

## Muscle

In a very simple model of Kinesiology, muscle is a structure that generates force. Muscle forces cause movements of segments about joints which ultimately end in a performance. In an Exercise Physiology class, you would likely focus on the mechanism that muscles convert stored chemical energy to mechanical energy (i.e., energy systems). In a motor behavior course, you would likely focus on coordination and control of muscle forces and/or how to learn a skill. In a sports medicine course, you would learn how to prevent and rehabilitate injuries to muscles. In our biomechanics course, we will focus on understanding factors that influence the ability of a muscle to generate force.

There are two primary factors that we need to be familiar with that influence muscle force: 1. The velocity of contraction and 2) the length of the muscle.

First, let's review some basic functional anatomy. Muscles are designed to always shorten ... that is, they generate a pulling force on the ends of the muscle. There are three basic terms that we use to describe the 'type' of contraction:

1. Concentric: Muscle physically shortens during contraction.
2. Isometric: Muscle length does not change during contraction.
3. Eccentric: Muscle becomes longer even though it is contracting (and trying to prevent lengthening).

In addition to these terms, we should be familiar with the following terms used to describe the type of resistance a muscle is working against:

1. Isotonic: The same weight is applied throughout the range of motion (in the gym, we refer to this type of exercise as 'free weights').
2. Isokinetic: Resistance varies in such a way that no matter how much muscle force is applied, the speed of contraction is held constant.

We also will need to recognize the difference between testing of muscle *in vitro* (out of the body) and *in vivo* (inside the body).

### *Length-Tension Relationship*

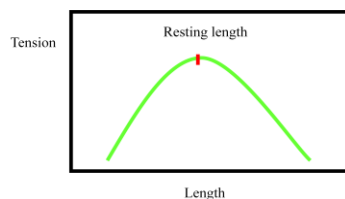
The ability of a muscle to generate force is partly dependent on how long the muscle is as it starts to contract. This is easy to understand by doing the simple exercise illustrated in the picture below. Grasp two fingers and squeeze as hard as you can. Then, move your wrist into extension and try gasping as hard as you can again ... you won't be able to squeeze as hard with the wrist in extension!



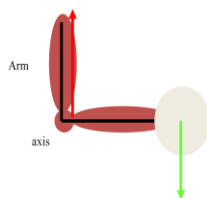
Why not? Because the muscles that cause finger flexion are stretched with the wrist is moved into extension. The length of the finger flexors influences how much force the muscles can generate.

The classic work on the Length-Tension relationship is in vitro work that determined the amount of tension (or force) a sarcomere (the contractile element of a muscle) can generate isometrically is a function of how long the muscle is. At the resting length, the sarcomere could generate the most force, but as it was stretched or shortened, the ability of the muscle to generate force decreased.

The figure below is a simple representation of the relationship between tension and length of the muscle (in vitro). There are two important points that need to be recognized. Testing is done in vitro and the resting length of the muscle is known. When we are testing in vivo, we do not know the resting length of the muscle. Nevertheless, we know that in general, as muscle is lengthened or shortened, the ability to generate force changes. There are some positions that the muscle can generate the most force ... but part of the challenge of testing this concept in vivo is that the muscle force is generating a torque ... and we know torque is a function of force and moment arm. In this case, the moment arm would be that of the muscle acting about a joint – and this is not a constant throughout the range of motion.



How do we test muscle strength in vivo? Most of the time, we are actually testing how much torque a muscle can generate. Consider a very simple model of the elbow:



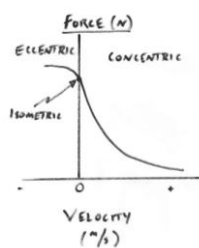
In this example, one muscle is working to cause elbow flexion whereas to another force is the resistance force. We know from our angular kinetic understanding, that (if these are the only torques acting about the axis)  $\sum T = I\alpha$ . In many research studies, we use an isokinetic

dynamometer to control angular velocity ... we do that because angular acceleration becomes zero and then the muscle torque will equal the resistance torque. The isokinetic dynamometer is a special piece of equipment that varies the resistance to match whatever torque the muscle can generate such that the angular velocity is constant.

If we tested how much torque could be generated about a joint through a full range of motion, we would expect to yield a torque curve that looks just like the length-tension relationship in large part because muscle length is changing throughout the range of motion. However, it is important to recognize that muscle torque is partly a function of force and partly a function of the muscles moment arm. The moment arm of the muscle changes through the range of motion ... and ultimately this is an important part in determining at which point of the range of motion a person can generate the most torque (i.e., the 'strongest' position).

### *Force-Velocity*

The other main factor that influences how much force a muscle can generate is how fast the contraction occurs. The original investigation of this relationship was from testing muscle in vitro ... and the relationship is illustrated below.



Velocity of contraction is on the x-axis ... positive velocities indicate shortening (concentric), negative velocities would be lengthening (eccentric) and a zero velocity would be no change in length (isometric). What this relationship tells us is that the ability of muscle to generate force in vitro decreases as the muscle contracts through faster concentric contractions. Also, as muscle is forcibly lengthened (while it is trying to contract), the ability of the muscle to generate force increases. Why is this?

We have to remember some muscle physiology ... the contraction of the muscle occurs due to an interaction between thin and thick myofilaments via formation of cross-bridges. As contraction velocity increases, there is reduced ability to generate cross bridges due to cycle time. At slower velocities, there would be a greater ability to have more cross-bridge formations and therefore more force.

On the eccentric side of the force-velocity relationship. The reason for the increased force production is that it is considered that it takes more force to break a cross-bridge (vs. allowing the cross-bridge to naturally decouple).

What happens in vivo? When we test the force-velocity relationship in vivo, we are really testing the torque-angular velocity relationship. Once again, we would use an isokinetic dynamometer for this type of testing and would test how much torque a muscle can generate when the speed of the machine is set to different speeds. We would expect to see the same type of relationship between torque and angular velocity (in vivo) and the force-velocity (in vitro) relationship. The only odd part of testing in vivo is what happens at slow angular velocities as well as on the eccentric side of the relationship. When velocities are set very slow (e.g., 5 degrees per second ... which would take about 20 seconds to go through 100 degrees of movement), the torque-angular velocity relationship may not follow the in vitro model perfectly. It may be that the muscle fatigues within the long the contraction. Likewise, it is not easy to perform eccentric contractions and these can lead to some muscle damage ... the person may not be able to increase the amount of torque eccentrically as expected.

Nevertheless, we have a general understanding that the amount of force a muscle can generate is influenced by the speed of contraction.

### **Putting it all together**

Muscles generate force. When they generate force, the length of the muscle may not change (isometric), may shorten (concentric), or lengthen (eccentric). When muscle length changes, the ability of the muscle to generate force changes following the length-tension relationship of muscle contraction. The challenge of applying this concept in vivo is knowing what the resting muscle length is.

When a muscle changes length, the ability of the muscle to generate force is a function of how fast the muscle length is changing. During faster concentric contractions, the ability to generate force decreases. During faster eccentric contractions, it may be that the ability of the muscle to generate force increases ... but this is not always consistent between people (in vivo testing).