# BE172 Spring 2018

## Week III: Mechanical properties of skeletal muscle

## II. The Force-Velocity Relationship

### Introduction

The objective of this experiment is to examine muscle force generating ability as a function of the muscle load. We will expand the set-up of last week to include a measure of velocity in addition to force, and use the computer system for data acquisition.

### Background

The relation between force and speed in muscle contraction as investigated by A.V. Hill and others (Hill, 1938; Katz, 1939) has given us much information about the energy relations of muscle in its performance of physical work. It can be shown that when the muscle is required to lift heavy loads, the initial speed of shortening of the muscle is small when compared to contractions against lighter loads. The dependence of the initial velocity of shortening on load can be obtained experimentally with the use of an isotonic lever device which allows one to measure the initial length changes after loaded contractions for a series of applied loads. The result is a hyperbolic relation between force and velocity summarized by Hill's equation:

$$V(P + a) = b(P_o - P)$$

where V=velocity, P=force, $P_o$ is the maximum isometric force (tetanic), and a & b are constants. The main goals of this lab are to measure the force-velocity relation in an isolated muscle and estimate the constants in the Hill equation.

### Equipment

- Stimulator
- Oscilloscope
- Muscle chamber
- Syringe/tube for fluid transfer
- Isometric and isotonic transducers
- Calibration weights
- Pole/clamp setup
- Computer data acquisition system with Labview

**Supplies/Tissue:** same as Muscle I

### Prelab Questions

- Why does force generated by a muscle go down when the velocity of contraction goes up?
- In this lab we use an "angular displacement" transducer to measure a linear velocity (isotonic velocity transducer in Figure 1). Explain how this is done and what the limitations are.
- When the muscle is contracting (shortening), we assume it is isotonic as the muscle shortens and the weight is lifted. But in reality the force is not constant during the contraction. Based on your findings and the lab last week, what is one reason force is not constant during an "isotonic" contraction?
- What does Hill's equation imply about energy consumption during a muscle contraction?

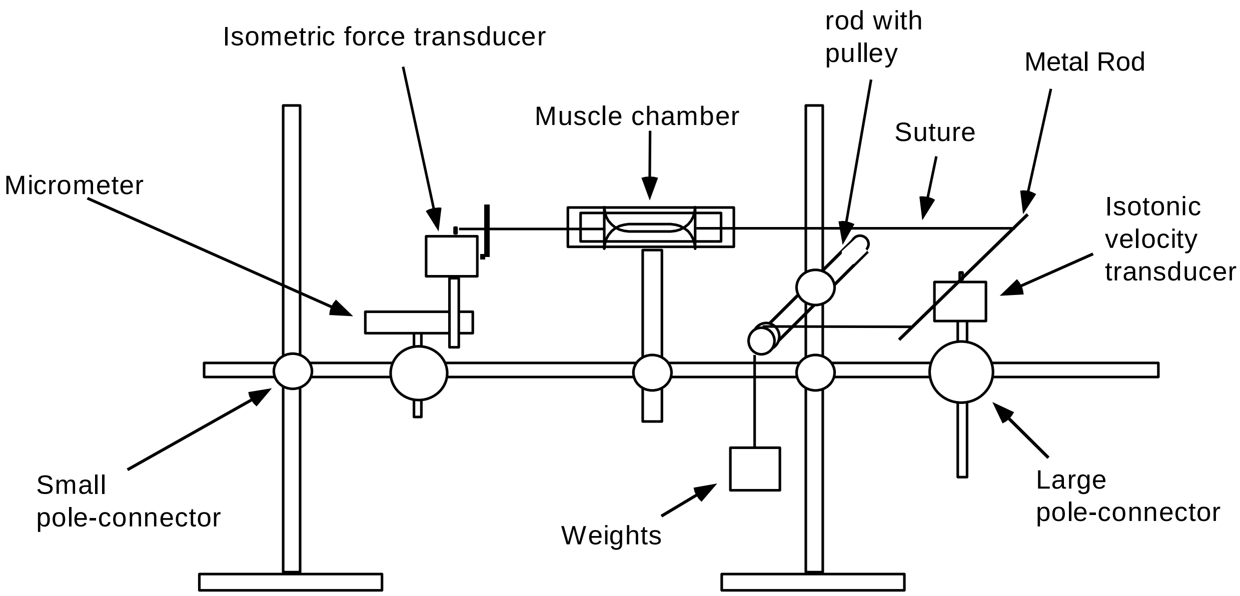


**Figure 1: Force/velocity muscle setup**

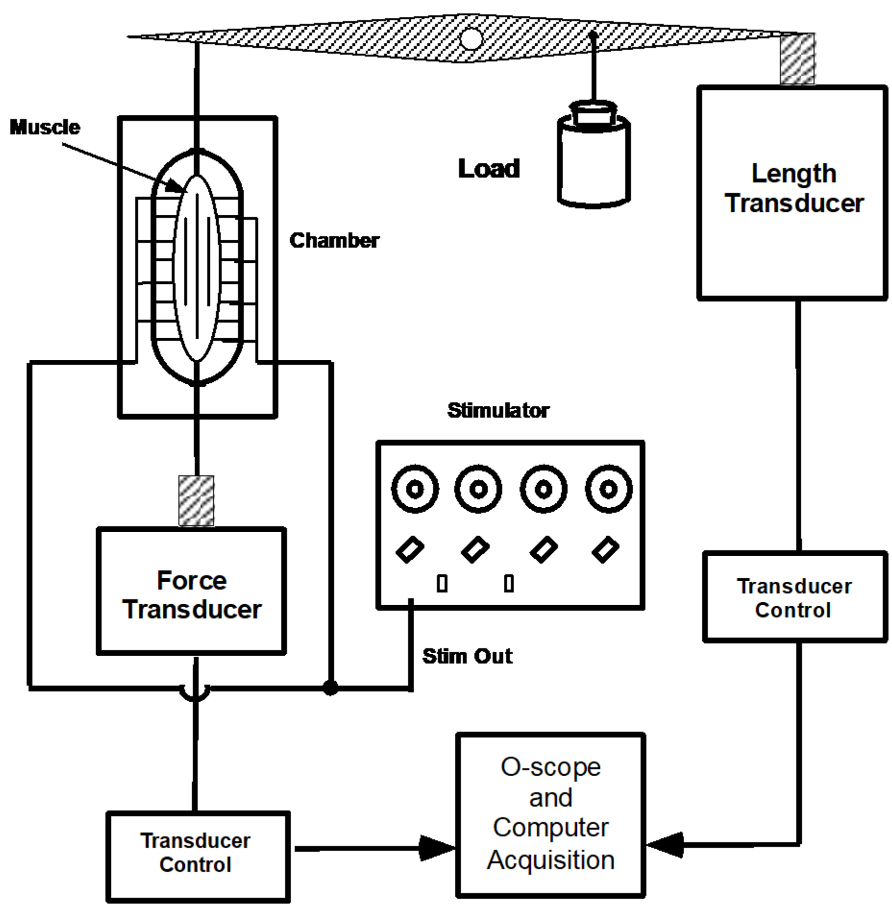


**Figure 2: Block diagram for isotonic recording.**

## Experimental Procedure

The experimental setup for the force-velocity experiments is similar to the isometric set-up of the Muscle I lab, and is shown in Figure 1, except here we add the displacement (isotonic) transducer. Remember not to tie a tight knot on the force transducer, and make sure your sutures are straight and not impeded in any way.

## Calibration and muscle sample

(1) Set up the system as show in Figure 1; you will not need the muscle chamber for calibration. You can calibrate both gauges with the setup as shown.

(2) Calibrate the isometric force transducer as was done in the previous lab using the oscilloscope. You should set up the system as shown in Figure 1, and use weights to make the calibration curve. Obtain a calibration factor for force in terms of voltage. Remember to take into account the distances from the pivot point to the suture ties leading to the muscle and to the weight pan (if they are not the same, the weight in the pan is not transmitted directly to the muscle).

(3) Calibrate the length/velocity transducer by using the micrometer to move the lever known distances and recording the voltage changes on the oscilloscope. You should then generate a calibration factor so that you may refer to distance in terms of millimeters rather than volts. Enter both force and length calibration factors into the Labview computer acquisition program, and verify that the program acquires data properly from both transducers. Write your calibration factors on the white board as usual.

(4) Excise the dorsal semitendinosis muscle of the frog as you did in the previous experiment. Note the in-situ reference length of the muscle, and make sure you have tight knots on the tendons!

## Force-Velocity Measurements

(4) From this point on, use the computer acquisition system for all data acquisition. Mount the muscle isometrically at reference length: Attach one suture from the muscle to the isotonic transducer by securing it around the metal rod which is attached to the isotonic lever. Connect the other suture to the isometric transducer; loop it over the transducer, do not tie it tightly! Adjust the micrometer so muscle is extended to its reference length. Using a pulse duration of 0.5 msec, stimulate the muscle with single twitches (isometric) with increasing voltage to determine how the twitch force increases with increasing stimulus voltage (voltage range of 1-10V). Set the stimulus voltage so that the total twitch force is between 5-10 grams, this should produce an appropriate tetanic contraction. If the twitch force is too high or low, vary the length of the muscle. Record and report your peak twitch force.

(5) Leave the voltage setting at this level for the remainder of the lab, and produce an isometric tetanic contraction with about 1000-2000 msec of 50Hz pulses, and record the maximum tetanic tension, Po, with the computer acquisition system. This will be the first point of the force-velocity curve. For each tetanic force, save the data set for post-analysis (NOT a screen shot!), and write down values from the curves displayed on the computer as you go as backup (i.e. estimates of velocity and force for each tetanus; use the “cursors” in Labview).

(6) Obtain a series of force/displacement measurements at different afterloads in order to create a force-velocity curve. Pause 2 minutes between each recording to allow the muscle to recover from fatigue, and keep the muscle bathed in Ringer's solution at all times when not stimulating. Use the value of maximum tetanic force (isometric) to determine proper weight increments so that you will have 7-8 measurements of force/velocity. Start at the highest force (about Po) and work your way down to a small force. Before you attempt "0" force, check the isometric force again for stability, and finally perform the 0-force test (maximum velocity). Note that you cannot actually have 0 grams, you will need a small weight to keep the passive state stable. Save calibrated data files on the computer for each test, and write down your force/velocity estimates as you go as a backup (using the cursor functions), making sure you leave the lab with enough information to produce the force-velocity curve. Determine the velocity from the initial linear slope of the displacement. Remember the muscle needs only to shorten a small distance to record velocity. Use the mechanical stops on the isotonic transducer to prevent the muscle from shortening more than needed. Comment on this determination of velocity, i.e. note at least one source of error in the calculation.

(7) Calculate the initial velocity of shortening for each load. Use the value of force (possibly an average) during the same period of time you estimate velocity. Express velocity in m/sec. Comment on the limitations of the force estimation used for this analysis.

(8) Generate and plot the full experimental force-velocity curve for the muscle.

(9) Plot Hill's equation on the same plot as in (8) based on a mathematical equation: Estimate the constants a and b in Hill's equation from your experimental data by curve fitting. Hill's equation is a hyperbolic-type relationship between force and velocity, with constants that determine the shape of the curve. One way to find the constants is to use a curve fitting program on the computer such as Sigmaplot, and convert the best fit parameters to the appropriate Hill's constants. There are notes on the Web page on how to use Sigmaplot for curve fitting. With the 2 constants known, you will be able to plot the hyperbolic function.

(10) In a separate graph, plot the power developed by the muscle vs. force of contraction. Include units on both axes.

**Write-up notes:**

Introduction:

As in the previous write-ups, include an introduction that gives the theoretical background of the topic, and how you are going to use experimental measurements to examine part of that topic. You shouldn't mention specific methods here, but only in general. Include important literature references, and some short intro to the molecular mechanisms thought to regulate the force-velocity relationship.

Methods:

Since most of these are given in this handout, this section should only be a brief summary of the methods given here. Do not include figures in this section. Remember to only include methods, no results.

Results:

These are given in the force-velocity measurements section above. Any calibrations should be only briefly mentioned, if at all. The most important plot is of the force-velocity curve, including the mathematical "fit" curve.

Discussion:

Include a brief explanation of how the experimental system works for measuring force vs. velocity. Limitations of this experimental setup.

Explain the shape of the recording of force with this experiment, and why you use the initial value of velocity.

Explain the shape of your force-velocity curve and power-force curve, in terms of force and velocity.

Compare your force-velocity curve to previously published results, including at least 1 specific literature reference.

Discuss a physiologic example of skeletal muscle motion in humans which is related to the force-velocity relation.

**References**

Gordon, et al (1966) "Tension Development in Highly Stretched Vertebrate Muscle Fibers" J. Physio. v184 :143.

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