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Influence of Foot Position on Lower Extremity Muscle Activity

Hayley J. Letvin
University of North Dakota

INFLUENCE OF FOOT POSITION ON LOWER EXTREMITY MUSCLE ACTIVITY

by

Hayley J. Letvin
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This Scholarly Project, submitted by Hayley J. Letvin is partial fulfillment of the requirements for the Degree of Doctor of Physical Therapy from the University of North Dakota, has been read by Advisory and Chairperson of Physical Therapy under whom the work has been done and is hereby approved.

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(Graduate School Advisor)

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Title	Influence of Foot Position on Lower Extremity Muscle Activity
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ABSTRACT

Being that the anterior cruciate ligament (ACL) is the most commonly torn ligament, much research has been performed regarding this matter. Females have been found to be more likely to tear their ACL. This may be due to strength, structural (anatomical), hormonal, and neuromuscular differences compared to men. Several studies have also been conducted to help improve preventative measures with using strengthening and neuromuscular training programs. Many speculations have been made about the precipitating factors of an ACL injury. The general consensus in regard to foot placement is that the foot is usually placed in pronation during an ACL tear.

This research study was conducted to determine if differing foot placements made a difference in muscle activity of the tibialis anterior, lateral gastrocnemius, biceps femoris, rectus femoris, gluteus medius, and gluteus maximus muscles. Participants performed a single leg squat on 5 different angled surfaces while electromyographic (EMG) electrodes recorded muscle activity data. The different surfaces included 5° and 10° of pronation, 5° and 10° of supination, and neutral.

The results showed a significant difference in muscle activity of the lateral gastrocnemius, gluteus maximus, and biceps femoris. All 3 muscles showed the highest mean activity during pronation. These findings support the research hypothesis that

there is a difference in muscle activity in the lateral gastrocnemius, biceps femoris, and gluteus maximus muscles during pronation.

Large standard deviations were found during statistical analysis of all 5 foot positions. The large standard deviations can be attributed to the following: decreased balance and unsteadiness of the participants during squats; not having time to practice squats prior to participating in the study; prior pronation tendencies were not screened prior to the study; measuring the degree of knee flexion during the squat was not done (some participants may have squatted deeper than others); and a low sample size of participants was used. Because a significant difference was found among muscle activity, there may be a connection with ACL injuries and foot positions.

CHAPTER I

INTRODUCTION

An estimated 80,000 anterior cruciate ligament (ACL) injuries occur in the United States per year. The majority of these injuries occur in individuals between 15 to 25 years of age who are engaged in pivoting sports.[1] Several studies on ACL injuries have been conducted over the years. Debate has surfaced regarding the cause of ACL tears among individuals. The ACL and knee anatomy, mechanism of injury, biomechanics, training, neuromuscular control, and physiology have been studied to determine what puts one at risk for injury. Many studies have researched the position of the hip and subsequent knee position in relation to increased ACL tears; however, little research is available on foot positions which cause increased strain on the ACL. The purpose of the current study is to determine if susceptibility to ACL tears is increased with overpronation of the foot. To further understand the ACL and the loads placed on it, the basic structural anatomy must first be appreciated.

CHAPTER II

LITERATURE REVIEW

The ACL and posterior cruciate ligament (PCL) are called the cruciate ligaments because they cross over each other and are the primary rotary stabilizers of the knee joint. The ACL has anteromedial, posterolateral, and intermediate portions. This ligament extends from the tibia to the femur. The ACL's main functions are to limit lateral rotation of the tibia on the femur, prohibit movement anteriorly of the tibia on the femur, limit extension and hyperextension of the knee, and help control the rolling and gliding knee components. The anteromedial ACL bundle becomes tight in knee flexion and extension while the posterolateral ACL bundle becomes tight only in extension. The ACL has the least amount of stress on it between 30 and 60 degrees of flexion.[2]

The knee has several compensatory actions to assist the ACL. For instance, the medial collateral ligament placed on the medial side of the knee joint secondarily controls anterior translation of the tibia on the femur and the hamstring muscles also resist anterior tibial translation. These structures help to compensate for the ACL if it is injured. However, many times when the ACL is damaged, the compensatory mechanisms are inadequate to compensate for the ACL loss.[3,4]

The ACL is the most commonly injured ligament. Men and women often sustain this injury between 20 and 40 years of age during sport related activities. These injuries can occur by contact or noncontact mechanisms. The most common contact injury is sustained from a lateral blow to the knee causing a valgus force. Injury to the ACL is often times accompanied by injuries to the medial meniscus and medial collateral ligament, the combination of which is deemed the "terrible triad". The most common noncontact injury sustained to the ACL occurs when the tibia is externally rotated on a planted foot; this can account for up to 78% of all ACL injuries. The second most common noncontact injury occurs from knee hyperextension.[4]

Common disabilities arising from sustaining an ACL injury include: immediate swelling, pain, instability, inhibition of the quadriceps muscle, not being able to ambulate without an assistive device, instability, and the knee giving way while weight bearing.[4] Another source found complete ACL tears to be associated with knee instability, secondary menisci and chondral surface disruption, and the onset of osteoarthritis.[5]

Many studies have found women to have an increased risk of ACL tears or ruptures than men. One resource stated women are three times more likely to tear their ACL than men.[6] In 1982, the National Collegiate Athletic Association (NCAA) began a program to count the number of ACL injuries across sports in Division I, II, and III schools. From 1997-1998, 15 sports were assessed "(football, men's and women's soccer, field hockey, women's volleyball, men's and women's gymnastics, wrestling, ice hockey, men's and women's basketball, spring football, softball, and men's and women's lacrosse)".[6(p150)] From 1990-1991 through 1997-1998, female basketball players obtained 2.89 times the ACL injuries than male basketball players. Also, female soccer athletes obtained 2.29 times the ACL injuries compared to males. All mechanisms of injury which included contact and collision, noncontact, ball contact, and surface contact were considered in the findings.[7] Several other studies have indicated that females exceed males in ACL injuries by 2 to 8 times. These findings strongly imply a level of gender specificity.[5,8,9,10,11]

Risk factors for women to obtain an ACL injury include environmental, anatomical factors, hormonal, and biomechanical. Environmental factors include knee braces to prevent knee injuries and a shoe-to-surface interface which increases performance but may also increase risk of injury. Anatomical includes femoral notch size, ACL size, and lower extremity alignment differences in females compared to males. Hormonal differences have been thought to lead to increased ACL tears in females. Estrogen and progesterone receptor sites have been found in human ACLs and will be discussed in length later. Biomechanical risk factors include the effect of the total chain of trunk, hip, knee, and ankle on ACL injuries, awkward or improper dynamic body movements, deceleration and change of direction, and neuromuscular control of the knee joint.[6]

It has also been suggested that females demonstrate increased dynamic valgus angulation of the knee while landing from a jump compared to males; males and females have also been found to have similar forces around the knee when landing from a jump prior to maturation into adulthood.[12,13,14,15,16] One study compared mature males to females during single-leg squats. Electromyography readings of the rectus femoris, vastus lateralis, medial gastrocnemius, biceps femoris, gluteus maximus, gluteus medius, rectus abdominis, and erector spinae were gathered. Analysis of the muscle reading found women to have greater muscle activation than men. The study found females to have "significantly more ankle dorsiflexion, ankle pronation, hip adduction, hip flexion, hip external rotation, and less trunk lateral flexion than men [during a single-leg squat]."[17] These factors were associated with the decreased ability of females to keep knee varus during the single-leg squat as compared to males. The study found females to have more hip adduction than males during the squat possibly because of weaker gluteus medius muscles. Once the hip adducts, the femur internally rotates which causes the knee to go into valgus.[17] A systematic review also found females to land with greater knee abduction motion than males in multiple variety of movements common with high-risk sports which were measured in studies of biomechanics.[18]

Another contributing factor to the difference of prevalence of ACL injuries between male and female is a deficit in dynamic neuromuscular control of joint stability during proximal-distal, anterior-posterior, and medial-lateral axes of motion along with the kinetic chain of the entire lower extremity.[19] One study assessed male and female landing techniques from a jump. Males with a poor landing technique were associated with a low BMI, increased Q-angle, and weak gluteus medius muscles. Females with weak hamstrings and gluteus medius muscles were found to have poor jump-landing techniques. The poor landings are considered to be a high-risk movement pattern which could cause an ACL rupture/injury.[20]

Neuromuscular strategies differ between male and female athletes. These differences include muscle recruitment and timing of muscle activation, both of which affect dynamic knee stability. "Neuromuscular preplanning allows feed forward recruitment of the musculature that controls knee joint positioning during landing and pivoting maneuvers."[18(p.347)] Lack of adequate balance or ineffective timing in the neuromuscular firing can cause improper limb positioning which may put the ACL under increased strain and an injury may ensue. Feed forward control develops during previous movements and will activate muscles surrounding the knee joint before loading occurs in order to absorb the force and decrease stress on the ligaments. Some studies have found that females display longer latency periods of electromechanical delay between preparatory and reactive muscle activity.[19]

It has been suggested that during hip adduction, knee valgus, tibial external rotation, foot pronation and foot external rotation, the leg assumes a "point of no return" as deemed by Ireland.[7] The "point of no return" can be caused by deficits in neuromuscular strategies. Once this position is obtained, the hip abductors and extensors have shut down and the pelvis and hips have lost control of the body movement.[7] The ACL may fail once the leg has gone into this position.[7] The "safe" landing position is described as normal lordosis of the low back, hips flexed and in neutral alignment, knees flexed, tibias in neutral positions, and feet in a controlled and center-balanced midfoot stance.[7] Training to obtain this "safe" landing position is described in detail later.

The mechanism of injury during noncontact ACL injuries has also been suggested to be caused by multiplane knee loadings. Excessive ACL loading may occur when vigorous quadriceps forces occur along with frontal-plane and/or transverse-plane knee loadings with weak hamstring cocontraction forces while the knee is nearly extended or hyperextended. One review of literature found that several different knee positions could cause ACL injuries.[21] Several people with ACL injuries reported their knee moved into valgus with either internal or external rotation with knee hyperextension or in shallow knee flexion. One group reported ACL injury most often occurred with near full knee extension or hyperextension. The review also found noncontact ACL injuries mostly occurred during weight bearing activities.[21]

One study which reviewed videos of athletes sustaining an ACL injury found the average angle of knee flexion to be about 18 to 24 degrees during the injury (this number could be more due to the difficulty of assessing knee flexion angles on a video analysis). This study concluded that knee flexion angles during the time of injury were higher in male athletes than female athletes and females had a 5.3 times higher chance of attaining a valgus collapse than males. Valgus collapse was defined as the knee collapsing medially with the component motions of hip internal rotation, knee valgus, and external rotation of the tibia. It also found that males and females did not have a great difference in knee valgus angles (females 4 degees and males 3 degees; however, shortly after initial contact, the female athletes had a larger average valgus angle of 8 degees compared to 4 degees in males.[22,23] A review of literature named these static posture malalignments as possible precursors for an ACL tear: knee recurvatum, external tibial torsion, and excessive foot pronation.[24]

It has been suggested that knee joint laxity and subtalar pronation also contribute to an increased risk of ACL injury. A study by Woodford-Rogers also found ACL injured athletes to have a navicular drop of 5.0 $\pm$ 2.5 mm while non ACL-injured athletes had a navicular drop of 3.0 $\pm$ 1.1 mm.[25] Women have been found to have increased navicular drop and pronation of the feet compared to men possibly due to increased ligamentous laxity in the feet.[26]

One study looked at fatigue and neuromuscular control as a potential mechanism of injury.[26] Twenty-five female athletes were fatigued by repeated leg squats then jumped according to anticipated and unanticipated light stimuli. The findings found fatigue caused significant increase in hip extension and internal rotation upon contact and in peak stance knee abduction and internal rotation and ankle supination angles. The effects of fatigue and decision making may make a worst case scenario for anterior cruciate ligament injury risk during dynamic landings on a single leg.[26]

ACL injury occurs when the knee sustains a high dynamic loading and active muscular restraints do not appropriately dampen the load, causing increased load on the passive restraints such as the ACL. This decrease in neuromuscular control of the knee may place an overwhelming stress on the passive ligaments exceeding the ligament's failure strength. Neuromuscular recruitment patterns which may compromise the knee's active restraints will cause passive joint restraints to sustain a greater load, decrease the knee's dynamic stability, and increase the risk of an ACL injury.[19]

Research has found that estrogen decreases collagen production within tendons by weakening fibroblast activity, therefore increasing compliance.[27,28] A study by Bryant et al.[27] found that significantly elevated estrogen increased extensibility of connective tissue and/or decreased neuromuscular control. Fluctuation in estrogen levels may be a factor in the increased number of ACL injuries in females.

Several intervention strategies have been implemented to help decrease the likelihood of sustaining an ACL injury. Some special training techniques for individuals at risk for ACL injury include landing instruction; this includes teaching the individual to land with less hip flexion and internal rotation and less valgus angle at the knee. This is especially true for females as they are more prone than males to sustain an increased valgus load during side stepping compared to males.[29] These strategies to decrease ACL tear can help to keep the ligament safe during landing and cutting activities.

One study found that by inserting bilateral 5 degree medial post insert into the shoes, there was a significant decrease in knee valgus during a landing from a jump. This provided a significant decrease in knee valgus angles for initial contact (1.24 degree decrease) and maximum values (1.21 degree decrease). The use of the medial post was calculated to cause a moderate to large effect on reducing knee valgus and foot pronation and eversion at initial contact.[30] The decrease in pronation by the medial post insert could have also aided in lessening the strain on the ACL. It has been suggested through research that hyperpronation assessed by navicular drop is correlated with an increased likelihood of an ACL injury. One study found the group of subjects who had suffered ACL injuries had higher navicular drop values than the group of individuals who had never sustained an ACL injury.[31]

Neuromuscular control is the efferent response to an afferent signal corresponding to dynamic joint stability.[7] Implementation of a proprioceptive and neuromuscular training program can aid in preventing the occurrence of an ACL injury.

One study sent out videos demonstrating therapeutic exercises to female athletes across the US.[7] This video included education, 3 warm-up activities, 5 stretches for the trunk and lower extremity, 3 strength exercises, 5 plyometric activities, and 3 soccer-specific drills used for agility. The athletes were also instructed in the video as to how to perform the exercises in the proper biomechanical alignment. Plyometrics consisted of lateral hops, forward hops, single-leg hops, vertical jumps, and scissors jumps. These exercises were implemented for 2 years. The study found after 2 years an overall 74% reduction in ACL tears in the group receiving therapeutic exercises as opposed to the age and skill-matched control group. This program was used to address the feed-forward mechanism used to anticipate external forces in order to stabilize the joint to protect joint structures before the force is applied.[7]

Another study also researched the effect of a pre-workout routine consisting of warm-up, stretching, strengthening, plyometrics, and agility prior to the workout of soccer players. This study found noncontact ACL injuries occurred two times more often in the control group than the intervention group in the first six weeks of the season. After the last six weeks of the season, the difference between the two groups became statistically significant as no members of the intervention group sustained injury in the second half of the season.[32]

Injury prevention interventions can also include an analysis of movement biomechanics and education for awareness of dangerous body positions. Areas suggested for future study include the use of orthotics with plyometrics, education on movement, biomechanical enhancement and training protocols.[26]

One study looked at the difference in EMG activity in the gluteus maximus and gluteus medius during a double leg squat (DLS), single leg squat (SLS), and a front step up (FSU) onto a platform. All of these squats were performed with and without an applied load to the knee for a total of 6 exercises. This load pulled the knee into valgus. The results found the SLS showed the highest electrical activation from the gluteus maximus and gluteus medius with or without the load. These results suggest the SLS is the most effective exercise of the three for activation of the gluteus maximus and gluteus medius muscles.[6,33]

In a similar study, two participants with excessive hip adduction and knee pain performed functional, non weight bearing, and weight bearing exercises to increase strength in the gluteus maximus and medius, hip abductors, and lateral rotators. One patient showed an 80% decrease in hip adduction during a step-down cycle suggesting increased control of the movement.[34]

A lateral step-up exercise may be beneficial for strengthening the gluteus medius. Participants in this study stepped straight up onto a platform 21.5 cm high for a forward step-up exercise. For lateral step-ups, the platform was placed enough to the side of the participant so the subject could safely step down into a normal stance. The participants stepped up with their right lower extremity and descended with their left lower extremity. The EMG results found the gluteus medius activity was significantly greater for the lateral step-ups than for the forward step-ups for the left lower extremity during the step-up phase and for both lower extremities during the descent phase of the exercise. Also, the right gluteus medius had significantly higher EMG readings during the ascent than during the descent for both exercises.[35]

As stated above, pronation may attribute to ACL injury. The research questions as stated previously still remain. Does foot overpronation cause reduced muscle activity which in turn puts the ACL at risk for a tear? Can the foot position in general influence lower extremity muscle activity? This research study hypothesizes overpronation of the foot will cause reduced muscle activity which will put the ACL at risk. Participants will engage in single-leg squats in several foot positions as described in the Methods section.

CHAPTER III

METHODS

Before any of the data was collected, IRB approval was obtained for the study. Subjects were chosen from a group of physical therapy students. These students were notified by word of mouth. All subjects were required to read, understand, and sign a consent document in order to participate in the study. All research was conducted in the Physical Therapy Department located in the UND School of Medicine & Health Sciences building. A data sheet was completed which documented any previous injuries or surgeries and current stage of menstrual cycle (if applicable).

Subjects were aged 18 to 30 and included male and females. They were screened for prior injuries and allergies to rubbing alcohol or to electrode gel. Exclusion criteria included any acute injuries or pregnancy.

The “dominant leg” was found by placing a ball in front of the participant and then kicked by whichever leg felt most natural. The ball was kicked 3 times to determine the dominant leg. The dominant leg was considered to be the stance leg during the kick. This dominant leg was used for electrode placement.

Next, the subjects received electrode placements. First the skin was prepared by lightly scraping with sandpaper then wiping with alcohol. If excessive hair was present, it was clipped. This was all done to ensure optimal electrical conductance from the muscle to the interpretive equipment. Two electrodes were then placed on either side of the specific point on the 6 tested muscles. The impedance of the electrodes was checked with a Noraxon® electrode impedance checker (Noraxon, Scottsdale, AZ); the impedance needed to be less than 50000 ohms. If impedance was greater than 50000 ohms, the electrodes were placed closer together then checked again.

The electrodes for the gastrocnemius were placed over the muscle belly 1/3 the distance from the fibular head to the calcaneous. The electrodes for the anterior tibialis were placed over the muscle belly 1/3 the distance from the inferior patellar pole to the lateral malleolus. The electrodes for the rectus femoris were placed at the midpoint of a line from the anterior superior iliac spine (ASIS) to the superior pole of the patella. The electrodes for the biceps femoris were placed at the midpoint of a line from the ischial tuberosity to the lateral femoral condyle. The electrodes for the gluteus maximus were placed on the midpoint of a line from the inferior lateral angle of the sacrum to the greater trochanter. The electrodes for gluteus medius were placed on the proximal third of the distance from the iliac crest to the greater trochanter. A ground electrode was also placed on the fibular head and an electric goniometer was placed on the lateral knee. An electromyographic (EMG) recording device was used to measure electrical activity in the muscle during activity without imparting any electrical current to the subject.

Next the subjects were asked to perform a single leg squat. The participants were asked to remove their shoes and socks and performed squats on wooden surfaces covered by a towel. The leg performing the squat was the one with electrode placement. First a few squats were performed on a flat surface to check the connection of the electrodes to the computer. The order of squats was randomly assigned by the participant drawing cards. Types of squats included neutral, 5 degrees supination, 10 degrees supination, 5 degrees pronation, and 10 degrees pronation. Pronation was provided by having the participant step on a 5- or 10- degree wedge placed under the lateral aspect of their foot. Supination was provided by placing a 5- or 10- degree wedge under the participant's medial foot.

The subjects practiced their squats 4 to 5 times before performing with recorded electrode data. When electrode data was being recorded, the subjects performed 5 squats. All practice and data-recording squats were performed in time with a 60 beat per minute metronome, performing each squat at a 30 Hz rate. The subjects were instructed to squat until about 50° to 60° of knee flexion. After performing all 5 squats 5 times each, the electrodes were removed and discarded. Then the subject's skin was wiped with alcohol.

Very little risk of injury is involved in this study. This is because the squats performed only involve moderate physical effort. Loss of balance may be an issue; however, a spotter was present in case of participant hesitation or possible falls. Also, sometimes mild skin reactions occur in response to the electrode adhesive which resolves spontaneously.

CHAPTER IV

RESULTS

Muscle activation of the lateral gastrocnemius, rectus femoris, biceps femoris, gluteus medius, gluteus maximus, and tibialis anterior was monitored and recorded during a single leg squat in 5 foot positions. A percent of the maximal voluntary contraction (%MVC) was found by comparing muscle activation to the maximal voluntary contraction (MVC) value determined by taking the average MVC values of participants in the preceding study. The mean and standard deviation for each foot position are listed in Tables 2.1 to 2.6, Friedman's Test is listed in Table 1, and Mauchley's is presented in Tables 3.1 to 3.6. Friedman's Test was run due to the study violating assumptions of a normal distribution. The post hoc tests were performed on muscles found to be significant to study the interaction between foot positions.

Muscle activity of the tibialis anterior, rectus femoris, and gluteus medius was not statistically significant between foot positions according to Friedman's.

Muscle activity of the lateral gastrocnemius was found to be statistically significant with changing foot position (P=.014). According to the post hoc analysis there was a significant difference in lateral gastrocnemius muscle activity between the following positions: neutral foot position and 5 degrees pronation (P=.050); 5 degrees supination and 10 degrees pronation (*P*=.035); 10 degrees supination and 5 degrees pronation (*P*=.020); 10 degrees supination and 10 degrees pronation (*P*=.035).

Muscle activity of the biceps femoris was found to be statistically significant with changing foot position (*P*=.046) According to the post hoc analysis there was a significant difference in biceps femoris muscle activity between the following positions: neutral foot position and 5 degrees pronation (*P*=.010); neutral foot position and 10 degrees pronation (*P*=.008).

Muscle activity of the gluteus maximus was found to be statistically significant with changing foot position (*P*<.001) According to the post hoc analysis there was a significant difference in gluteus maximus muscle activity between the following positions: neutral foot position and 5 degrees supination (*P*=.021); neutral and 10 degrees supination (*P*=.023); neutral and 5 degrees pronation (*P*=.002); neutral and 10 degrees pronation (*P*=.001); 5 degrees supination and 10 degrees pronation (*P*=.003); 5 degrees pronation and 10 degrees pronation (*P*=.036).

Table 1. Friedman's Test

Muscle	N	Chi-square	df	*P* (significance)[a]
Anterior tib	10	2.240	4	0.692
Lateral Gastroc	10	12.560	4	0.014[b]
Rectus Femoris	10	5.246	4	0.263
Biceps Femoris	10	9.680	4	0.046[b]
Glut Medius	10	6.080	4	0.193
Glut Max	10	22.814	4	< .001[b]

[a]Friedman's Test showing significance of muscle activity compared to %MVC for each muscle.
[b]Muscles found to be significant were the lateral gastrocnemius, biceps femoris, and gluteus maximus.

Tables 2: RM ANOVA Data – Mean and Std. Deviation for Each Muscle in Each Position

Table 2 – 1. RM ANOVA of Tibialis Anterior

Muscle – position[c]	Mean[a]	Standard Deviation[b]
Ant tib – standard	62.4500[d]	11.05976
Ant tib – supination 5°	55.1500[d]	17.38162
Ant tib – supination 10°	58.2500[d]	10.97788
Ant tib – pronation 5°	60.3500	14.35752
Ant tib – pronation 10°	64.9200	19.27686

[a]Mean for RM ANOVA of tibialis anterior.
[b]Standard deviation values for RM ANOVA of the tibialis anterior.
[c]Foot position.
[d]The mean is expressed as %MVC.

Table 2-2. RM ANOVA of Lateral Gastrocnemius

Muscle – Position[c]	Mean[a]	Standard Deviation[b]
Lat gastroc – standard	74.1600[d]	7.02032
Lat gastroc – supination 5°	76.9700[d]	22.38859
Lat gastroc – supination 10°	74.2200[d]	13.29969
Lat gastroc – pronation 5°	82.9200[d]	11.43871
Lat gastroc – pronation 10°	88.4900[d]	20.72038

[a]Mean for RM ANOVA of lateral gastrocnemius.
[b]Standard deviation values for RM ANOVA of the lateral gastrocnemius.
[c]Foot position.
[d]The mean is expressed as %MVC.

Table 2-3. RM ANOVA of Rectus Femoris		
Muscle – Position[c]	Mean[a]	Standard Deviation[b]
Rectus Femoris – standard	66.8400[d]	8.87170
Rectus Femoris – supination 5°	74.1200[d]	31.97064
Rectus Femoris – supination 10°	72.4800[d]	31.55605
Rectus Femoris – pronation 5°	70.9500[d]	28.14227
Rectus Femoris – pronation 10°	70.1200[d]	33.81334

[a]Mean for RM ANOVA of rectus femoris.
[b]Standard deviation values for RM ANOVA of the rectus femoris.
[c]Foot position.
[d]The mean is expressed as %MVC.

Table 2-4. RM ANOVA of Biceps Femoris		
Muscle – Position[c]	Mean[a]	Standard Deviation[b]
Biceps Femoris – standard	68.4000[d]	7.14967
Biceps Femoris – supination 5°	76.4000[d]	26.53446
Biceps Femoris – supination 10°	87.6900[d]	29.47422
Biceps Femoris – pronation 5°	81.8100[d]	16.66890
Biceps Femoris – pronation 10°	87.1100[d]	20.43828

[a]Mean for RM ANOVA of biceps femoris.
[b]Standard deviation values for RM ANOVA of the biceps femoris.
[c]Foot position.
[d]The mean is expressed as %MVC.

Table 2-5. RM ANOVA of Gluteus Medius		
Muscle – position[c]	Mean[a]	Standard Deviation[b]
Glut med - standard	75.7300[d]	8.27500
Glut med – supination 5°	82.0200[d]	18.36572
Glut med – supination 10°	85.8000[d]	17.67251
Glut med – pronation 5°	86.9100[d]	13.53903
Glut med – pronation 10°	88.7400[d]	14.33575

[a]Mean for RM ANOVA of gluteus medius.
[b]Standard deviation values for RM ANOVA of the gluteus medius.
[c]Foot position.
[d]The mean is expressed as %MVC.

Table 2-6. RM ANOVA of Gluteus Maximus		
Muscle – position[c]	Mean[a]	Standard Deviation[b]
Glut Max – standard	68.6700[d]	5.41542
Glut Max – supination 5°	81.7700[d]	16.31421
Glut Max – supination 10°	91.9700[d]	29.94955
Glut Max – pronation 5°	87.2100[d]	16.35240
Glut Max – pronation 10°	101.4800[d]	22.43251

[a]Mean for RM ANOVA of gluteus maximus.
[b]Standard deviation values for RM ANOVA of the gluteus maximus.
[c]Foot position.
[d]The mean is expressed as %MVC.

Tables 3: Mauchly's Test of Sphericity (tests of within-subjects effects)

Table 3-1. Mauchly's Test of Sphericity for Tibialis Anterior					
Muscle – ant tib	Type III Sum of Squares	df	Mean Square	F	Sig. (*P*)[a]
Sphericity assumed	566.655	4	141.664	.827	.517
Error – sphericity assumed	6165.513	36	171.264		
[a]Mauchley's Test of Sphericity demonstrating nonsignificance (P>.05)					

Table 3-2. Mauchly's Test of Sphericity for Lateral Gastrocnemius					
Muscle – lat gastroc	Type III sum of squares	df	Mean square	F	Sig. [a]
Sphericity assumed	1552.019	4	388.005	3.060	.029
Error - sphericity assumed	4564.565	36	126.793		
[a]Mauchley's Test of Sphericity demonstrating significance (*P*<.05)					

Table 3-3. Mauchly's Test of Sphericity for Rectus Femoris					
Muscle – rectus femoris	Type III Sum of Squares	df	Mean square	F	Sig.[a]
Sphericity assumed	299.593	4	74.898	.335	.853
Error – sphericity assumed	8053.567	36	223.710		
[a]Mauchley's Test of Sphericity demonstrating non-significance (*P*=.852)					

Table 3-4. Mauchly's Test of Sphericity for Biceps Femoris					
Muscle – biceps femoris	Type III Sum of Squares	df	Mean Square	F	Sig. [a]
Sphericity Assumed	2600.867	4	650.217	2.727	.044
Error – sphericity assumed	8582.189	36	238.394		
[a]Mauchley's Test of Sphericity demonstrating significance (*P*=.044)					

Table 3-5. Mauchly's Test of Sphericity for Gluteus Medius					
Muscle – glut med	Type III sum of squares	df	Mean square	F	Sig. [a]
Sphericity assumed	1063.610	4	265.903	2.695	.046
Error - sphericity assumed	3551.358	36	98.649		
[a]Mauchley's Test of Sphericity demonstrating significance (*P*=.046)					

Table 3-6. Mauchly's Test of Sphericity for Gluteus Maximus					
Muscle- glut max	Type II sum of squares	df	Mean square	F	Sig. [a]
Sphericity assumed	5947.152	4	1486.788	8.696	<.001
Error - sphericity assumed	6155.176	36	170.977		
[a]Mauchley's Test of Sphericity demonstrating significance (*P*=.001)					

CHAPTER V

DISCUSSION

As stated in the Results section, out of the 6 muscles tested, only the lateral gastrocnemius, biceps femoris, and gluteus maximus muscles were found to have significant values among the different 5 foot positions during squats. The mean values of muscle activity for the lateral gastrocnemius were higher during pronation at 5 and 10 degrees compared to the other foot positions (Table 2-2). The highest mean muscle activity levels for biceps femoris were recorded at 10 degrees supination and 10 degrees pronation (Table 2-4). The highest mean muscle activity level recorded for gluteus maximus was recorded at 10 degrees of pronation (Table 2-6). These muscles showed heightened activity during pronation; according to several studies, increased pronation can lead to an ACL tear.[7, 24, 25, 31] These findings support the research hypothesis that there is a difference in muscle activity in the lateral gastrocnemius, biceps femoris, and gluteus maximus during pronation.

We found large standard deviations among all muscles tested in the 5 different positions. We assume decreased balance and unsteadiness during the squats caused high standard deviations as the muscles are recruited differently in every individual to help regain balance. To help lower standard deviation during future testing, the participants could receive instruction for a single leg squat several days in advance in order to practice. Another way to decrease standard deviation is to allow the participants to use 2 fingers on a stable surface such as a table to steady themselves during squats. We also did not screen for pronation tendencies prior to testing. Some individuals may pronate more than others and this factor may skew the results. Another issue which may have caused increased standard deviation values is that we did not standardize a squat angle. Some individuals may have performed deeper squats than others thus causing differing muscle activity. Also, a low number of subjects were used for this study.

Unfortunately, not much research has been done in the area of muscle activity during single leg squats on differing angled surfaces. For this reason, comparison of results is made difficult.

Significant differences of muscle activity in the lateral gastrocnemius, biceps femoris, and gluteus maximus muscles during 5 different foot positions during squats indicates differing muscle activity is elicited during pronation, supination, and neutral foot positions. The question of how squatting muscle activity affects the ACL is yet to be determined. Continuing research is needed to answer this question.

CHAPTER VI

CONCLUSION

Due to large standard deviations and violating assumptions, little data could be used for interpretation. However, important findings such as increased activity of the lateral gastrocnemius, biceps femoris, and gluteus maximus activity were found during pronation. Ways to improve subject performance during research is stated above and may contribute to more accurate findings. Because differences in muscle activity were present in changes of foot incline positions (especially pronation), there may be a connection with ACL injuries and foot positions. Further research with less assumption violations should be conducted in this area.

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