AN EXPLORATION OF TIBIAL TUBERCLE TO TROCHLEAR GROOVE DISTANCE ON ANTERIOR CRUCIATE LIGAMENT INJURY

By

Matt Davey

A Thesis Presented to

The Faculty of Humboldt State University

In Partial Fulfillment of the Requirements for the Degree

Masters of Science in Kinesiology Exercise Science

Committee Membership

Dr. Rock Braithwaite, Committee Chair

Dr. Tina Manos, Committee Member

Dr. Justus Ortega, Committee Member

Dr. Rock Braithwaite, Graduate Coordinator

August 2013

Abstract

AN EXPLORATION OF TIBIAL TUBERCLE TO TROCHLEAR GROOVE DISTANCE ON ANTERIOR CRUCIATE LIGAMENT INJURY

Matt Davey

The Q-angle has long been hypothesized to be useful in predicting anterior cruciate ligament injury in athletes, but is difficult to reliably measure clinically. Tibial tubercle to trochlear groove is a reliable and accurate measurement that has the potential to replace Q-angle as a predictor for ACL injury. Magnetic resonance images of 42 subjects, 24 with ACL injury and 18 with no ACL injury, were analyzed and mean TTTG compared for differences between groups. A significant increase in mean TTTG (p=.035) was seen in male subjects and a significant decreases in mean TTTG (p=.028) was seen in women over 40. Results indicate TTTG may be useful in predicting ACL injury but further research is needed utilizing prospective measures and focusing on more specific demographics before TTTG can be used to predict ACL injury.

Acknowledgements

I wish to extend my deepest gratitude to the staff of the Kinesiology department at HSU, specifically to Rock and to T.K.. The commitment of my committee and all the professors I had while in classes proves that they truly care about their students' success. Without such a supportive and encouraging staff I'm sure I would not have finished this paper!

I also want to thank my parents and my loving wife, Natalie. Their continuing and persistent support throughout my overly drawn out writing process gave me the strength to follow through on my project. Natalie is a continuous inspiration to me in her dedication to her education and to her craft, it was this dedication that ultimately drove me to finish. I could not let her graduate before me!

Table of Contents

List of Figures

List of Tables

Chapter 1

Introduction

Injuries to the anterior cruciate ligament (ACL) (see Figure 1) account for an extensive amount of time lost from athletics and the workplace (Dunn, Lincoln, Hinton,

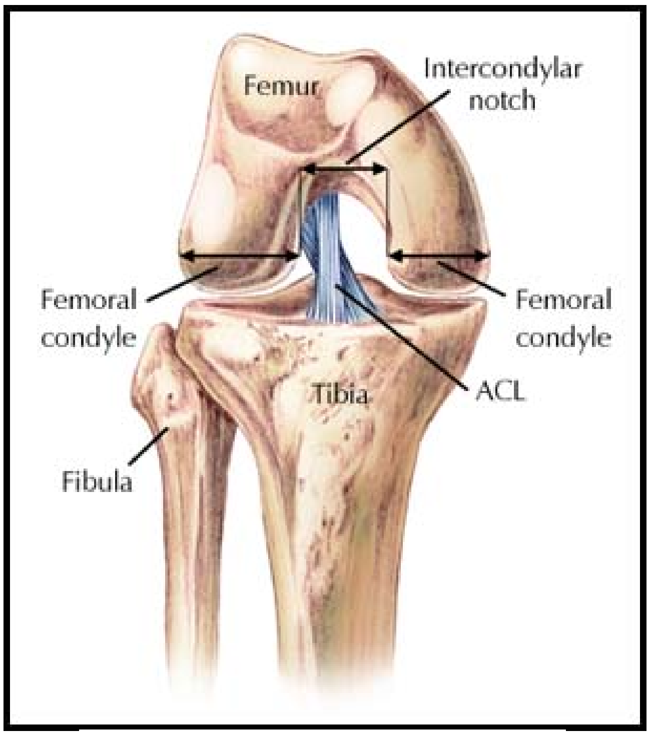


Figure 1 Anterior cruciate ligament provides stability to the knee by preventing excessive anterior translation of the tibia on the femur, www.hughston.com/hha/a_11_3_2.htm

Smith & Amoroso, 2003), as well as a considerable financial burden costing an estimated 1 billion dollars annually (Park, Wilson & Zhang, 2008). Identifying methods to determine risk factors associated with ACL injuries could have a significant impact on reducing the time lost and diminishing this financial burden. The ACL is the most commonly injured body part to Army personnel and collegiate athletes as studies have found 9.3% and 2.6% of all injuries are to the ACL, respectively (Agel, Evans, Dick, Putukian & Marshall, 2007; Lauder, Baker, Smith, Lincoln, 1994). The National Collegiate Athletic Association (NCAA) and the National Athletic Trainers Association (NATA) both advocate for research to identify risk factors and prophylactic measures associated with knee injuries. One measure that has been identified as a potential risk factor for knee injury is Q-angle. Messick (1999) demonstrated that athletes with a greater Q-angle had increased incidence of knee injury, and further hypothesized that a greater Q-angle is a potential cause of the increased incidence of ACL injuries.

Q-angle is identified by the lines between the quadriceps and patellar tendon and has undergone extensive research as a potential risk factor for ACL injuries. A biomechanical analysis of Q-angle and the lower leg kinetic chain demonstrate a theoretical relationship between an increased Q angle to a lateralization of the tibial tubercle and increased tibial tubercle to trochlear groove distance (TTTG). Muneta, Yamamoto, Ishibashi, Asahina and Furuya (1994) reported that tibial tubercle lateralization may be a major factor in patellofemoral pain and patellar subluxation. A lateralized tibial tubercle creates an insertion of the patellar tendon that will tend to pull the patella laterally out of the femoral groove and corresponds to the Mizuno et al. findings of an increased Q angle.

Using Q-angle as a diagnostic measurement technique is not without criticism. Measuring Q angle is unreliable as indicated by a low inter-rater reliability which prevents using this technique as an objective measure (Piva, et al., 2006). Jones, Bartlett, Vainright and Carroll (1995) stated the need for either a more reliable measurement for

Q-angle or developing another method of measuring the tibiofemoral angle in the frontal plane. Shakespeare and Fick (2005) attempted to establish a measurement of lateralization of the tibial tubercle by using lateral distance from the center of tibial tubercle to the center of the patella as an alternative to Q-angle but were unable to confirm this as a reliable measurement technique.

More recently, research has provided a potential solution by measuring the tibial tubercle to trochlear grove distance (TTTG) which is an indication of lateralization of the tibial tubercle (Schoettle, Zanetti, Seifert, Pfirrmann, Fucentese &Romero, 2006) and has the potential to be a consistent and reliable measurement for the tibiofemoral angle in the frontal plane. The TTTG is calculated by using computed tomography (CT) or magnetic resonance (MR) images to measure the distance from the anterior portion of the tibial tubercle to the deepest point in the trochlear groove. TTTG may be a useful tool in diagnosing tibiofemoral structural irregularities in the frontal plane, previously referred to as Q-angle (Beaconsfield, Hons, Pintore, Maffulli & Petri (1994). Using MR images to calculate the three-dimensional TTTG measurement is highly accurate and reliable (Schoettle, et al., 2006).

Statement of the Problem

Research suggests that there is a direct link between rotary forces on the knee and the incidence of ACL injury (Bonci, 1999). Currently no method exists to identify or quantify predisposing factors for ACL injury though continued research identifies a link between the lateral distance from the trochlear groove to the tibial tubercle that may provide this method. Therefore, further investigation is necessary to contribute to existing data on normal values for tibial tubercle to trochlear groove distance.

Purpose

To determine differences in TTTG measurements between non-contact ACL injured and non-injured populations.

Review of Literature

Q-Angle. Greene, Edwards, Wade and Carson (2001) define Q-angle as the angle formed by the intersection of a line connecting the anterior superior iliac spine to the center of the patella and a line from the center of the tibial tubercle through the center of the patella (see Figure 2). The Q-angle normally ranges from 6° to 27° (Mizuno, Kumagai, Mattessich, Elias, Ramrattan, Cosgarea & Chao, 2001) with a mean in women of 13.3-14.4° and a mean in men of 11.3-11.6° (Herrington and Nester, 2004). Hip width was initially thought to be the major determining factor in Q-angle, thereby predisposing athletes with wider hips to potentially greater stresses on the knee as a result of the greater Q-angle (Greene, et al., 2001). Recent studies, however, show that greater Q-angles exist independently of hip width with a greater effect stemming from a more laterally located tibial tubercle (TT) and that neither patellofemoral nor tibiofemoral joint kinematics are effected by hip adduction or abduction alone (Mizuno et al. 2001; Byl,Cole and Livingston, 2000).

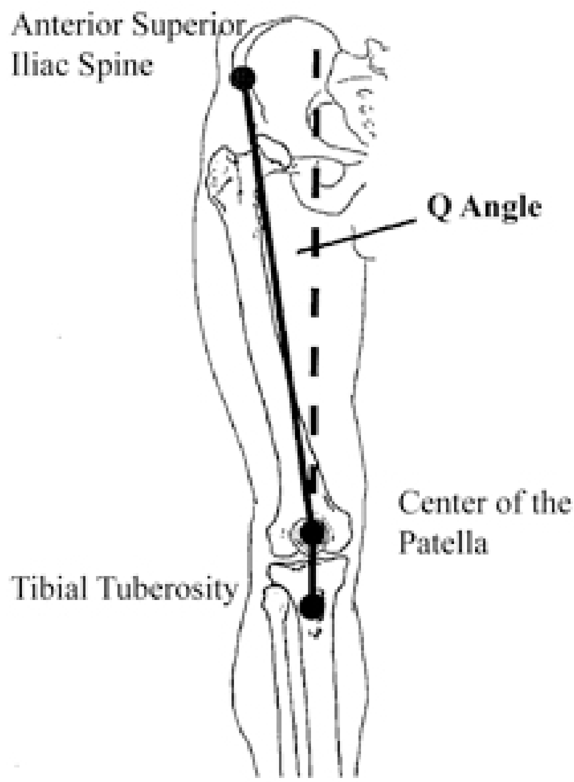


Figure 2 Q angle is the angle formed by the intersection of a line connecting the anterior superior iliac spine to the center of the patella and a line from the center of the tibial tubercle through the center of the patella, www.massagetoday.com/mpacms/mt/article.php?id=13838

Patellofemoral syndrome, or patellar malalignment, is a source of significant and often debilitating knee pain amongst the general public and competitive athletes alike. Mizuno et al., (2001) identified the patella as a sesamoid bone acting within the extensors of the leg that serves as a fulcrum for the quadriceps muscle group to extend the leg. A slight malalignment as the patella glides through the trochlear groove could result in pain from increased contact. In addition, considering the amount of force generated by the quadriceps muscle group, increased Q-angle may result in increased incidence of patellar dislocation. Increased Q-angle is associated with increased angle of force of the quadriceps acting on the patella. As the angle of force increases the patella can effectively be pulled out of the trochlear groove by the quadriceps contraction.

Mizuno et al. (2001) showed that while an increased Q-angle is associated with greater tibial external rotation and lateral shift of the patella. Conversely, a decreased Q-angle resulted in tibial internal rotation and patellar medialization. Heiderscheit, Hamill and Caldwell (2000) have demonstrated that subjects with an increased Q-angle had an increased time to maximal tibial internal rotation during running. What is unclear from their research is the kinematic change that would produce knee pain or injury. Their results do, however, indicate an externally rotated tibial tubercle will take longer to reach maximal internal rotation and identify a possible correlation between increased Q-angle and tibial external rotation.

Biomechanics. Jones, et al. (1995) noted that patients complaining of anterior knee pain tended to be those with a tibial tubercle that is located more lateral than normal in relation to the trochlear groove of the femur. An increase in the Q-angle transfers the force through the medial aspect on the knee and lower leg resulting in a decrease in the medial longitudinal arch (pes planus) of the foot (Derek, Cooke, Scudamore, & Greer, 2000). As the foot pronates the subtalar joint moves into calcaneal eversion, the tibia moves into internal rotation as the talus internally rotates. and Reischl, Powers, and Rao (1999) determined this rotation to average 3.7° after initial ground contact. They also noted a number of subjects with an average of 9.1° of internal rotation at heel strike but were unable to attribute a cause to this high degree of rotation (Reischl, et al., 1999). Tiberio (1987) found similar results in subjects complaining of patellofemoral pain after they excessively internally rotated their femur. This excessive femoral internal rotation brought about a relative external rotation of the tibia when the amount of rotation of the femur was greater than that of the tibia.

Powers, Maffucci, and Hampton (1995) described a condition where an increase in femoral internal rotation rotates the center of the femoral groove, and therefore the patella, medially in relation to the ASIS causing an increase in Q-angle. Mizuno et al. (2001) concluded that increased Q-angle results in increased lateral patellofemoral contact pressure. The resulting dysfunction causes pain and inflammation with physical activity and increases the possibility for patellar tendonitis if the changes in patellar alignment result in abnormal forces through the patellar tendon.

The same condition described by Powers et al. (1995) as affecting the force distribution through the patellar tendon also has the potential to create an uneven loading force distribution in the tibiofemoral joint. Insall, Scuderi and Komistek (2002) suggested that this abnormal loading is a cause of cartilage injury, with one side of the joint taking more stress than it would if the Q-angle were normal or the tibial tubercle not deviated laterally. Mizuno et al. (2001) also determined that decreased valgus orientation of the knee occurred with Q-angle decrease, and the resulting varus orientation could predispose the individual to ligmentous injury. This increased stress eventually leads to tissue failure with overuse or traumatic incidences inherent to physical activity, highlighting the effect on structural tissues in the knee Q angle have. Measuring surface Q-angle is highly unreliable because it is dependent on surface anatomy for necessary landmarks. While the patella is an important reference point for measurement of malalignment, the patella (Donell, 1996) is rarely the cause of malalignment. The patella provides a central reference point of the measurement, yet it is a free-floating bone and any medial or lateral deviation of the patella will affect the measurement (Jones et al., 1995). In addition, a dislocated patella or chronically subluxated patella may provide a surface reference that is abnormally altered laterally resulting in an inaccurate measure. Measuring Q-angle traditionally uses a surface goniometer centered on the patella and aligned along the femur with the ASIS and distally along the shaft of the tibia. Results have found that the measurement involves a significant amount of intra-rater and inter-rater variability (Piva, et al., 2006). Other measures have demonstrated methods for measuring the alignment of the patella and of the angle of the tibia on the femur including radiographic imaging of tibial tubercle lateralization (Beaconsfield et al., 1994).

Tibial Tubercle to Trochlear Groove Distance. A more accurate and more reliable measure for lower limb malalignment is the trochlear groove to tibial tubercle distance. The lateral distance from the center of the trochlear groove (TG, see Figure 3) of the femur to the anterior point of the tibial tubercle (TT, see Figure 4) provides a direct measure of the lateralization of the tibia in relation to the femur, with increased lateralization resulting in increased TT-TG distance (TTTG, see Figure 4) (Schoettle, et al., 2006). The attachment of the patellar tendon from the inferior pole of the patella to the tibial tubercle provides lateral stability to the alignment of the patella within the trochlear groove of the femur. An abnormal TT located laterally to the TG can cause tibial rotation increasing the Q-angle and can pull the patella out of its normal tracking

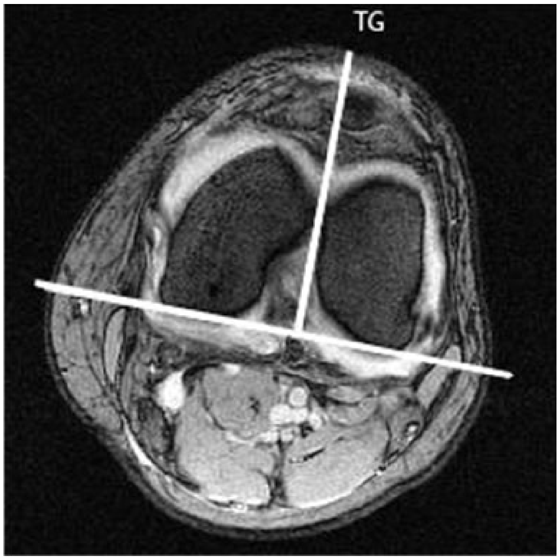


Figure 3 MRI showing trochlear groove with transverse condylar line and perpendicular line through trochlear groove.

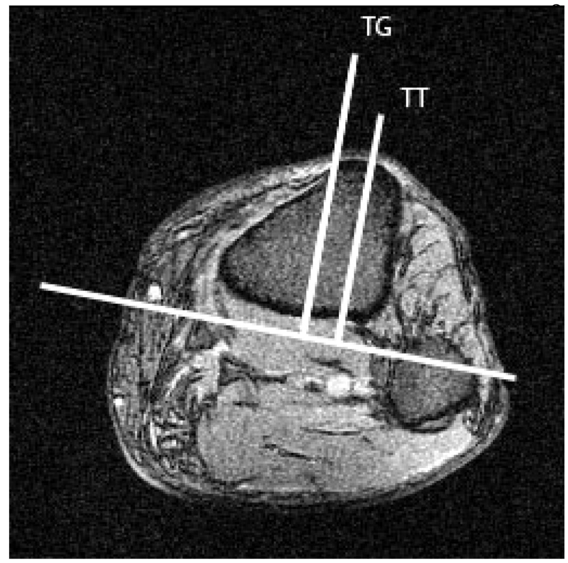


Figure 4 MR image of tibial tubercle with transverse condylar line and perpendicular lines indicating locations of trochlear groove (TG) and tibial tubercle (TT) to allow measurement of TTTG.

pattern. The resulting abnormal patellar tracking results in pain and dysfunction, possibly putting sufficient stress on the patella to cause subluxation or dislocation.

Lateralization of the tibia may affect more structures in the knee than just the patella. In a review of a number of studies on the epidemiology of ACL injuries, Shimokochi and Shultz (2008) presented significant evidence that at near full extension excessive valgus orientation and internal rotation of the femur on the tibia place the ACL at a greater risk for injury. External rotation of the lower leg, as indicated by a lateralized tibial tubercle, is an important mechanism for ACL injury because of the force on the ACL caused by the lateral motion of the tibia on the femur to the point where the ACL impinges on the lateral condyle of the femur (Fung & Zhang, 2003). The impingement causes a shearing affect on the ACL by the lateral femoral condyle and results in partial tearing or complete rupture of the ACL (Park et al., 2008).

McNally, Ostlere, Pal, Phillips, Reid and Dodd (2000) studied patellar tracking using magnetic resonance imaging (MRI) and reported that all subjects complaining of patellofemoral syndrome had TTTG distances of greater than 20mm. These results confirm previous findings that TTTG of greater than 20mm is highly predictive of symptoms in the affected side of patients with unilateral anterior knee pain (Jones et al., 1995). Jones and colleagues demonstrated that symptomatic knees had a TTTG of 12.2mm while TTTG of asymptomatic knees was 9mm. They determined that radiographic imaging is useful in effectively measuring the distance of the anterior tibial tubercle to femoral trochlear groove that will permit a more accurate diagnosis of anterior knee pain. Further research by Dejour, Walch, Nove-Josserand and Guier (1994) agrees with these values, establishing a normal range of 9-12mm for TTTG, recommending surgical medialization of the tibial tubercle of any TTTG greater than 20mm. Shakespeare et al. (2005) confirm these recommendations, stating that surgical reduction of TTTG greater than 20mm to 10mm or less is necessary to prevent further dysfunction.

To date no studies have examined the differences in TTTG to ACL injury or tibiofemoral cartilage damage, the possibility exists that increased TTTG will have a similar effect on ACL stability as it has on patellofemoral function. Values outside of the accepted normal may cause abnormal loading through the joint and may result in a change in muscular force on the joint. Abnormal force loading and muscular pull are hypothesized to be a major influence in causing non-contact ACL injury (Shimokochi & Shultz, 2008).

Studies of TTTG using conventional radiography and computed tomography (CT) scans have developed a method of measuring TT lateralization with high accuracy and reliability. While Donell (1996) reported that conventional radiographic studies such as x-rays and CT scans provide important information about patellar malalignment, two dimensional x-ray views are not suitable to accurate 3D measurements and CT scans provide only bony structure information. Cartilaginous and other soft tissue impact on the patellar alignment cannot be measured with x-rays or CT scans (Schoettle et al., 2006). Previous studies using CT scans required multiple scans to obtain three-dimensional views and to assess the cartilaginous trochlear groove resulting in more time spent on imaging, reading the images, and cost for the imaging (Schoettle et al.). The reliable and accurate measure of TT lateralization can provide a valuable tool in the assessment of knee pain and a potential preemptive strike on Anterior Cruciate Ligament injuries.

Anterior Cruciate Ligament. Physicians perform between 80,000 and 175,000 anterior cruciate ligament (ACL) reconstruction surgeries in the United States every year, at a cost of over $2 billion (Gottlob, Baker, Pellisser & Colvin, 1999 and Shimokochi et al., 2008), with an estimated 70% of these involving a non-contact mechanism (Park et al., 2007). In an analysis of injuries reported by the National Collegiate Athletic Association (NCAA) Injury Surveillance System (ISS) over a 16 year period from 1988-2004, Dick, Hootman, Agel, Vela, Marshall, and Messina (2007) reported an increase in ACL tears by 1.7% each year of the study, with 88% of ACL injuries result in loss of play time of 10 days or more.

Injury to the ACL occurs when excessive force is applied to the ligament. Non-contact injury occurs when this force is as a result of forces generated by the person only, without physical contact with another person or object, through excessive loading, lateral, or rotational forces on the tibiofemoral joint (Yu & Garrett, 2007). Most non-contact ACL injuries occur in sports that involve sudden deceleration, landing and cutting (Yu et al.) with the NCAA reporting highest incidence of ACL injury occurring in gymnastics, women's soccer, and men's football, followed closely by women's volleyball and lacrosse and men's soccer (Dick et al., 2007). Further, Dick et al. reported 17.7% of match injuries and 36.8% of practice injuries in collegiate field hockey were non-contact.

An increased valgus angle during a compressive force, such as landing or a plant/cut action, increases the strain on the ACL (Withrow, Huston, Wojtys, & Ashton-Miller, 2006) resulting in a non-contact mechanism of injury (MOI) to the ACL. Ireland (1999) described the "position of no return" as the position of the lower limb resulting in the most likely mechanism for ACL injury. This position is one of forefoot pronation and the resultant internal rotation of the tibia on the foot, knee extended with valgus force and the hip adducted and internally rotated. The position of no return prohibits the hip abductors and extensors from functioning to stabilize the body over the leg, and leaves the pelvis uncontrolled. The "position of no return" causes a complete loss of control and a resulting collapse of the affected lower limb as the tibia internally rotates with the pronation of the foot, the knee is brought into a more valgus position.

Shimokochi et al. (2008) suggest that control of body position and activation of thigh muscle is critical in preventing ACL injury in sudden deceleration and landing motions. The internal rotation and valgus force on the knee produces an internal rotation of the femur that, due to the positioning of the leg, the gluteal muscles are unable to control and is greater in magnitude than the rotation of the tibia. Effectively there is an external rotation of the tibia on the femur as the leg collapses medially and the femur rotates medially a greater amount than the tibia. A lateralized tibial tubercle results in the ACL being anchored in a more lateral position and amplifies the impingement of the ACL on the lateral femoral condyle during medial collapse.

Magnetic Resonance Imaging. Schoettle, et al. (2006) looked at the efficacy of magnetic resonance imaging (MRI) on assessing TTTG distance using a single image that includes both cartilaginous structures and three-dimensional image. The researchers concluded that MRI provides these aspects of the imaging as well as providing an accuracy of measure equal to that of the CT scan. Schoettle, et al. postulated that by knowing the cartilaginous structure the assessor gains a representation of the true points of reference for measure rather than strictly the bony landmarks. In this respect, MRI is a better tool for measuring TTTG than CT. The comparison of MRI TTTG with those patients suffering an ACL injury to the TTTG of patients with intact ACL may provide us as practitioners with important information on the causes of ACL tears in some individuals, and potentially a method for preventing ACL tears or recurrence of ACL injury. Early identification of athletes with these risk factors may prevent season and career-ending injuries.

Hypothesis

Non-contact anterior cruciate ligament injuries will have a greater tibial tubercle to trochlear groove distance when compared to individuals not sustaining an ACL injury.

Limitations

The limitations of this study include the external validity of the study. The (i) low sample size represents a wide age range, preventing the possibility to generalize results. Patient history (ii) is another limitation; the level of activity of the subject prior to injury and the incidents leading up to the injury are not known, (iii) the athletic status of the subjects is not known. Predisposing factors such as the subjects' history may have a profound effect on the cause of injury and the results of this study.

Delimitations

This study is delimited to subjects (i) within the age 19-57, (ii) have sustained a non-contact knee injury, and (iii) do not have a previous history of anterior knee pain. All subjects who meet these requirements will be included in the study.

Operational Definitions

For the purposes of this study a non-contact mechanism of injury (MOI) is considered an injury sustained without the influence of a force outside the subject's production.

TTTG refers to tibial tubercle to trochlear groove distance. The lateral distance from the center of the trochlear groove of the femur to the center of the tibial tubercle (Schoettle, et al., 2006)

Chapter 2

The purpose of this study is to determine the ability of the TTTG measurement to identify differences in non-contact ACL injuries further adding to existing knowledge regarding the "normal" TTTG measurement. The TTTG measurement has the potential to identify a predisposing factory in injury to the ACL. The ability to accurately and reliably measure TTTG may allow clinicians to prophylactically treat those individuals at higher risk of injury in an attempt to prevent injury from occurring. In order to determine the differences in injury status to TTTG measurement the following procedure was developed. The Internal Review Board (IRB) for the use of human subjects approved this study before any data was collected.

Subjects

The data set consisted of 42 subjects classified in an ACL injury group (n =24) and the non-ACL injury group (n =18). There were 12 female and 12 male in the ACL injury group and 13 female and 5 male in the non-ACL injury group, with an age range of 19-57 years for both groups. The average age of subjects in the ACL group was 35 years 2 months and the average age of the non-ACL group was 38 years 6 months.

Instruments

The primary researcher calculated the TTTG measurement by performing three independent measurements for each knee MRI using T2 weighted axial view images. The averages of the three measurements of the valid medical records were used for the study. The researcher took measurements of each subject in the group one time, and then went back through all MRI re-taking measurements in the group a second and third time to avoid bias from previous measurements.

Procedures

All records used for data collection were from patients between the ages of 19 and 57 with the percentage of records for female patients (57%) corresponding with NCAA's reports indicating that 61% of all ACL injuries to college athletes are sustained by women (Hootman, Dick & Agel, 2007). Records of patients who had any previous or current injury to other knee ligaments, meniscal tears or associated cartilage damage were excluded from the study. A chart review was conducted on existing patient records by the medical assistant of a local orthopedic surgeon to identify medical records meeting these requirements, with isolated non-contact ACL tears. All records meeting the selection criteria were used in the study.

In order to ensure patient confidentially, the physician's medical assistant conducted the chart review to identify medical records for data collection. The medical assistant maintained all medical records identified for use in this study in a location that was not accessible to the researcher. Further, the medical assistant loaded the CD containing the patients MRI images into the computer, as well as launched the viewing and data collection program and opened the required MRI images. The computer program used for viewing the MRI images and data collection allowed for removal of the patient's personal information from the image viewer. The researcher was not present in the room anytime that the medical assistant was loading and removing the patient personal information on the computer screen. Once the medical assistant had the corresponding MRI images displayed on the computer screen the researcher entered the room to collect data. Since the researcher did not have excess to any patient personal information for this retrospective study an informed consent was not required from the patients whose files data was be collected from.

Magnetic Resonance Images

Retrospective MR images from a standard axial T2 weighted knee MRI examination were used to calculate the tibial tubercle to trochlear groove (TTTG) measurement. This view provided the cross-sectional cut and the clearest view of bony structures necessary to identify landmarks in this study. The first proximal image that depicted the complete cartilaginous trochlea (see Figure 3) was used to determine the deepest point of the trochlear groove. This point offered the most accurate identification of the center of the groove needed for identifying the center of the groove, from which the lateralization of the tibial tubercle was measured. Using the line tool of the MRI viewing program a line was drawn tangent to the posterior edges of the femoral condyles, known as the “transverse condylar line”. The perpendicular line tool was then used to draw a line perpendicular to the transverse condylar line through the center of the trochlear groove (see Figure 4). These lines remained on all subsequent images.

Next the researcher scrolled through the images that depicted the tibial tubercle and identified the image that provided the clearest view of the tubercle and allowed determination of the most anterior point of the tibial tubercle, and drew a line perpendicular to transverse condylar line through that most anterior point. The measurement tool was then used to accurately measure the distance between the two parallel lines, which was the tibial tubercle to trochlear groove (TTTG) distance (Figure 4). Using the tangent- and perpendicular-line tools included in the MRI viewing program the lines are ensured to be straight and parallel thus making the measurements objectively accurate.

Statistical Analysis

Independent variables in the current investigation were categorical and included injury (ACL or Non-ACL), gender (male or female), and age (under 40 years or over 40 years). The dependent variable was TTTG measurement in millimeters. Descriptive statistics (means and standard deviations) were calculated for the TTTG measurement across all categorical variables. Independent T-tests compared mean TTTG of the ACL group versus the mean TTTG of the non-ACL injured group for the primary analysis. Secondary analyses also used independent t-Tests for TTTG measurements between males and females and age groups. Secondary analyses Statistical Packages for the Social Sciences (SPSS) version 20.0 was used to perform all analyses.

Chapter 3

The purpose of this study was to explore the effectiveness of the TTTG measurement as a predictor for ACL injury. TTTG after non-contact ACL injury was compared to TTTG of non-ACL injured knees and analyzed using an independent samples *t*-Test on SPSS 20.0. The results displayed in Table 1 show the difference of mean TTTG between ACL injured subjects and non-ACL injured subjects with continued analyses amongst various demographics.

Table 1
Descriptive & Inferential Statistics for TTTG measurements

	non-ACL Injured	non-ACL n	ACL Injured	ACL n	*p*-value
All Subjects	11.16 (3.14)	18	12.01 (3.91)	24	.436
Male Subjects	9.68 (2.63)	5	13.43 (4.19)	12	.035
Female Subjects	11.79 (3.09)	13	10.59 (3.18)	12	.349
All Subjects Age 18-25	13.89 (.41)	2	12.53 (2.89)	5	.357
All Subjects Age 26-55	11.58 (3.04)	15	12.09 (4.19)	19	.673
Male College Aged (18-25)	N/T	0	N/T	3	N/T
Female College Aged (18-25)	12.28 (1.15)	2	13.89 (.41)	2	.202
Male over 40	12.91 (5.29)	3	12.38 (2.93)	9	.822
Female over 40	12.86 (4.7)	6	8.74 2.54	12	.028
All Subjects over 40	12.88 (4.83)	10	10.00 (3.25)	21	.081

Summary of results of mean (standard deviation) TTTG measurements (mm) compared to ACL injury status across a variety of demographics. Mean (standard error) values are recorded in millimeters (mm). Male College Aged subjects not tested (N/T) due to lack of subjects for comparison.

No significant increase in ACL injury with increased TTTG distance was found between the mean TTTG of the ACL injury group 12.01mm and of the non-ACL injury group 11.16mm (see Table 1, *p*=. 436). Further analysis showed that all male subjects a significantly increased TTTG in the ACL group with mean 13.43mm compared to non-ACL with mean 9.68mm (*p*=.035). Women had an insignificant difference in TTTG between groups (*p*=.349) with mean TTTG in the non-ACL group of 11.79mm and in the ACL group of 10.59. Women over the age of 40 showed a significant difference in TTTG from the Non-ACL group to the ACL group (*p*=.026). Men of all ages had a strong but insignificant increased mean TTTG of 12.27mm while women of all ages had a mean TTTG of 11.21mm (see Figure 5, *p*=.110).

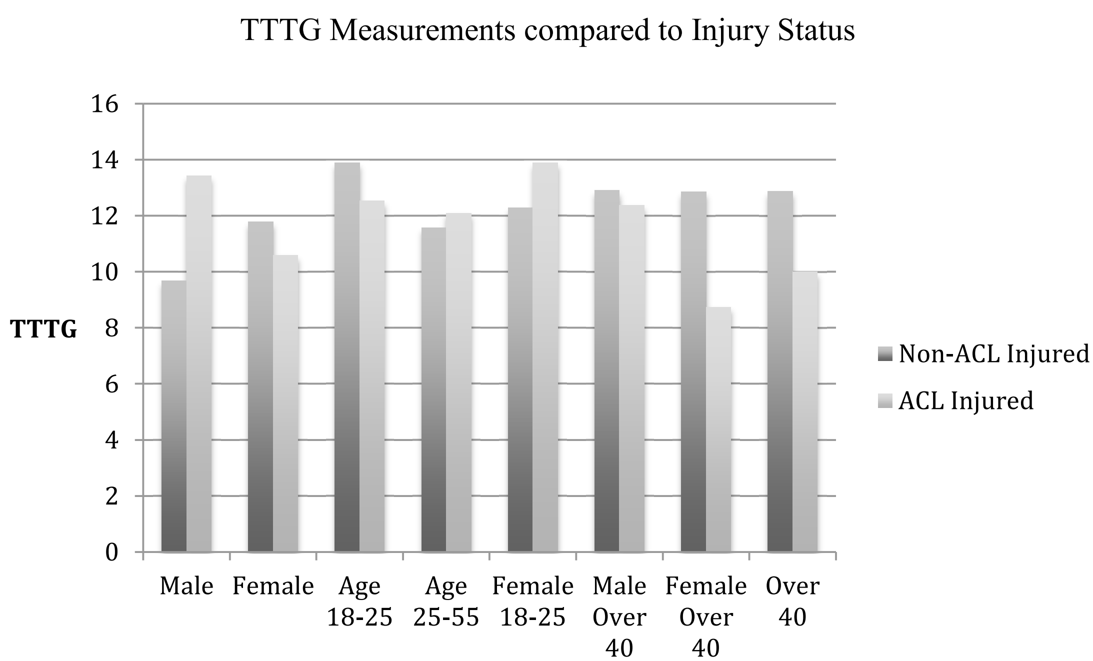


Figure 5 Comparison of the relationship of mean TTTG to ACL injury between specific subject groups.

Chapter 4

Purpose

The purpose of this study was to explore the differences between tibial tubercle to trochlear groove distance and ACL injury. Dejour and colleagues (2004) established a normal TTTG across all demographics of 9-12mm in asymptomatic knees. The results shown here (see Table 1) support the established normal with a mean non-ACL injured TTTG of 11.16mm and a mean ACL injured TTTG of 12.01mm. The lack of significance (p=.436) does not support the hypothesized increased TTTG in ACL injured subjects. Analysis of more specific demographics further explores the differences between TTTG and ACL injury.

In a study of 143 subjects Boden, Dean, Feagin, and Garrett (1990) found 72% were of a non-contact mechanism of injury (MOI) with the majority of those involving a mechanism that included external tibial rotation. Boden, et al. (1990) hypothesized that a greater Q-angle in women leads to the greater ACL injury in women. The hypothesized link between increased Q-angle and increased ACL injury and to date has yet to be substantiated by research (Sutton & Bullock, 2013). The hypothetical connection between Q-angle and ACL injury is exemplified in the “point of no return” theory presented by Ireland (1999). Increased lateralization of the tibial tubercle would make the knee more susceptible to injury in the “point of no return” mechanism by placing the ACL under increased tension (Bonci, 1999).

The current study suggests a trend in the data as there was an increased TTTG measurement with a mean of non-ACL TTTG of 9.68mm compared to a mean ACL injured TTTG of 13.43mm (*p*=.035). The non-ACL injured TTTG results for men also support the normal values for TTTG established by Dejour et al., (2004) of 9-12mm for asymptomatic knees. Studies have found that men have a lower Q-angle compared to women (Mizuno, et al., 2001) and the current results support the connection between Q-angle and TTTG with mean TTTG in non-ACL injured men being lower (9.68mm) compared to women (11.79mm).

However, the results do not fit with the theoretical link between Q-angle and increased TTTG measurement with ACL injury in women presented in a study from Gwinn, Wilckens, McDevitt, Ross and Kao (2000). According to Gwinn, et al. (2000) an increased Q-angle and corresponding increase in TTTG predisposes the individual to ACL injury. The results presented here for women do not support the existing data or the hypothesis as those results are not significant (*p*=.349), suggesting that the difference between TTTG and ACL injury exist independently of Q-angle as TTTG values recorded for all female subjects of both groups in this study were within the normal values established by Dejour, et al. (1994).

A possible explanation for this inconsistency is that there exists more than one predisposing factor for women experiencing an ACL injury. The current findings support previous studies, as summarized by Bonci (1999), suggesting that attempting to identify one single factor will not fully explain the documented increased incidence of female ACL injury. An alternative explanation to increased incidence of ACL injury in females is the hormonal differences between men and women. Vescovi (2011) suggested that there is a tissue change in women correlating menses related to low estrogen and progesterone concentrations. Menstrual changes could predispose women to ligamentous or other soft-tissue injury, though accurately identifying phase of menstrual cycle during which injury occurred is difficult when analyzing retrospectively, making conclusions unreliable.

Lipps, Oh, Ashton-Miller, and Wojtys (2012) have determined that there are gender differences in incidence of ACL injury. Lipps and colleagues propose that differences exist because females have a smaller cross-sectional area of the ACL making them more susceptible to injury. Gender differences might also be attributed to female sports movement technique training, specifically during landing and cutting movements (Lipps et al). Female athletes sustaining ACL injury have been shown to have decreased single-leg stance stability than male counterparts (Hewett, Paterno & Myer, 2002) and that female athletes tended to land with a greater valgus angle (Ford, Myer & Hewett, 2003).

Huston and Wojtys (1996) have found that men and women exhibited different strength characteristics upon landing, with women utilizing more quadriceps dominance to absorb the force of landing and men using more hamstring dominance. This muscular disparity creates a situation where the force of the quadriceps can pull the tibia anteriorly with such force in the female athlete that the ACL is overpowered and fails. Research suggests that TTTG measurements are predictive of ACL injury in men, indicating that men are more specific as to their predisposition to ACL injury. However, multiple factors affect women including Q-angle/TTTG, hormone balance, neuromuscular strength and balance, and sport-related movement technique and intensity (Cimino, Volk,

& Setter, 2010). It is these factors that combine to make TTTG much less accurate in predicting ACL injury in women, as shown in this study.

A significantly increased TTTG in ACL injured subjects compared to non-ACL injured subjects is not seen in any other groups besides men. All subjects over the age of 40 showed a trend (p=.081), with women over the age of 40 showing a significant decrease (p=.026) in ACL injured TTTG compared to non-ACL injured TTTG. Since all of the results for the over 40 subjects are outside of the normal TTTG values established by Dejour et al., (2004) normal values for TTTG are potentially not valid for older people. Bonci (1999) cited data that suggests the tibial tubercle becomes more laterally rotated as people age. Further, the types of activity and intensity of activity change as people get older decreasing the effect technique and musculoskeletal strength have on causing higher rates of injury to the ACL in women. The results of this study correspond with Bonci's study and suggest that TTTG has more of an effect on ACL injury as women get older, becoming the primary predisposing factor in women over 40.

The results of this study identify trends of increased TTTG in ACL injured men as compared to TTTG in non-ACL injured men, but could not identify a difference in women. While research indicates that females are at a higher risk for injury to the ACL (Hootman et al., 2007), based on these results prophylactic treatments targeted at addressing structural deficiencies related to increased Q-angle as estimated by TTTG will not have an effect in preventing injury to the ACL in women.

Limitations

One major limitation of this study is the lack of information on individual patients' history. To make the study more specific to a particular the specific mechanism of injury would need to be known. Future studies should be focused to injuries sustained during athletic activity. The current study was able to control for non-contact injuries, however increased specificity as to the mechanism of injury and to the time since the injury would ensure the mechanism is entirely free of outside influence. A second limitation is the small sample size. Due to the lack of available images for study, the age range was expanded to improve sample size and thus improve the reliability of the study. This made the study much less specific as it covered a very broad demographic.

Chapter 5

The current research does suggest a link between TTTG and ACL injury amongst men, but does not support the connection between increased Q-angle and TTTG to ACL injury in women. There is a need for further research focusing on a sample more specific to college aged subjects and with increased sample size to explore the differences between TTTG and ACL injury. The ability to obtain MRI prior to injury as a predictor would be much more beneficial in proving differences and establishing TTTG as a cause of ACL injury. Further research is also needed analyzing the link between Q-angle and TTTG. A study correlating Q-angle to TTTG is necessary to confirm the proposed link between the two measurements. A prospective study of athletes measuring TTTG and Q-angle prior to injury would give valuable insight into the role structure of the knee plays in injury. Further, established normal values for TTTG should be examined and revised to represent the potential differences between age groups.

References

Agel, J., Evans, T.A., Dick, R., Putukian, M., & Marshall, S.W. (2007). Descriptive epidemiology of collegiate men's soccer injuries: National Collegiate Athletic Association injury surveillance system, 1988-1989 through 2002-2003. *Journal of Athletic Training 42,* 270-277.

Beaconsfield, T., Hons, B.S., Pintore, E., Maffulli, N., & Petri, G.J. (1994). Radiological measurements in patellofemoral disorders: A Review. *Clinical Orthopaedics and Related Research, 308,* 18-28.

Boden, B.P., Dean, G.S., Feagin, J.A., & Garrett, P. (2000). Mechanisms of anterior cruciate ligament injury. *Orthopedics, 23,* 573-578.

Bonci, Christine M. (1999). Assessment and evaluation of predisposing factors to anterior cruciate ligament. *Journal of Athletic Training, 34,* (2), 155-164.

Byl, T., Cole, J.A., & Livingston, L.A. (2000). What determines the magnitude of the Q angle? A preliminary study of selected skeletal and muscular measures. *Journal of Sports Rehabilitation*, 9, 26-34.

Cimino, F., Volk, B.S., & Setter, D. (2010). Anterior cruciate ligament injury: diagnosis, management, and prevention. *American Family Physician 82*(8), 917-922.

Dejour, H., Walch, G., Nove-Josserand, L., & Guier, C., (1994). Factors of patellar instability: An anatomic radiographic study. *Knee Surgery, Sports Traumatology, Arthroscopy, 2,* 19-26.

Derek, T., Cooke,V., Scudamore, R.A., & Greer, W. (2000). Axial alignment of the lower limb and its association with disorders of the knee. *Operative Techniques in Sports Medicine, 8*(2), 98-107.

Dick, R., Hootman, J.M., Agel, J., Vela, L., Marshall, S.W., & Messina, R. (2007). Descriptive epidemiology of collegiate women's field hockey injuries: National Collegiate Athletic Association injury surveillance system, 1988-1989 through 2002-2003. *Journal of Athletic Training, 42* (2), 211-220.

Donell, Simon (1996). Petello-femoral malalignment radiological assessment. *The Knee 3.* 73-105.

Dunn, W.R., Lincoln, A.E., Hinton, R.Y., Smith, G.S., & Amoroso, P.J. (2003). Occupational disability after hospitalization for the treatment of an injury of the anterior cruciate ligament. *Journal of Bone and Joint Surgery 85,* 1656-1666.

Ford, K.R., Myer, G.D., & Hewett, T.E. (2003). Valgus knee motion during landing in high school female and male basketball players. *Medicine & Science in Sports & Exercise, 35*(10), 1745-1750.

Fung, D.T. & Zhang, L. (2003). Modeling of ACL impingement against the intercondylar notch. *Clinical Biomechanics, 18,* 933-941.

Garrick, J. G., & Requa, R. K. (2001). Anterior cruciate ligament injuries in men and women: how common are they. *Prevention of Noncontact ACL Injuries. Rosemont, Ill: American Academy of Orthopaedic Surgeons,* 1-9.

Gottlob, C.A., Baker Jr., C.L., Pellissier, J.M., & Colvin, L. (1999). Cost effectiveness of anterior cruciate ligament reconstruction in young adults. *Clinical Orthopaedics and Related Research, 367,* 272-282.

Greene, C.G., Edwards, T.B., Wade, M.R., & Carson, E.W. (2001). Reliability of the quadriceps angle measurement. *American Journal of Knee Surgery, 14,* 97-103.

Gwinn, D.E., Wilckens, J.H., McDevitt, E.R., Ross, G., & Kao, T.C. (2000). The relative incidence of anterior cruciate ligament injury in men and women at the United States Naval Academy. *American Journal of Sports Medicine, 28,* 98-102.

Heiderscheit, B.C., Hamill, J., & Caldwell, G.E. (2000). Influence of Q-angle on lower extremity running kinematics. *Journal of Orthopaedic & Sports Physical Therapy*, 30(5), 271-278.

Herrington, L. & Nester, C. (2004). Q-angle undervalued? The relationship between Q-angle and medio-lateral position of the patella. *Clinical Biomechanics, 19,* 1070-1073.

Hewett, T.E., Paterno, M.V., & Myer, G.D. (2002). Strategies for enhancing proprioception and neuromuscular control of the knee. *Clinical Orthopaedics & Related Research, 402,* 76-94.

Hootman, J.M., Dick, R., & Agel, J. (2007). Epidemiology of collegiate Injuries for 15 Sports: Summary and recommendations for injury prevention initiatives. *Journal of Athletic Training, 42,* 311-319.

Insall, J.N., Scuderi, G.R. & Komistek, R.D. (2002). Correlation between condylar lift-off and femoral component alignment. *Clinical Orthopaedics and Related Research, 403,* 143-152.

Ireland, M.L. (1999). Anterior Cruciate Ligament Injury in Female Athlete: Epidemiology. *Journal of Athletic Training, 34* (2), 150-154.

Jones, R.B., Bartlett, E.C., Vainright, J.R., & Carroll, R.G. (1995). CT determination of tibial tubercle lateralization in patients presenting with anterior knee pain. *Skeletal Radiology, 24,* 505-509.

Lauder, T.D., Baker, S.P., Smith, G.S., & Lincoln, A.E. (2000). Sports and physical training injury hospitalizations in the army. *American Journal of Preventative Medicine, 18* (3S), 118-128.

Lipps, D.B., Oh, Y.K., Ashton-Miller, J.A., & Wojtys, E.M. (2012). Morphologic characteristics help explain the gender difference in peak anterior cruciate ligament strain during a simulated pivot landing. *American Journal of Sports Medicine, 40*(1), 32-40.

Lowe, W. 2006. [*Image of Q-angle*]. Retrieved from www.massagetoday.com/mpacms/mt/article.php?id=13838

McNally, E.G., Ostlere, S.J., Pal, C., Phillips, A., Reid, H., & Dodd, C. (2000). Assessment of patellar maltracking using combined static and dynamic MRI. *European Radiology, 10,* 1050-1055.

McLindon, Robert. n.d.. [Image of ligament structures of knee]. Retrieved from www.hughston.com/hha/a_11_3_2.htm

Messick, R.E., (1999) The role of the Q angle and quadriceps strength in knee injuries in female college athletes. Thesis Obtained From The Sage Colleges Division of Health and Rehabilitation Sciences.

Mizuno, Y., Kumagai, M., & Mattessich, S.M. (2001). Q-angle influences tibiofemoral and patellofemoral kinematics. *Journal of Orthopaedic Research, 19* (5), 834-840.

Muneta, T., Yamamoto, H., Ishibashi, T., Asahina, S., & Furuya, K. (1994). Computerized tomographic analysis of tibial tubercle position in the painful female patellofemoral joint. *The American Journal of Sports Medicine, 22,* (1) 67-71.

Park, H.-S., Wilson, N.A., & Zhang, L.-Q. (2008). Gender differences in passive knee biomechanical properties in tibial rotation. *Journal of Orthopaedic Research, Jul.* 937-944.

Piva, S.R., Fitzgerald, K., Irrgang, J.J., Jones, S., Hando, B.R., Browder, D.A. & Childs, J.D., (2006). Reliability of measures of impairments associated with patellofemoral pain syndrome. *BMC Musculoskeletal disorders, 7,* 1471-1484.

Powers, C.M., Maffucci, R. & Hampton, S. (1995). Rearfoot posture in subjects with patellofemoral pain. *The Journal of Orthopaedic and Sports Physical Therapy, 22* (4), 155-160.

Reischl, S.F., Powers, C.M., Rao, S., & Perry, J. (1999). Relationship between foot pronation and rotation of the tibia and femur during walking. *Foot & Ankle International, 20* (8), 513-520.

Schoettle, P.B., Zanetti, M., Seifert, B., Pfirrmann, C.W.A., Fucentese, S.F., & Romero, J. (2006). The tibial tuberosity-trochlear groove distance; A comparative study between CT and MRI scanning. *The Knee, 13,* 26-31.

Shakespeare, D. & Fick, D. (2005). Patellar instability- can the TT-TG distance be measured clinically? *The Knee, 12,* 201-204.

Shimokochi, Y. & Shultz, S.J. (2008). Mechanisms of noncontact anterior cruciate ligament injury. *Journal of Athletic Training, 43* (4), 396-408.

Sutton, K.M., & Bullock, J.M. (2013). Anterior cruciate ligament rupture: differences between males and females. *Journal of the American Academy of Orthopaedic Surgeons, 21,* (1), 41-50.

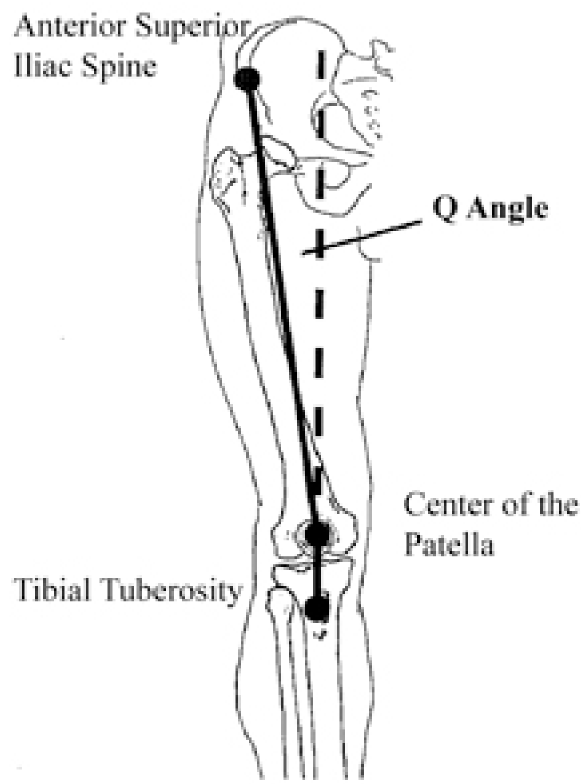
Tiberio, D. (1987). The effect of excessive subtalar joint pronation on patellofemoral mechanics: A theoretical model. *The Journal of Orthopaedic and Sports Physical Therapy, October, 160-16.*

Vescovi, J.D., Rupf, R., Brown, T.D., & Marques, M.D. (2011). Physical performance characteristics of high-level female soccer players 12-21 years of age. *Scandinavian Journal of Medicine & Science in Sports, 21*(5), 670-678.

Withrow, T.J., Huston, L.J., Wojtys, E.M., & Ashton-Miller, J.A., (2006). The effect of an impulsive knee valgus moment on in vitro relative ACL strain during a simulated jump landing. *Clinical Biomechanics,21,* 977-983.

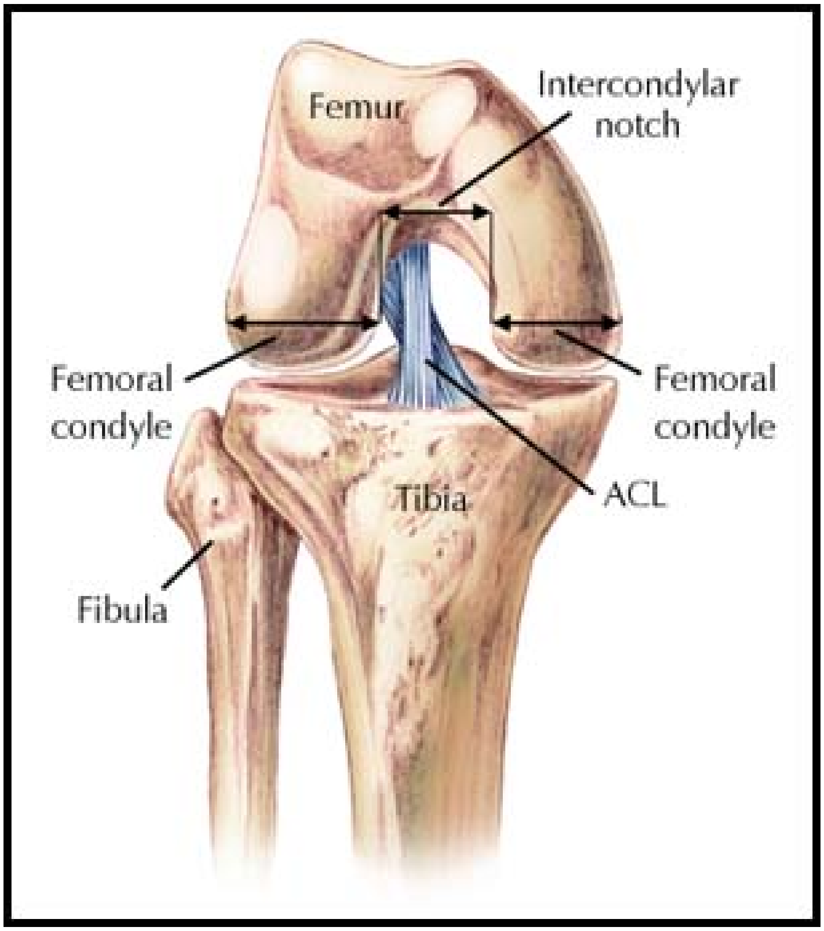
Yu, B. & Garrett, W.E. (2007). Mechanisms of non-contact ACL injuries. *British Journal of Sports Medicine, 41 (Suppl),* 47-51.

Figure 1



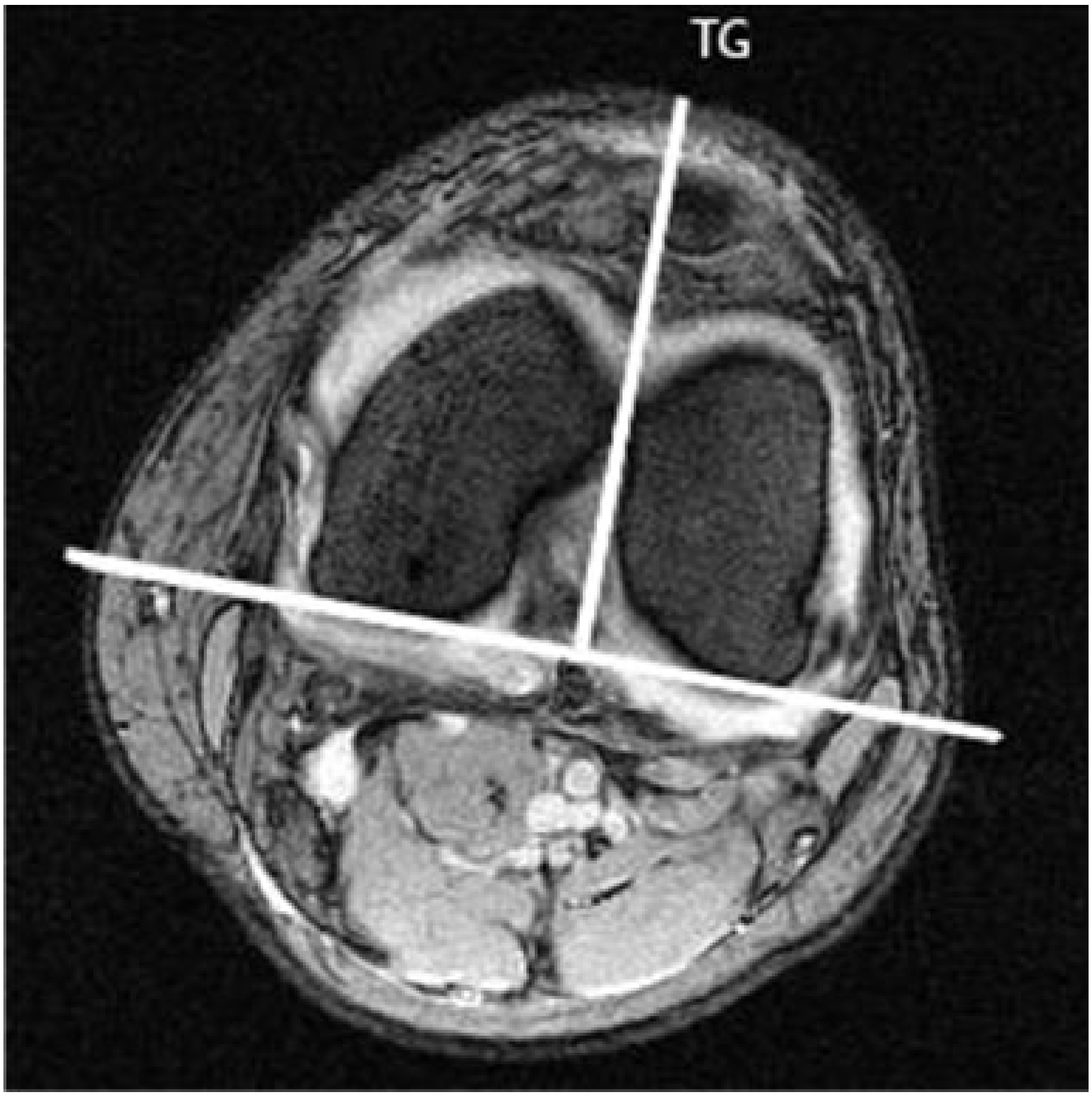
Q angle is the angle formed by the intersection of a line connecting the anterior superior iliac spine to the center of the patella and a line from the center of the tibial tubercle through the center of the patella.

Figure 2



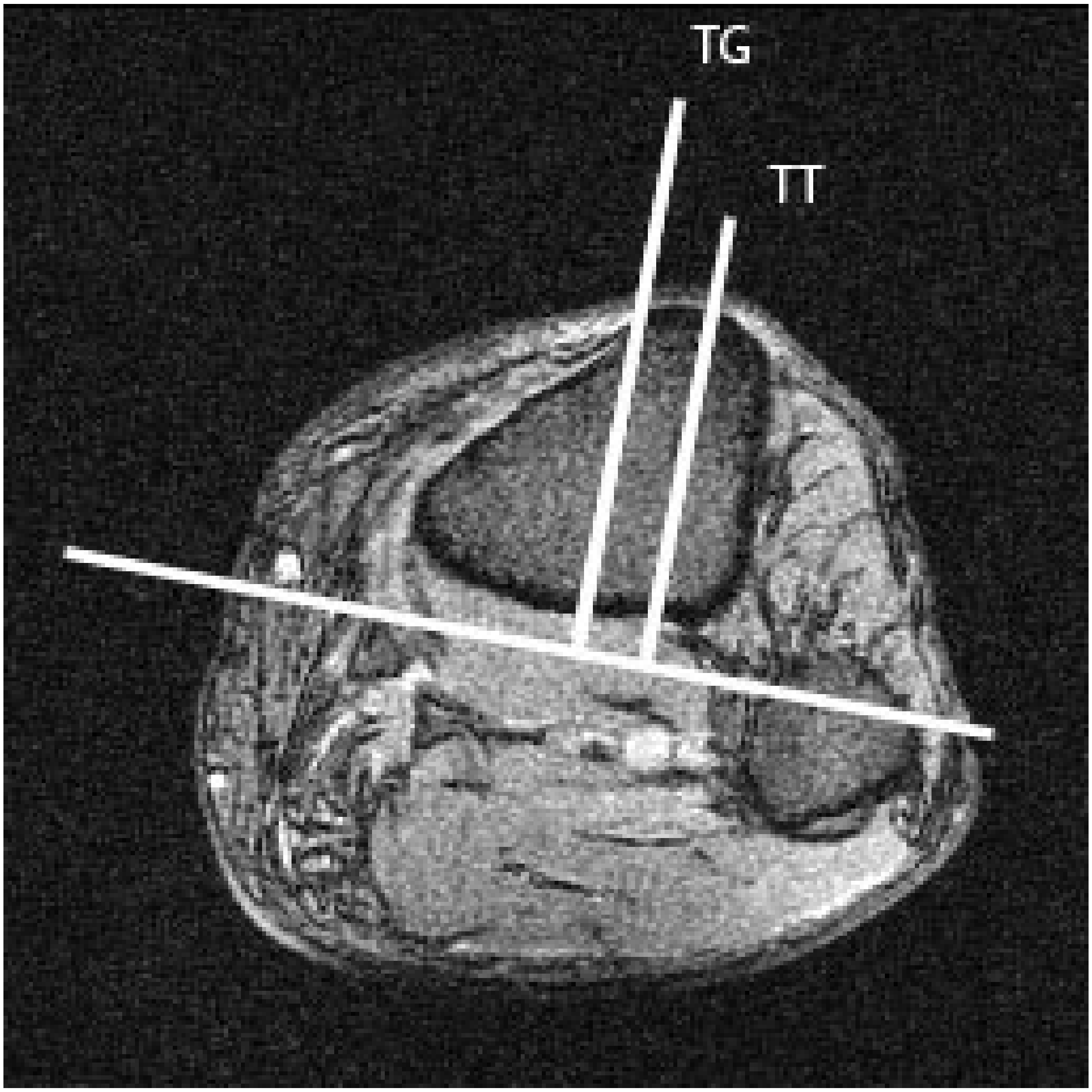
Anterior cruciate ligament provides stability to the knee by preventing excessive anterior translation of the tibia in relation to the femur.

Figure 3



MRI showing trochlear groove with transverse condylar line and perpendicular line through trochlear groove.

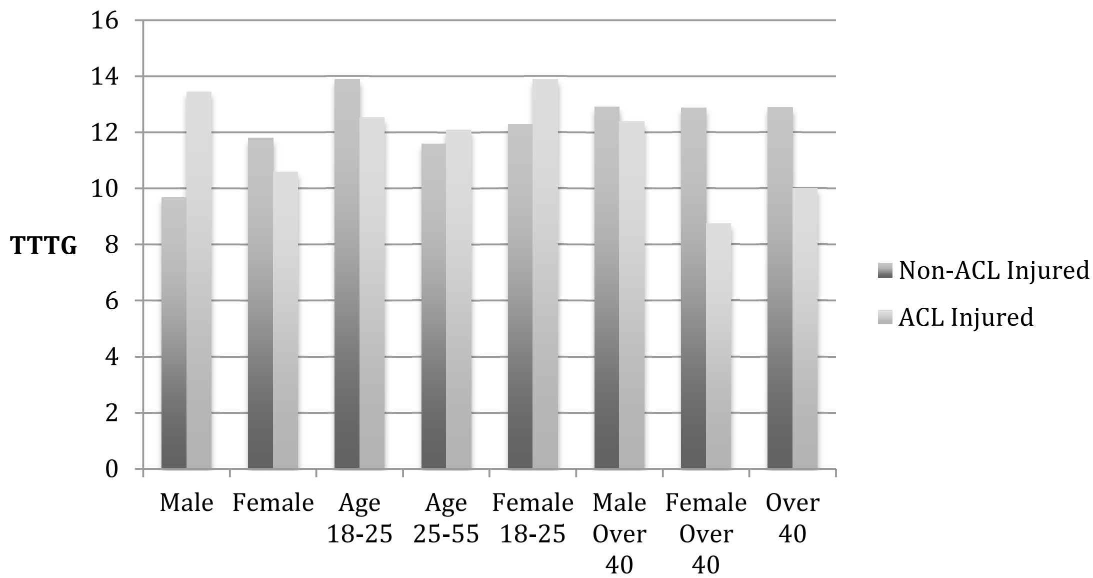
Figure 4



MR image of tibial tubercle with transverse condylar line and perpendicular lines indicating locations of trochlear groove (TG) and tibial tubercle (TT) to allow measurement of TTTG

Figure 5

Relationship of TTTG to ACL Injury



Comparison of the relationship of mean TTTG to ACL injury between specific subject groups.

Table 2
Descriptive & Inferential Statistics for TTTG measurements

	non-ACL Injured	non-ACL n	ACL Injured	ACL n	*p*-value
All Subjects	11.16 (3.14)	18	12.01 (3.91)	24	.436
Male Subjects	9.68 (2.63)	5	13.43 (4.19)	12	.035
Female Subjects	11.79 (3.09)	13	10.59 (3.18)	12	.349
All Subjects Age 18-25	13.89 (.41)	2	12.53 (2.89)	5	.357
All Subjects Age 26-55	11.58 (3.04)	15	12.09 (4.19)	19	.673
Male College Aged (18-25)	N/T	0	N/T	3	N/T
Female College Aged (18-25)	12.28 (1.15)	2	13.89 (.41)	2	.202
Male over 40	12.91 (5.29)	3	12.38 (2.93)	9	.822
Female over 40	12.86 (4.7)	6	8.74 2.54	12	.028
All Subjects over 40	12.88 (4.83)	10	10.00 (3.25)	21	.081

Summary of results of mean (standard deviation) TTTG measurements (mm) compared to ACL injury status across a variety of demographics. Mean and standard deviation values are recorded in millimeters (mm). Male College Aged subjects not tested (N/T) due to lack of subjects for comparison.