Muscle Physiology

The functional unit of skeletal muscle is the sarcomere.

One sarcomere extends from a z-line to the next z-line.

Within the sarcomere we will see the contractile proteins that interact with each other in the "sliding filament theory" of muscle contraction.

The main components of the sarcomere that you should be familiar with are: actin, myosin, troponin, and tropomyosin. It is also important to understand how the terminal cisternae fits into the picture. Remember that the terminal cisternae is a pouchlike region of the sacroplasmic reticulum.

It is also important to understand the structure of the thick and thin filaments.

The thick filament is actually several myosin molecules bundled together. Each individual myosin molecule is divided into a tail and two heads. It is the movement of these heads that provides the "power stroke" of the muscle contraction. The tail of the myosin molecule contains a hinge region which allows for cross bridge binding. At this point we should also consider one of the actions of ATP. Hydrolysis of ATP transfers energy to one of the myosin heads and places it in the high energy conformation. The second myosin head is then available to form a cross bridge.

The thin filament is made up of three components:

1. Actin: this is the major component of the thin filament. Actin subunits are bound together and wound together to form a double helical chain. Each actin subunit has a binding site for a myosin head.

2. Tropomyosin: is a regulatory protein. It is wrapped around the actin double helix in such as way as to cover the myosin binding sites. This prevents cross bridge formation.

3. Troponin: Troponin is attached to the tropomyosin molecule. It functions to move the tropomyosin away from the binding sites. This can only occur when calcium ions bind to the troponin. The binding of calcium ions to the troponin causes a conformational change in the troponin-tropomyosin complex which pulls the tropomyosin off of the binding sites.

There are 6 steps that must be considered when describing the contractile process of skeletal muscle.

1. The influx of calcium ions from the terminal cisternae which triggers the exposure of the actin binding sites.

2. Binding of the already charged (high energy conformation) myosin to the actin.

3. The "power stroke" of the myosin head that causes the movement of the thin filament.

4. The binding of ATP to the myosin head which causes the disconnecting of the cross bridge.

5. The hydrolysis of ATP which re-energizes and repositions the myosin molecule (returns it to the high energy conformation).

6. Transport of calcium ions back into the sarcoplasmic reticulum. This involves the active transport of calcium using calcium ion pumps in the membrane of the sarcoplasmic reticulum. These pumps require ATP for the energy to drive the pump.

Remember that the sarcomere is made up of thick and thin filaments laid out in an array which gives the muscle a striated pattern. These striations are actually defined regions (bands) within the sarcomere.

The A band is the entire width of the thick filament and therefore includes the area of myosin/actin overlap.

The I band is the region where we find the thin filament only (However this band runs from one sarcomere to the next and therefor is bisected by the z-line. We also see some sub filaments which act to anchor the thick and thin filaments).

The H zone is inside the A band and is defined as the area where there is only myosin (no actin/myosin overlap).

During muscle contraction the sarcomere shortens. The I band also shortens, as does the H zone. However the width of the A band does not change.

Remember that ATP is very important in muscle contraction.

1. ATP is required to put the myosin molecule into the high energy conformation. Here it is hydrolyzed to become ADP and inorganic phosphate.

2. ATP provides the energy to disconnect the myosin cross bridge from the actin.

3. ATP provides the energy that drives the calcium ion pumps which return the calcium ions to the terminal cisternae.

Note that none of this can occur without nervous stimuli to the muscle cell. This brings up the topic of the motor unit. A motor unit is a single motor neuron and all of the muscle cells that it innervates. The motor neuron terminates at the muscle cell at the neuromuscular junction. Here we see a gap between the neuron and the muscle cell. This is called the synaptic cleft. Neurotransmitters are released from the neuron into the synaptic cleft. On the muscle cell there are specialized receptors for these neurotransmitters. If a neurotransmitter binds to these receptors the impulse is continued through the muscle cell membrane and down to the terminal cisternae where is causes a release of calcium ions into the sarcomere. This is a very brief description of this process. This will be covered in more detail during our studies of the nervous system and the conduction of impulses.