freshman Engineering Honors

The Biomechanics of the Knee: Hamstring Curl and Quadriceps Extension

Mathew Deremer, Kyle Ulversoy

Faculty Advisor: Philip T. McCreanor, Ph.D.

Mercer University - School of Engineering, Macon, GA

Abstract

The knee undergoes constant stress from everyday activities, such as walking, running, and even standing. Achieving a basic understanding of muscle activity during simple leg motions, like the hamstring curl and quadriceps extension, would help an individual tailor an exercise plan that would promote a healthier standard of living. The purpose of this project was to analyze muscle activity and quantify the biomechanical forces of the knee during leg extension and contraction.

In order to determine the forces acting upon the knee, tests involving leg extension and contraction were conducted on one individual. The joints and tendon insertion points were tagged during the experiment under low intensity, controlled movement to provide a visual aid of the biomechanical forces about the knee. An Arduino system with an EKG sensor was used to analyze the muscle activity during exercise. This analysis helped pinpoint the muscles active during exercise.

The hamstring curl machine requires the most force from the hamstring muscle at the resting position and gradually decreases as the angle from the resting position increases. This occurs because the machine is constructed of a CAM that has varying lengths from the point of tension to the rotational focus of the CAM. The quadriceps extension machine, however, required the same amount of force from the quadriceps muscle throughout the duration of the exercise.

Methodology

A video analysis of the quadriceps extension and hamstring curl was conducted to determine the forces acting upon the knee at the following angles: 0, 15, 30, 45, 60, 75, and 90 degrees, with the resting position beginning at 0°. The force of the thigh was derived by using the moments of each component. The moment of the quadriceps is the product of the force applied and the moment arm (length).

$$F_{quad} MA_{quad} = M_{quad} \quad (1)$$

The moment of the machine is assumed to be equal to the moment of the roller because they are fixed. So the moment of the roller will be the product of the machine weight and length of the cam as shown in equation (2).

$$W_{machine} MA_{cam} = M_{machine} = M_{roller} \quad (2)$$

The moment of the roller is equal to the moment of the quadriceps because the quadriceps must exert a moment equal to the roller in order to produce motion. Through equation manipulation, an equation for the force is achieved. This equation is also used to calculate the force of the hamstring by substituting "ham" for "quad".

$$F_{quad} = \frac{W_{machine} MA_{cam}}{MA_{quad}} \quad (3)$$

In addition to the video analysis, an Arduino UNO along with a Muscle Sensor v3.0 was used to analyze muscle movement. The Arduino UNO and Muscle Sensor v3.0 were assembled together. An Arduino program was written to accompany the hardware. The hardware was attached to the active muscle via three 24" cable leads and three disposable surface electrodes. The goal of the program is to output a graph that displays the current intensity of the firing muscle, as shown in Figure X.

Results / Analysis

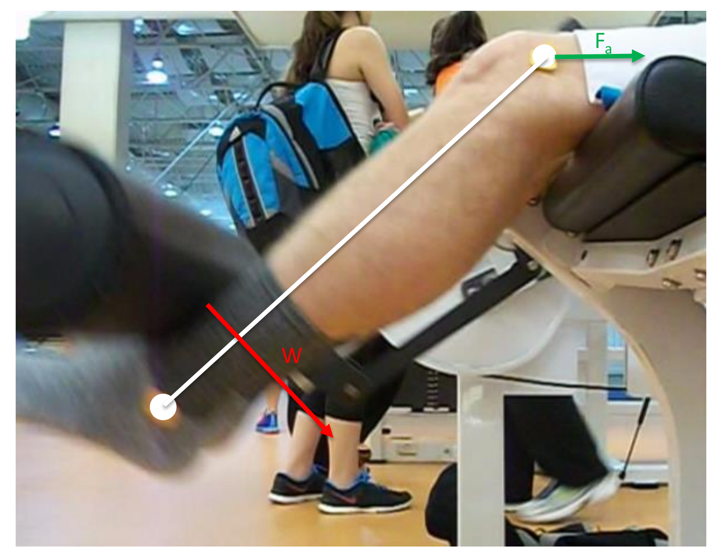

Figure 1. Quadriceps Extension Force Analysis

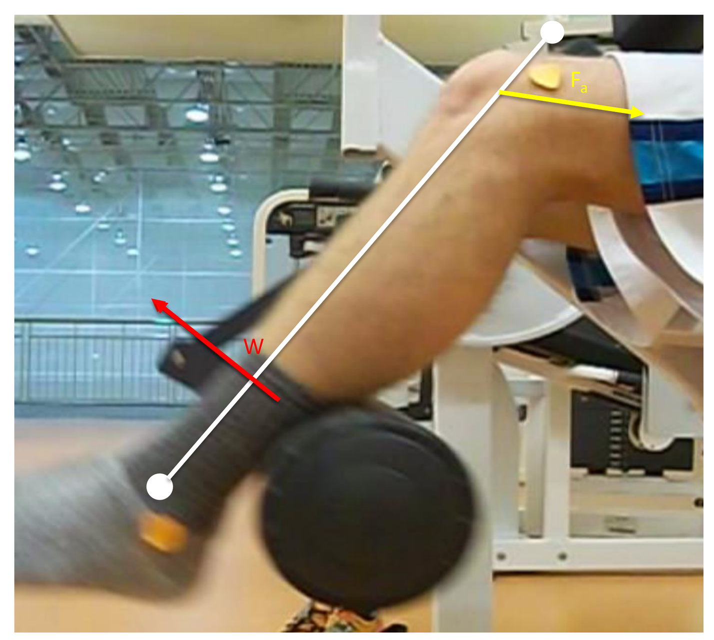

Figure 3. Hamstring Curl Force Analysis

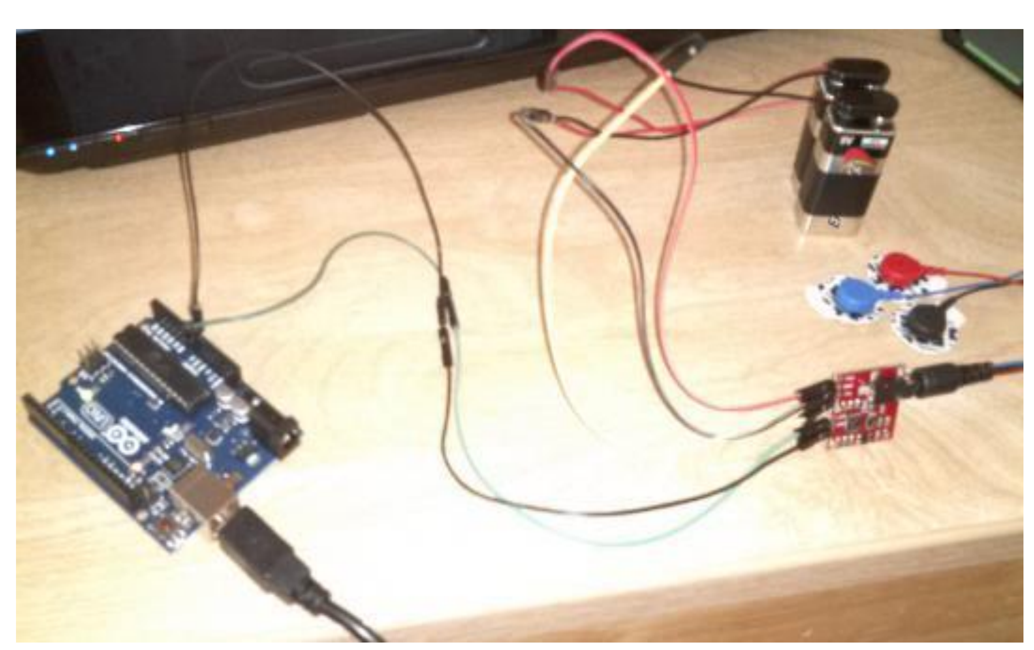

Figure 6. Arduino UNO and Muscle Sensor v3.0 system

In order to determine the force applied by the quadriceps, the insertion point of the quadriceps had to be determined. This would be the point at which the quadriceps pulls, extending the leg. The four muscles of the quadriceps come together and attach to the patella, or knee cap, as shown in Figure 2. The patellar ligament then connects from the patella to the tibia, on average, 4.45 cm from the top of the tibia. From this point, the applied force of the quadriceps pulls the tibia toward the patella.

To calculate the applied force of the hamstring muscles, the insertion point of the hamstring was determined. The hamstring attaches directly to the tibia, on average, four cm from the top of the tibia (Figure 2). From this point, the hamstring applies a force that curls the leg and brings the foot toward the dorsal side of the body.

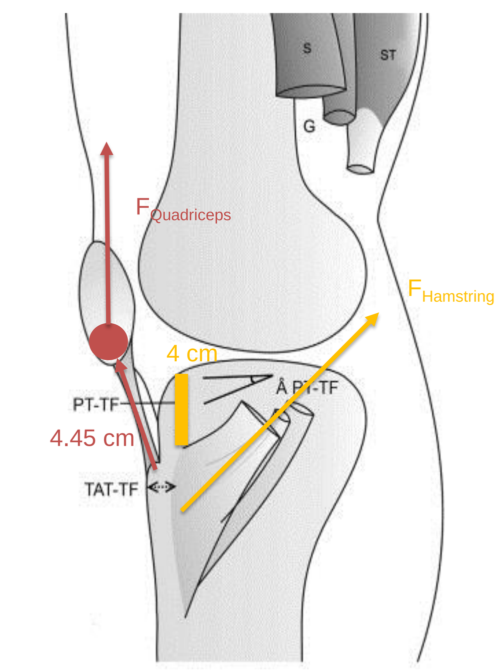

Figure 2. Insertion Points of Hamstring and Quadriceps (From: http://origin-ars.els-cdn.com/content/image/1-s2.0-S2255497113001018-gr1.jpg)

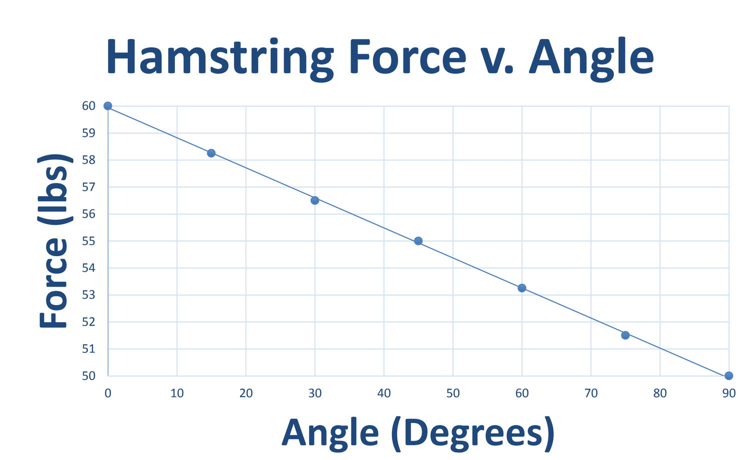

Figure 4. Hamstring force required to lift 10 lbs.

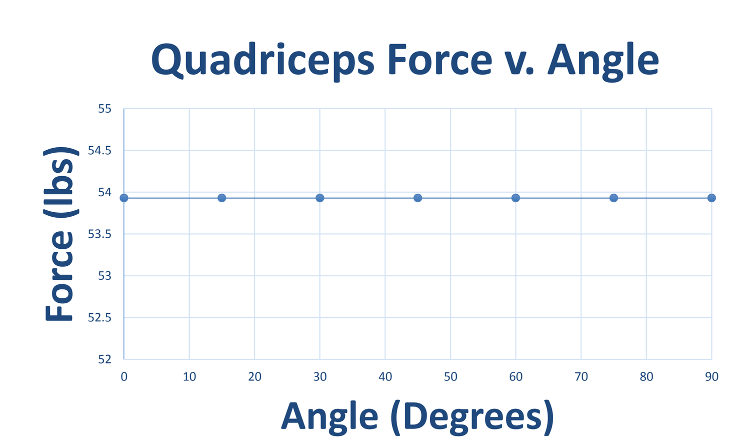

Figure 5. Quadriceps force required to lift 10 lbs.

The calculated results were compared to the results from the Arduino UNO and Muscle Sensor v3.0 system (shown in Figure 6). The quadriceps extension output values (Table 1) were relatively even until 90°. We believe this is caused by how the machine forces to flex the quadriceps at maximum extension. The hamstring curl output values (Table 2) proved to be consistent with the calculated values. The muscle worked hardest at the beginning of the hamstring exercise but the exercise became easier as the motion extended.

Table 1. Arduino output value for quadriceps extension of 10 lbs

Quadriceps Extension	
Position (angle from resting position)	Arduino output value
Resting	180
0° (holding)	190
45°	197
90°	230

Table 2. Arduino output value for hamstring curl of 10 lbs

Hamstring Curl	
Position (angle from resting position)	Arduino output value
Resting	166
0° (holding)	190
45°	180
90°	170

References

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Discussion

Nearing the close of this experiment, several important observations were made. The machines used in the experiment provided a tension force that opposed motion of the leg perpendicularly as shown in figures 1 and 3. Because of the structure of the hamstring curl machine, the applied force of the hamstring decreased as the angle from the starting position increased (figure 4). The machine used a cam plate to support the tension of the weight, so as the angle increased, the distance from the focal decreased. This decreased the required work of the hamstring. The quadriceps extension machine targeted the muscles of the quadriceps. However, we used a uniform plate to support the tension of the weight, so the required work of the quadriceps remained constant (figure 5). For these specific machines, the quadriceps will be worked consistently for the entirety of the exercise, while the hamstring will perform less work as the angle of the curl increases.

Conclusion

Exercise is used as a way to strengthen muscles and to enhance the range of motion in joints. Exercise and physical activity can prolong life for several more years. Two exercises were tested in this experiment. The Arduino UNO and Muscle Sensor v3.0 system taught us that machines can prove to require an inconsistent force (as shown in the quadriceps extension results). This could be because, at full extension, the quadriceps uses every muscle to keep the leg parallel to the ground, causing a large increase in quadriceps activity. The biomechanical and electrical analyses of these exercises provides an understanding of the work done during these exercises.

Future Work

In the future, we could analyze the squatting motion. This study would be more complicated than analyzing quadriceps extension and hamstring curls because squatting requires a complex system of muscles to work together, and there would be several more angles to calculate.

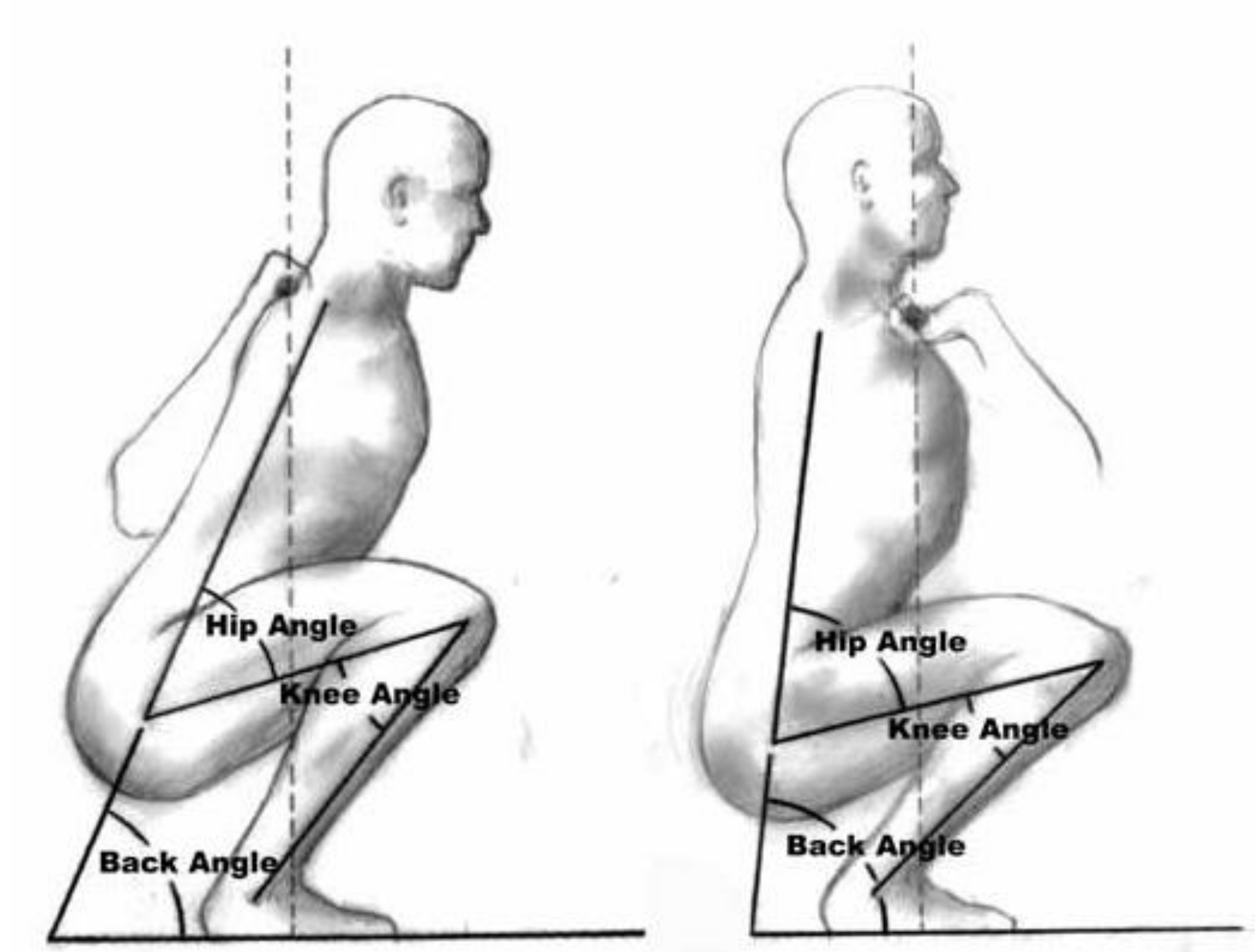

Figure 7. Diagrams of back squat (left) and front squat (right). Retrieved from http://www.excelsiorgroup.co.uk/system/files/uploads/Squat.bmp