MEDIAL AND LATERAL HAMSTRINGS RESPONSE AND FORCE PRODUCTION AT VARYING DEGREES OF KNEE FLEXION AND TIBIAL ROTATION IN HEALTHY INDIVIDUALS

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ABSTRACT

Background: Hamstring weakness is a contributor to lower extremity pathology. Influence of knee flexion and tibial rotation on hamstrings muscle activation and knee flexion force has not been documented in the literature.

Hypothesis/Purpose: The purpose of the study was to determine the angle of knee flexion and tibial rotation that elicits the greatest knee flexion force and hamstrings activation in healthy, physically active adults.

Study Design: Descriptive, observational cohort study

Methods: Eighteen young healthy adults were recruited for study participation. Each individual performed maximal voluntary isometric hamstrings contractions at six different knee flexion angles (15°, 30°, 45°, 60°, 75° & 90°), each positioned at three different tibial rotation positions (internal rotation, neutral rotation and external rotation). Electromyographic activity of the medial and lateral hamstrings and knee flexion force production were recorded.

Results: On average, greatest force production was recorded at 30° knee flexion with tibia either in neutral rotation (124.1% of max) or in external rotation (123.5% of max). This same lower limb orientation also produced the highest amount of lateral hamstring activation (156.4% of max). Results also showed that force production and lateral hamstring activation decreased as knee flexion angle increased. Muscle activation for the medial hamstrings was not affected by knee flexion angle but did show higher activation in neutral or tibial internal rotation.

Conclusion: The results of the current research describe the relationship between knee flexion and tibial rotation and their effect on overall knee flexion force production and hamstrings activation. This research provides key insights about the specific knee joint angles and tibial orientation that may be preferred in exercise prescription for maximizing hamstring activation.

Level of Evidence: Level III

Key Words: Hamstrings, EMG, force production, muscle activation

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The protocol for this study was approved by the Institutional Review Board of the University of Minnesota.

The authors have no conflict of interest to disclose.

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INTRODUCTION

Hamstring weakness has been proposed as a contributor to lower extremity pathology.¹⁻⁶ Hamstring strains, traumatic anterior cruciate ligament (ACL) rupture and patellofemoral pain syndrome (PFPS) comprise a large percentage of musculoskeletal injuries incurred during sports.²⁻¹⁶ These injuries are extremely disruptive and disabling to athletes. Weakness of the hamstring musculature is considered a likely contributing factor to many of these musculoskeletal injuries.^{1,9,12-24} The exact mechanism by which hamstring muscle dysfunction contributes to tears of the muscle itself, ACL rupture and PFPS is poorly understood.

Several authors have described the role of the proximal hip musculature for frontal and transverse plane kinematic control of the lower extremity and the resultant positional consequences at the femur and tibiofemoral joint.^{17, 20-22,25-26} This contributes to dynamic valgus positioning and altered tibial rotation relative to the femur. Factors influencing the distal element of the tibiofemoral joint have not been as clearly defined.

In addition to knee flexion and hip extension, the hamstrings also act to rotate the tibia. Rotation of the tibia has been used to isolate the strength of the medial and lateral hamstrings during manual testing of the knee flexors as described by Kendall in the principles of manual muscle testing.^{12,13,17,18,22-24,27-29} External rotation of the tibia is thought to bias the lateral hamstring musculature, the long head of the biceps femoris muscle. In addition, internal rotation of the tibia is thought to bias the medial hamstrings, the semitendinosus and semimembranosus. These muscle testing modifications for medial and lateral hamstring isolation are based on clinical experience and anatomical information, but have not been confirmed through scientific study.

Given their function in tibial rotation, the medial and lateral hamstring musculature may have an effect on lower extremity pathology. In order to more accurately assess medial or lateral hamstring strength or weakness, it is important to understand if it is possible to biomechanically bias the medial and lateral hamstring musculature. Onishi et al. reported that by altering the knee flexion angle, the lateral

hamstring created greater torque at more extended knee angles and medial hamstring produced higher torque values at more flexed knee angles.³⁰ He did not use tibial rotation to bias the musculature.

Mohamed et al. looked at tibial rotation at 70° of knee flexion only and found statistically greater torque production and electromyography (EMG) activation of the medial hamstrings with prepositioning into internal tibial rotation and significantly increased lateral hamstrings activation with prepositioning of the tibia into external rotation.²⁹ However, only one knee flexion angle was tested. Both studies results demonstrated statistically significant differences in torque production and muscle activation depending on changes in either joint angle or tibial rotation, but did not look at which degree of knee flexion coupled with tibial rotation that elicited the greatest force production and activation of the medial and lateral hamstrings.

The purpose of the study was to determine the angle of knee flexion and tibial rotation that elicits the greatest knee flexion force and hamstrings activation in healthy, physically active adults.

This study also set out to establish normative activation data of medial versus the lateral hamstrings in order to better appreciate possible implications muscular imbalance at the hamstrings may have on tibial orientation and injuries associated with excessive or abnormal tibiofemoral joint motion in the transverse plane. It was hypothesized that peak hamstring activation would be greatest at more extended knee flexion angles and that lateral hamstrings would demonstrate greater peak activation with external tibial rotation and medial hamstrings would demonstrate greater peak activation with internal tibial rotation.

METHODS

Subjects

A convenience sample of 18 healthy subjects (10 male and 8 female) participated in this observational study. Subject mean age was 24.4 years (range, 18-34). Mean height was 68.9 inches (range, 65-73) and mean weight was 159.2 pounds (range, 110-195). Subjects reported regular activity participation, defined as a minimum of thirty minutes per day, for a minimum of three

days per week. Subjects were excluded if they were experiencing a current lower extremity injury, or if they had a history of low back pain, hip pathology, radicular symptoms, surgery on their dominant lower extremity, systemic disease or current pregnancy. The study was approved by the University of Minnesota Institutional Review Board, and informed consent was obtained from all subjects prior to participation.

Procedure

The study took place at the Human Sensorimotor Control Laboratory at the University of Minnesota. Surface electrodes were placed onto the medial and lateral hamstrings per the standardized Surface EMG placement protocol.³¹ Each subject performed a five-minute warm up jog at a self-selected pace. Each subject was then asked to lie in the prone position on a plinth and positioned with a hip flexion angle of 0°, and their knee flexed to 90° and in neutral tibial rotation. Their hips were secured using a standard stabilization belt fixed to the plinth, and tibial rotation was confirmed by placing the patient into maximal dorsiflexion to lock out the talocrural joint, with a member of the research team stabilizing the foot with two hands at all times. For internal and external tibial rotation, maximal manual rotation was performed by the researcher until firm end-feel was present. Subjects were asked to perform two separate, three-second maximal voluntary isometric contractions in the standardized manual muscle testing position (90 degrees of knee flexion) against a force transducer attached to a fixed apparatus designed by the authors (Figure 1). All study data was normalized against the maximum output of these two trials. The fixed force transducer was used to obtain quantitative measurements of isometric torque production.

The experimental protocol consisted of two consecutive, three-second isometric contractions, randomized at angles of 30°, 45°, 60°, 75°, 90°, and 105° of knee flexion, coupled with maximal internal, external and neutral tibial rotation. EMG activity (peak-to-peak muscle activation) and maximum force output were recorded.

To eliminate a potential order effect, knee flexion angles were randomized. A minimum of 30 seconds of rest was required between individual trials, and midway through the testing (after approximately 18

Figure 1. Overhead view of the isometric hamstring contraction apparatus attached to a portable plinth.

contractions), subjects had a 20- to 30-minute rest to eliminate effects of possible muscle fatigue.

At the start of each session, two separate 1-repetition maximum contractions in 90° of knee flexion with neutral tibial rotation were performed. Following this, two trials at each knee flexion/tibial rotation combination were performed in randomized order, with the larger of the two maximum peak-to-peak activation and force output values used for further data analysis. Raw EMG data was filtered with a 20-500Hz band pass Butterworth filter and then rectified. In order to normalize the data, all maximum outputs of EMG muscle activation and force production were converted to a percentage of the initial, 90-degree 1-rep max contraction.

Statistical Analysis

Two-way, repeated measures ANOVAs were utilized to determine the effect of knee angle and tibia orientations. One-way ANOVAs were used to determine differences in tibia rotation for each hamstrings muscle group. Post-hoc t-tests were then performed to determine where the significant differences existed. Statistics were performed with SPSS v.21 (SPSS, Inc, Chicago, IL).

Results

Medial Hamstrings

Peak muscle activation of the medial hamstrings at each angle of knee flexion and tibial rotation is shown in Figure 1. There was no significant effect of knee flexion angle ($p = .123$) on peak medial hamstrings activation. Thus, muscle activation was statistically the same regardless of the angle at which the knee was flexed. However, a significant effect was seen for tibial rotation, with a higher amount of muscle activation seen while the tibia was internally rotated or in the neutral position as compared to externally rotated ($p < .001$).

Finally, there was a significant interaction between knee flexion angle and tibial rotation ($p = .048$). This revealed that as the angle of knee flexion increased, the difference in muscle activation between an internally and externally rotated tibia was decreased, if not eliminated (Figure 2). Based on descriptive

statistics, 60 degrees of knee flexion with the tibia in the neutral position elicited the maximum medial hamstrings activation (119% of max).

Lateral Hamstrings

There was a significant effect of knee flexion angle ($p < .001$) on peak lateral hamstrings activation, with greater activation seen as the angle of knee flexion decreased (i.e. as the leg was further extended) (Figure 3). A significant effect of tibial rotation was also seen ($p < .001$), with a higher amount of activation seen while the tibia was externally rotated or in the neutral position as compared to internally rotated ($p < .001$). Further, there was a significant interaction between knee flexion angle and tibial rotation ($p < .001$). This revealed that as the angle of knee flexion increased, the difference in muscle activation between an internally and externally rotated tibia was decreased, if not eliminated (Figure 3).

Figure 2. Medial hamstrings activation at differing degrees of knee flexion and tibial rotation.

Figure 3. Lateral hamstrings activation at differing degrees of knee flexion and tibial rotation.

Figure 4. Maximum isometric force output at differing degrees of knee flexion and tibial rotation.

At 30 degrees of knee flexion, lateral hamstrings peak muscle activation differed non-significantly ($p = .129$) between internal tibial rotation (120% of max), neutral tibia (141% of max) and external tibia rotation (156% of max).

At 45 degrees of knee flexion, a significant difference ($p = .022$) was seen in lateral hamstrings peak muscle activation across tibial rotation conditions: internally rotated tibia (115% of max), neutral tibia (140% of max) and externally rotated tibia (153% of max). Further analyses revealed that internal rotation of the tibia elicited significantly lower lateral hamstrings muscle activation than external rotation of the tibia (115% vs. 153%, $p = .007$), while muscle contractions performed in internal rotation trended toward being significantly lower than when performed with the tibia in neutral (115% vs. 140%, $p = .069$).

At 60 degrees of knee flexion, a non-significant, yet clinically relevant difference ($p = .107$) was seen in lateral hamstrings peak muscle activation between internally rotated tibia (108% of max), neutral tibia (130% of max) and externally rotated tibia (136% of max). This pattern of results was not seen at any of the three highest degrees of knee flexion.

Descriptive statistics showed maximum lateral hamstrings peak muscle activation was seen at 30° knee flexion, while the tibia was externally rotated (156% of max).

Force Output

There was a significant effect of knee flexion angle ($p < .01$) on peak force production, with significantly

less force produced as the knee became more flexed (Figure 4). A significantly higher effect of tibial rotation was also seen, with greater muscle activation seen while the tibia was externally rotated or in the neutral position as compared to internally rotated throughout the ranges tested ($p < 0.01$).

With the tibia internally rotated, a significant decrease in peak muscle activation was seen as knee flexion angle increased ($p < 0.01$). Further, peak force output was significantly lower at a knee flexion angle of 105° compared to all other degrees of knee flexion ($p < .01$) (Figure 4).

With the tibia in neutral rotation, a significant decrease in peak muscle activation was seen as the knee became more flexed ($p < 0.01$). Peak force output was significantly lower at a knee flexion angle of 90° compared to all other lesser degrees of knee flexion ($p < 0.01$). Furthermore, peak force output was significantly lower at a knee flexion angle of 105° compared to all other degrees of knee flexion ($p < 0.01$).

With the tibia in external rotation, a significant decrease in peak muscle activation was seen as knee flexion angle increased ($p < 0.01$). Peak force output was significantly lower at a knee flexion angle of 105° compared to all other degrees of knee flexion ($p < 0.01$).

Maximum force production was seen at 30° knee flexion, while the tibia was in the neutral position.

All normalized percentages are based on the mean data for maximum values across subjects, which are presented in Table 1.

Table 1. Mean raw data values for maximum EMG and force output.			
	Maximum Medial Hamstrings EMG (mV)	Maximum Lateral Hamstrings EMG (mV)	Maximum Force Output (N-m)
Mean	2.165	1.345	119.5
SD	0.88	0.80	29.1
SD= standard deviation, EMG= Electromyography, mV=Millivolts. N-m= Newton meters			

DISCUSSION

For hamstring musculature, EMG activity and force is influenced by knee flexion and tibial rotation angles during maximal voluntary isometric contractions. These findings reveal the degree of knee flexion and tibial rotation that elicits maximal force production and activation of the hamstring muscles. Supporting the hypothesis, this study found that peak force and peak lateral hamstrings muscle activation were greatest at 30° with the tibia in neutral and maximal external rotation, respectively. Peak medial hamstring muscle activation was seen at 60° of knee flexion, with the tibia in the neutral position.

When looking at medial hamstring muscle activation, there was no significant effect of knee flexion angle. Muscle activation was statistically the same regardless of the angle at which the knee was flexed. The significant finding of note was the decreased medial hamstrings muscle activation seen with the tibia externally rotated as compared to both neutral and internal rotation. Other authors have shown there to be a fewer degree of tibial internal rotation anatomically present in the human body compared external rotation, therefore coupling knee flexion with incremental degrees of internal tibial rotation may not produce a significant effect on medial hamstring activation.^{32,33}

Conversely, with lateral hamstring activation (as well as overall force output), the overall magnitude of peak muscle activation continued to decrease as the knee angle became more flexed throughout the testing range, with the greatest activation and force being generated at the most extended knee angle tested (30°). This held true for all three orientations of the tibia, and to the author's knowledge is the first time this has been shown in a controlled experimental setting. This likely occurs due to the length tension relationship of the hamstring musculature and the force they are capable of generating at varying lengths.

These results supported the hypothesis that at more extended knee angles, hamstring force would be greatest and internal rotation of the tibia would elicit greater medial hamstrings activation, while external rotation of the tibia would elicit greater lateral hamstrings activation. The statistically significant differences in activation found in this study are in agreement with Mohamed and Onishi.^{24-25,29-30} Mohamed et al. felt the findings in their study were not clinically relevant since altering the tibial rotation angle only altered average maximal activity by 13%. However, they only investigated this at 70° of knee flexion. The present study examined several positions of knee flexion and showed a range of 31%-74% greater maximal activation, depending on the angle of knee flexion and tibial rotation. These differences are clinically relevant for eliciting greater muscle activation during strength testing, as it appears that activation of medial and lateral hamstring musculature may be biased by altering knee flexion angles and tibial rotation.

The findings of this study give clinicians a method to more specifically assess medial versus lateral hamstring strength. The results allow clinicians to make better judgments about how to selectively bias the varied portions of the hamstrings during an assessment or evaluation and may provide insight regarding how best to isometrically strengthen the hamstrings.

For future research, implementing these findings may allow clinicians to more accurately evaluate differences between pathologic patients and healthy individuals to see if hamstring weakness does or does not contribute to lower extremity pathology. Future studies should also include the investigation of possible differences in strength assessments of medial and lateral hamstrings with and without hip stabilization.

Limitations to this study include the accuracy and validity of surface electrodes to record true muscle

activation. Electrodes were positioned according to previously recommended anatomic positions for recording the medial and lateral hamstrings independent of each other, however, there still may be an undefined amount of shared signal (cross-talk) due to the proximity of the leads. The exact amount of internal and external tibial rotation was also unable to be controlled for due to the nature of the study. Although the investigator did secure the foot in the most internally or externally rotated position, this obviously varied among participants. In addition, upon the onset of maximum contraction, the tibia has a natural tendency to rotate into the neutral position, which had to be manually counteracted by the investigator. Finally, with the experimental setup requiring 36 maximal contractions of three to four seconds, a certain level of fatigue was assumed to have occurred. This was addressed by randomizing the knee angle condition throughout the experiment, and also by the incorporation of a 20-minute break after the completion of the first 18 contractions.

Future research studies looking at injured populations, particularly those with knee and hip pathology, should be further explored. Additionally, looking at muscle activation during strength specific (therapeutic) exercises and comparing those results to static contractions could give clinicians a better understanding of lower extremity biomechanics as pertaining to the hamstrings. It could also be beneficial to see how muscle activation is altered immediately following a series of therapeutic sessions incorporating certain exercises that isolate specific lower extremity muscle groups.

CONCLUSION

The results of the current study report the activation and force production of the hamstring musculature in varied conditions. In healthy subjects, maximum force production of the hamstrings was seen at 30° knee flexion, while the tibia was in the neutral position. Peak lateral hamstrings muscle activation was greatest at 30° with the tibia in maximal external rotation. Peak medial hamstring muscle activation was seen at 60° of knee flexion, with the tibia in the neutral position. The results also demonstrate that as the knee became more flexed, the muscle activation and torque production decreased. This

research provides insights about the specific knee joint angles and tibial orientation that may be preferred during strength assessment for maximizing hamstring activation.

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