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Effect of frontal plane foot position on lower extremity muscle activation and limb positioning in a single leg squat

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EFFECT OF FRONTAL PLANE FOOT POSITION ON LOWER EXTREMITY
MUSCLE ACTIVATION AND LIMB POSITIONING
IN A SINGLE LEG SQUAT

by

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Bachelor of Science, Colorado State University, 2001

A Scholarly Project Submitted to the Department of Physical Therapy Faculty in partial
fulfillment of the requirements for the degree Doctor of Physical Therapy at University of
North Dakota in partial fulfillment of the requirements for the degree of Doctor of
Physical Therapy

Grand Forks, North Dakota

May 2013
This scholarly project, submitted by Brady Stokes in partial fulfillment of the requirements for the Degree of Doctor of Physical Therapy from the University of North Dakota, has been read by the Faculty Advisor under whom the work has been done and is hereby approved.

______________________________
(Graduate School Advisor)

______________________________
(Chairperson, Physical Therapy)
PERMISSION

Title  Effect of Frontal Plane Foot Position on Lower Extremity Muscle Activation and Limb Positioning in a Single Leg Squat

Department  Physical Therapy

Degree  Doctor of Physical Therapy

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ABSTRACT

PURPOSE: Anterior cruciate ligament (ACL) injuries at the knee are quite common, especially in the athletic population involved in sports in which jumping, landing, and cutting activities occur frequently. Previous studies have suggested that lower extremity muscle control plays a role in preventing these injuries. This study set out to determine if foot position influences muscle activation in the lower extremity and, by extension, possibly contributes to the risk of ACL injury. This project examined the activity of lower extremity muscles and the kinematics (movement patterns) of the lower extremity in various foot positions during a single-leg body lowering action. Lower extremity muscle activity influenced by foot position may alter the position of the knee, resulting in changes to stresses on the anterior cruciate ligament. This study attempted to determine whether foot position affects lower extremity muscle activity.

PROCEDURE/METHODS: The activity of the lower extremity muscles in various foot positions during a single-leg squat was measured using EMG analysis of the muscles influencing the knee. The six muscle we tested include gluteus maximus, gluteus medius, quadriceps femoris, biceps femoris, anterior tibialis, and lateral gastrocnemius. The EMG recording device measured the electrical activity of the muscles during muscle action. Subjects performed a barefoot single-leg squat (to 45 to 60 degrees knee flexion) on the dominant stance leg 5 times, then returned to standing erect while weight bearing as EMG activity recorded for each of 5 different foot positions. Through varying foot
positions during a single leg squat, this study helped explore a possible component to the mechanism of ACL injuries. The subjects performed 5 repetitions in each position, with data collection resetting after each position. Muscle activity was reported as a percentage of maximal voluntary contraction (MVC) of the respective muscle for each subject.

RESULTS: Data analysis was performed on each of the six muscle groups being tested (gluteus maximus, gluteus medius, biceps femoris, rectus femoris, lateral gastrocnemius, and anterior tibialis) comparing the baseline single leg squat to each of the four test positions (supination 5˚, supination 10˚, pronation 5˚, pronation 10˚). Our data analysis showed that there was no significant difference (p > 0.05) between the baseline muscle activity and five of the muscles tested: gluteus maximus, gluteus medius, biceps femoris, rectus femoris, and lateral gastrocnemius. The only significant difference (p < 0.05) found was in the anterior tibialis muscles.

CONCLUSION: The results from this study indicate that tibialis anterior was the only muscle that showed significant muscle activation in alternate foot positions. There was no significant difference found in any of the other muscles tested. Further research with more participants is needed to see if there maybe any difference in any of the other muscles tested.
CHAPTER I
INTRODUCTION

Anterior cruciate ligament (ACL) tear is a common injury resulting in over 100,000 surgical reconstructions per year in the United States. ACL injuries are sustained by both male and female athletes, with females having an incidence four to six times higher than males.\(^1\) This injury is more common in athletes performing high impact sports such as soccer and basketball.\(^1,2\) Other factors that play into ACL injuries include the type of playing surface (higher friction surfaces increase risk), previous knee injuries, and high risk lifestyle choices. These factors and others have led to an increased research into the differences in gender related ACL tears.\(^3-11\) ACL tears are a debilitating injury that can affect the athlete’s education, financial factors like scholarships, and/or future livelihood.\(^12-13\) Along with the previous factors it is also an expensive procedure to repair and rehabilitate at a conservative cost of $17,000 to $25,000.\(^2,5,14\) There are many hypotheses as to the causes of ACL tears which include neuromuscular, anatomical, biomechanical, hormonal, and genetic factors, along with others.

The biomechanics of the ACL are threefold; to limit anterior translation of the tibia on the femur, to limit interior rotation of the tibia, and to facilitate a smooth kinetic motion in the knee. Our study looked at the effect of frontal plane foot position on lower extremity muscle activation and limb positioning in a single leg squat. With an increased understanding of how foot position effects muscle activation, it could lead to further
knowledge of potential factors leading to an ACL tear. This information could then be used in prevention and rehabilitation techniques to aid in maintaining or rehabilitating an ACL injury.
CHAPTER II
REVIEW OF THE LITURATURE

Since our study focused on foot position and muscle activation of the lower limb the focus of this literature review was aimed more toward the anatomical and neuromuscular theories, but will also look slightly into other theories.

Regarding anatomical and neuromuscular theories, Hewett et al\(^8\) looked at many articles that focused on several main neuromuscular and anatomical predictors for ACL injuries which included ligament dominance, quadriceps dominance, leg dominance, and trunk dominance.\(^4,13-17\) Starting with ligament dominance, Hewett described it as being a condition in which, “muscles do not sufficiently absorb the ground reaction forces, so the joint and the ligament must absorb high amounts of force.”\(^14\) Because of this increased force being absorbed over a sudden instance by the ligaments rather than through the appropriate musculature, there is a greater risk of injury. Hewett also spoke about leg dominance which was explained as having a more dominating leg when performing activities that should require normal symmetry between the two limbs. Due to an over dominance of a single leg in females, they tend to tear their ACL with all their weight on the single leg.\(^17\) Next, trunk dominance was examined and defined, “as the inability to precisely control the trunk in three-dimensional space.”\(^14\) Zazulak et al\(^17\) found that when the trunk was laterally displaced outside the base of support there was an increase in stress; this inability to control the trunk led to an increased risk of an ACL injury. It was
observed that during growth spurts males tended to go through not only a physical size change, but also a neuromuscular size change which helps them control trunk motion better. Females on the other hand only went through a physical size change without as much of an increase in neuromuscular function causing more of a loss in control over their trunk. The final area looked at was quadriceps dominance and for our purpose is the key focus. In the study they found that females tend to land with a more extended knee with little to no flexion due to over active quadriceps muscles and not enough active posterior muscle activity from the hamstrings and gastrocnemius. Too much quadriceps strength/activity and not enough posterior muscle activity cause a sheer force on the ACL due to a forward translation of the tibia on the femur. Being that the ACL’s main job is to anchor the tibia from anteriorly translating on the femur and the quadriceps musculature translates the tibia anterior when contracted, it can be seen that without proper forces from muscles such as the hamstrings and gastrocnemius, there would be an excessive force transmitted to the ACL. With this information we may be able to find a similarity between foot position and lower extremity muscle activation. In conclusion, the author stated that there are many factors that contribute to ACL injuries from neuromuscular to genetics, but he feels that “neuromuscular control may play an important role in injury risk and is the most modifiable factor.”

Hewett also performed a study which looked at the pre and post pubescent time frames and whether there was a decrease in neuromuscular control. Their study focused on 181 male and female middle school and high school soccer and basketball players. They found that both males and females had similar neuromuscular strength before puberty, but post puberty males increased in strength, power, and coordination while
females had very little change in these categories. One of the discoveries that was found during the study was that females had a greater knee valgus at initial contact along with a greater maximal valgus angle. Males were found to have a much greater peak hamstring torque, which goes along with the findings reported in Hewlett’s previous review.\textsuperscript{12,14} Overall, the findings show that there is a difference in the landing mechanics of females pre/post puberty, which may be due to decreased neuromuscular control, leading to more of a shear force on the ACL. The findings of Hewett et al\textsuperscript{18} suggest that females have a greater loss of neuromuscular function following the anatomical changes accompanied by puberty. Due to this decrease in neuromuscular control females have an increased injury risk following puberty.

Going along with the previous study performed by Hewett et al\textsuperscript{18}, Joseph et al\textsuperscript{19} looked at knee valgus further. Along with knee valgus the study also looked at ankle pronation during a drop-jump landing in NCAA Division I female athletes and whether or not a medial post decreased knee valgus and ankle pronation. Their hypothesis was that a medial post would decrease the amount of knee valgus and ankle pronation with these athletes. This study is a good follow up to the findings of Hewitt.\textsuperscript{18} The results of the study found that the participants had a much greater initial and maximal valgus without the medial post. Also they found that the medial post also decreased the amount of pronation motion in the ankle. These results indicate that this may be a good intervention strategy for decreasing ACL injuries in that post-puberty female population.

Allen et al\textsuperscript{20} looked more into the anatomical structure of the foot. In this study they looked at individuals, who sustained an ACL injury and matched them with individuals of the same sex, age, and involved limb who had not sustained an ACL
injury. They then measured the amount of navicular drop in each of the participants. They found individuals that had sustained an ACL injury had a greater navicular drop resulting in too much foot pronation than those who had not sustained an ACL injury. The study concluded that over-pronation of the foot due to navicular drop may be another factor resulting in an ACL injury.

The Jenkins et al\textsuperscript{21} study was similar to the study performed by Allen et al,\textsuperscript{20} but included more participants. This study not only measured navicular drop but also the subtalar joint neutral position. The results of this study found that there was no statistical difference between the ACL-injured participants and the non-injured participants. They concluded that there was no relationship between subtalar neutral and navicular drop with ACL injury in collegiate basketball and soccer players, both male and female. Although this study looked at more individuals overall, Allen looked at more ACL-injured participants. By looking at both of these studies we can conclude that more research into the anatomy of the foot can be done to gain a better overall picture into whether foot structure affects ACL injuries.

As previously stated there are many facts and theories that point to possible ACL injury risk factors. From the literature it shows that neuromuscular issues may be the most modifiable issue that is seen at this point. Anatomical theories also show that knee valgus may play an extensive role in ACL injuries and may also be able to be modified through use of a medial post. As for foot anatomy there are conflicting findings whether or not it affects the ACL and in what way. We can conclude from those articles that further research is needed in this area to clarify the findings of whether or not the ACL is affected by foot structure and positioning. Other areas of interest that are not modifiable
at this time are genetics factors and hormonal factors. ACL injuries will continue to be a burden for not only athletes young and old, but also for everyday individuals.
CHAPTER III

METHODS

Our study involves a sample of 12 participants, 4 male and 8 female, from the age of 18 to 30 years old. Exclusion criteria included participants with acute lower extremity injuries and/or participants who were pregnant. Prior to testing, each participant completed an informed consent. A data sheet was completed which addressed previous injuries/surgeries and current stage of menstrual cycle when applicable. Following the collection of medical history, muscle activity and foot positioning in space were recorded through an electromyogram (EMG). To collect this data the patients had electrodes placed on the skin over each lower extremity muscle to be tested including gluteus maximus, gluteus medius, quadriceps femoris, biceps femoris, anterior tibialis, and gastrocnemius. The skin under the electrode placements was prepped prior to placement by: shaving off any hair from the area, lightly abrading the skin with very fine sandpaper, and finally cleaning the area with rubbing alcohol. This was done to ensure the best electrode conductance from the muscle groups to the equipment. After skin preparation and electrode placement EMG measurements were taken in five different foot positions. The subject was asked to perform a barefoot, single leg squat on his/her dominant leg in each of these positions. The positions included flat surface with the foot in a relaxed position, promoting a neutral foot position; standing on a 5 degree and 10 degree medial to lateral inclined, promoting a pronated foot position; and standing on a 5 degree and 10
degree lateral to medial incline, promoting a supinated foot position. Each participant was asked to perform the squat three times in each of the five positions. To analyze our data an ANOVA was conducted to identify significant differences among groups followed by post hoc analysis when differences were observed. A P value of .05 was used to determine any significant difference during analysis.
CHAPTER IV

RESULTS

Data analysis was performed on each of the six muscle groups being tested (gluteus maximus, gluteus medius, biceps femoris, rectus femoris, lateral gastrocnemius, and anterior tibialis), comparing the baseline single leg squat to each of the four test positions (supination 5°, supination 10°, pronation 5°, pronation 10°). Our data analysis shows that there is no significant difference (p > 0.05) between the baseline muscle activity and five of the muscles tested: gluteus maximus, gluteus medius, biceps femoris, rectus femoris, and lateral gastrocnemius. The only significant difference (p < 0.05) found was in the anterior tibialis muscles (Table 1).

<table>
<thead>
<tr>
<th>Table 1. Mauchly’s Test of Sphericity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MUSCLE</strong></td>
</tr>
<tr>
<td>Anterior Tibialis</td>
</tr>
<tr>
<td>Lateral Gastroc</td>
</tr>
<tr>
<td>Rectus Femoris</td>
</tr>
<tr>
<td>Biceps Femoris</td>
</tr>
<tr>
<td>Gluteus Medius</td>
</tr>
<tr>
<td>Gluteus Maximus</td>
</tr>
</tbody>
</table>
Table 2. *Estimated Marginal Means: Anterior Tibialis*

<table>
<thead>
<tr>
<th>Position</th>
<th>Mean</th>
<th>Std. Error</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lower Bound</td>
</tr>
<tr>
<td>Standard</td>
<td>81.158</td>
<td>3.468</td>
<td>73.525</td>
</tr>
<tr>
<td>Supination 5°</td>
<td>68.508</td>
<td>3.762</td>
<td>60.228</td>
</tr>
<tr>
<td>Supination 10°</td>
<td>68.542</td>
<td>6.642</td>
<td>53.924</td>
</tr>
<tr>
<td>Pronation 5°</td>
<td>68.567</td>
<td>6.098</td>
<td>55.146</td>
</tr>
<tr>
<td>Pronation 10°</td>
<td>63.783</td>
<td>6.545</td>
<td>49.378</td>
</tr>
</tbody>
</table>

Figure 1. *Estimated Marginal Means.*
CHAPTER V

DISCUSSION

The results show that there was not a significant difference between a squat in a neutral foot position and a squat in any of the four altered foot positions for gluteus maximus, gluteus medius, biceps femoris, rectus femoris, and lateral gastrocnemius muscle activity. The only muscle that was observed to have a significant difference between foot positions was the tibialis anterior. A possible reason for the tibialis anterior showing a difference and not any of the other musculature could be secondary to its insertion. This could be the only muscle that is directly affected by foot positioning, because of it insertion onto the plantar surface of the foot, first metatarsal, and medial cuneiform. Although the gastrocnemius also crosses the ankle joint and inserts onto the posterior calcaneus, due to its insertion point there is not as large of a muscle length change as what the tibialis anterior has in pronation and supination.

There were several limitations that could be addressed in any future studies. One of the most noticeable limitations that was faced during this study was prepping and electrode placement. For the first few patients there was a learning curve of proper skin preparation and also where and how electrodes should be placed. Without proper skin preparation there was increased skin impedance which could have had an effect on data
collection. Also without inter-tester reliability for placement of electrodes there can be no consistency in data collection. With this limitation and the limited number of participants there was not a lot of room for error without getting skewed data. Another big limitation that was seen was the lack of standardization of the squatting technique between participants. Although the squat was performed along with a metronome and the participants were given similar instruction, each person had a little different squat (eg. depth, alignment, speed). These differences although they may seem small, could have had a big enough impact to show no difference in our results. Other factors that may have contributed to poor results include biomechanical components, athletic ability, and possibly gender differences. Each of these could have played a role in skewing the data. The other possibility for not seeing significant differences in our results could also be due to the lack of relationship between foot positioning and lower muscle activation in the gluteus maximus, gluteus medius, biceps femoris, rectus femoris, and lateral gastrocnemius.
In conclusion looking back to the findings discussed in the literature (eg. quadriceps dominance, etc.) and due to the results of this study, it is too early to start looking at any type of correlations or relationships to one another. Although there was a significant difference in tibialis anterior secondary to the small sample size and possible limitations, further research must be done to validate these findings. Further research could also help corroborate the remainder of our research results. Overall this is a good starting point but must be developed to a further extent for more definitive results.
APPENDIX A

ELECTRODE PLACEMENT DIAGRAM
Gluteus Maximus - midpoint of a line running from the inferior lateral angle of the sacrum to the greater trochanter
Biceps Femoris - midpoint of a line from the ischial tuberosity to the lateral femoral condyle
Semitendinosus - midpoint of a line from the ischial tuberosity to the medial femoral condyle
Rectus Femoris - midpoint of a line from the ASIS to superior pole of patella (minimum of 10 cm above the patella)
Vastus Medialis - along a line 1/3 of the distance from the medial knee joint line to the ASIS
Vastus Lateralis - along a line 1/4 the distance from the lateral knee joint line to the ASIS and over the belly of the vastus lateralis
Anterior Tibialis - over the muscle belly 1/3 the distance from the inferior patellar pole to the lateral malleolus
Peroneus Longus - 1/4 the distance from the fibular head to the lateral malleolus
Gastrocnemius - over the muscle belly 1/3 the distance of the leg (fibular head to calcaneus)
Soleus - just medial to the calcaneal tendon, 1/4 the distance of the leg (popliteal line to calcaneus)

Figure 2. Electrode Placement for Lower Extremity Muscles

REFERENCES


