The skin &
Muscloskeletal system

PHYSIOLOGY

SLIDES ☐
SHEET ■
LECTURE # 3

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In the last lecture we have seen the structure of muscle fibers, the mechanism of contraction and how we are regenerating ATP in slow muscles and fast muscles (Slow muscles use oxidative phosphorylation so they have higher amount of myoglobin for storing oxygen, and also they have higher vascularization for replenishing it). In this lecture we will discuss the mechanics of the muscle to understand its activity.

Muscle mechanics:

Imagine you have fixed the heads of a muscle fiber and stimulated it (by adding calcium), what would happen? There will be a contraction by the interactions between thin and thick filaments, but without shortening of the fiber, because the heads are fixed. However, there will be a tension force exerted on the point of fixation, and this tension can be measured by using an electronic force transducer. This type of contraction is known as isometric contraction.

- Now, if we took a myofibril and stretched it until there is no overlap between thin and thick filaments, which can be achieved when the sarcomere's length is more than 3.8 μm (length of one thick filament and 2 thin filaments); the tension that can develop is almost zero.
- If we reduced the stretch (decreased the sarcomere length), the tension increases as the overlap increases and the cross bridges that can be recruited for muscle contraction increase.
- If we only fixed the heads without stretching, we will have the highest possible tension. This maximum tension develops at the sarcomere length of 2.0-2.2 μm (this is known as optimal length or resting length). Here we have the maximum overlap between the thick filaments and one half of thin filaments.
- Below this length (from 2.0-1.6 μm), part of the thin filaments is overlapping the second half of the thick filaments, so there will be an interaction between thin filaments and cross bridges from the other half of sarcomere, which means there are two forces opposing each other, which reduces the tension.
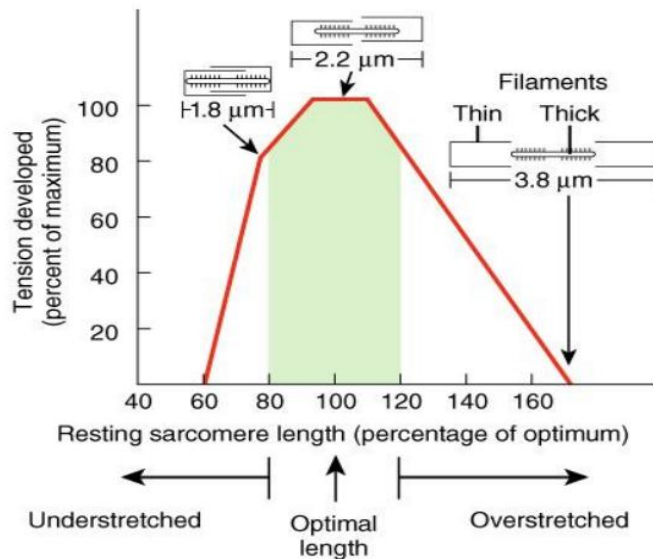
This curve shows the relation between the length of the sarcomere and the tension that can develop.

◘ Notice the overlap between the filaments in each length.

Now if we looked at the <u>muscle as a whole,</u> like any elastic material (rubber as an example), when it is stretched we will record a tension force. The muscle has an elastic property and it's trying to get to the normal state without even stimulating it to contract. This tension is called **Passive Tension.**

If we stimulated it to contract after stretching it each time, we will record a new tension, which is the summation of the tension due to its elasticity and the tension due to the contraction. This whole tension is called **Total Tension**.

To calculate the **Active tension**, which is the one due to contraction only, subtract the passive tension from the whole tension.

Length-Tension Curve of a Muscle
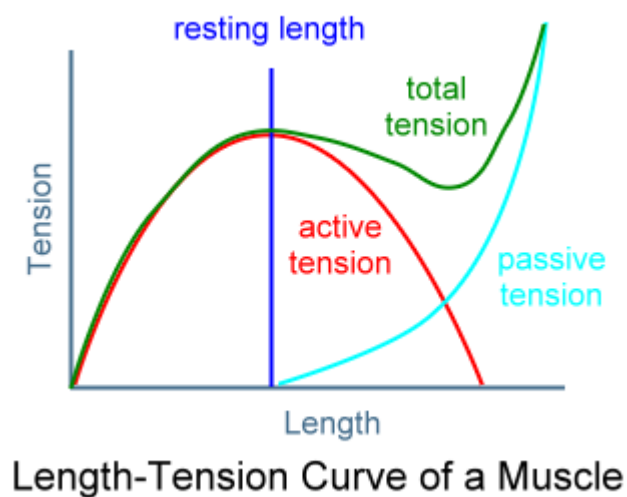
Notice that when the length is below the resting length there will be no passive tension, so the total tension recorded equals the active tension. However when we are stretching it to higher length there will be a passive tension due to elasticity and the total tension equals the active tension plus the passive one.

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Also notice that the maximum active tension was recorded at the resting length and it decreased after stretching. (Explained earlier)

** The muscle fiber also has some elasticity so it has some passive tension which is too small and thus negligible. In the whole muscle there are other tissues involved, so it has higher elasticity.

When a muscle contracts by changing its length without changing its tension, the contraction is said to be **isotonic**.

The correlation between velocity of muscle contraction and muscle load:

Imagine we hang one head of a muscle and placed changing loads at the other head and stimulated the muscle to contract and studied the relation between the velocity of contraction and the load:

- If the load was zero the muscle will contract with the maximum velocity.
- By increasing the weight, the velocity will decrease until reaching a point where there is no contraction.
   ➔ The velocity of shortening is inversely proportional to the load.
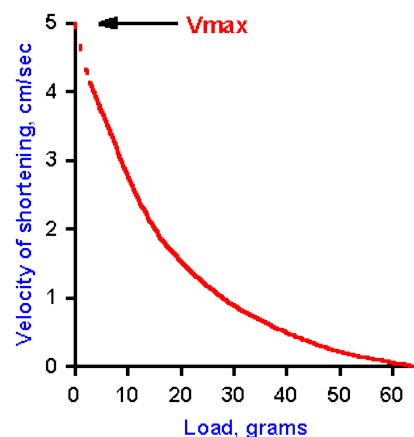
Muscle twitches and characteristics:

In another perpetration, we fixed one head and inserted the other head on an arm in a system to record the shortening process. When the muscle contracts, it will pull the arm indicating the degree (force) of contraction.

So now we can record the contraction of the muscle during a period of time after stimulating the muscle as in the curve below.
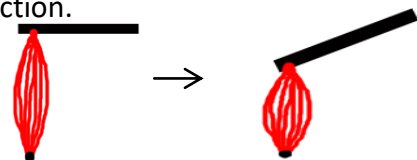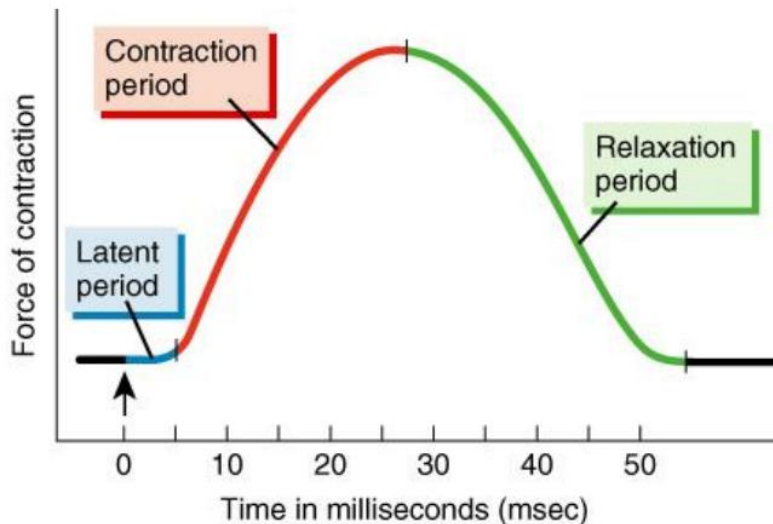
We stimulate here by placing tow electrodes, one connected at each side of the membrane of the nerve and once we close the electrical switch we will get a stimulus for the muscle to contract. We will get three periods; 1-Latent period 2-Contraction period 3-Relaxation period.

The shortening of the muscle happens at the contraction period, where we have high concentration of calcium ions in the sarcoplasm. Any event that takes place after stimulation and before the release of calcium is referred to as the Latent period. **Notice that the stimulation occurred at time zero while the contraction did not start there.

In this period many events take place, such as the generation of action potential in the nerve, then transmission of that action potential towards the terminal, then the release of neurotransmitters, then the stimulation of the membrane of the muscle to get an action potential. When Calcium ions are released, the Contraction period starts and is then followed by the relaxation period.

The curve is called **Simple Muscle Twitch curve.

Now what happens if we stimulated the muscle again?

(a) If it was after the relaxation, we will have another complete twitch or wave separated from the previous one. In other words, if the time between the two stimuli exceeds the time of twitch we will have two separate twitches.
(b) If it was during the relaxation, we will have a new contraction starting from that point reaching a higher level. There will be a summation of the two twitches.
(c) If there were frequent stimuli, so that the next stimulus is during the contraction period, we will have a continuous contraction without relaxation. This process is called **Tetanization**. (It is a summation also)

It happens when you contract a muscle in your body for several minutes without relaxation.(voluntary)
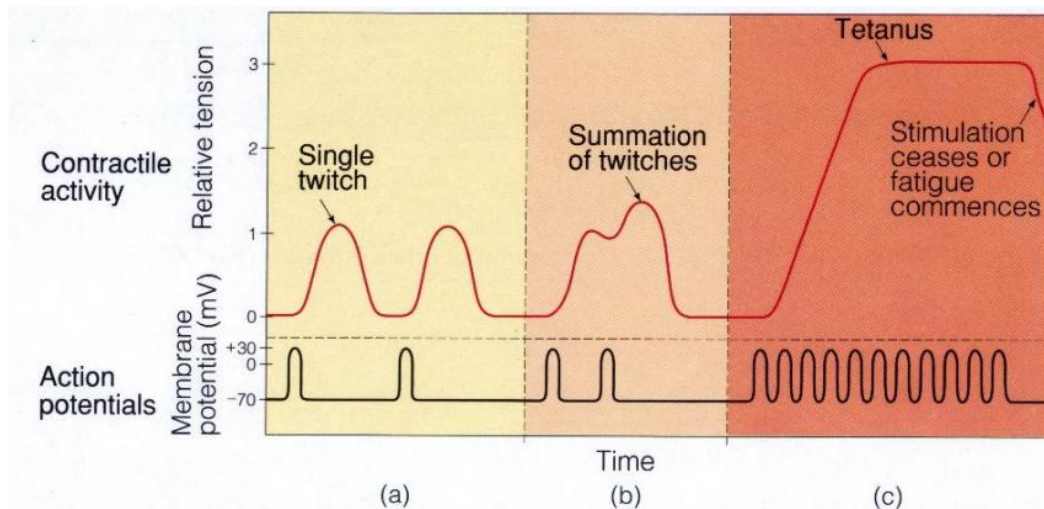
We can also reach tetanus if we keep stimulating in the relaxation period (with little relaxation) and it is called incomplete tetanization.
The one mentioned above is called complete tetanization (a straight line).

The summation mentioned above is called **Frequency summation (wave summation)**.
There is another type of summation called **Motor unit summation**, which will be discussed later.

From the figure below you can notice that when we have two separate twitches, the later one will reach higher amplitude until reaching maximum amplitude. This phenomenon is called **Staircase effect (Treppe phenomena)** and it is not a summation, but it is due to the increase in Ca++ concentration inside the cytosol with each muscle stimulation and inability of sarcoplasmic reticulum to recapture Ca++ immediately.
By having more calcium concentration there will be a higher probability to have more Troponin C active and thus there will be more shortening reflected as higher amplitude.
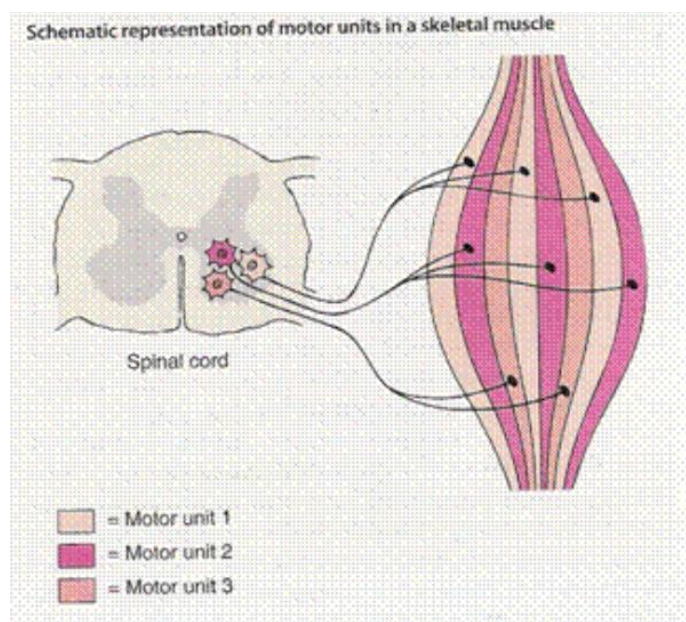
Treppe — Repeated stimuli (0.5 sec intervals) — Time
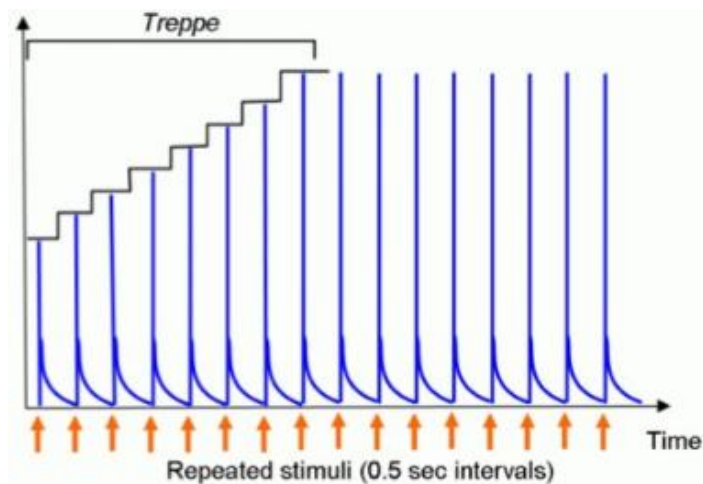
* That's why before doing any sport we should use our muscles by contracting them several times to enhance their performance.

Motor unit summation

For each muscle we have a cable of nerves innervating it. Each nerve fiber has many terminals and each terminal will end in one muscle fiber so that every muscle fiber is receiving impulse from one terminal. So we will have a group of muscle fibers innervated by one motor neuron, and are thus working and contracting as one unit (motor unit).

So if we stimulated one motor neuron we would have small contraction of the muscle because only a group of fibers did contract; whereas if we stimulated all motor neurons innervating that muscle we will have more contraction (higher amplitude of contraction) because all the fibers participated in the contraction. This is called Motor unit summation.

Schematic representation of motor units in a skeletal muscle

Spinal cord

= Motor unit 1
= Motor unit 2
= Motor unit 3

Application:

When you want to lift a light object you won't need a great force, so you won't use all the muscle fibers. For much heavier object you are recruiting more motor unit to lift it. You notice it when you want to lift a heavy object thinking it is light; initially you won't be able to do so until after a few seconds when the cortex recruits more motor units and you can activate a higher number of motor units.

For muscles that are needed for fine functions, such as those used for writing, we have lower number of muscle fibers innervated by one motor neuron for better control.

For muscles that are not needed for fine function, such as the muscles of the back, we have a high number of muscle fibers innervated by the same neuron.

If you remember we said that there is a principle called all or none principle for muscle fibers, so how are we changing the force of contraction? Actually, it applies to the single muscle fiber. If only we reach the threshold it will contract, but for the whole muscle we can change the strength of contraction by changing the number of fibers participating.

**IT ALWAYS SEEMS
IMPOSSIBLE
UNTIL IT'S DONE**