THE RELATIONSHIP BETWEEN QUADRICEPS/HAMSTRING STRENGTH AND ANTERIOR TIBIAL SHEAR FORCE DURING A JUMP LANDING TASK

by

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Abstract

DOUGLAS R. BENNETT: The Relationship Between Quadriceps/Hamstring Strength and Anterior Tibial Shear Force During a Jump Landing Task
(Under the direction of Dr. J Troy Blackburn, PhD, ATC)

Objective: To evaluate relationships between Anterior Tibial Shear Force (ATSF) and eccentric quadriceps strength (Quad_{Ecc}), concentric hamstring strength (Ham_{Con}), and the $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratio. **Design:** Correlational. **Setting:** Research laboratory. **Participants:** Thirty-three healthy female recreational athletes. **Main Outcome Measure(s):** ATSF was measured during a landing task via inverse dynamics. Quad_{Ecc} and Ham_{Con} were assessed at 60˚/s, 180˚/s, and 300˚/s using isokinetic dynamometry. **Results:** Quad_{Ecc} and Ham_{Con} were not significantly related to ATSF at any testing velocity ($p > 0.05$). $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ was significantly related to ATSF at 60˚/s ($r = 0.529$, $p = 0.005$) and 180˚/s ($r = 0.556$, $p = 0.003$). **Conclusion:** Quad_{Ecc} and Ham_{Con} in isolation are not significantly related to ATSF. However, when considered as a functional ratio, these strength measures are predictors of ATSF. This suggests that high $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratios may predispose female athletes to higher ATSF and ACL injury risk. **Key Words:** knee injury, ACL, torque, strength ratios

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Chapter 1

Introduction

With incidence rates ranging from 80,000 to 200,000 anterior cruciate ligament (ACL) injuries annually in the United States alone, ACL injury has become one of the most researched topics in the field of sports medicine (E. Arendt & Dick, 1995; Griffin et al., 2000). It is estimated that at least 1 out of every 3,000 Americans suffers an injury to his or her ACL (Lephart, Abt, & Ferris, 2002). One major concern is that females are 2 to 8 times more likely to sustain an ACL tear than their male counterparts (E. Arendt & Dick, 1995; Lephart, Abt, & Ferris, 2002). The causes behind these statistics are unclear. Research has begun to determine what factors cause this debilitating injury, and more specifically, why females are more prone to ACL injury. Studies have even gone as far as describing preventative strategies in order to minimize the number of injuries. A set of intrinsic and extrinsic risk factors has been proposed throughout the Sports Medicine literature, and an emphasis placed specifically on the differences between males and females. It is important for researchers and clinicians to address these risk factors and develop strategies to reduce the prevalence of ACL injury in females. As female participation in athletics continues to grow in high schools, colleges, and recreationally, the issue of prevention becomes even more important (Huston, Greenfield, & Wojtys, 2000).

The knee joint is stabilized by both static and dynamic structures. When these structures do not sufficiently support the knee, excessive anterior tibial translation (ATT) can occur. The ACL provides as much as 86% of the static restraint to anterior tibial translation (ATT) on the femur (Butler, Noyes, & Grood, 1980). When anterior tibial shear forces (ATSF) are great enough, the tibia will translate anteriorly, and ACL rupture can occur. During the dynamic activities of sports such as jumping, cutting, and landing, these forces can greatly exceed the loading capacity of the ACL (Baratta et al., 1988; Pflum, Shelburne, Torry, Decker, & Pandy, 2004; Simonsen et al., 2000; Withrow, Huston, Wojtys, & Ashton-Miller, 2006). Thus, there is a need for additional stability at the knee joint. This additional stabilitity is derived via dynamic stabilizers (musculotendinous structures).

Dynamic stability is primarily achieved by two major muscle groups acting at the knee, the quadriceps and hamstrings. Cadaver studies have shown that an increase in quadriceps isometric force can significantly increase the anterior tibial shear force (ATSF) at the knee as well as ACL stress and strain, especially with the knee near full extension (G. Li et al., 1999; Markolf et al., 1995; Withrow, Huston, Wojtys, & Ashton-Miller, 2006). On the other hand, the hamstrings provide a posterior shear force at the knee, and subsequently reduce the strain on the ACL (Draganich & Vahey, 1990; Renstrom, Arms, Stanwyck, Johnson, & Pope, 1986). Research shows that as the knee progresses into flexion, the hamstrings have an increasing mechanical advantage for controlling anterior-posterior tibial translation (Markolf et al., 1995; Markolf, O'Neill, Jackson, & McAllister, 2004). Comparisons of the muscle activation strategies of the quadriceps and the hamstrings shows the quadriceps have an increased ability to produce anterior tibial shear forces at less than 60˚of knee flexion, and that high quadriceps activations contribute to decreased antagonist hamstrings coactivation (Baratta et al., 1988). Furthermore, a reciprocal relationship exists between the tibial shear forces provided by the quadriceps and hamstrings. As the knee joint approaches full extension, the ability of the quads to produce ATSF is increasingly enhanced, while the ability of the hamstrings to provide posterior tibial shear forces (PTSF) is compromised. The reverse is true as the knee progresses into flexion. Therefore, at angles of knee flexion less than 30˚, the quadriceps are placed at a mechanical advantage to provide an ATSF, and the hamstrings are mechanically unable to reduce the anterior shear and provide dynamic support. Additionally, when the quadriceps are highly active, the hamstrings' activation is also decreased (Wilk et al., 1996). With the more dominant quadriceps activating prior to the hamstrings, and the inability of the hamstrings to counteract the quadriceps anteriorly directed pull, high anterior tibial shear forces would be expected (Anderson, Dome, Gautam, Awh, & Rennirt, 2001; Lephart, Ferris, Riemann, Myers, & Fu, 2002; Withrow, Huston, Wojtys, & Ashton-Miller, 2006). While muscle activation and knee joint position may be linked to an increase in ATSF, the relationship between the strength of the quadriceps and hamstring musculature and shear forces at the knee has received little attention.

The most compelling of the factors to explain the increased risk of ACL injury in females may be their neuromuscular and biomechanical properties (Griffin et al., 2000). Research has shown that there are gender-specific neuromuscular and biomechanical differences (Colby et al., 2000; Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001). Females exhibit quadriceps dominant muscle activation patterns (Huston & Wojtys, 1996). In a comparison of elite athletes, females demonstrated a preference to contract their quadriceps first, relative to their hamstrings, in response to an anterior tibial translation (Huston & Wojtys, 1996). Peak torque of the quadriceps was attainted 5-7ms earlier than that of the hamstrings in female athletes (Huston & Wojtys, 1996). Other research shows a quadriceps dominance in gait, cutting, and landing activities (Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001). This combination of increased quadriceps activation and later onset of hamstring activation in females suggests that females may experience excessive anterior tibial shear forces at the knee (Huston & Wojtys, 1996).

In addition to muscle activation differences, females demonstrate significantly less isometric, concentric, and eccentric muscle strength in the quadriceps and hamstrings compared with males (Hakkinen, Kraemer, & Newton, 1997; Huston & Wojtys, 1996; Lephart, Ferris, Riemann, Myers, & Fu, 2002). Particularly, females demonstrate substantially weaker hamstring muscles when compared to their quadriceps (Kannus & Beynnon, 1993). This holds true for the athletic population as well. Anderson et al. (2001) have shown that hamstring muscles are relatively weaker than in male athletes when compared with the quadriceps muscles. Combining our knowledge of the quadriceps' and hamstrings' abilities to produce shear forces and the fact that females have altered neuromuscular activation and muscular strength, we can hypothesize that when in positions of decreased knee flexion, females' anterior tibial shear forces may be increased as compared to males.

Strength differences across genders may provide a reasonable explanation why females have higher incidence rates of ACL injury than males. In addition, strength imbalances have also been related to increased injury rates. These imbalances may be due to differences between the right and left leg, or abnormal ratios between antagonistic muscle groups (Knapik, Bauman, Jones, Harris, & Vaughan, 1991). Strength imbalances of the hip extensors bilaterally have been linked to an increase in rates of lower extremity injury and low back pain (Nadler, Malanga, DePrince, Stitik, & Feinberg, 2000). In regard specifically to knee injury, The Hunt Valley Consensus Conference on ACL injuries concluded that strong quadriceps activation during eccentric contraction was considered to be a major factor in injury to the ACL (Griffin et al., 2000). Strength imbalances between the quadriceps and hamstring muscles measured at 180˚/s have been related to an increased injury rate in female collegiate athletes (Knapik, Bauman, Jones, Harris, & Vaughan, 1991). This higher velocity may be closer to those experienced during athletic events. The same authors also demonstrated that if the knee flexion strength was less than 75% of the knee extension strength (at 180˚/s) athletes were 1.6 times more likely to get injured (Knapik, Bauman, Jones, Harris, & Vaughan, 1991).

The literature suggests that 70% of ACL injuries involve a non-contact mechanism (EA Arendt, Agel, & Dick, 1999; E. Arendt & Dick, 1995; Boden, Dean, Feagin, & Garrett, 2000). Non contact ACL injuries, which involve foot-ground reaction and segmental forces but no other external contact forces, commonly occur during jump landings (Kirkendall & Garrett, 2000). Jump landing is involved in many common athletic activities, such as hitting and blocking in volleyball, heading in soccer, and shooting and rebounding in basketball. Impact forces alone during a jump landing task can be up to four times the person's body weight (Dufek & Bates, 1991). In addition, the quadriceps muscles can provide an anteriorly directed eccentric force of 5,000 N (Arms et al., 1984). The tensile strength of the ACL in young individuals (22-25 year old) has been estimated at 2,100 N (Woo, Hollis, Adams, Lyon, & Takai, 1991). Therefore, dynamic stabilization of the knee joint is crucial in preventing ACL injury.

Jump landing strategies in females differ significantly from their male counterparts. Females tend to land with the knee in a more extended position than males, thus predisposing them to a greater quadriceps pull and decreased hamstring co-activation (Lephart, Ferris, Riemann, Myers, & Fu, 2002). Females landed with an average of only 17˚ of knee flexion, while their male counterparts landed with an average 31˚ of flexion (Lephart, Ferris, Riemann, Myers, & Fu, 2002). In addition to landing in a more extended position, females activate the quadriceps to a greater extent relative to their hamstrings (Colby et al., 2000). From a muscle action standpoint, the quadriceps are contracting eccentrically to decelerate knee flexion during a landing task. The antagonist hamstrings are concentrically contracting to flex the knee and absorb the ground reaction forces of the landing. It has been proposed that because of the prominent influence of quadriceps activity on ATT, it is important for the hamstrings to counter this movement, particularly in the presence of increased quadriceps/hamstrings strength ratios (Q/H) (Baratta et al., 1988).

Quadriceps to hamstring strength ratios have been reported in the literature from both conventional and functional perspectives. Conventionally, the ratio is measured as a maximal concentric isokinetic quadriceps contraction relative to a maximal concentric isokinetic hamstring contraction (Osternig, 1986). Recently, Aagaard et al. (1998) proposed a new concept for the measurement of isokinetic Q/H ratios, the functional eccentric quadriceps/concentric hamstring comparison ($\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$). The development of the functional ratio allows for more in depth analysis of the types of forces the muscles stabilizing the knee joint create during dynamic activities. Rosene et. Al (2001) calculated traditional Q/H ratios in intercollegiate athletes and found the averages to range between 1.70-1.99 depending on testing velocity. Functional $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratios are slightly higher than the conventional method, and range from 2.5-3.33 (Aagaard, Simonsen, Magnusson, Larsson, & Dyhre-Poulsen, 1998; Aagaard, Simonsen, Trolle, Bangsbo, &

Klausen, 1995). A highly developed quadriceps muscle group contributes to decreased antagonist hamstring co-activation through reciprocal inhibition and thus allows for an increased anterior pull on the tibia (Baratta et al., 1988). These high quadriceps to hamstring ratios, both conventionally and functionally, suggest the quadriceps muscles may provide an anterior shear force on the tibia that is greater than the associated posterior shear force generated by the hamstrings. Regardless of what the ratios may suggest, the relationship between shear forces at the knee and the strength of the quadriceps, strength of the hamstrings, and quadriceps to hamstrings ratios have yet to be identified.

Understanding the factors that predispose the recreational female athlete to anterior cruciate ligament injury may help us develop strategies to prevent these injuries from occurring. The comparison of quadriceps and hamstrings strength appears to be important in determining the dynamic stability of the knee joint during times of excessive loading. Therefore, the purpose of this study is to determine if a relationship exists between the anterior tibial shear forces at the knee during a jump landing task and the functional isokinetic eccentric strength of quadriceps and concentric strength of the hamstrings musculature that accompany this task.

Research Questions

1. Is there a relationship between Quad_{Ecc} strength at each velocity of testing (60˚/s, 180˚/s, and 300˚/s) and ATSF during a jump landing task?

2. Is there a relationship between Ham_{Con} strength at each velocity of testing (60˚/s, 180˚/s, and 300˚/s) and ATSF during a jump landing task?

3. Is there a relationship between a functional $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratio at each velocity of testing (60˚/s, 180˚/s, and 300˚/s) and ATSF during a jump landing task?

Null Hypotheses

1. H_0 : There is no relationship between Quad_{Ecc} mean peak torque at each velocity of testing (60˚/s, 180˚/s, and 300˚/s) and ATSF.

2. H_0 : There is no relationship between Ham_{Con} mean peak torque at each velocity of testing (60˚/s, 180˚/s, and 300˚/s) and ATSF.

3. H_0 : There is no relationship between a functional $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ mean peak torque ratio at each velocity of testing (60˚/s, 180˚/s, and 300˚/s) and ATSF.

Research Hypotheses

1. There will be a positive relationship between Quad_{Ecc} mean peak torque at each velocity of testing (60˚/s, 180˚/s, and 300˚/s) and ATSF.

2. There will be a negative relationship between Ham_{Con} mean peak torque at each velocity of testing (60˚/s, 180˚/s, and 300˚/s) and ATSF.

3. There will be a positive relationship between a functional $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ mean peak torque ratio at each velocity of testing (60˚/s, 180˚/s, and 300˚/s) and ATSF.

Operational Definitions

Dominant Leg : The leg that the subject would use to kick a soccer ball for maximum distance.

Jump Landing Task : Jumping off a 30 cm high platform with both legs from a horizontal distance equal to 50% of the subject's height from the front edge of a forceplate. After landing subjects were instructed to recoil and perform a rebound jump for maximal vertical height.

Anterior Tibial Shear Force : The amount of force directed in an anterior direction at the tibiofemoral joint in the sagittal plane.

Mean Peak Torque : The mean of 3 trials of the peak torque moment created around a stationary axis through the tibiofemoral joint.

$\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratio : a ratio calculated by dividing the mean peak torque of eccentric quadriceps contractions by the mean peak torque of concentric hamstring muscle contractions.

Isokinetic Concentric Contraction : a shortening contraction of the muscle at a constant velocity (60˚/s, 180˚/s, and 300˚/s).

Isokinetic Eccentric Contraction : a lengthening contraction of the muscle at a constant velocity (60˚/s, 180˚/s, and 300˚/s).

Assumptions

1. The subjects provided a maximal effort during strength testing.

2. The Flock of Birds and forceplate derivative of anterior tibial shear force were a reliable and valid measures.

3. The jump landing task accurately portrayed the manner in which athletes would land during a sport related jump.

Delimitations

1. Subjects had no previous medical history of lower extremity injury within the past 6 months and no previous anterior cruciate ligament injury or reconstruction.

2. All subjects were college aged, 18-25 years old, physically active recreational athletes.

3. All analyses were completed on the dominant leg.

Limitations

1. Subjects were tested in a laboratory setting instead of a sport setting.

2. Range of motion for isokinetic strength testing was set from 20˚ - 90˚ due to pilot testing revealing an inability of the subject to initiate movement on the dynamometer at angles less than 20˚ of knee flexion

3. Peak torque values may differ across these tasks (jump-landing, isokinetic dynamometry), as the length-tension characteristics of the knee and hip flexors and extensors likely differ

Chapter 2

Literature Review

Introduction

Injury to the anterior cruciate ligament (ACL) is a common and debilitating condition in the athletic population. The Sports Medicine community works countless hours evaluating, rehabilitating, and attempting to prevent ACL injury. Mechanisms of injury to the ACL can be a result of contact with another player, apparatus, or playing surface, as well as from a non-contact mechanism. Risk factors for non-contact ACL injury include biomechanical, hormonal, anatomical, and environmental conditions. One proposed biomechanical risk factor is the position of the knee joint when landing from a jump. Specifically, landing from a jump with the knee in an extended position can increase the Anterior Tibial Shear Forces (ATSF) at the knee and subsequently result in injury to the ACL. Injury rates have demonstrated that muscle weakness, as well as muscular strength imbalance, can be associated with increased incidence of injury. The quadriceps and hamstring musculature provide the major muscular forces acting on the tibiofemoral joint. Understanding what relationship the subsequent strength or imbalance of the muscles acting on the knee has with the ATSF may help in the development of strategies to reduce the likelihood of future injuries. The objective of this literature review is to justify investigating the relationship between the strength of the musculature supporting the knee and the ATSF acting when landing from a jump.

Epidemiology of Anterior Cruciate Ligament Injuries

ACL injury is one of the most researched injuries in the Sports Medicine community. The prevalence of ACL injury in the United States exceeds 1 injury in every 3,000 persons (Lephart, Abt, & Ferris, 2002). It is estimated that between 80,000 and 200,000 ACL injuries occur each year (E. Arendt & Dick, 1995; Griffin et al., 2000). Approximately 50,000 of these injuries are surgically reconstructed at an average cost of $17,000 per procedure, creating a financial impact of close to one billion dollars (Frank & Jackson, 1997). These statistics do not take into consideration the cost of the conservative treatment or lengthy rehabilitation associated with ACL injuries.

Population

ACL injury is primarily an issue in the physically active population. Young children, the elderly, and sedentary individuals are not as susceptible, and therefore do not sustain as many ACL injuries (Griffin et al., 2000). Sports participation and physically active lifestyles are common between the ages of 15 and 45 years old. Daniel and Fritschy (1994) tracked insurance statistics of the general United States population, and found that this group of individuals is at the greatest risk for ACL injury, and that 70% of the injuries that were tracked involved sports activity (Daniel & Fritschy, 1994).

Recently it has been demonstrated that ACL injury rates are higher in women than men (EA Arendt, Agel, & Dick, 1999). Females are two to eight times more likely to sustain an ACL injury when compared to their male counterparts (E. Arendt & Dick, 1995; Lephart, Abt, & Ferris, 2002). The reasons behind these statistics are unclear. Research has begun to determine a set of factors that may explain these gender differences. Consideration has been given to anatomical, environmental, biomechanical, and hormonal factors that may contribute to the gender differences in ACL injury rates.

In addition to age, gender, and activity level, there is also a correlation between the type of sport or activity and ACL injury. Sports that involve cutting, pivoting, and jumping have a higher incidence of ACL injuries than sports that do not involve those tasks (Boden, Dean, Feagin, & Garrett, 2000). Sports such as basketball, lacrosse, soccer, and volleyball all involve these types of movement patterns. Researchers have studied these sports across time and gender to determine if these sports and activities place athletes at higher risk for ACL injuries (EA Arendt, Agel, & Dick, 1999; E. Arendt & Dick, 1995; Lephart, Ferris, & Fu, 2002).

Gender Differences

The National Collegiate Athletic Association (NCAA) uses an Injury Surveillance System (ISS) to track data regarding injuries and injury patterns over time. This system has been used to compare the rates of men's and women's soccer and basketball injuries (EA Arendt, Agel, & Dick, 1999). The authors chose these two sports because of the consistency between the men's and women's rules and gameplay. Results showed that college-age women involved in basketball or soccer injure their ACLs at significantly higher rates than college-age men involved in the same sports (EA Arendt, Agel, & Dick, 1999). No investigator has found any evidence of systematic bias that might be responsible for this difference (Griffin et al., 2000). Since the inception of Title IX in 1972, opportunities for female sport participation have grown significantly. Both the NCAA and National Federation of State High School Associations have reported increases in women's participation in sport over the last 15 years (EA Arendt, Agel, & Dick, 1999; , "National

Federation of High School (NFHS) Press Release: High school athletics participation continues to rise", 1998). With increases in participation comes an increase in the level of competition for women. One theory regarding the increased prevalence of injury in female athletes is that females have not received the proper training to compete at the level at which they are participating (Huston & Wojtys, 1996). The current methods of strength training and conditioning of female athletes may not adequately prepare them for their activities.

Anatomy

Understanding the anatomy of the knee and the complex structures involved in its function is important in researching the ACL. The primary motions at the tibiofemoral joint are sagittal plane flexion and extension, both of which are accompanied by arthrokinematic motions of rolling, spinning, and gliding (Fu, Harner, Johnson, Miller, & Woo, 1994). The boney anatomy of the knee provides limited support; it is the soft tissue structures that are primarily responsible for the static and dynamic support of the joint (Lephart, Abt, & Ferris, 2002). These soft-tissue structures include the joint capsule, surrounding ligaments, menisci, and muscle-tendon units (Fu, Harner, Johnson, Miller, & Woo, 1994). The medial and lateral meniscus of the knee serve to cushion the joint, deepen the socket, distribute weight–bearing forces, lubricate the joint, and provide stability (Houglum, 2001). The knee joint capsule merges with the collateral ligaments, and provides rotational stability about the knee (Houglum, 2001). The medial collateral ligament (MCL) is a broad, fan-shaped ligament that joins the medial femoral condyle and the tibia (Hoppenfeld, 1976). Its primary function is to restrict valgus motion at the knee as well as provide stability of the knee during external tibial rotation (Butler, Noyes, & Grood, 1980). Laterally, the knee joint is supported by the lateral collateral ligament (LCL), which is a stout cord that joins the lateral femoral condyle and the fibular head (Hoppenfeld, 1976). The LCL acts to restrain varus motion at the knee. The posterior cruciate ligament (PCL) is one of two intracapsular knee ligaments that provide joint stability. The PCL acts to prevent posterior tibial translation as well as rotational stability (Butler, Noyes, & Grood, 1980). The ACL is responsible for resisting anterior translation of the tibia on the femur (Fu, Harner, Johnson, Miller, & Woo, 1994). Specifically, as much as 86% of the static restraint to anterior tibial translation (ATT) is provided by the ACL (Butler, Noyes, & Grood, 1980). The ACL is composed of 2 bundles of fibers, both of which arise from the posterior medial femoral condyle and insert into the anterior medial aspect of the tibial plateau (Fu, Harner, Johnson, Miller, & Woo, 1994). Excessive anterior tibial shear forces (ATSF) result in rupture of the ACL (DeMorat, Weinhold, Blackburn, Chudik, & Garrett, 2004).

Often, the activities of sports provide forces that can greatly exceed the loading capacity of the ACL alone (Baratta et al., 1988; Pflum, Shelburne, Torry, Decker, & Pandy, 2004; Simonsen et al., 2000; Withrow, Huston, Wojtys, & Ashton-Miller, 2006). Therefore, it is necessary for the muscles and tendons surrounding the knee to provide dynamic support. The quadriceps, hamstrings, and gastrocnemius muscles are the major muscle groups acting on the knee. Dynamic stabilization of the knee joint by the muscles is largely dependent upon the angles of the knee and hip. A larger knee valgus moment during loading has been shown prospectively to predict ACL injury risk in female athletes (Hewett et al., 2005). Increased hip internal rotation and/or flexion at initial contact of a jump landing task may compromise the ability of medial muscle groups to adequately resist knee valgus loads (McLean, Huang, & van den Bogert, 2005).

Cadaver studies have shown that an increase in quadriceps isometric force can significantly increase the ATSF at the knee, especially with the knee near full extension (G. Li et al., 1999; Markolf et al., 1995; Withrow, Huston, Wojtys, & Ashton-Miller, 2006). The quadriceps can provide an excessive amount of anterior tibial shear force at the knee, especially at knee flexion angle angles between 0˚ and 45˚ (Markolf et al., 1995; Markolf, O'Neill, Jackson, & McAllister, 2004; Renstrom, Arms, Stanwyck, Johnson, & Pope, 1986). During squatting activities, when hip flexion angle increases quadriceps activity decreases (Wilk et al., 1996). Within this range (0-45˚) of knee flexion eccentric muscle loads on the anterior tibia have been estimated at 5,000 N (Arms et al., 1984). Research by Woo et al. (1991) indicates that the tensile strength of the ACL in young individuals (22-25 years old) is only 2,100N. As such, it appears as though quadriceps force alone is capable of inducing ACL injury (DeMorat, Weinhold, Blackburn, Chudik, & Garrett, 2004).

The hamstring muscles also provide dynamic stability to the knee joint that opposes the quadriceps. Research has shown that the hamstrings are most influential in achieving a posterior shear force on the tibia between 15˚-30˚ of knee flexion (Baratta et al., 1988). This posterior shear on the tibia is able to resist the quadriceps' anteriorly-directed pull, and decrease the strain placed upon the ACL (Markolf, O'Neill, Jackson, & McAllister, 2004; Renstrom, Arms, Stanwyck, Johnson, & Pope, 1986). This supports the theory that at specific knee flexion angles, an antagonist hamstring contraction is essential in protecting the ACL from excessive loads placed upon it by quadriceps contractions. In addition, it has been demonstrated that the gastrocnemius muscle also provides dynamic support to resist anterior tibial translation (Sherbondy, Queale, McFarland, Mizuno, & Cosgarea, 2003).

ACL Injury Risk Factors

In June of 1999, members from the American Orthopaedic Society for Sports Medicine, the Orthopaedic Research and Education Foundation, the National Athletic Trainers Association Research and Education Foundation, and the National Collegiate Athletic Association met for the Hunt Valley Consensus Conference to discuss the non-contact risk factors and prevention strategies associated with ACL injuries (Griffin et al., 2000). Potential risk factors that were identified as being associated with non-contact ACL injuries included anatomical, hormonal, biomechanical, and environmental (Griffin et al., 2000).

Hormonal

The potential role hormones play in predisposing female athletes to ACL injury gained attention after estrogen and progesterone receptor sites were found in human ACL cells (Liu et al., 1996). Research also indicated that the tensile properties of the ACL in rabbits were reduced upon administration of estrogen (J. Slauterbeck, Clevenger, Lundberg, & Burchfield, 1999). Along with these findings came attempts to link ACL injury to the female menstrual cycle, with day 1 of the cycle being the first day of menses. Some research points to an increase in ACL injury during the ovulatory phase (days 10-14 , when estrogen levels peak) (Wojtys, Huston, Lindenfeld, Hewett, & Greenfield, 1998), while other research has shown an increase in ACL injury during days 1 and 2 of the menstrual cycle (J. R. Slauterbeck et al., 2002). Current research has attempted to link oral contraceptive use to ACL injury rate with no significant findings. Also, females tend to have increased joint laxity than males. In recreational soccer players, it was concluded that girls, after menarche, have increased joint laxity when compared to boys of the same physical maturity (Ahmad et al., 2006). While the hormonal considerations remain an interesting topic, no conclusive data have established any pattern of menstrual cycle involvement in ACL injuries.

Anatomical

There are several theories regarding anatomical structures that may predispose female athletes to ACL injury. Considerations including increased Quadriceps angle (Q angle), decreased femoral notch width, and general increased joint laxity have all been theorized. The Q angle is the angle formed between a line connecting the ASIS to the midpoint of the patella and a line connecting the tibial tubercle and the mid point of the patella. A Q-angle of 20˚ or more is considered excessive in both males and females. The Q-angle can be affected by bony alignments such as femoral anteversion, a wider pelvis, or knee valgus. Women tend to have a relatively wider pelvis that may lead to an increased Q angle (Hewett, Myer, & Ford, 2006). However, little research has been completed attempting to link an increased Q angle to an increase in ACL injury rates in females.

The Hunt Valley conference outlined 6 established trends in femoral notch width measurements. They concluded that, on average, the width of the notch is less in females than males, and less in ACL injured patients than a control group (Griffin et al., 2000). Nonetheless, no relationship between the femoral notch and ACL injury could be established partially as the result of the variability in measurement techniques of femoral notch width (Griffin et al., 2000).

Environmental

Environmental risk factors associated with ACL injury are factors that are extrinsic to the body, and in some cases modifiable. The use of prophylactic knee braces has often been associated with a decrease in the risk of knee injury. Research into knee braces shows limited results supporting or refuting this claim. However, functional knee braces have been shown to modify proprioception, electromyographic activity, and muscle activation timing (Nemeth, Lamontagne, Tho, & Eriksson, 1997; Ramsey, Wretenberg, Lamontagne, & Nemeth, 2003). Joint proprioception and activity of the musculature surrounding knee and its effect on ACL injury risk will be discussed later in this review. Another environmental risk factor believed to play a role in ACL injury is the shoe-to-surface interface. Previous research suggests that the relationship between the shoe and surface is highly variable and inconsistent (Dixon, Batt, & Collop, 1999). Many factors such as type of shoe, type of surface, weather conditions, and athletic task may influence this relationship.

Biomechanical

The Hunt Valley Conference concluded that gender differences in neuromuscular control and biomechanical function are the most likely risk factors to explain the different rates in men and women (Griffin et al., 2000). Video analysis of ACL injury during competitive sports indicates a common body position that is associated with non-contact ACL injury. This body position is indicated by the knee close to full extension and the foot planted when decelerating, which leads to a valgus collapse at the knee (Boden, Dean, Feagin, & Garrett, 2000).

Recent research has also shown that gender differences exist between quadriceps and hamstring activation during dynamic movement involving the knee joint (Colby et al., 2000; Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001). In a comparison of elite athletes, females demonstrated a preference to contract their quadriceps first in response to an anterior tibial translation (Huston & Wojtys, 1996). The hamstrings reached peak torque 5-7 milliseconds after that of the quadriceps in the elite female athletes (Huston & Wojtys, 1996).

This combination of quadriceps activation before hamstring activation in females suggests that females may experience excessive anterior tibial shear forces at the knee.

In addition to muscle activation differences, females demonstrate significantly less muscle strength as normalized to body weight in the quadriceps and hamstrings compared with males (Hakkinen, Kraemer, & Newton, 1997; Huston & Wojtys, 1996; Lephart, Ferris, Riemann, Myers, & Fu, 2002). More importantly females tend to demonstrate a quadriceps dominance, or higher quadriceps strength relative to hamstring strength. Research has demonstrated that female athlete's hamstring muscles are relatively weaker than in male athletes when compared with the quadriceps muscles (Anderson, Dome, Gautam, Awh, & Rennirt, 2001). A standard assessment of strength is the quadriceps to hamstrings ratio (Q/H). Conventionally, the ratio is measured as a maximal concentric isokinetic quadriceps contraction relative to a maximal concentric isokinetic hamstring contraction (Osternig, 1986). Recently, a new concept in isokinetic Q/H ratios has been proposed, the functional eccentric quadriceps/concentric hamstring comparison ($\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$) (Aagaard, Simonsen, Magnusson, Larsson, & Dyhre-Poulsen, 1998). The development of the functional ratio allows us to look more in depth at the types of forces the muscles stabilizing the knee joint produce during dynamic activities.

In the conventional testing, Q/H ratios range from 1.25-2.00 depending on the velocity at which the testing was tested (Aagaard, Simonsen, Magnusson, Larsson, & Dyhre-Poulsen, 1998; Ahmad et al., 2006; Hiemstra, Webber, MacDonald, & Kriellaars, 2004; Rosene, Fogarty, & Mahaffey, 2001). Q/H ratios in intercollegiate athletes ranged between 1.70 and 1.99 (Rosene, Fogarty, & Mahaffey, 2001). However, skeletally mature female recreational soccer players have shown a significantly higher Q/H ratio (2.06) than matched male counterparts (1.48) (Ahmad et al., 2006).

However, eccentric contraction involves higher forces than a concentric contraction, so we would expect functional $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratios to be higher than conventional values. Functional $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratios have been reported between 2.50 and 3.33 (Aagaard, Simonsen, Magnusson, Larsson, & Dyhre-Poulsen, 1998) in elite track and field athletes. No current data have established a functional $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratio in recreational athletes. Even though the exact magnitude of the influence of given hamstring or quadriceps muscle moments on the amount of ATSF is unknown, the $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratio may represent an estimate of the ability of the hamstrings to counteract anteriorly directed shear forces of the tibia (Aagaard, Simonsen, Magnusson, Larsson, & Dyhre-Poulsen, 1998). It is hypothesized that females are at increased risk for ACL injury because this quadriceps dominance may lead to an increase in ATSF. Also, their quadriceps dominance is more pronounced in angles of decreased knee flexion. Females landing in a position of extension may not have sufficient strength available to decelerate the body by the eccentric quadriceps contraction (Lephart, Ferris, Riemann, Myers, & Fu, 2002). Thus, females must activate their quadriceps to a greater extent due to their decreased quadriceps strength.

Strength Imbalances

Strength imbalances have been suggested as possible predisposing factors to injury. For example, female athletes with one hamstring more than 15% weaker than the other were 2.6 times more likely to sustain a lower extremity injury (Knapik, Bauman, Jones, Harris, & Vaughan, 1991). Also, it has been reported that such left-right imbalances occurred in 20% to 30% of female athletes (Knapik, Bauman, Jones, Harris, & Vaughan, 1991). Additionally, athletes with a Q/H ratio of greater than 1.33 were 1.6 times more likely to be injured (Knapik, Bauman, Jones, Harris, & Vaughan, 1991). As for velocity of testing, it has been found that Q/H strength ratios of females were significantly lower than those of males at 60˚/s, 180˚/s, and 300˚/s (Moore & Wade, 1989). Females have been reported to have Q/H ratios in the 40% range (Wojtys, Huston, Taylor, & Bastian, 1996).

Research has investigated differences in selected predictors of ACL injury between male and female NCAA Division I collegiate basketball players from the same institution participating in identical conditioning programs. Sex differences in quadriceps and hamstring strength were examined isokinetically. Male athletes demonstrated significantly higher eccentric hamstrings-to-eccentric quadriceps ratio bilaterally than female athletes (Moul, 1998). The author concluded that a deficit in eccentric hamstring strength relative to eccentric quadriceps strength could predispose an athlete to an ACL injury during stressful athletic activities, particularly deceleration or landing maneuvers (Moul, 1998). During these activities, flexion moments are occurring at the knee and hip. Another theory involving the contraction of the hamstring and quadriceps muscles is that eccentric contraction of the hamstrings promotes hip stabilization, while eccentric contraction of the quadriceps promotes knee stabilization (Palmitier, An, Scott, & Chao, 1991). In closed chain conditions, the hamstrings act as a powerful hip extensor. Thus forceful hamstring contraction that stabilizes the hip flexor moment helps to neutralize the tendency of the quadriceps to cause anterior translation of the tibia on the femur (Moul, 1998; Palmitier, An, Scott, & Chao, 1991).

Mechanisms of ACL Injury

Contact

Contact ACL injuries account for 28%-30% of all ACL injuries (E. Arendt & Dick, 1995; Boden, Dean, Feagin, & Garrett, 2000) . Injury mechanisms to the ACL that involve direct contact are typically a result of a valgus collapse at the knee (Boden, Dean, Feagin, & Garrett, 2000). In these cases, a contact blow to the lateral aspect of the knee joint places a valgus stress at the knee.

Non-Contact

Approximately 70% of all ACL injuries are the result of non-contact mechanisms that occur while the body is decelerating during gait and landing activities (EA Arendt, Agel, & Dick, 1999; E. Arendt & Dick, 1995; Boden, Dean, Feagin, & Garrett, 2000). The main non-contact mechanisms of ACL injury are planting and cutting, landing from a jump on a straight/extended knee, and one-step landing with a hyper-extended knee (EA Arendt, Agel, & Dick, 1999; Boden, Dean, Feagin, & Garrett, 2000). Similar to contact ACL injuries, the non-contact injuries often involve a valgus collapse at the knee. Other commonly noted motions associated with ACL injury are excessive anterior tibial translation, knee hyper-extension, and excessive tibial rotation. The ACL functions to control anterior tibial translation, and assists other static and dynamic structures of the knee in preventing knee valgus, knee varus, tibial internal rotation, and femoral external rotation. Any excessive or uncontrolled amounts of these motions can lead to ACL strain or rupture.

Excessive anterior tibial translation is often the primary mechanism involved in ACL injury (Kirkendall & Garrett, 2000). A maximal quadriceps contraction combined with a decreased knee flexion angle, less than 45˚, can create ATSF at the knee (Markolf et al., 1995; Withrow, Huston, Wojtys, & Ashton-Miller, 2006). This ATSF produces excessive anterior tibial translation on the femur, thus stressing the ACL (Durselen, Claes, & Kiefer, 1995; Shelburne & Pandy, 1997). The quadriceps and hamstring muscle groups play an antagonistic role to each other in determining the shear forces placed upon the knee joint. The hamstring muscles are able to help resist the quadriceps' anteriorly-directed pull when the knee is flexed 30˚ or greater (Markolf, O'Neill, Jackson, & McAllister, 2004; Renstrom, Arms, Stanwyck, Johnson, & Pope, 1986). Functional sport related tasks, such as a landing from a jump, often involve simultaneous quadriceps and hamstring contractions in varying angles of knee flexion.

Jump Landing Task

Jump landing is a common functional activity used in many sports, especially basketball, soccer, and volleyball. Landing from a jump has been identified throughout the literature as a common mechanism of non-contact ACL injury (EA Arendt, Agel, & Dick, 1999; Boden, Dean, Feagin, & Garrett, 2000). An athlete is at risk for ACL injury during a jump landing task due to the excessive ATSF placed upon the ligament. To decelerate the body and absorb the landing forces, the quadriceps contract eccentrically, and thus pull the tibia anteriorly. The hamstring muscles concentrically contract in an attempt to flex the knee and absorb the forces transferred to the tibia during landing. If the ATSF applied by the eccentric quadriceps contraction is great enough, and the hamstring muscles cannot provide an adequate posterior shear force, the ACL is at risk for strain or rupture (Pflum, Shelburne, Torry, Decker, & Pandy, 2004; Withrow, Huston, Wojtys, & Ashton-Miller, 2006).

In simulated computer modeling of a jump landing task, the ACL was loaded during the first 25% of the landing phase as the knee flexed (Pflum, Shelburne, Torry, Decker, &

Pandy, 2004). The peak shear force acting on the knee occurred in the first 70 milliseconds, and was directed in the anteriorly (Pflum, Shelburne, Torry, Decker, & Pandy, 2004). Immediately after initial impact, the ground reaction forces applied a large posterior shear force to the lower leg (Pflum, Shelburne, Torry, Decker, & Pandy, 2004). It appears as the foot impacts the ground the subsequent action on the knee is an anterior shear. However, the remainder of the landing involves a posteriorly directed shear force. This is a result of a quadriceps muscle contraction acting to decelerate the flexing knee by pulling the tibia anteriorly through the patellar tendon (Pflum, Shelburne, Torry, Decker, & Pandy, 2004). However, the soft-style landing in this study may not accurately represent the ground reaction forces being dissipated through the body during a more functional or hard landing condition. Ground reaction forces ranging from 3 to 14 times body weight have been measured for landing activities, suggesting that tremendous loads normally are absorbed by the body during these activities (Dufek & Bates, 1991; Ozguven & Berme, 1988). Also, smaller degrees of knee flexion may be associated with increased peak vertical ground reaction forces (Dufek & Bates, 1991). Research using cadavers has concluded similar findings regarding the quadriceps’ and hamstrings’ abilities to produce shear forces at the knee. Recent cadaver research simulating a jump landing task showed that the change in ACL strain was highly correlated with the change in quadriceps force and the change in knee flexion induced by the impact force (Withrow, Huston, Wojtys, & Ashton-Miller, 2006).

When comparing jump landing strategies in males and females, researchers have found significant differences (Colby et al., 2000; Griffin et al., 2000; Lephart, Ferris, Riemann, Myers, & Fu, 2002; Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001). As previously mentioned, higher ground reaction forces have been linked with an increase in

ATSF. It has also been shown that females produce higher ground reaction forces during landing tasks when normalized to body weight (Hewett, Stroupe, Nance, & Noyes, 1996). In addition to the ground reaction forces, females have been linked with landing with less knee flexion than males (Colby et al., 2000; Lephart, Ferris, Riemann, Myers, & Fu, 2002; Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001). Females landed with an average of only 17˚ of knee flexion while their male counterparts displayed an average of 31˚ (Lephart, Ferris, Riemann, Myers, & Fu, 2002). In addition to landing in a more extended position, females activate their quadriceps musculature to a greater extent than their hamstrings (Colby et al., 2000). Combined with the previously mentioned research concerning the quadriceps' and hamstrings' abilities to provide shear forces at the knee joint, it could be hypothesized that females would be prone to increased ATSF when landing from a jump.

Summary

Non-contact anterior cruciate ligament injury is common in athletics. Female athletes are more susceptible to ACL injury than their male counterparts. One common mechanism of non-contact ACL injury is landing from a jump. Females tend to land from a jump with their knee in a more extended position than males do. Females also demonstrate a quadriceps dominance from both a muscle activation and muscle strength perspective. Moreover, this quadriceps dominance is more pronounced in positions of decreased knee flexion. Knowing females land in positions of knee extension where their quadriceps are exhibiting an increase anterior pull on the tibia, it could be hypothesized that this predisposes them to ACL injury. However, more research needs to be completed to establish a link between increased quadriceps-to-hamstrings strength and the subsequent ATSF placed upon the knee.

Chapter 3

Methodology

Subjects

Thirty-three recreational athletes were recruited from the University of North Carolina at Chapel Hill (UNC-CH) student population. Each subject was required to have 2 years of varsity, club, or intramural experience in a sport that implements a jump landing task such as basketball, volleyball, or soccer without having followed a professionally designed training or ACL injury prevention program. To be eligible for participation, all subjects met the following criteria: 1) between the ages of 18 and 25 years old, 2) participate in sporting activity 2-3 times per week for at least 30 minutes per session, 3) no current lower extremity injury, and 4) no prior history of ACL injury, ligamentous reconstruction, or any knee surgery with the past 2 years. In addition, to avoid possible fatigue, no testing took place within one hour of physical activity or other strenuous activity.

Prior to participation, all subjects read and signed an approved informed consent agreement in accordance with the standards set forth by the University of North Carolina Biomedical Institutional Review Board outlining the procedures of the study. All subjects were recruited verbally through the Physical Education Activity courses at UNC-CH, and by informational flyers that were posted around the UNC-CH campus.

During the testing session, subjects completed 2 separate tasks; 1) a jump landing task, and 2) an isokinetic strength task. The jump landing task was used to calculate the subject's peak ATSF when landing. Strength testing was used to measure Quad_{Ecc} and

Ham_{Con} mean peak torque. Analyses were conducted to determine if relationships exist between ATSF during the jump landing task and quadriceps and hamstring strength.

Measurement and Instrumentation

Isokinetic Dynamometer

An isokinetic dynamometer (Biodex Medical Systems, Inc.; Shirley, NY) was used to measure quadriceps and hamstrings strength as normalized to the product of body weight (N) and height (m). Both Ham_{Con} strength and Quad_{Ecc} strength were measured using 2 separate protocols; 1 for knee flexion, and 1 for knee extension. Starting at 90˚ of knee flexion, quadriceps strength (i.e. knee extension) was measured using a concentric\eccentric protocol where the eccentric data were used for statistical analysis. Starting at 90˚of knee flexion, hamstrings strength (i.e. knee flexion) was measured using an eccentric\concentric protocol where the concentric data were used for statistical analysis. Five repetitions of each protocol were completed at 3 testing velocities (60º/s, 180º/s, and 300º/s) for which the peak torque was determined. Peak torque was standardized to the product of body weight and height and averaged across the middle three trials. The orders in which the 2 protocols and 3 velocities were assessed were counterbalanced.

Flock of Birds/Forceplate

The Flock of Birds Electromagnetic Motion Analysis System (Ascension Technologies, Inc., Burlington, VT) was used in conjunction with the Motion Monitor Software System (Innovative Sports Training Inc., Chicago, IL) and a non-conductive forceplate (Bertec Corporation, Columbus, OH) to calculate peak anterior tibial shear force (ATSF). Kinematic data was sampled at 144Hz and kinetic data were sampled at 1,440Hz. The 3-dimensional coordinate system for testing was a right handed system so that the participants faced the positive X direction, the positive Y direction was to their left, and the positive Z axis was directed superiorly.

Procedures

Setting

Subjects reported to the Sports Medicine Research Laboratory at the University of North Carolina at Chapel Hill. All testing was performed in one session per subject, lasting approximately 60 minutes.

Subject Preparation

Each subject completed a health questionnaire, and anthropomorphic data were collected prior to the start of the testing session including age, height, weight, and leg dominance. The subjects were required to wear athletic shoes, athletic shorts, and a t-shirt for their testing session. The dominant lower extremity of each subject was used as the test limb, and defined as the leg used to kick a ball for maximum distance. Subjects rode a stationary bicycle at moderate intensity for 5 minutes in order to simulate pre-activity warm-up. The order in which the 2 tasks were performed (jump landing and isokinetic strength) was counterbalanced and 10 minutes of rest was provided between the 2 tasks to minimize the risks of fatigue.

Jump Landing Task

First, the examiner demonstrated the jump landing task and the subjects were allowed to practice this task a maximum of 5 times. Electromagnetic tracking sensors were then placed on each subject at the apex of the sacrum, midpoint of the lateral thigh, and anteromedial shank. The sensors placed over the thigh and shank were placed over areas of least muscle mass to minimize potential motion artifact. The sensors were affixed to the skin by pre-wrap, athletic tape, and double-sided tape. Once the electromagnetic sensors were attached, the subjects were asked to stand in a neutral posture with their arms relaxed at their sides. The following bony landmarks were then digitized, in the following order, using a mobile electromagnetic sensor attached to a stylus: 1) T12 spinous process, 2) xyphoid process, 3) medial femoral condyle, 4) lateral femoral condyle, 5) medial malleolus, 6) lateral malleolus, 7) left ASIS, and 8) right ASIS. Digitization of bony landmarks served to define the segment end-points and joint centers of the lower extremity segments. The knee joint center was defined as the midpoint between the medial and lateral femoral condyles, and the ankle joint center was defined as the midpoint between the medial and lateral malleolus.

During the jump-landing task, subjects jumped from a 30 cm high platform and landed on a force plate with the dominant foot, and with the non-dominant foot off to the side of the force plate. The platform was set at a horizontal distance equal to 50% of the subject's body height from the front edge of the force plate. Each subject was instructed to jump straight forward off the 30 cm platform, and land on the forceplate, and then vertically jump for maximum height. During testing, the subjects performed 10 trials with 30 seconds of rest between trials to minimize the risk of fatigue. Trials in which the subject failed to land with the foot of the dominant leg on the force plate were deleted, and a new trial was performed.

Isokinetic Strength

The Biodex 3 Isokinetic dynamometer (Biodex Medical System, Inc., Shirley, NY) was used to measure quadriceps and hamstrings peak torque in Newton · meters. Velocity was set at 60˚/s, 180˚/s, or 300˚/s and knee motion was set from 20˚ to 90˚ of knee flexion. A magnetic level attached to the dynamometer arm was used to assure the accuracy of the range of motion. Five repetitions were performed at each velocity, and the order of testing velocities was counterbalanced. The weight of the limb was calculated using the Biodex software to assure that gravity was accounted for during the measurements. The isokinetic dynamometer was calibrated prior to data collection.

The isokinetic dynamometer was used to measure knee extension concentric/eccentric peak torque and knee flexion eccentric/concentric peak torque for the quadriceps and hamstrings strength, respectively. Each test consisted of one set of five repetitions at maximal effort with data taken from the middle three trials. The first repetition was eliminated for to account for a potential learning effect, and the fifth repetition was eliminated for possible fatigue. The order in which the quadriceps and hamstrings were tested was counterbalanced.

Subjects were positioned sitting upright, and were secured using torso, pelvic, thigh, and shin stabilization straps. The input shaft of the dynamometer was aligned with the axis of rotation of the subject's knee, considered to be the point at the center of a line that passes transversely through the femoral condyles. The shin pad attachment was placed 1-2 cm proximal to the subject's lateral malleolus.

The strength testing began with familiarization (warm-up) repetitions. Each subject performed three sub-maximal attempts (50% capacity) that were not included in data analysis. Then the subject completed five maximal contractions of either the concentric/eccentric knee extension or eccentric/concentric knee flexion that were used for data analysis. One minute of rest was provided between each velocity of testing, and 5 minutes of rest between the quadriceps and hamstrings protocols. Instructions and verbal encouragement were the same for all subjects during the maximum strength testing. For the concentric/eccentric quadriceps test, subjects were instructed to "kick as hard as they can against the resistance as far as the machine will let them, and then resist the machine as it pulls their leg back as hard as possible." During the test, subjects received constant verbal encouragement to "kick out" during the concentric phase and "resist" during the eccentric phase. For the eccentric/concentric hamstring test, subjects were instructed to "resist the machine as it pulls their heel away and then pull their heel toward them as hard as possible." During the test they received verbal encouragement to "resist" during the eccentric phase and "pull back" during the concentric phase.

Data Reduction and Statistical Analysis

Strength was defined as the average of the peak torque of the middle 3 trials at each testing velocity. Peak ATSF was measured between the time of initial ground contact to the first local minimum following the peak in vertical ground reaction forces (Figure 1). Initial ground contact was defined as the instant that the vertical ground reaction force exceeds 10 N. Peak ATSF as normalized to body weight was then calculated as the average of the peaks of each of the 10 trials. Peak isokinetic torque normalized to the product of body weight and height was averaged across the middle 3 trials. Simple linear regression analyses were performed on the data to evaluate the relationship between 1.) Quad_{Ecc} and ATSF, 2.) Ham_{Con} and ATSF, and 3.) The $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratio and ATSF. An *a priori* statistical power analysis for regression models was performed on pilot test data , and it was determined that to obtain a statistical power of 0.80, 26 subjects would be needed (Yu, Lin, & Garrett, 2006). Statistical significance was set with an alpha level of $\alpha < 0.05$. Data conversion/reduction was performed by the Biodex Advantage Software version 3.2 and Matlab 12 (The Math Works, Inc.). Statistical analyses were performed using SPSS software version 13.0 (Chicago, IL).

Research Questions

RQ	Description	Data Source	Hypothesis	Method
1	Is there a relationship b/w Quad_{Ecc} and ATSF?	DV: ATSF IV: Quad_{Ecc}	(+) relationship	Simple linear regression
2	Is there a relationship b/w Ham_{Con} and ATSF?	DV: ATSF IV: Ham_{Con}	(-) relationship	Simple linear regression
3	Is there a relationship b/w $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ and ATSF?	DV: ATSF IV: $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$	(+) relationship	Simple linear regression

Chapter 4

Results

Anthropomorphic Data

Thirty-three female recreational athletes between the ages of 18 and 25 participated in this study. Six subjects were eliminated from data analyses due to instrumentation error. Specifically, the forceplate measuring ground reaction forces was unable to maintain a correct calibration. Descriptive statistics for the 27 subjects included in data analyses are presented in Table 1. Means and standard deviations for all assessment variables are presented in Table 2.

Regression Analyses

Regression analyses indicated that neither Quad_{Ecc} nor Ham_{Con} strength were significant predictors of peak ATSF when considered in isolation. Simple linear regressions between each strength measure and ATSF for each muscle at each velocity were non-significant ($p > 0.05$). However, when considered in combination in the form of a functional ratio (i.e. $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$), these strength measures were significantly and positively related to peak ATSF at both 60°/s ($r = 0.529$, $p = 0.005$) and 180°/s ($r = 0.556$, $p = 0.003$). No other correlations were statistically significant. Correlation coefficients and associated probability statistics are presented in Table 3. Simple linear regression models and R-squared values for each of the significant findings are presented in Figures 2 (60°/s) and 3 (180°/s).

Chapter 5

Discussion

The primary findings of this study were that eccentric quadriceps strength and concentric hamstring strength alone are not significant predictors of anterior tibial shear force. However, when considered in combination as a functional $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratio, these strength measures are significantly and positively related to ATSF. This suggests that in the presence of high functional $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratios, female recreational athletes may be predisposed to high ATSF.

Comparison of our data to previous literature is limited because we are unaware of any previous attempts to directly correlate strength measures and ATSF. Conventionally, the Q/H ratio is measured as a maximal concentric isokinetic quadriceps contraction relative to a maximal concentric isokinetic hamstring contraction (Osternig, 1986). Another method has been proposed for the measurement of isokinetic Q/H ratios, the functional eccentric quadriceps/concentric hamstring ratio (Aagaard, Simonsen, Magnusson, Larsson, & Dyhre-Poulsen, 1998). Functional $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratios are slightly higher than the conventional method, and range from 2.5-3.33 in elite athletes (Aagaard, Simonsen, Magnusson, Larsson, & Dyhre-Poulsen, 1998; Aagaard, Simonsen, Trolle, Bangsbo, & Klausen, 1995). Our data shows slightly lower $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratios ranging from 1.80 (60˚/s) to 1.64 (300˚/s) in female recreational athletes. The greater ratio values reported by these authors may be attributable to differences in the samples, as these previous investigations included elite athletes, while our sample consisted of recreational athletes. Our data are also consistent with previous research involving isokinetic strength assessment in that as the velocity of the test increases, the quadriceps to hamstring ratio decreases (Aagaard, Simonsen, Trolle, Bangsbo, & Klausen, 1995; Kannus & Beynnon, 1993; Rosene, Fogarty, & Mahaffey, 2001).

Conventional quadriceps to hamstring ratios tested at 60˚/s have been found to be higher than the functional $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratios found in our data. Previous research found conventional Q/H ratios in female collegiate athletes to be 1.99 and 1.70 at 60˚/s and 180˚/s, respectively (Rosene, Fogarty, & Mahaffey, 2001). Our functional ratios at 60˚/s and 180˚/s were 1.80 and 1.76 respectively. Since eccentric muscle force is greater than concentric force production (Aagaard, Simonsen, Magnusson, Larsson, & Dyhre-Poulsen, 1998; Drury, Stuempfle, Mason, & Girman, 2006; Gleeson & Mercer, 1996), our functional ratios would be expected to be greater than those of Rosene et. Al. (2001). This may suggest that female collegiate athletes have more developed quadriceps muscles in relation to their hamstrings when compared to recreational athletes, a notion supported by Bennell et. Al (1998) who suggested that differences in Q/H between groups ratios may be due to differences in the level of competition. Normal Q/H ratios range from 1.25 to 2.00 averaged over the entire range of motion, with higher ratios at faster velocities (Aagaard, Simonsen, Trolle, Bangsbo, & Klausen, 1995; Grace, Sweetser, Nelson, Ydens, & Skipper, 1984; Rosene, Fogarty, & Mahaffey, 2001). As the ratio approaches 1.00, the hamstrings have an increased functional capacity for providing stability at the knee joint (Harter, Osternig, & Standifer, 1990). This increased knee stability may reduce the anteriorly directed shear of the tibia on the femur (R. C. Li, Maffulli, Hsu, & Chan, 1996).

Injury patterns in female athletes have been demonstrated to be related to muscular imbalances (Hewett, Lindenfeld, Riccobene, & Noyes, 1999; Knapik, Bauman, Jones, Harris,

& Vaughan, 1991). In a study by Hewett et al. (1999), it was demonstrated that untrained females were 4.8 to 5.8 times more likely to sustain a knee injury than males, while neuromuscularly trained female athletes were only 1.3 to 2.4 times more likely to sustain a knee injury than males. Knapik et al. (1991) demonstrated that female athletes were 1.6 times more likely to sustain a lower extremity injury if they had a Q/H ratio greater than 1.33 at 180˚/s. In ACL deficient patients Li et al. (1996) found a significant relationship between Q/H ratios and recreational athletes score on a functional ability rating system. Therefore, the application of our data regarding functional $\mathrm{Quad}_{\mathrm{Ecc}}/\mathrm{Ham}_{\mathrm{Con}}$ ratios may provide a reason behind the increased injury rates.

Similar investigations have attempted to reproduce functional loading of the quadriceps and hamstrings by applying external forces to cadaveric musculature (DeMorat, Weinhold, Blackburn, Chudik, & Garrett, 2004; Markolf et al., 1995; Markolf, O'Neill, Jackson, & McAllister, 2004; Renstrom, Arms, Stanwyck, Johnson, & Pope, 1986; Withrow, Huston, Wojtys, & Ashton-Miller, 2006). Numerous studies have demonstrated that quadriceps activation causes ACL strain by producing ATSF (Beynnon et al., 1995; Durselen, Claes, & Kiefer, 1995; G. Li et al., 1999; Pandy & Shelburne, 1997). DeMorat et al. (2004) demonstrated that quadriceps loading alone is capable of producing enough force to strain and rupture the ACL. Withrow et al. (2006) concluded that an increase in applied quadriceps force correlated with an increase in ACL strain in cadaveric knees during a simulated one-legged landing task. Research has also shown that the hamstrings have the ability to provide a posterior tibial shear force that counteracts the ATSF provided by the quadriceps (Baratta et al., 1988; Durselen, Claes, & Kiefer, 1995; G. Li et al., 1999; Markolf, O'Neill, Jackson, & McAllister, 2004). Our data would suggest that the presence of strong hamstring musculature in relation to its antagonist quadriceps musculature would indeed lead to decreased ATSF's at the knee.

Clinical Application

The development of the functional strength ratio allows us to look more in depth at what types of forces the muscles stabilizing the knee joint are creating during dynamic activities. The functional $Quad_{Ecc}/Ham_{Con}$ ratio used in our study is representative of the eccentric muscle function of the quadriceps that is absorbing the force of the landing task and the concentric muscle function of the hamstrings that are acting to stabilize the knee joint. As research continues to link abnormal Q/H ratios to increased risk of injury (Hewett, Lindenfeld, Riccobene, & Noyes, 1999; Hiemstra, Webber, MacDonald, & Kriellaars, 2004; Knapik, Bauman, Jones, Harris, & Vaughan, 1991), alternative isokinetic strength measures may prove more important when implementing clinical practice. Isokinetic testing has long been used in clinical practice as a return to function gauge following ACL reconstruction rehabilitation. By testing the affected side in relation to the unaffected side clinicians are able to attempt to increase the strength of the affected side to be similar to the unaffected side.

This functional ratio may provide a better return-to-function criterion, as it is linearly related to ATSF. Other researchers have proposed the use of Q/H ratios as a screening tool for susceptibility to injury (Bennell et al., 1998). As the functional $Quad_{Ecc}/Ham_{Con}$ strength ratio predicts ATSF, this measure may also be useful from an injury prevention perspective. Recently, neuromuscular and strength training programs have been designed to reduce the risk of ACL injuries (Heidt, Sweeterman, Carlonas, Traub, & Tekulve, 2000; Hewett, Lindenfeld, Riccobene, & Noyes, 1999; Soderman, Werner, Pietila, Engstrom, & Alfredson, 2000). Strategies to decrease ATSF have been shown to decrease the load placed on the ACL (Lephart, Ferris, Riemann, Myers, & Fu, 2002; Yu, Lin, & Garrett, 2006). Therefore, it is important, as clinicians, to recognize the relationship between functional $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratios and ATSF, and begin to develop strategies in our athletes to decrease abnormal $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratios.

Future Research

Future research needs to be conducted using the functional $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratios used in this study and proposed by Aagaard et. Al (1998). Research should concentrate on establishing the relationship between ATSF and $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratios in wider populations, such as male recreational athletes, collegiate athletes, and athletes with a history of ACL injury. In addition, evaluating conventional Q/H ratios may provide some insight into their relationship with ATSF. Future research should also concentrate on comparing the functional $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratios at specific ranges of motion. Kannus et al. demonstrated that peak torque values vary with the velocity of testing (Kannus & Beynnon, 1993). While our investigation evaluated the relationship between ATSF and peak torque values, torque assessment at the angle of knee flexion at which peak ATSF occurred may provide a more powerful estimate. Similarly, the relative abilities of various Q/H ratios (e.g. functional vs. conventional) to predict ATSF should be evaluated.

Limitations

There were limitations in this study that warrant discussion. Firstly, our study was completed in a research laboratory which differs significantly from the playing fields and courts of our research participants. Furthermore, tethering of the subject to the data collection apparatus may alter landing patterns in the research setting. In addition, the strength testing protocol required the subject to be sitting upright, while ATSF it was compared to came from a landing task. Peak torque values may differ across these tasks, as the length-tension characteristics of the knee and hip flexors and extensors likely differ. Also, our study was limited in the fact that the range of motion for isokinetic strength testing was set from 20°-90° due to pilot testing revealing an inability of the subject to initiate movement on the dynamometer at angles less than 20° of knee flexion. Peak torque values for the tested muscles may very well occur in that specific range of motion, however we cannot conclude this from our data.

Table 1: Descriptive Statistics

Measures	**Mean**	**SD**
Age (years)	19.48	1.83
Height (cm)	165.52	6.45
Weight (kg)	61.84	9.75

Table 2: Assessment Variable Means and Standard Deviations

Variable	Mean	SD
ATSF	0.473	0.378
Peak $Quad_{Ecc}$ Torque @ 60°/s	0.136	0.030
Peak $Quad_{Ecc}$ Torque @ 180°/s	0.139	0.024
Peak $Quad_{Ecc}$ Torque @ 300°/s	0.148	0.031
Peak Ham_{Con} Torque @ 60°/s	0.084	0.027
Peak Ham_{Con} Torque @ 180°/s	0.084	0.022
Peak Ham_{Con} Torque @ 300°/s	0.092	0.015
$Quad_{Ecc}$/ Ham_{Con} @ 60°/s	1.798	0.807
$Quad_{Ecc}$/ Ham_{Con} @ 180°/s	1.763	0.569
$Quad_{Ecc}$/ Ham_{Con} @ 300°/s	1.641	0.360

--ATSF value reported as normalized to body weight
--Torque values reported as normalized to body weight and height

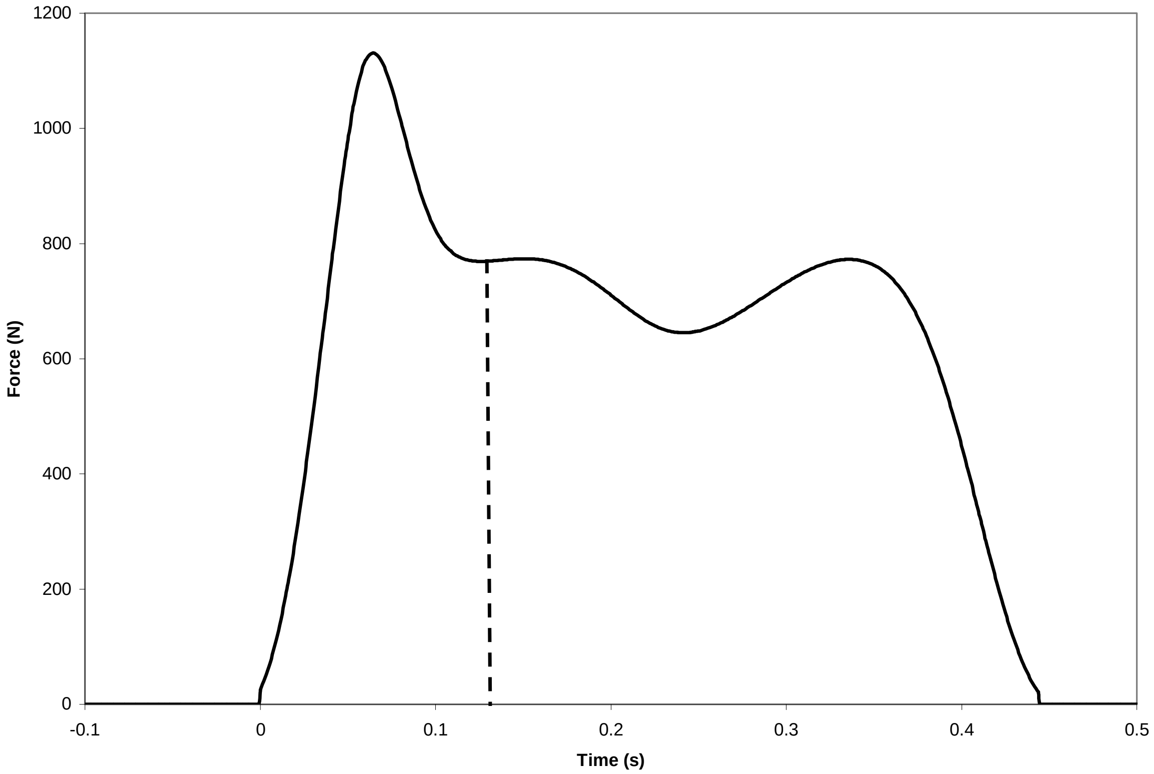
<u>Table 3:</u> The Relationship Between Strength Measures and Anterior Tibial Shear Force at Each testing Velocity

Strength Measure	60˚/s	180˚/s	300°/s
RQ1: Quad_{Ecc}	r = 0.179 *p* = 0.371	r = 0.335 *p* = 0.088	r = 0.264 *p* = 0.183
RQ 2: Ham_{Con}	r = -0.262 *p* = 0.186	r = -0.228 *p* = 0.253	r = 0.233 *p* = 0.243
RQ 3: Quad_{Ecc}/ Ham_{Con} Ratio	r = 0.529 *p* = 0.005*	r = 0.556 *p* = 0.003*	r = 0.105 *p* = 0.602

*indicates significant relationship ($p < 0.05$)

Figure 1

Vertical Ground Reaction Force vs. Time



-Time 0 represents initial ground contact
-Vertical dashed line represents local minimum used in determining interval over which peak ATSF was defined (i.e. initial ground contact to local minimum)

Figure 2

ATSF vs. $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ @ 60˚/s

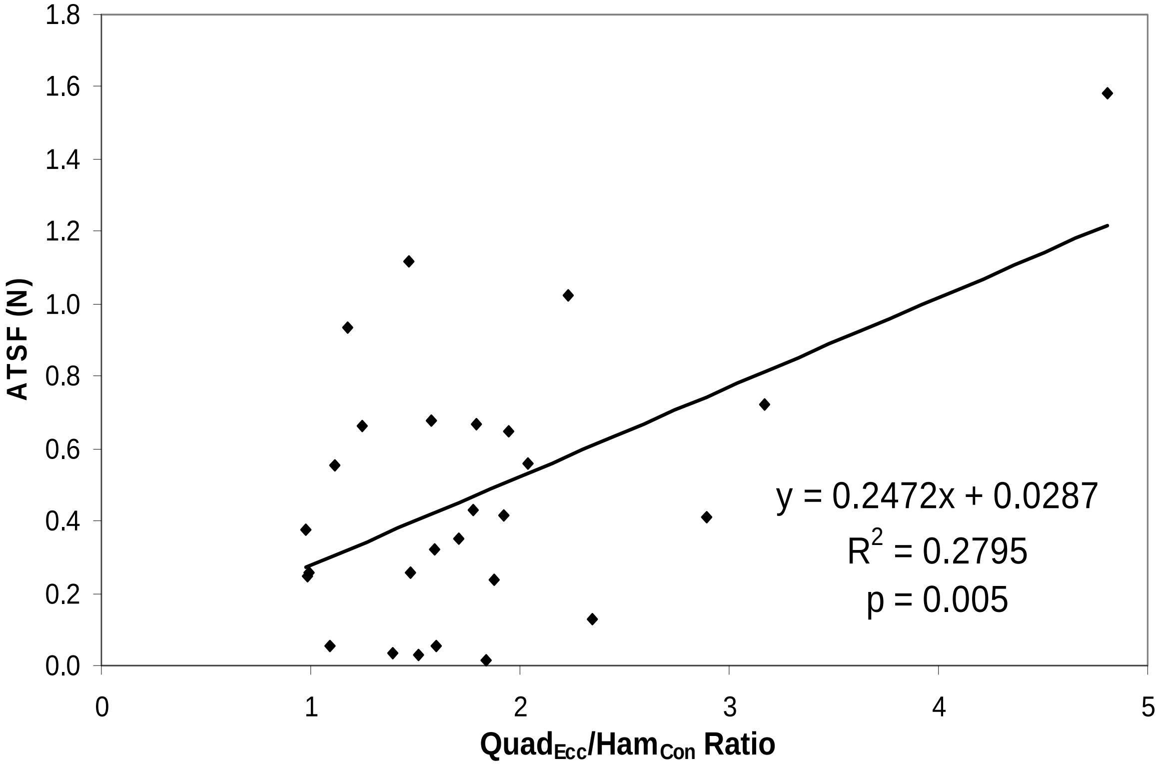
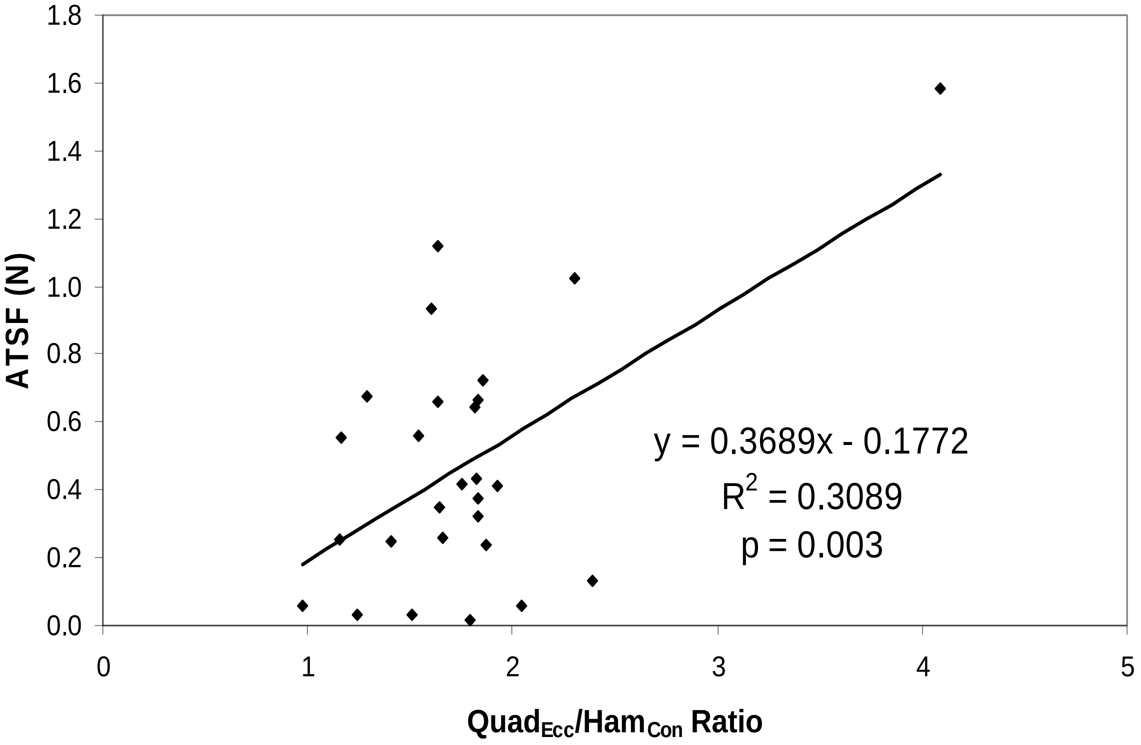


Figure 3

ATSF vs. Quad$_{Ecc}$/Ham$_{Con}$ @ 180˚/s



Appendix A

Manuscript

Abstract

Objective: To determine if a relationship exists between Anterior Tibial Shear Force (ATSF) and eccentric quadriceps strength (Quad_{Ecc}), concentric hamstring strength (Ham_{Con}), and a functional $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ strength ratio.

Design: Correlational analyses were conducted to determine the relationships between the measures of lower extremity strength and ATSF.

Setting: Sports Medicine Research Laboratory.

Participants: Twenty-seven female recreational athletes with no prior history of ACL injury, ligamentous reconstruction, or any knee surgery in the past 2 years**.**

Main Outcome Measure(s): ATSF was measured during a jump landing task via inverse dynamics. Quad_{Ecc} strength, Ham_{Con} strength , a functional $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratio were assessed at 3 testing velocities (60˚/s, 180˚/s,and 300˚/s) using an isokinetic dynamometer.

Results: In isolation, Quad_{Ecc} or Ham_{Con} were not significant predictors of ATSF at any of the testing velocities. However, significant positive correlations were found between ATSF and the functional $\text{Quad}_{\text{Ecc}}/ \text{Ham}_{\text{Con}}$ ratio at both 60˚/s ($r = 0.529$, $p = 0.005$) and 180˚/s ($r =0.556$, $p =0.003$). At 300˚/s the $\text{Quad}_{\text{Ecc}}/ \text{Ham}_{\text{Con}}$ ratio was not significantly related to ATSF.

Conclusion: Quad_{Ecc} strength and Ham_{Con} strength alone are not significant predictors of ATSF. However, when considered in combination as a functional $\text{Quad}_{\text{Ecc}}/ \text{Ham}_{\text{Con}}$ ratio, these strength measures are significantly and positively related to ATSF. This suggests that in the presence of high functional $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratios, female recreational athletes may be predisposed to higher anterior tibial shear forces and, therefore, at a greater risk of ACL injury. **Key Words:** Anterior tibial shear force, torque, quadriceps to hamstring strength ratios

Introduction

Incidence rates of Anterior Cruciate Ligament (ACL) injuries range from 80,000 to 200,000 yearly.[1, 2] It is estimated that at least 1 out of every 3,000 Americans suffers an ACL injury.[3] One major concern is that females are 2 to 8 times more likely to sustain an ACL injury than their male counterparts.[1, 3] However, the factors that cause this debilitating injury, and more specifically, why females are more prone to ACL injury are not clear.

Jump landing is a common functional activity used in many sports, especially basketball, soccer, and volleyball. Landing from a jump has been identified throughout the literature as a common mechanism of non-contact ACL injury.[4, 5] Dynamic activities of sports such as jumping, cutting, and landing, anterior tibial shear forces can greatly exceed the loading capacity of the ACL.[6-9] To prevent injury to the ACL, dynamic structures surrounding the knee must help in providing stability. This is primarily achieved by two major muscle groups acting at the knee, the quadriceps and hamstrings. Cadaver studies have shown that an increase in quadriceps isometric force can significantly increase the anterior tibial shear force (ATSF) at the knee, especially with the knee near full extension.[9-11] On the other hand, the hamstrings provide a posterior shear force at the knee, and subsequently reduce the strain on the ACL.[12, 13]

If the ATSF applied by the eccentric quadriceps contraction is great enough, and the hamstring muscles cannot provide an adequate posterior shear force, the ACL is at risk for strain or rupture.[7, 9] When comparing jump landing strategies in males and females, researchers have reported that females activate a greater percentage of their quadriceps musculature than their hamstrings musculature.[2, 14-16] In addition, females contract their quadriceps first in response to anterior tibial translation.[17]

In addition to the quadriceps dominant activation patterns, females demonstrate significantly less isometric, concentric, and eccentric muscle strength in the quadriceps and hamstrings compared with males.[15, 17, 18] Particularly, females demonstrate substantially weaker hamstring muscles when compared to their quadriceps.[19, 20] Given the stability demands placed on these muscles during jump landing, these findings suggest that females may be exposed to excessive ATSF during jump landing tasks. [17]

Strength differences across genders may provide a reasonable explanation why females have higher incidence rates of ACL injury than males. These imbalances may be due to differences between the right and left leg, or abnormal ratios between antagonistic muscle groups.[21] In regard specifically to knee injury, The Hunt Valley Consensus Conference on ACL injuries concluded that large magnitude eccentric quadriceps activation was considered to be a major risk factor for injury to the ACL.[2] Strength imbalances between the quadriceps and hamstrings have been related to an increased lower extremity injury rate in females, and athletes who demonstrate hamstring strength less than 75% of the quadriceps were 1.6 times more likely to sustain a lower extremity injury. It has been proposed that because of the prominent influence of quadriceps activity on ATSF, it is important for the hamstrings to counter this force, particularly in the presence of increased quadriceps : hamstrings strength ratios (Q/H).[6]

Understanding the factors that predispose the female recreational athlete to ACL injury may help us to develop strategies to prevent these injuries from occurring. The comparison of quadriceps and hamstrings strength appears to be important in determining the dynamic stability of the knee joint during times of excessive loading. Therefore, the purpose of this study was to determine if a relationship exists between the ATSF during a jump landing task and the strength of the quadriceps and hamstrings musculature.

Methods

Twenty-seven female recreational athletes (age = 19.48 ± 1.83 years, height = 165.62 ± 6.45 cm, mass = 61.84 ± 9.75 kg) participated in this study. Each subject was required to have at least 2 years of varsity, club, or intramural experience in a sport that implements a jump landing task (e.g basketball, volleyball, or soccer) without having followed a professionally designed training or ACL injury prevention program. To be eligible for participation, all subjects met the following criteria: 1) between the ages of 18 and 25 years, 2) participate in sporting activity 2-3 times per week for at least 30 minutes per session, 3) no current lower extremity injury, and 4) no prior history of ACL injury, ligamentous reconstruction, or any knee surgery within the past 2 years. In addition, to reduce the likelihood of fatigue, no testing took place within one hour of physical activity or other strenuous activity. Prior to participation, all subjects read and signed an approved informed consent agreement. During the testing session, subjects completed 2 separate tasks: 1) a jump landing task, and 2) isokinetic strength testing. The jump landing task was used to calculate the subject's ATSF. Isokinetic strength testing was used to assess eccentric quadriceps and concentric hamstrings isokinetic strength.

Procedures

All testing was performed in a single testing session, lasting approximately 60 minutes. The dominant lower extremity of each subject was used as the test limb, defined as the leg used to kick a ball for maximum distance. Subjects rode a stationary bicycle at moderate intensity for 5 minutes prior to testing in order to simulate pre-activity warm-up. The order in which the two tasks (jump landing and isokinetic strength) were conducted was counterbalanced, and 10 minutes of rest were provided between tasks to minimize the likelihood of fatigue.

Jump Landing Task

The Flock of Birds electromagnetic motion analysis system (Ascension Technologies, Inc., Burlington, VT) was used in conjunction with the Motion Monitor Software System (Innovative Sports Training Inc., Chicago, IL) and a non-conductive forceplate (Bertec Corporation, Columbus, OH) to calculate peak ATSF. Kinematic data were sampled at 144Hz. The 3-dimensional coordinate system for testing was a right handed system so that the participants faced the positive X axis, the positive Y axis was to their left, and the positive Z axis was directed superiorly. Thee forceplate measured the ground reaction forces during the jump landing task at a rate of 1440 Hz. Peak ATSF was measured between the time of initial ground contact to the first local minimum following the peak in vertical ground reaction forces (Figure 1). Initial ground contact was defined as the instant that the vertical ground reaction force exceeds 10 N. Peak ATSF as normalized to body weight was then calculated as the average of the peaks of each of the 10 trials.

The examiner demonstrated the jump landing task, and the subjects were allowed to practice this task a maximum of 5 times. Electromagnetic tracking sensors were then placed on each subject at the apex of the sacrum, midpoint of the lateral thigh, and the anteromedial shank. The sensors on the thigh and shank were placed over areas of least muscle mass to minimize the potential for motion artifact. The sensors were affixed to the body by pre-wrap, athletic tape, and double-sided tape. Once the electromagnetic sensors were attached, the subjects were asked to stand in a neutral posture with their arms relaxed at their sides. The following bony landmarks were then digitized, in the following order, using a mobile electromagnetic sensor attached to a stylus: T12 spinous process, xyphoid process, medial and lateral femoral condyles, medial and lateral malleoli, and the left and right ASIS. Digitization of bony landmarks served to define the segment end-points and joint centers to create a segment linkage model. The knee joint center was defined as the midpoint between the medial and lateral femoral condyles, and the ankle joint center was defined as the midpoint between the medial and lateral malleolus.

During the jump-landing task, subjects jumped from a 30 cm high platform and landed on the forceplate with the dominant foot, and with the non-dominant foot off to the side of the forceplate. The platform was set at a horizontal distance equal to 50% of the subject's body height from the front edge of the forceplate. Each subject was instructed to jump straight forward off the 30 cm platform, and to land on the forceplate, and then vertically jump for maximum height. During testing, the subjects performed 10 trials with 30 seconds of rest between trials to minimize the risk of fatigue. Trials in which the subject failed to land with the foot of the dominant leg on the forceplate were deleted, and a new trial was performed.

Isokinetic Strength

The Biodex 3 Isokinetic dynamometer (Biodex Medical System, Inc., Shirley, NY) was used to measure quadriceps and hamstrings peak torque in Newton · meters. Both concentric hamstring strength and eccentric quadriceps strength were measured using 2 separate protocols; 1 for knee flexion, and 1 for knee extension. Subjects were positioned sitting upright, and were secured using torso, pelvic, thigh, and shin stabilization straps. The input shaft of the dynamometer was aligned with the axis of rotation of the subject's knee, considered to be the point at the center of a line that passes transversely through the femoral condyles. The shin pad attachment was placed 1-2 cm proximal to the subject's lateral malleolus. Starting at 90˚ of knee flexion, quadriceps strength was measured using a concentric/eccentric protocol where the eccentric data were used for statistical analysis (Quad_{Ecc}). Starting at 90˚ of knee flexion, hamstrings strength was measured using an eccentric/concentric protocol where the concentric data were used for statistical analysis (Ham_{Con}). Pilot testing indicated that a number of subjects were unable to produce a large enough knee moment to engage the dynamometer at knee flexion angles less than 20°. Therefore, the range of motion was set from 20˚ to 90˚ of knee flexion to ensure strength testing across a consistent range in all subjects. Five repetitions were completed at each speed of testing (60˚/s, 180˚/s and 300˚/s), and peak torque was averaged across the middle 3 repetitions. The order of the speed of testing, as well as the order in which the quadriceps and hamstrings were tested, were counterbalanced. Torque data were gravity corrected via the Biodex software.

The strength testing began with familiarization (warm-up) repetitions for both protocols. Subjects completed five maximal contractions of either the concentric/eccentric knee extension or eccentric/concentric knee flexion. One minute of rest was provided between each speed of testing, and 5 minutes of rest between the quadriceps and hamstrings protocols. Instructions and verbal encouragement were the same for all subjects during the maximum strength testing.

Data Reduction and Statistical Analysis

Data reduction was performed by the Biodex Advantage Software version 3.2 and Matlab 12 (The Math Works, Inc.). Peak ATSF data was normalized to body weight, and peak torque values were normalized to the product of body weight and height. Simple linear regression analyses were performed on the data to evaluate the relationship between 1) Quad_{Ecc} and ATSF, 2) Ham_{Con} and ATSF, and 3) The functional $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratio and ATSF. We chose to use this ratio rather than conventional assessment strategies due to the fact that it is likely a better representation of the contractile status of the quadriceps (eccentric) and hamstrings (concentric) during the loading phase of landing. An *a priori* statistical power analysis for regression models was performed on pilot test data, and it was determined that to obtain a statistical power of 0.80, 26 subjects would be needed. Statistical significance was set at $\alpha < 0.05$. Statistical analyses were performed using SPSS software version 13.0 (Chicago, IL).

Results

Regression Analyses

Regression analyses indicated that neither Quad_{Ecc} nor Ham_{Con} strength were significant predictors of peak ATSF when considered in isolation. Simple correlations between each strength measure and ATSF for each muscle at each velocity were non-significant ($p > 0.05$). However, when considered in combination in the form of a functional ratio (i.e. $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$), these strength measures were significantly and positively related to peak ATSF at both 60°/s ($r = 0.529$, $p = 0.005$) and 180°/s ($r = 0.556$, $p = 0.003$). No other correlations were statistically significant. Means and standard deviations for all assessment variables are presented in Table 1. Correlation coefficients and associated probability statistics are presented in Table 2. Simple linear regression models and R-squared values for each of the significant findings are presented in Figures 2 (60°/s) and 3 (180°/s).

Table 1: Assessment Variable Descriptive Statistics

Variable	**Mean**	**SD**
ATSF	0.473	0.378
Peak Quad_{Ecc} Torque @ 60°/s	0.136	0.030
Peak Quad_{Ecc} Torque @ 180°/s	0.139	0.024
Peak Quad_{Ecc} Torque @ 300°/s	0.148	0.031
Peak Ham_{Con} Torque @ 60°/s	0.084	0.027
Peak Ham_{Con} Torque @ 180°/s	0.084	0.022
Peak Ham_{Con} Torque @ 300°/s	0.092	0.015
Quad_{Ecc}/ Ham_{Con} @ 60°/s	1.798	0.807
Quad_{Ecc}/ Ham_{Con} @ 180°/s	1.763	0.569
Quad_{Ecc}/ Ham_{Con} @ 300°/s	1.641	0.360

--ATSF value reported as normalized to body weight
--Torque values reported as normalized to body weight and height

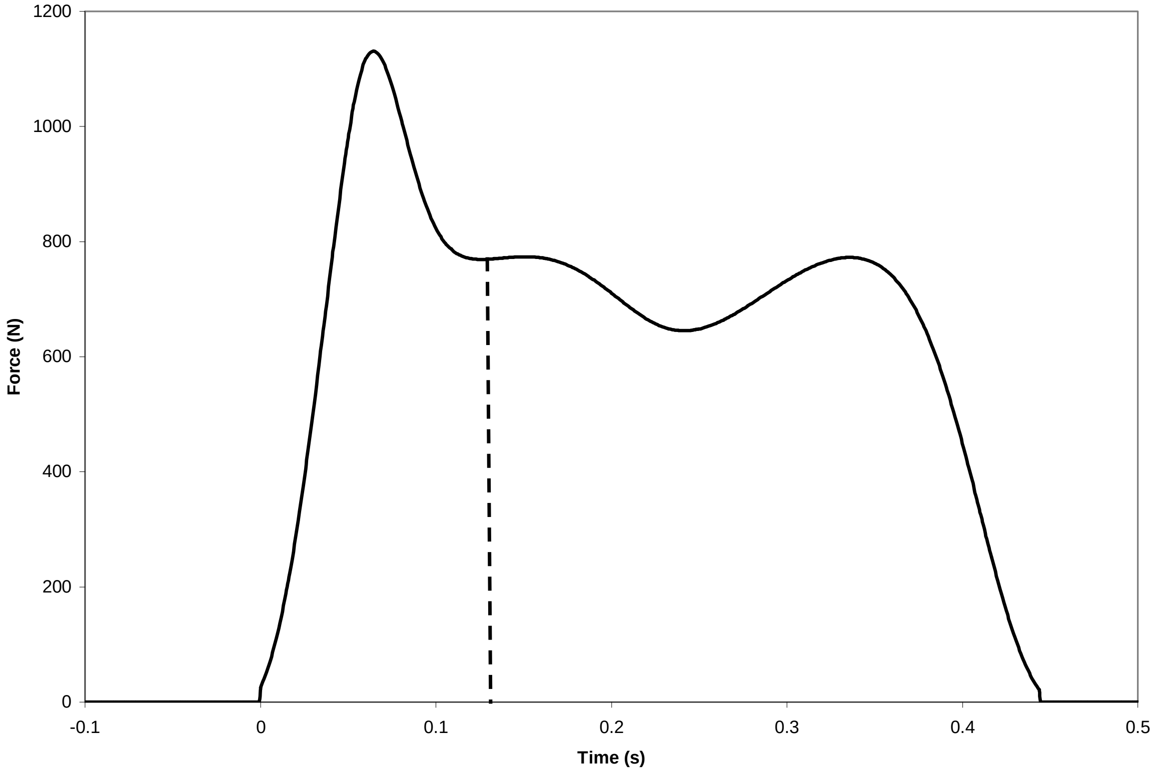
Table 2: **The Relationship Between Strength Measures and Anterior Tibial Shear Force at Each testing Velocity**

Strength Measure	60˚/sec	180˚/sec	300°/sec
Quad_{Ecc}	p = 0.371 r = 0.179	p = 0.088 r = 0.335	p = 0.183 r = 0.264
Ham_{Con}	p = 0.186 r = -0.262	p = 0.253 r = -0.228	p = 0.243 r = 0.233
Quad_{Ecc}/ Ham_{Con} Ratio	p = 0.005* r = 0.529	p = 0.003* r = 0.556	p = 0.602 r = 0.105

* indicates significant relationship ($p < 0.05$)

Figure 1

Vertical Ground Reaction Force vs. Time



-Time 0 represents initial ground contact
-Vertical dashed line represents local minimum used in determining interval over which peak ATSF was defined (i.e. initial ground contact to local minimum)

Figure 2

ATSF vs. Quad$_{Ecc}$/Ham$_{Con}$ @ 60˚/s

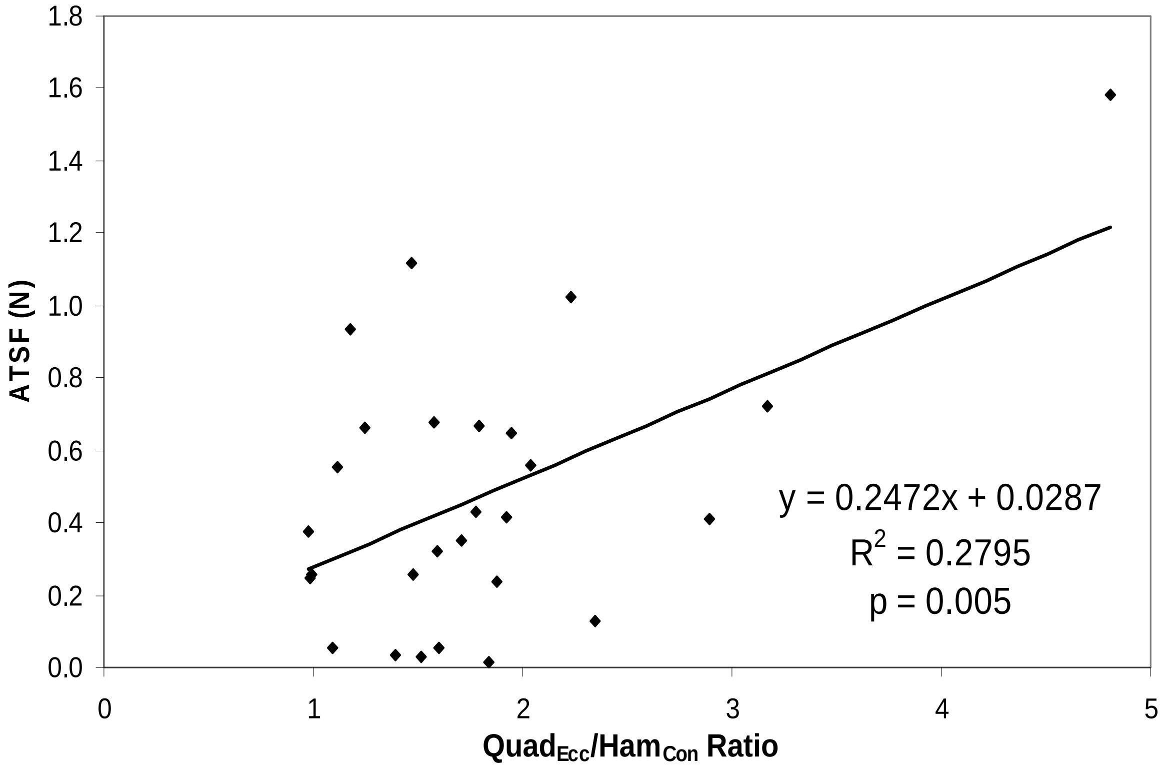
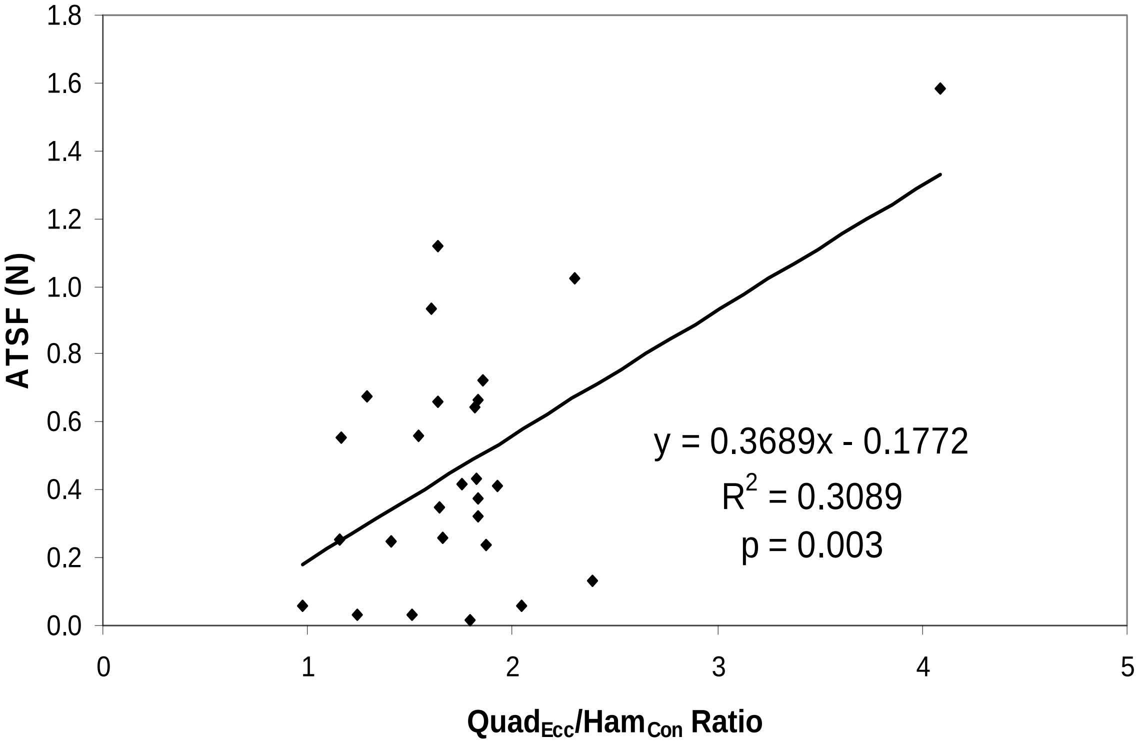


Figure 3

ATSF vs. Quad$_{Ecc}$/Ham$_{Con}$ @ 180˚/s



Discussion

The primary findings of this study were that Quad_{Ecc} strength and Ham_{Con} strength alone are not significant predictors of ATSF. However, when considered in combination as a functional $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratio, these strength measures are significantly and positively related to ATSF. This suggests that in the presence of high functional $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratios, female recreational athletes may be predisposed to higher ATSF.

Comparison of our data to previous literature is limited because we are unaware of any previous attempts to directly correlate strength measures and ATSF. Conventionally, the Q/H ratio is measured as a maximal concentric isokinetic quadriceps contraction relative to a maximal concentric isokinetic hamstring contraction.[22] Aagaard et al.[23] proposed a new concept for the measurement of isokinetic Q/H ratios, the functional eccentric quadriceps/ concentric hamstring comparison. Functional $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratios are slightly higher than the conventional method, and range from 2.5-3.33 in elite athletes.[23, 24] Our data found slightly lower $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratios, ranging from 1.80 (60˚/s) to 1.64 (300˚/s) in female recreational athletes. The greater ratio values reported by previous authors may be attributed to differences in the samples, as these previous investigations included elite athletes, while our sample consisted of recreational athletes. Our data are also consistent with previous research involving isokinetic strength assessment in that as the velocity of the test increases, the Q/H ratio decreases.[20, 24, 25]

Conventional Q/H ratios tested at 60˚/s have been found to be higher than the functional $\text{Quad}_{\text{Ecc}}/\text{Ham}_{\text{Con}}$ ratios found in our data. Rosene et al.[25] found conventional

Q/H ratios in female collegiate athletes to be 1.99 and 1.70 at 60˚/s and 180˚/s, respectively. Our functional ratios at 60˚/sec and 180˚/sec were 1.80 and 1.76 respectively. Since eccentric muscle force is greater than concentric force production it would be expected to see our values higher than those of Rosene et. al.[23, 26, 27] This may suggest that female collegiate athletes have more developed quadriceps muscles in relation to their hamstrings when compared to recreational athletes, a notion supported by Bennell et al.[28] who suggested that differences in Q/H ratios may be functions of the level of competition. Ratios greater than 1.00 indicate greater quadriceps strength relative to hamstrings strength. As the ratio approaches 1.00, the hamstrings have an increased functional capacity for providing stability at the knee joint.[29] This increased knee stability may reduce the anteriorly directed shear of the tibia on the femur and the subsequent load placed on the ACL.[30]

Injury patterns in female athletes have been shown to be affected by muscular imbalances.[21, 31] In a study by Hewett et al.,[31] it was demonstrated that untrained females were 4.8 to 5.8 times more likely to sustain a knee injury than males, while neuromuscularly trained female athletes were only 1.3 to 2.4 times more likely to sustain a knee injury than males. Knapik et al.[21] demonstrated female athletes were 1.6 times more likely to sustain a lower extremity injury if they had a Q/H ratio greater than 1.33 at 180˚/s. In ACL deficient patients, Li et al.[30] found a significant relationship between Q/H ratios and recreational athletes' scores on a functional ability rating system.

Similar investigations have mimicked quadriceps and hamstring torque by applying external forces to cadaveric musculature.[9, 11, 13, 32, 33] Numerous studies have demonstrated that greater quadriceps activation causes ACL strain by producing anterior tibial shear forces.[10, 34-36] DeMorat et. al demonstrated that quadriceps loading alone is capable of producing enough force to strain and rupture the ACL.[32] Withrow et. al concluded that an increase in applied quadriceps force correlated with an increase in ACL strain in cadaveric knees during a simulated one-legged landing task.[9] Research has also shown that the hamstrings have the ability to provide a posterior tibial shear force that counteracts the ATSF provided by the quadriceps.[6, 10, 33, 35] Our data would suggest that the presence of strong hamstring musculature in relation to its antagonist quadriceps musculature would indeed lead to decreased ATSF at the knee.

Clinical Application

The development of the functional $\mathrm{Quad}_{\mathrm{Ecc}}/\mathrm{Ham}_{\mathrm{Con}}$ strength ratio allows us to look more in depth at what types of forces the muscles stabilizing the knee joint produce during dynamic activities. The functional $\mathrm{Quad}_{\mathrm{Ecc}}/\mathrm{Ham}_{\mathrm{Con}}$ used in our study is representative of the eccentric muscle function of the quadriceps that absorbs the force of the landing task and the concentric muscle function of the hamstrings that acts to stabilize the knee joint. As research continues to link abnormal Q/H ratios to increased risk of injury,[21, 31, 37] alternative isokinetic strength measures may prove more important when implementing clinical practice. Isokinetic testing has long been used in clinical practice as a return to function gauge following ACL reconstruction rehabilitation. By testing the affected side in relation to the unaffected side, clinicians are able to attempt to increase the strength of the affected side to be similar to the unaffected side.

This functional ratio may provide a better return-to-function criterion, as it is linearly related to ATSF. Bennell et al.[28] have proposed the use of Q/H ratios as a screening tool for susceptibility to injury. As the functional $\mathrm{Quad}_{\mathrm{Ecc}}/\mathrm{Ham}_{\mathrm{Con}}$ strength ratio predicts ATSF, this measure may also be useful from an injury prevention perspective. Recently, neuromuscular and strength training programs have been designed to reduce the risk of ACL injuries,[31, 38, 39] and strategies to decrease ATSF have been shown to decrease the load placed on the ACL.[15, 40] Therefore, it is important as clinicians to recognize the relationship between functional $\mathrm{Quad}_{\mathrm{Ecc}}/\mathrm{Ham}_{\mathrm{Con}}$ ratios and ATSF, and begin to develop strategies in our athletes to decrease abnormal $\mathrm{Quad}_{\mathrm{Ecc}}/\mathrm{Ham}_{\mathrm{Con}}$ ratios.

Future Research

Future research needs to be conducted using the functional $\mathrm{Quad}_{\mathrm{Ecc}}/\mathrm{Ham}_{\mathrm{Con}}$ ratios used in this study and proposed by Aagaard et. al [23] Research should concentrate on establishing the relationship between ATSF and $\mathrm{Quad}_{\mathrm{Ecc}}/\mathrm{Ham}_{\mathrm{Con}}$ ratios in wider populations, such as male recreational athletes, collegiate athletes, and athletes with a history of ACL injury. In addition, evaluating conventional Q/H ratios may provide some insight into their relationship with ATSF. Future research should concentrate on comparing the functional $\mathrm{Quad}_{\mathrm{Ecc}}/\mathrm{Ham}_{\mathrm{Con}}$ ratios at specific ranges of motion. Kannus et al. demonstrated that peak torque values vary with the speed of testing.[20] Evaluating the relationship between ATSF and the functional $\mathrm{Quad}_{\mathrm{Ecc}}/\mathrm{Ham}_{\mathrm{Con}}$ ratio at specific values of knee flexion (e.g. knee flexion angle at peak ATSF) may improve the productive power. Similarly, the relative abilities of various Q/H ratios (e.g. functional vs. conventional) to predict shear forces should be evaluated.

Limitations

There were limitations in this study that warrant discussion. Firstly, our study was completed in a research laboratory which differs significantly from the playing fields and courts of our research participants. Furthermore, tethering of the subject to the data collection apparatus may alter landing patterns in the research setting. In addition, the strength testing protocol required the subject to be sitting upright, while ATSF it was compared to came from a landing task. Peak torque values may differ across these tasks, as the length-tension characteristics of the knee and hip flexors and extensors likely differ. Also, our study was limited in the fact that the range of motion for isokinetic strength testing was set from 20˚-90˚ due to pilot testing revealing an inability of the subject to initiate movement on the dynamometer at angles less than 20˚ of knee flexion. Peak torque values for the tested muscles may very well occur in that specific range of motion, however we cannot conclude this from our data.

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Appendix B

Statistical Output

Correlations

Descriptive Statistics

	Mean	Std. Deviation	N
atsf_norm_avg	.47302	.3784356	27
Ptqeccavg_60_n	.136110	.0301653	27
Ptqeccavg_180_n	.139373	.0236500	27
Ptqeccavg_300_n_n	.148208	.0308865	27
Ptqconavg_60_n_hams_n	.084178	.0266710	27
Ptqconavg_180_n_hams	.083600	.0216710	27
Ptqconavg_300_n_n	.091459	.0146596	27
pquadecc_hamcon_60_n	1.798403	.8074285	27
pquadecc_hamcon_180_n	1.763404	.5687972	27
pquadecc_hamcon_300_n	1.641138	.3596409	27

Correlation

		atsf_ norm_avg	Ptqeccavg_ 60_n	Ptqeccavg_ 180_n	Ptqeccavg_ 300_n_n	Ptqconavg_ 60_n_hams_ n	Ptqconavg_ 180_n_hams	Ptqconavg_ 300_n_n	pquadecc_ hamcon_60_ n	pquadecc_ hamcon_ 180_n	pquadecc_ hamcon_ 300_n
atsf_norm_avg	Pearson Correlation	1	.179	.335	.264	-.262	-.228	.233	.529**	.556**	.105
	Sig. (2-tailed)		.371	.088	.183	.18	.253	.243	.005	.003	.602
	N	27	27	27	27	27	27	27	27	27	27
Ptqeccavg_60_	Pearson Correlation	.179	1	.739**	.640**	.31	.167	.121	.273	.312	.514**
	Sig. (2-tailed)	.371		.000	.000	.11	.404	.548	.168	.113	.006
	N	27	27	27	27	27	27	27	27	27	27
Ptqeccavg_180_n	Pearson Correlation	.335	.739**	1	.750**	.32	.358	.265	.188	.324	.522**
	Sig. (2-tailed)	.088	.000		.000	.09	.067	.181	.348	.099	.005
	N	27	27	27	27	27	27	27	27	27	27
Ptqeccavg_300_n_n	Pearson Correlation	.264	.640**	.750**	1	.304	.301	.327	.168	.222	.742**
	Sig. (2-tailed)	.183	.000	.000		.123	.127	.096	.402	.267	.000
	N	27	27	27	27	27	27	27	27	27	27
Ptqconavg_60_n_hams_ n	Pearson Correlation	-.262	.314	.326	.304	1	.657**	.374	-.737**	-.474*	.028
	Sig. (2-tailed)	.186	.110	.097	.123		.000	.055	.000	.013	.888
	N	27	27	27	27	27	27	27	27	27	27
Ptqconavg_180_n_hams	Pearson Correlation	-.228	.167	.358	.301	.657**	1	.391*	-.560**	-.678**	.021
	Sig. (2-tailed)	.253	.404	.067	.127	.000		.044	.002	.000	.918
	N	27	27	27	27	27	27	27	27	27	27
Ptqconavg_300_n_n	Pearson Correlation	.233	.121	.265	.327	.374	.391*	1	-.103	-.077	-.372
	Sig. (2-tailed)	.243	.548	.181	.096	.055	.044		.609	.704	.056
	N	27	27	27	27	27	27	27	2	27	27
pquadecc_hamcon_60_n	Pearson Correlation	.529**	.273	.188	.168	-.737**	-.560**	-.103	1	.825**	.225
	Sig. (2-tailed)	.005	.168	.348	.402	.000	.002	.609		.000	.258
	N	27	27	27	27	27	27	27	2	27	27
pquadecc_hamcon_180_ n	Pearson Correlation	.556**	.312	.324	.222	-.474*	-.678**	-.077	.825**	1	.246
	Sig. (2-tailed)	.003	.113	.099	.267	.013	.000	.704	.000		.217
	N	27	27	27	27	27	27	27	2	27	27
pquadecc_hamcon_300_ n	Pearson Correlation	.105	.514**	.522**	.742**	.028	.021	-.372	.225	.246	1
	Sig. (2-tailed)	.602	.006	.005	.000	.888	.918	.056	.258	.217	
	N	27	27	27	27	27	27	27	27	27	27

** Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Appendix C

Institutional Review Board Materials

University of North Carolina-Chapel Hill
Consent to Participate in a Research Study
Adult Participants Female Recreational Athletes ages 18-25
Social Behavioral Form

IRB Study # 06-0543
Consent Form Version Date: Version 2 – 11/29/2006

Title of Study: The Relationship between Anterior Tibial Shear Force and Quadriceps\Hamstring Strength, Knee Flexion Angle, Hip Flexion Angle, and Trunk Flexion Angle during a Jump Landing Task

Principal Investigator: Douglas R. Bennett LAT, ATC
UNC-Chapel Hill Department: Exercise and Sport Science
UNC-Chapel Hill Phone number: 919-962-2067
Email Address: drb215@email.unc.edu
Co-Investigators: Hollie J. Walusz LAT, ATC; Darin Padua, PhD, ATC; Troy Blackburn, PhD, ATC; Michelle Boling, MS, ATC; Melanie McGrath, MS, ATC; Chris Hirth MS, PT, ATC
Faculty Advisor: Darin Padua, PhD, ATC
Funding Source:

Study Contact telephone number: 919-962-2067
Study Contact email: drb215@email.unc.edu

What are some general things you should know about research studies?

You are being asked to take part in a research study. To join the study is voluntary. You may refuse to join, or you may withdraw your consent to be in the study, for any reason.

Research studies are designed to obtain new knowledge that may help other people in the future. You may not receive any direct benefit from being in the research study. There also may be risks to being in research studies.

Deciding not to be in the study or leaving the study before it is done will not affect your relationship with the researcher, your health care provider, or the University of North Carolina-Chapel Hill. If you are a patient with an illness, you do not have to be in the research study in order to receive health care.

Details about this study are discussed below. It is important that you understand this information so that you can make an informed choice about being in this research study. You will be given a copy of this consent form. You should ask the researchers named above, or staff members who may assist them, any questions you have about this study at any time.

What is the purpose of this study?

The purpose of this study is to determine if a relationship exists between lower extremity motion and strength with forces at the knee during a jump landing task. The ACL provides as much as 86% of the static restraint to anterior tibial translation (ATT) on the femur. When anterior tibial shear forces are great enough, the tibia will translate anteriorly, and ACL rupture can occur. During the dynamic activities of sports such as jumping, cutting, and landing, these forces can greatly exceed the loading capacity of the ACL. Thus, there is a need for additional stability at the knee joint. This additional stability is derived via dynamic stabilizers (musculotendinous structures). Also, more erect sagittal plane postures have been found to increase strain on the ACL. Therefore, determining if such relationships exist may aid us in preventing ACL injury.

You are being asked to participate in the study because you are a female recreational athlete between the ages of 18 and 25 who may participate in sporting activities that involve a jump-landing.

Are there any reasons you should not be in this study?

You should not participate in this study if any of the following apply to you:

- You have a previous history of an anterior cruciate ligament (ACL) injury
- You have had ligamentous reconstruction or any knee surgery within the past two years
- You have had a current lower extremity injury that would affect your performance of a jumping task.

How many people will take part in this study?

If you decide to participate in this study, you will be one of approximately 40 females in this research study.

How long will your part in this study last?

All testing will be performed in one session lasting approximately 60 minutes

What will happen if you take part in the study?

During the course of this study, the following will occur:

- You will report to the Sports Medicine Research Laboratory in Fetzer Gymnasium for one 60-minute testing session. You will be asked to wear athletic shorts, a t-shirt, and your athletic shoes. You will then complete a health questionnaire, and data will be collected from you including your age(years), height(cm), mass(kg), and leg dominance prior to the start of the testing session. Next you will ride a stationary bicycle at moderate intensity for 5 minutes as part of a warm-up prior to the jumping activity. Demonstration of the jumping task will be shown to you and you will be able to practice prior to data collection.

- You will have electromagnetic motion-tracking sensors placed on your upper back, low back, thigh, and shin that are designed to measure the movement patterns of the lower extremity and trunk. A female examiner (Hollie Walusz) will perform all sensor placements. Once the electromagnetic sensors are attached, you will be asked to stand in a neutral position with your arms relaxed at your sides. We will then define the following bony landmarks for the motion tracking software: T12 spinous process (middle of back), xyphoid process (lower end of breast bone), medial femoral condyle (inside of knee), lateral femoral condyle (outside of knee), distal end of medial malleolus (inside of ankle), distal end of lateral malleolus (outside of ankle), left Anterior Superior Iliac Spine (ASIS) (hip bone at the top of your thigh) and right ASIS (hip bone at the top of your thigh).
- You will then be asked to perform a jump-landing task that involves jumping down from a 30-cm high box and landing with one foot on a force plate and the other off to the side on a carpeted surface. You will perform 10 trials with at least 30 seconds of rest between each trial.
- Next you will be set up on a dynamometer (measures force production) in order to test muscular strength. You will be positioned sitting upright and the female investigator (Hollie Walusz) will secure you using torso, hip, thigh, and shin stabilization straps. After an explanation of the strength testing task, you will be allowed to practice each task sub-maximally. You will then perform five maximal contractions of two different strength protocols, consisting of three different testing speeds, targeting your quadriceps and hamstring musculature.

What are the possible benefits from being in this study?

Research is designed to benefit society by gaining new knowledge. You will not benefit personally from being in this research study, however the benefits to society include gaining information that researchers can analyze to better understand how body movement and strength differences in females affect ACL injury. This may help to prevent ACL injury in the future.

What are the possible risks or discomforts involved from being in this study?

As with any physical activity, participation in this study carries the risk of injury. The motions that you will be asked to perform are performed regularly during sporting activities, therefore, you will be familiar with them and should be able to perform the tasks with minimal injury risk. Demonstration of jump-landing task will be shown to you prior to completing the task. Also, practice repetitions of both the jump landing task and strength testing procedures will be allowed for familiarization. In case of injury, medical personnel (certified athletic trainers) will be located in the same building as where the testing will take place, and ice will be available if needed. You will be free to cease participation at any time. In addition, there may be uncommon or previously unknown risks that might occur. You should report any problems to the researchers.

How will your privacy be protected?

No participants will be identified in any report or publication about this study. You will be assigned an identification number (ID) for data collection that will be matched to the identifiers listed above in an excel document. This document will be stored on a separate CD apart from all other data that will be collected. These CDs will be stored in a locked cabinet with access only to members of the research team. Once all participants have completed the testing, identifiers will be deleted from the excel document. All data will be stored on CDs which will be kept in the Sports Medicine Research Laboratory. All data analysis will be performed on computers in the Sports Medicine Research Laboratory where a password is necessary for access to the computers. Only members performing research have access to these computers, therefore identification of any participants or data is very unlikely. If disclosure is ever required, UNC-CH will take all steps allowable by law to protect the privacy of personal information.

Personal privacy during testing sessions will be maintained by limiting the people within the research lab to current employees of the lab and the testers themselves. The only door to enter the lab is locked with key card access to ensure privacy. Although every effort will be made to keep research records private, there may be times when federal or state law requires the disclosure of such records, including personal information. This is very unlikely, but if disclosure is ever required, UNC-Chapel Hill will take steps allowable by law to protect the privacy of personal information. In some cases, your information in this research study could be reviewed by representatives of the University, research sponsors, or government agencies for purposes such as quality control or safety.

What will happen if you are injured by this research?

All research involves a chance that something bad might happen to you. This may include the risk of personal injury. In spite of all safety measures, you might develop a reaction or injury from being in this study. If such problems occur, the researchers will help you get medical care, but any costs for the medical care will be billed to you and/or your insurance company. The University of North Carolina at Chapel Hill has not set aside funds to pay you for any such reactions or injuries, or for the related medical care. However, by signing this form, you do not give up any of your legal rights. Certified Athletic Trainers will be present during all testing sessions in the rare possibility that an injury occurs.

Will you receive anything for being in this study?

You will not receive anything for taking part in this study.

Will it cost you anything to be in this study?

It will not cost you anything to be in this study. Each participant is only responsible for her own transportation to the Sports Medicine Research Laboratory for their one-hour testing session.

What if you are a UNC student?

You may choose not to be in the study or to stop being in the study before it is over at any time. This will not affect your class standing or grades at UNC-Chapel Hill. You will not be offered or receive any special consideration if you take part in this research.

What if you are a UNC employee?

Taking part in this research is not a part of your University duties, and refusing will not affect your job. You will not be offered or receive any special job-related consideration if you take part in this research.

What if you have questions about this study?

You have the right to ask, and have answered, any questions you may have about this research. If you have questions, or if a research-related injury occurs, you should contact the researchers listed on the first page of this form.

What if you have questions about your rights as a research participant?

All research on human volunteers is reviewed by a committee that works to protect your rights and welfare. If you have questions or concerns about your rights as a research subject you may contact, anonymously if you wish, the Institutional Review Board at 919-966-3113 or by email to IRB_subjects@unc.edu.

- -

Title of Study: The Relationship between Anterior Tibial Shear Force and Quadriceps\Hamstring Strength, Knee Flexion Angle, Hip Flexion Angle, and Trunk Flexion Angle during a Jump Landing Task
Study # : 06-0543

Participant's Agreement:

I have read the information provided above. I have asked all the questions I have at this time. I voluntarily agree to participate in this research study.

_____________________________________ ________________
Signature of Research Participant Date

____
Printed Name of Research Participant

_____________________________________ ________________
Signature of Person Obtaining Consent Date

____
Printed Name of Person Obtaining Consent

University of North Carolina – Chapel Hill
Research Study Questionnaire
Adult Participants

Behavioral IRB Study # 06-0543

Title of Study: The Relationship Between Anterior Tibial Shear Force and Quadriceps\Hamstring Strength, Knee Flexion Angle, Hip Flexion Angle, and Trunk Flexion Angle during a Jump Landing Task
Principal Investigator: Douglas R. Bennett, LAT, ATC
UNC-CH Department: EXSS
Phone Number: 919-962-7187
Co-Investigators: Hollie J. Walusz LAT, ATC; Darin Padua, PhD, ATC; Troy Blackburn, PhD, ATC; Michelle Boling, MS, ATC; Melanie McGrath, MS, ATC; Chris Hirth MS, PT, ATC
Sponsor: None

Name__________________________ Age___________________________

Height (cm) _____________________ Weight (kg)_____________________

1. Are you currently in good general health?

YES / NO

2. Do you currently have a lower extremity injury that has required days missed from physical activity?

YES / NO

3. Do you have a prior history of ACL injury, ligamentous reconstruction, or any knee surgery within the past two years?

YES / NO

4. Do you have any current symptoms of injury?

YES / NO

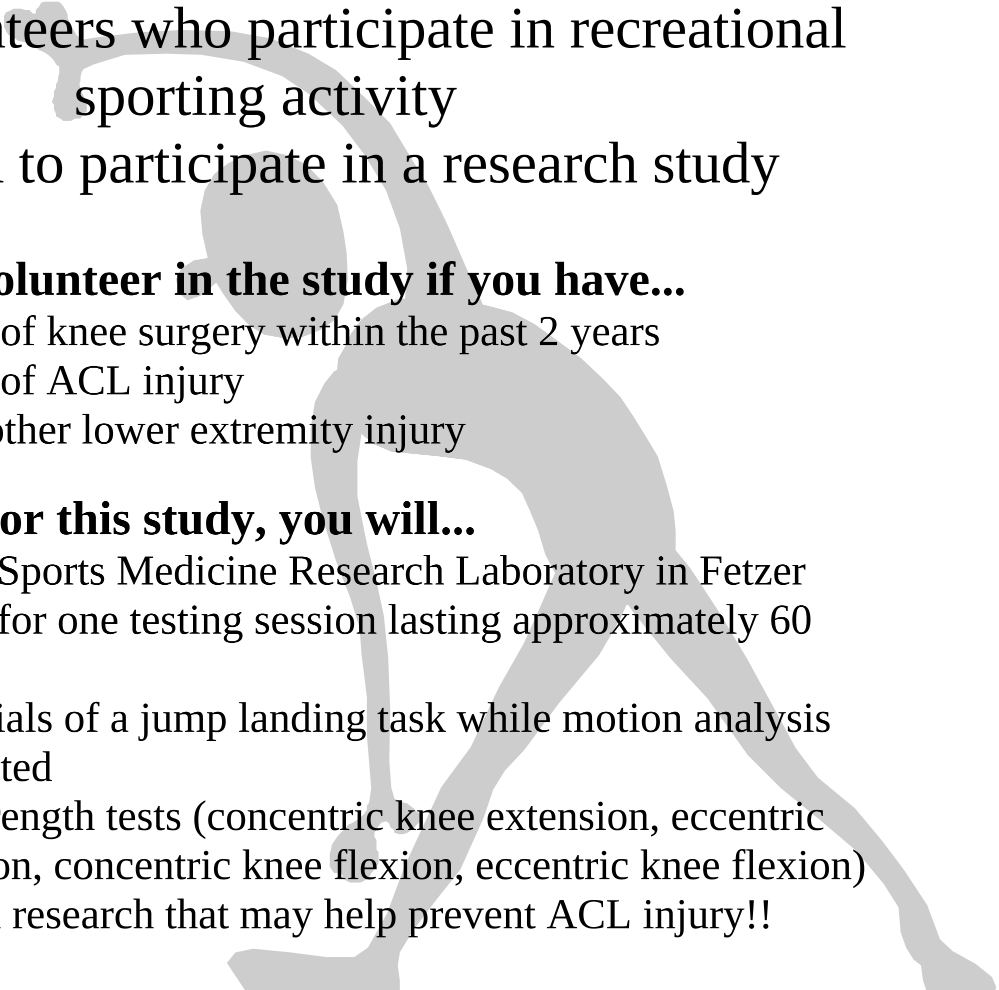
5. How often do you exercise per week? ___________________ Days

6. Approximately how many minutes do you exercise on those days?________Minutes

7. What type of exercise activity do you most often participate in (soccer, volleyball, basketball, etc.)?

____

VOLUNTEERS NEEDED FOR RESEARCH STUDY



Female volunteers who participate in recreational sporting activity
are needed to participate in a research study

You should not volunteer in the study if you have...

- prior history of knee surgery within the past 2 years
- prior history of ACL injury
- presence of other lower extremity injury

If you volunteer for this study, you will...

- report to the Sports Medicine Research Laboratory in Fetzer Gymnasium for one testing session lasting approximately 60 minutes
- perform10 trials of a jump landing task while motion analysis data is collected
- perform 4 strength tests (concentric knee extension, eccentric knee extension, concentric knee flexion, eccentric knee flexion)
- participate in research that may help prevent ACL injury!!

Contact Doug Bennett or Hollie Walusz if you are interested in volunteering for this study.

Doug Bennett, LAT, ATC
Hollie Walusz, LAT, ATC
Phone number: 814-244-2803
Phone number: 319-830-0796
Email: drb215@email.unc.edu
Email: walusz@email.unc.edu

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