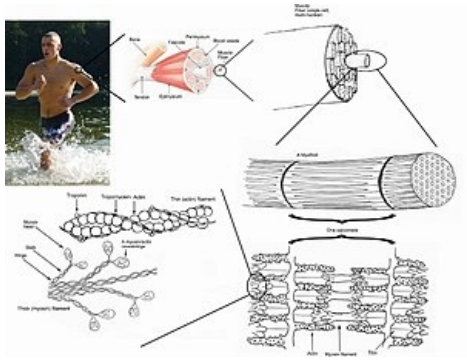
Contraction in skeletal muscle

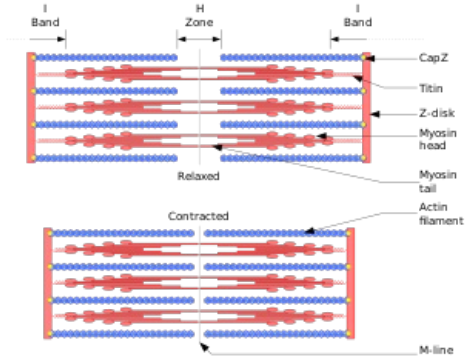
Structural differences between Striated and Smooth muscle



Skeletal muscle composition

- Smooth muscle fibers do not have their myofibrils arranged in strict patterns as in striated muscle, thus no distinct striation is observed in smooth muscle cells under the microscopical examination.
- In smooth muscle, the thin filaments (actin) are attached on structures called densed bodies playing the same role as Z disks in the striated muscle. They provide an anchoring site for the thin filaments allowing them to perform mechanical work.
- Smooth muscle cells contain a single rod-like nucleus located in the center of the cell, whereas striated muscle cells are polynucleated and their nuclei are located on the periphery.
- Smooth muscle cells have a fusiform shape introducing a very distinct pattern of cell arrangement, whereas striated muscle cells have a rather rod-like shape.
- The resting membrane potential of a smooth muscle fiber is about -40 mV whereas in the striated muscle is about -90 mV.

Functional differences between Striated and Smooth muscle



Sarcomere

- The smooth muscle contraction is much slower than in the striated muscle primarily due to the presence of G protein coupled ligand receptors instead of ion channel coupled ligand gated receptors present in striated muscle. Also, after activation of the receptors there is a long process in order to elicit an action potential, involving second messengers and activation of enzymes.
- Smooth muscle thin actin filaments lack troponin protein.
- In both striated and smooth muscle, contraction entirely depends on Ca^{2+} intracellular concentration but through different pathways. In striated muscle Ca^{2+} exposes actin binding sites promoting cross bridge formation between myosin and actin filaments. This contrasts to smooth muscle where Ca^{2+} will bind to calmodulin and activate myosin kinase molecules which will induce conformational changes of the myosin heads allowing cross bridges to form.
- Smooth muscle cell contraction compresses the cell from every direction since the myofibrils are not arranged solely on the longitudinal axis of the cell. In striated muscle cell the overall contraction compresses mainly the two end towards the center of the cell reducing the overall length.

Skeletal muscle contraction - Step by Step

1. An action potential travels through the axon terminal and eventually reaches the synaptic terminal
2. The depolarization of the synaptic terminal from the action potential induces opening of the Ca^{2+} voltage gated channels
3. Opening of these channels allows flux of Ca^{2+} ions inside the neuron.
4. Increase of the intracellular Ca^{2+} concentration introduces conformational changes of the microtubular component of the neuronal synaptic terminal cytoskeleton.
5. These cytoskeletal changes lead the exocytotic process concerning the synaptic vesicles containing acetylcholine (ACh) neurotransmitter.
6. Through exocytosis ACh is secreted from the synaptic terminal membrane into the post synaptic cleft (40 nm space between membranes) towards the sarcolemma (plasma membrane of the skeletal musce fiber) directly opposite the synaptic terminal.
7. As soon as the neurotransmitter reaches the sarcolemma it binds to receptors on a ligand gated ion channel, these receptors specific for ACh. The receptors are called nicotinic receptors and are sensitive to nicotine besides ACh.
8. As soon as the neurotransmitter-receptor complexes are formed they induce conformational changes in an integral protein coupled with the nicotinic receptor
9. These conformational changes allow the opening of the channel which in turn cause an influx of Na^{+} ions into the muscle fiber.
10. Accumulation of Na^{+} within the cell commence the depolarization of the membrane giving rise to the end plate potential that keeps rising towards an action potential threshold, once the threshold is exceed positive feedback of Na^{+} opening more Na^{+} ensure that depolarisation to the normal level seen in action potential (+ 30 mV) will occur.
11. The action potential spreads across sarcolemma and deep into the interior of the muscle fiber via T tubules (invaginations of sacrolemma).
12. The spreading of depolarization promotes activation of the Ca^{2+} voltage gated channels located on the

plasma membrane and in the T tubules.
13. Opening of the Ca^{2+} channels cause a small initial influx of Ca^{2+} ions inside the cell increases the intracellular calcium concentration which in turn opens Ca^{2+} voltage gated channels in the membrane of the sarcoplasmic reticulum allowing even greater increase of intracellular Ca^{2+}.
14. The Ca^{2+} that accumulates after a skeletal muscle cell depolarization is the reason for the initiation and the maintenance of the contraction of the sarcomere, thus increasing the Ca^{2+} inside the cell, will also increase the contractile force produced by the fibers.
15. The free Ca^{2+} binds with the troponin C protein component of the thin actin filaments introducing the active calcium-troponin complex
16. This binding causes the conformational change of the troponin C.
17. The conformational change of the troponin C induces the alteration of the conformation of the tropomyosin protein component of the thin actin filaments.
18. These changes, all together, promote the exposure of the actin binding sites in order to provide anchoring of the myosin filament heads in effect allowing interactions between the thick and thin filaments and elicit contraction.
19. Myosin binds to the newly uncovered binding sites on the thin filament. Once bound ADP and phosphate are released and the power stroke occurs. This will pull the Z bands towards each other, thus shortening the sarcomere and the I band.
20. Following the power stroke ATP binds to myosin, this allows the myosin head to once again detach from the actin filament.
21. The myosin then hydrolyzes the ATP and uses the energy to move into the "cocked back" conformation.
22. The cycling of myosin heads will continue to repeat until either the muscle has been fully contracted or there is a decrease in intracellular Ca^{2+} this normally is due to either voluntary relaxation of the muscle or is induced via signals from the golgi tendon organ.

Links

Neuromuscular Transmission
Excitation-contraction coupling in skeletal muscle
Contraction in smooth muscle

Bibliography

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- Lecture Notes: Prof. MUDr. Jaroslav Pokorný DrSc.