2.3.2

Factors that Influence the Force of Muscle Contraction

Obviously, our muscles are capable of generating differing levels of force during whole muscle contraction. Some actions require much more force generation than others; think of picking up a pencil compared to picking up a bucket of water. The question becomes, how can different levels of force be generated?

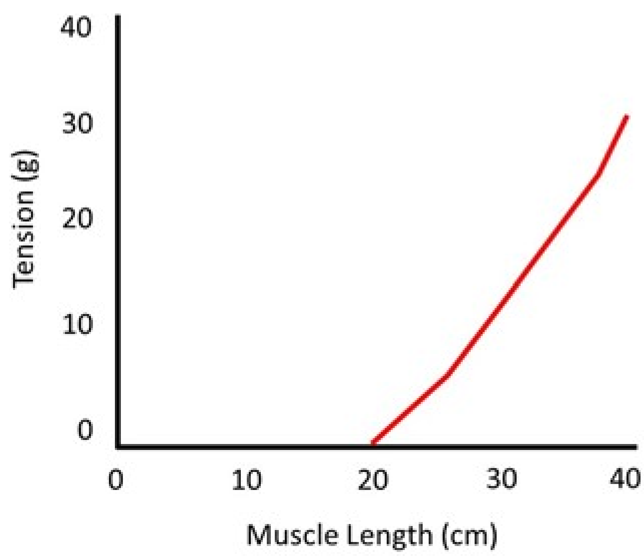
Multiple-Motor Unit Summation or Recruitment

One way to increase the amount of force generated is to increase the number of motor units that are firing at a given time, a phenomenon called recruitment. The greater the load we are trying to move the more motor units that are activated. However, even when generating the maximum force possible, we are only able to use about 1/3 of our total motor units at one time. Normally they will fire asynchronously in an effort to generate maximum force and prevent the muscles from becoming fatigued. As fibers begin to fatigue they are replaced by others in order to maintain the force. There are times, however, when under extreme circumstances we are able to recruit even more motor units. You have heard stories of mothers lifting cars off of their children, this may not be total fiction. Watch the following clip to see how amazing the human body can be. Muscle recruitment.

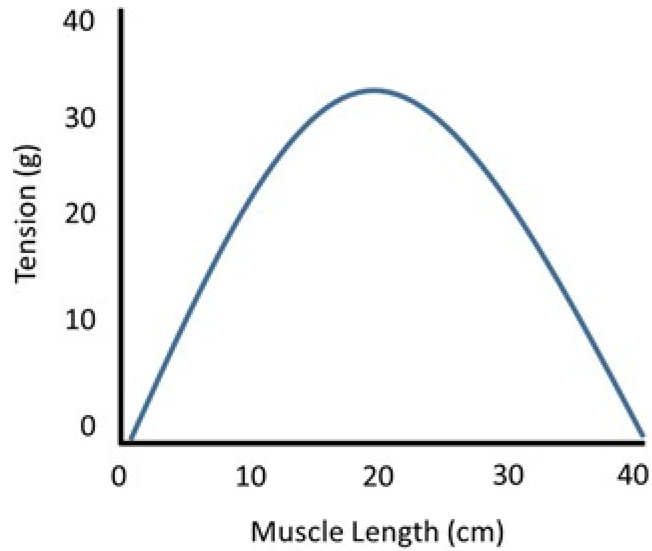
Length-Tension Relationship

Movement of the body is the result of force (measured as tension) that is generated as muscles contract. Most of the time when a muscle contracts to generate tension it shortens, but not always. Tension can also be generated when a muscle contracts but doesn't shorten. This is the basis of the length-tension relationship, and like many things in the physiological realm, it is a parameter invented by science to try and understand how something works, in this case, the biophysical properties of muscle. To dissect out the properties of length and tension, muscles are isolated and induced to contract, but under two conditions. In the first condition, the muscle is isolated, stretched between to stationary points, and induced to contract (zap it with an electrical current). In this condition, the muscle tries to contract, but it can't overcome the stationary points, so it generates tension without shortening, this maneuver is called an **isometric contraction**. Isometric contractions allow the experimenter to measure force (tension) but independent of length. In the second condition, the muscle is allowed to shorten, but the force is held constant, this maneuver is called an **isotonic contraction**. Isotonic contractions allow the experimenter to measure the effects of length. If the muscle contracts and shortens the movement is called a **concentric** contraction. If the muscle contracts but lengthens (think of the quadriceps muscle as you step downstairs) the movement is called an **eccentric** contraction. Eccentric contractions are much stronger, think of holding a rope that is hanging over a cliff with Shaw tied to it, vs trying to pull the rope up, hand over hand, with Hunt tied to it. Clearly, Hunt is in trouble. Subjecting muscles to varying lengths and tensions and then measuring the force, allows us to create a graph of the relationship between length and tension. Except for making another graph to try and interpret, what exactly does this tell us about muscles!?

For one, muscles apparently can generate some tension even without crossbridge interactions. We call this tension **passive tension,** and it is the result of the elastic protein titin, found within the myofibrils. An example of passive tension is the pull you feel in your hamstrings when trying to touch your toes. Passive tension changes when you change the length of the muscle by stretching the muscle. In passive tension, length and tension are directly proportional, with increased stretch (length) correlating with increased tension (see figure below). Stated another way, the further a muscle is stretched the more tension titin will generate to oppose the stretch.



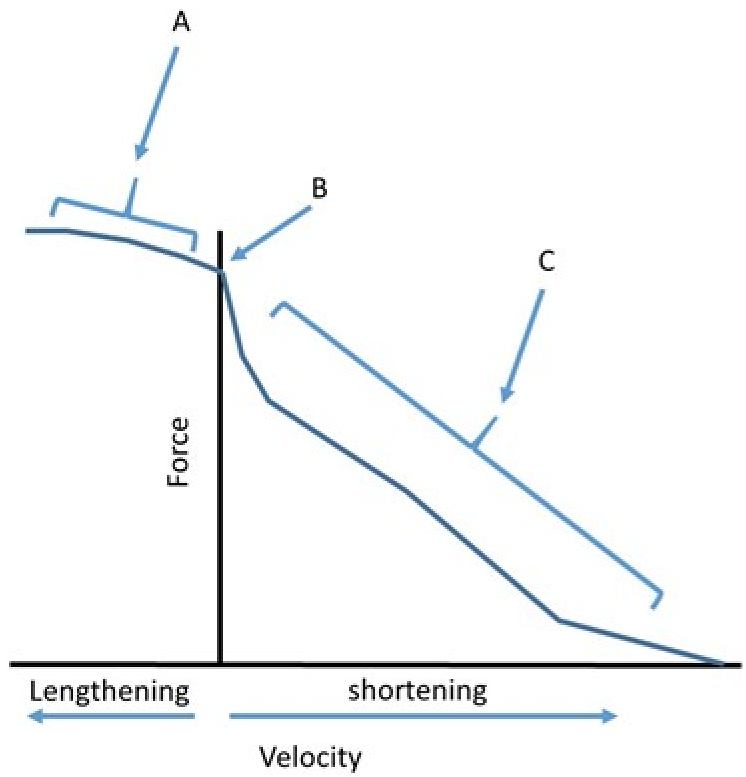
Another observation is that when muscles are stimulated to contract under conditions of alternating length and tension, we observed something known as **active tension**. Active tension is the tension of movement and is also dependent upon length. However, the relationship is not directly proportional. Instead, tension seems to peak at a given length, before or after this length muscle tension is reduced. This ideal length is called the **optimal length**. When muscles are stretched or shortened outside of this range the active tension decreases (see figure).



These observations lend support to the proposed sliding filament theory of muscle contraction, where sarcomeres are proposed to slide over each other (yes, we are still not 100% sure about this…). The graph of active tension demonstrates that at a length of 20 cm (2.0 µm), the sarcomeres are "optimally" overlapped. Said another way, if the sarcomeres overlap too much (below 2.0 µm) there is not enough room to shorten before running into the z-disc, while above 2.0 µm the sarcomeres become stretched too far so there is not enough overlap for the myosin heads to grab.

Force-Velocity Relationship

It was also observed that the velocity (speed) at which a muscle can contract is highly dependent on the amount of force required to shorten it. In other words, try bending your arm fast to slap yourself in the face. Next, hang on to a milk jug, then bend your arm fast and try and hit yourself in the face again, but with the milk jug. Even your rudimentary stopwatch on your iPhone could detect that difference. Thus, in the absence of a load, your muscle can contract the fastest. This speed is proportional to how quickly the myosin heads can utilize ATP (point B in the graph below). The maximum rate of contraction will be faster for fast twitch muscles when compared to slow twitch. If we increase the load to the point where shortening is not possible, then we can see the slowest velocity of crossbridge cycling (end of point C). As stated earlier, we could also lengthen the muscle beyond optimal and see force (Point A), although increases in velocity are pretty much maxed out.


A
B
C
Force
Lengthening
shortening
Velocity

Hunt, J. & Shaw, J. (n.d.). *BIO 461 Principles of Physiology*. BYU-I Books. https://books.byui.edu/bio_461_principles_o