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ARTICLE

The Science of Skiing: The Effect of Terrain, Gender and Orthotics on Quadriceps Load

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I have been a downhill skier for 16 years. I have often wondered why skiing moguls makes my quadriceps 'burn' and makes me more physically tired than skiing groomed terrain. When skiing a mogul run, knees are commonly bent between 90° and 110° angles, whereas on a groomed run, knees are commonly bent between 45° and 65° angles.

I have seen many skiers with knee injuries, especially females, and questioned if sex played a role in injury frequency. The Quadriceps Femoris Muscle Angle, or Q-angle, is the angle that your quadriceps muscle makes between your hip and knee. The Q-angle is measured by drawing a line from the anterior superior iliac spine to the center of the patella, with a second line drawn from the center of the patella to the tibial tubercle (Joyce, 2016). The angle between these lines is the Q-angle. Anatomically, males' hips form a straighter connection at the knee, while females' hips are wider, so female Q-angles are usually higher (Austin, 2003). The "normal" Q-angle measurement for males is 14° to 16°, and for females it is 16° to 18° (Piantanida and Yedlinsky, 2008). It is considered that Q-angle measurements are "abnormal" when they are greater than 20° for males and 25° for females (Christensen, 2001). I wondered if a higher Q-angle might lead females to incur more quadriceps load, and therefore more injuries.

My feet are pronated, so I wear custom orthotics in my ski boots. I noticed how the orthotics improved my stance and pondered if they might also affect quadriceps load.

PURPOSE

The purpose of this project was to determine if there will be more load on the quadriceps when skiing a mogul run than when skiing a groomed run. This project also examines if those with a higher Q-angle (typically females), would experience greater quadriceps load. In addition, it investigates if the use of orthotics could reduce Q-angle and therefore reduce quadriceps load. A better understanding of the science of skiing may help my family avoid injury.

HYPOTHESIS

There will be more load on the quadriceps muscles when skiing a mogul run (where the knee is commonly bent between 90° and 110° angles) than when skiing a groomed run (where the knee is commonly bent between 45° and 65° angles). At these knee angles, load on the quadriceps will be lowest for a 14° Q-angle (typical of males), greater for a 20° Q-angle (typical of females), and greatest for an 'extreme' 24° Q-angle (typical of females with pronation).

PROCEDURE

I constructed a mechanical model leg that could position the knee at variable angles using instructions found on the Science Buddies (2017) website. Pieces of wood were used to represent the femur (thigh bone), tibia (shin bone) and foot. Hinges were used as joints and the leg was attached to the wooden frame via the hip, which could travel up and down on casters seated in a metal track. The patella was represented by a strip of plastic, the quadriceps muscles was a spring and the quadriceps tendon was a nylon guitar string. The guitar string was attached to the spring at one end and a guitar tuner at the other end, which was used to adjust the string's tension. Figure 1 shows the layout of the model.

The load that was placed on the quadriceps muscle could be determined on the model leg by duplicating the knee angles of 45°, 65°, 90°, and 110°, as well as the Q-angles 14°, 20°, and 24°. The independent variables are the knee angle and Q-angle. The dependent variable is the amount the spring stretched. Displacement and force were determined through three complete rounds of tests which were run at four knee angles, three Q-angles, and using two different springs.

Figure 1. Mechanical Model.

I applied Hooke's Law, written as $F=kx$ where F is the force, k is the spring constant, and x is the spring extension (displacement). This law was used to calculate the relative force in the "quadriceps" spring as the angle of the model knee changed. First, the length of the spring was measured at rest. Then, the tension on the string was adjusted until it was tight. The angle of the knee was set using a protractor, and the new length of the

Figure 2. Measuring displacement.

Figure 3. Measuring Q-angle in custom ski boots.

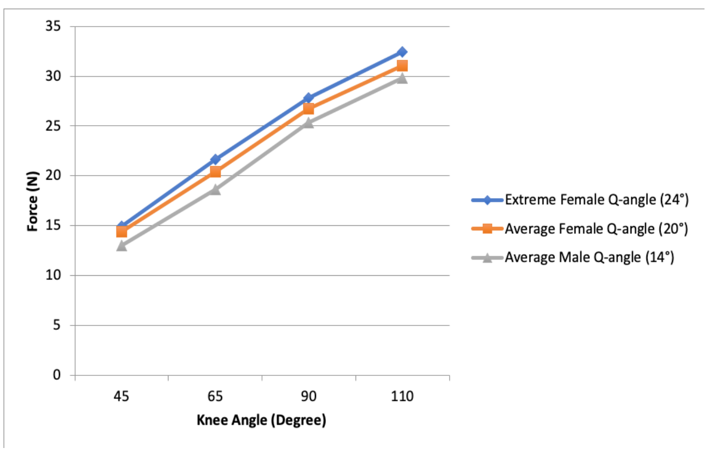

Figure 4. Spring #1: Q-angle comparison of Force vs. Knee Angle

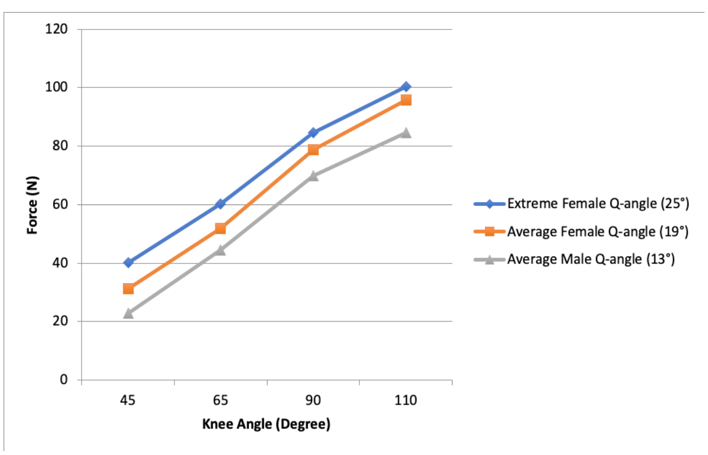

Figure 5. Spring #2: Q-angle comparison of Force vs. Knee Angle.

spring was measured. The difference between the spring's length under tension and its length at rest is the displacement (x). Figure 2 shows how I measured the spring displacement with the model knee bent at a 90° angle.

I made a spring scale to determine the spring constant (k) value, using instructions from the Science Buddies (2017) website. Weights were attached to each spring, and the displacement of the stretch was measured. The formula $k=F/x$ was used to find spring constant k, with F represented by the equation mg, where m is the mass of the attached weights and g is the acceleration of gravity. That completed $F=kx$ to determine the force on the quadriceps muscle at the various angles. I measured my own Q-angle with and without orthotics. Figure 3 shows how I measured my Q-angle in a custom ski-boot with orthotics. Other measurements were conducted in bare feet and in a sneaker orthotic.

RESULTS AND OBSERVATIONS

Displacement, and thus force, on the quadriceps was higher at the greater knee angles that are common while skiing moguls (90° and 110°) compared to the lesser knee angles that are common while skiing groomed terrain (45°and 65°). At every knee angle, the displacement and force on the quadriceps followed the same trend and was lowest for a 14°Q-angle ('average' for males), greater for a 20° Q-angle ('average' for females), and greatest for a 24° Q-angle ('extreme' for females). Figure 4 and Figure 5 show how the force on Spring #1 and Spring #2 increased as the knee angle increased, with the greatest force experienced at the 'extreme' Q-angle. Spring #2 was stiffer, wider, and shorter than Spring #1.

The Shapiro-Wilk normality test was used, and all the data passed the normality test which showed that no significant departure from normality was found. To test statistical significance, four Single Factor ANOVA tests were run, two for each spring. The knee angle data results were statistically significant for Spring#1 ($P < 0.001$) and Spring#2 ($P < 0.001$). However, the Q-Angle data results were not statistically significant for Spring#1 ($P = 0.896$) or Spring#2 ($P = 0.725$).

My own Q-angle changed dramatically from 25° in bare feet to 20° in a sneaker orthotic and 15° in a custom ski-boot with orthotic.

DISCUSSION

A 'normal' Q-angle is about 15°, and anything higher is considered a risk factor for knee injuries (Core Concepts, 2017). A high Q-angle interferes with the movement of the patella in the knee joint and over time, this wears down the knee cartilage and leads to muscle imbalances, which damage the knee joint (The Posture Clinic, 2011). In my case, the ski-boot orthotics essentially 'corrected' my extreme Q-angle and made it more 'normal'. Custom-made orthotics are an effective way to reduce excessive pronation, decrease the Q-angle and lower bio-mechanical knee load (Quinn, 2018).

Female athletes are more prone to knee injuries than males playing the same sports, mainly due to anatomical differences (Osborne, 2012). A high Q-angle causes the quadriceps to pull on the patella, causing the patella to track laterally (Quinn, 2018). While these results show that the effect of Q-angle is not significant to quadriceps load, there are also many other anatomical differences to consider. Women deal with different hormonal issues and typically have a narrower femoral notch and increased ligament laxity (Austin, 2003). For females like myself with foot pronation, it's important to wear orthotics to reduce pronation, improve the Q-angle, put less load on the knee and therefore help reduce the risk of injury (Austin, 2003).

CONCLUSIONS

This data partially supports my hypothesis, there will be more quadriceps load when skiing moguls than groomed runs. However, at these knee angles, while my data showed that there will also be more quadriceps load for anyone with a greater Q-angle (typically females), these findings were not statistically significant.

ACKNOWLEDGEMENTS

I acknowledge the assistance and carpentry tools of my father, Paul Burt, in helping me build and modify the wooden model. He also helped me physically conduct the measurements on the model leg and my own Q-angle, as the aid of a second person was required to hold measuring equipment. The assistance of my Physics teacher, Renee Boyce, is also acknowledged, in helping me understand the statistical relevance of my data.

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ERIN BURT

I'm currently in first year Engineering at Memorial University. I started science fair experiments in grade 9 and received 4 gold medals and 4 awards at regional fairs. I was delighted to participate in the 2018 Canada Wide Science Fair, earning a Bronze Medal of Excellence. I'm grateful for the many opportunities offered to me through science fair participation. I'm passionate about downhill skiing and my project was inspired during a ski vacation when I experienced my 'quads burning' after skiing moguls. I would like to further investigate the anatomical differences that put women at greater risk of skiing injuries.