibers are liable to fatigue

use anaerobic respiration, have stored glycogen have reduced vascular supply, fewer mitochondria, less myoglobin, “white fibers”

Muscle fatigue is associated with the build-up of lactic acid due to anaerobic metabolism of glucose

The production of lactic acid allows glycolysis to continue for short periods in the absence of oxygen but eventually lactic acid build-up inhibits enzymes of glycolysis

Lactic acid build-up produces an “oxygen debt”

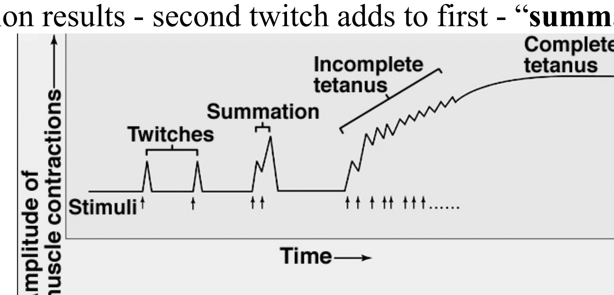
Lactic acid must be removed from muscle by aerobic metabolism after strenuous activity ceases

Muscle Fiber Twitch - A single brief contraction

a single impulse on motor neuron produces a single twitch contraction followed by rapid and relaxation

increasing stimulation can increase the strength of a twitch up to a maximum

If two impulses are applied in rapid succession a greater state of contraction results - second twitch adds to first - “**summation**”



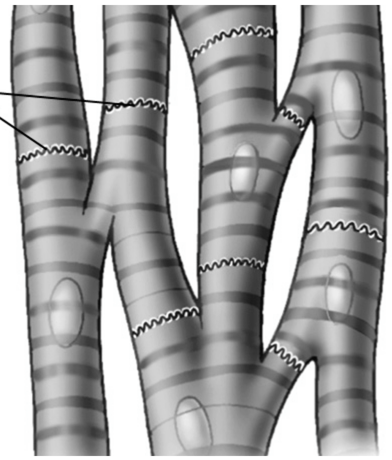
A series of rapid impulses applied at increasing frequency produces a smooth sustained contraction - “**tetanus**” - as in normal muscle contraction

Cardiac and Smooth Muscle can both contract spontaneously

Cardiac muscle is striated - but muscle cells are not arranged as in skeletal muscles

Muscle cells are branched and connected to each other at intercalated disks - have gap at disks that allow stimulation to be quickly passed from cell to cell

Stimulation begins at "pacemaker" cells



Smooth Muscle - surrounds hollow organs - stomach, intestine, arteries, bladder, uterus

Capable of sustained contractions

Thick and thin filaments lie parallel to each other but groups are arranged irregularly - anchored to cell membrane or dense bodies

Lack SR - Ca^{++} enters from extracellular fluid - Ca^{++} binds calmodulin - complex activates enzyme that phosphorylates myosin heads - allows cross-bridge formation -

variation in Ca^{++} concentration varies strength of contraction

Some smooth muscles do contract in response to nervous stimulation - e.g. muscles of iris

Other smooth muscles contract spontaneously - through the action of stimulatory cells within the muscle - e.g. gut

Smooth muscle is capable of contraction after extreme stretching - not true of striated muscle