Gender differences in anterior cruciate ligament injuries

Carey Ann Balderrama

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GENDER DIFFERENCES IN ANTERIOR CRUCIATE LIGAMENT INJURIES

A Project
Presented to the
Faculty of
California State University,
San Bernardino

In Partial Fulfillment
Of the Requirements for the Degree
Master of Arts
in
Education:
Kinesiology

by
Carey Ann Balderrama
June 2006
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ABSTRACT

Female Participation in intercollegiate athletics has increased dramatically over the past twenty years. Due to the increased awareness of health and medical issues specific to the female athlete, one such area of focus has been the Anterior Cruciate Ligament (ACL). Studies have shown a significantly higher rate of Anterior Cruciate Ligament injuries in females compared to males participating in the same sport. The primary mechanism of injury to the Anterior Cruciate Ligament has been noncontact in nature. Some possible causative factors for this increase in ACL injuries among females may be intrinsic (hormonal, anatomical, muscular imbalances and neuromuscular) and extrinsic (shoe-surface interface, body posture and movement, and skill level and conditioning). Current trends have focused on the implementation of prevention programs for female athletes that concentrate on neuromuscular control, muscular strengthening and body posture and movement techniques. Data have shown that none of these factors alone can cause a tear but with multiple factors present, females are at greater risk for ACL injury.
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CHAPTER ONE
THE ANTERIOR CRUCIATE LIGAMENT

Introduction

The Anterior Cruciate Ligament (ACL) is one of the most commonly disrupted ligaments in the knee. Each year in the United States there are approximately 250,000 ACL injuries, or 1 in 3,000 in the general population (Arendt & Dick, 1995). During the last twenty years participation among female athletes has increased dramatically (Arendt & Dick, 1995). With this increase, the focus of attention by athletes, coaches, athletic trainers, and physicians has turned to the higher incidence of ACL injuries among female athletes in comparison to their male counterparts participating in the same sport. Researchers have noticed the increased incidence of ACL injuries among female athletes who participate in jumping and pivoting sports. Many studies have focused their attention to the possible causative factors associated with the discrepancy between the genders. Studies have shown that many factors may contribute to the higher incidence of ACL injuries in females, including differences in intrinsic factors such as
hormones, anatomical differences, biomechanical considerations. Other factors associated with ACL injuries are extrinsic, or environmental, such as shoe-surface interface, body posture and movement, and skill level and conditioning (Arendt & Dick, 1995). Current trends focus on the implementation of preventative programs that emphasize neuromuscular control, muscular strengthening, body posture and movement. Whatever the factors may be, it is undeniably noticeable that the injury rate among females is greater than males of the same sport.

**Purpose of the Study**

The purpose of this study is to examine the injury rates associated with ACL injuries as it pertains to gender and the causative factors associated with the significant difference in injury rates between genders. Through the examination of existing literature covering injury rates and the factors that possibly contribute to the increased rates of noncontact ACL injuries for female athletes, this study plans to encompass all preventative aspects associated with identifying all risk factors of female ACL injuries and to present existing preventative programs that might help lower the injury rates.
Limitations of the Study

This study was limited to current literature on what has been perceived to be the possible causative factors associated with gender differences of noncontact ACL injuries. The data is relatively new and in a lot of cases can only be examined post injury. Common factors are noticed after injury and do not account for the possibility of some female athletes with predisposing factors and no ACL injuries.

Definition of Terms

Anterior tibial translation - forward or anterior movement of the tibia.

Anteversion - Forward displacement or turning forward of a body segment without bending.

Collagen synthesis - To build up the fibrous albuminoid constituent of bone, cartilage, and connective tissue.

Division I, II, III - Levels of the National Collegiate Athletic Association (NCAA), with specific requirements of the amount of sports offered, financial awards offered, amount of games played all of which must be meet to be a member of the NCAA.
Eccentric - The muscle lengthens while contracting.

Estrogen - A steroid hormone produced by the ovary.

Fibroblast - Fibrous tissue.

Genu Recurvatum - Hyperextension at the knee joint.

Genu Valgum - Knock-knee or a deformity marked by lateral angulation of the leg in relation to the thigh.

Hyperextension - Extreme stretching of a body part.

Hypertrophied - Enlargement of a part by an increase in the size of the cells.

Intercondylar - Between condyles (rounded articulatory prominence at the end of the bone)

Neuromuscular - Neural control of human movement.

Plyometrics - Type of exercise that maximizes the myotatic (muscle) or stretch reflex.

Progesterone - A female hormone secreted by the corpus luteum of the ovary prior to implantation of the fertilized egg.

Protagonists - The primary mover.

Q-Angle - The angle formed between the line of resultant force produced by the quadriceps muscles and the line of the infrapatellar tendon.
Relaxin - A female hormone secreted by the corpus luteum that helps soften the cervix and relax the pelvic ligaments in childbirth.

Shoe-Surface Interface - A surface forming a common boundary, by shoe and surface.

Sprain - A painful tearing of ligaments.

Valgus Stress - Position of a body part that is bent outward or away from the midline of the body.

Varus Stress - Position of a body part that is bent inward.
CHAPTER TWO
DEFINING THE ANTERIOR CRUCIATE LIGAMENT

Anatomy

The Anterior Cruciate Ligament is approximately three centimeters long and originates on the lateral femoral condyle within the intercondylar notch (Woodfor-Rogers, Cypert, & Denegar, 1995). The ACL inserts into the tibial plateau medial to the anterior horn of the lateral meniscus (Woodfor-Rogers et al, 1995). A ligament is a tough, relatively inelastic band of tissue that connects one bone to another. The ACL consists of an anteriomedial band and a posterolateral band. The anteriomedial band is tighter when the knee is flexed while the posterolateral band is tighter in extension. With the knee straight the secondary restraint action of the hamstrings is minimal and the posterolateral band provides additional stability. The ACL is considered a knee-joint stabilizer and is a primary restraint to anterior tibial translation and counteracts excessive rotation and valgus stress (Arendt & Dick, 1995). The ACL is the fulcrum for knee stability. It is able to resist a tensile force of 2,000 newtons(N) (Renstrom, Arms, 6
& Stanwyck, 1986). During normal daily function with small loads, the ACL only reaches 20% of its failure capacity and the highest loads of stress are experienced during quadriceps activated knee extension from 40 degrees to full extension (Renstrom et al, 1986).

**Injury Classification**

Torn ACL's are classified by degree of damage to the ligament (partial or complete disruption) and the presence or absence of damage to other structures in the knee (isolated or combined). The severity of the damage is commonly classified by three degrees of a sprain. A grade one sprain consists of some stretching and separation of the ligament fibers, with minimal instability of the joint. With a grade one sprain there is some mild to moderate pain, localized swelling and joint stiffness. A grade two sprain involves some tearing and separation of the ligament fibers, with moderate instability of the joint, which includes moderate to severe pain, swelling, and joint stiffness. A grade three sprain is the total tearing of the ligament, which leads to major instability of the joint. Initially, severe pain may be present, followed by little or no pain as a result of total disruption of nerve fibers.
Swelling may be great, and the joint tends to become very stiff some hours after the injury. Frequently, the force producing the ligament injury is so great that other ligaments or structures surrounding the joint may be also be injured. Partial sprains (grade one or two) account for about 15 percent of ACL problems, while 85 percent are complete disruptions (grade three) (Arendt & Dick, 1995).

**Mechanism of Injury**

ACL injuries occur due to either contact by an opponent or by no apparent contact or noncontact. Contact injuries occur due to a blow by an opponent to the lateral aspect of the knee or leg causing a valgus collapse or by a blow to the anterior aspect of the knee causing a forced hyperextension of the knee joint (Moul, 1998). A noncontact ACL injury is usually during a deceleration and change of direction with the foot planted and fixed. A noncontact injury includes stopping quickly, cutting sharply, and landing and changing direction with one or two feet planted. Moul’s (1998) study found that the noncontact mechanism occurred 72% of the time. During Arendt and Dick’s 1995 original study conducted from 1989 to 1993, they found that in the sports of soccer and basketball the
primary mechanism of injury was by "no apparent contact". While Arendt and Dick (1999) found that in women's soccer 63% of injuries were noncontact and in women's basketball 80% of the injuries were noncontact. Three major "no-hit" mechanisms were identified: pivoting and cutting (29%), straight knee landing (28%), and one-step stop landing with the knee hyperextended (43%) (Arendt et al, 1995). One proposed reason for this noncontact or "no hit" mechanism of injury is the close proximity of an opponent which causes the athlete to stop quickly or decelerate and cut, which causes a disruption in the injured athlete's coordination or motor pattern. With predisposing factors, this puts the athlete at risk of tearing the ACL.

Moul's (1998) study found that a popping was described in 70% of ACL failures. A pop usually signals that the ACL is torn completely. The average angle of knee flexion at the time of injury was estimated to be 21 degrees (Moul, 1998). The most commonly reported activities at time of injury are basketball and soccer. Even with these common injury mechanisms, sharp changes in direction, landing and rapid deceleration are normally repeated thousands of times without injury (Arendt & Dick, 1995)
CHAPTER THREE
INJURY RATES

Gender Differences in Injury Rates

Many studies have proven that female athletes are more likely to incur an ACL injury than their male counterparts. Arendt and Dick's (1995) study through the National Collegiate Athletic Association (NCAA) Injury Surveillance System (ISS), surveyed 739 collegiate soccer and basketball teams over a five-year span from 1989 to 1993. This study showed that both collegiate soccer and basketball exhibit consistent differences in ACL injuries between males and females in a large national sampling. Female soccer players had an ACL injury rate of 2.4 times the rate of their male counterparts throughout the five-year period. Female basketball players had an ACL injury rate of at least 3.0 times more than male basketball players. Another study by Oliphant and Drawbert (1996) examined 22 Wisconsin colleges from the Division I to the Division III level, which showed that female basketball players were at 2.3 times greater risk of ACL injury than males. Another study by Ireland (1999) reviewed data by the NCAA ISS, and found that from
1990 through 1998, female basketball players incurred 2.89 times the ACL injuries of male basketball players, and female soccer players sustained 2.29 times more ACL injuries than male soccer players. Mihata et al (2006) found similar rates for the years of 1989 to 2004, excluding the 1996-1997, using the NCAA ISS, where 1097 male soccer teams and 1034 female soccer teams submitted data. For basketball, 1488 male teams and 1530 female teams provided data to the ISS. The rate of soccer injuries over this 15 year span is almost three times higher in females than in their male counterparts. In basketball, the rate of injuries for females was almost four times higher than in males. Mihata et al (2006) and Arendt et al (1999) had both hypothesized that ACL injury rates between females and males in the sports of soccer and basketball would decrease due to the increased participation of females, the increased level of skill and conditioning, and the increased awareness of ACL injuries. If anything these recent studies have shown that the injury rates have increased.
Proposed Causes

Some proposed causes of the differences in ACL injuries between males and females are intrinsic factors (hormones, anatomical, biomechanical considerations) and extrinsic factors (shoe-surface interface, body posture and movement, and skill level and conditioning). Intrinsic factors are those factors that are considered to be player related, personal, and inherent or built in. Extrinsic factors are considered to be environment related or external. Arendt et al (1999) classifies intrinsic factors as those factors that are individual, physical, and psychosocial and extrinsic factors as those factors related to the type of sport, the manner in which that sport is practiced, environmental conditions, and the equipment used to participate in that sport. This study will examine both intrinsic and extrinsic risk factors and how these factors might affect the differences associated with injury rates.
CHAPTER FOUR

INTRINSIC FACTORS

Introduction

Intrinsic factors are those that are player related, or internal. Females have many intrinsic factors that may cause them to be at a greater risk for an ACL injury. These factors are hormones, anatomical (lower extremity alignment, joint laxity, ligament size, intercondylar notch dimensions), biomechanical (neuromuscular considerations and muscular imbalances).

Hormones

One proposed cause of ACL injuries in female athletes is the affect that hormones have on a female’s ACL during her menstrual cycle. The menstrual cycle is characterized by three different phases, follicular (days 1 to 9), ovulatory (days 10 to 14), and luteal (day 15 to end of the cycle) (Wojtys, Huston, Lindenfeld, Hewett, & Greenfeld, 1998). During the course of the cycle, the absolute levels of estrogen and progesterone and the ratio of these hormone concentrations change over the mean cycle duration of 28 days (Wojtys et al, 1998). In the follicular phase (days 1
to 9), concentrations of both estrogen and progesterone are low. Ovulation (days 10 to 14) is preceded by a midcycle surge of estrogen. During the luteal phase (days 15 to end of cycle), progesterone levels rise significantly because of secretion by the corpus luteum, and relaxin levels increase halfway through this phase (Wojtys et al, 1998).

Estrogen and progesterone have been reported to have receptor sites on the human ACL (Huston & Wojtys, 1996). It has been shown that an increase in estrogen directly affects collagen synthesis and fibroblast proliferation. Collagen, which is produced by fibroblasts, performs the major load-bearing function of the ACL (Huston & Wojtys, 1996) and any alteration in the metabolism of these collagen fibroblasts directly influences the type, quantity, and stability of the collagen in the ACL. This means any rise in estrogen, during the midcycle, may diminish the tensile strength of the ACL putting the female athlete at risk of injury. Collagen synthesis also decreases with the production of relaxin, which has been shown to be related to low back and pelvic pain during pregnancy and is thought to be associated with ligamentous relaxation of the pubis and pelvis to accommodate the size
of the fetus and fetal passage during birth (Heitz, Eisenman, Beck, & Walker, 1999).

Both estrogen and progesterone have been shown to also affect the central nervous system (Wojtys et al. 1998). Estrogen decreases fine motor skills by acting on the central and peripheral nervous systems (Huston & Wojtys, 1996). Motor skill deficits may diminish the normal neuromuscular protective mechanisms of the knee placing the female athlete at greater risk of an ACL injury.

Studies by Wojtys et al (1998), Heitz et al (1999), and Wojtys et al (2002) all agreed that a greater percentage of ACL injuries occurred during the ovulatory phase (days 10 to 14), and the least amount of ACL injuries occurred during the luteal phase (days 15 to end of cycle). The study by Wojtys et al (2002) examined 69 females who sustained an acute ACL injury. Within 24 hours of injury urine samples were collected, along with menstrual cycle details and history. This has been the largest study to date especially in relation to the close proximity of the time of injury and the ability to receive medical data from the athletes. This study observed that females not taking oral contraceptives were 2.5 times more at risk for injury.
during the ovulation phase. Further studies need to address the affects that oral contraceptives have on ACL injury rates.

**Anatomical**

Females are anatomically different than males and these differences are evident when examining the muscles and bones of a female’s hips and lower extremity. Females when compared to males of the same age have a wider pelvis, greater femoral anteversion, greater external tibial torsion, genu valgum and greater Q-angle. They also have increased flexibility, hyperextension, and greater rotational laxity in their knee joint. Females also have less developed thigh musculature, and have less muscle mass per total body weight, making the knee more dependent on the ligaments for stability. Excessive pronation and pes planus also might contribute to the injury rate increasing the external tibial rotation by placing greater strain on the ACL. Females also have a smaller ACL located in a narrower notch in the femur where the ACL is attached, and some studies suggest possible impingement of the ACL in this narrower notch. This study will review literature specifically concerning the anatomical areas of lower
extremity alignment, joint laxity, ligament size and intercondylar notch dimensions and the implications these possess as factors for ACL injuries in females.

In Bonci's (1999) study, Sahrmann (1987) defined ideal posture as "the state of muscular and skeletal balance that protects the supporting structures of the body against injury or progressive deformity, regardless of the attitude in which these structures are working or resting, i.e., erect, lying, running, squatting, jumping, etc." "Faulty alignment of limbs or skeletal segment deviations detract from the efficiency of limb motion, result in higher levels of energy consumption and mechanical stress, and contribute to potential or actual pathology of the neuromusculoskeletal system" (p. 156). During stages of excessive loading and strain, the supporting structures are placed under extreme loads where critical stress limits are being met. In relation to faulty structural alignments, it is theorized that the joints are already in positions of a preloading effect on the ligaments, subjecting them to complete structural failure. As mentioned before, a mechanism for complete structural failure of the ACL is a situation in which the body is in a position of forward
flexion, the hip in adduction, the femur in internal rotation, the knee in 20 to 30 degrees of flexion, the tibia is in external rotation and the foot is in pronation or another common mechanism is when the knee is in hyperextension, the foot is in a fixed position and torsional stresses are involved. With these mechanisms combined with the predisposed strain of excessive loading of a biomechanically faulty posture, and faulty limb alignment places the ACL at greater risk for disruption.

**Lower Extremity Alignment.** A possible factor for increased injury rates in relation to the ACL is the difference in lower extremity alignment. Females are more likely to have an anteriorly rotated pelvis or anteversion (Ireland, 2001). "In the anteriorly rotated pelvis position, the hip is interiorly rotated and varus, and the knee is in valgus recurvatum. The tibia is externally rotated, the forefoot is pronated, and the lumbar lordosis is increased" (Ireland, 2001, p.29). Femoral anteversion is characterized by the excessive internal rotation of the femoral shaft in stance (Bonci, 1999). It is defined as the projection of the angle between the long axis of the femoral neck and the axis through the femoral condyles in
the transverse plane and this angle measures approximately 15 degrees (Bonci, 1999).

Females also have a wider pelvis and greater quadriceps angle (Q-angle). An increased Q-angle can result from an increased femoral anteversion, excessive tibial torsion, or excessive pronation. The Q-angle is the angle formed by the intersection of a line from the anterior superior iliac spine to the center of the patella and a line from the center of the patella to the tibial tubercle. Normal Q-angle ranges from approximately 10 degrees to 15 degrees with the knee in full extension. A wider pelvis and greater Q-angle places the knee in a more valgus or unstable position (Oliphant & Drawphant, 1996). The physiologic valgus of the knee gives an angle, between the pull of the muscle and that of the tendon (Bonci, 1999). Q-angle is often associated with increased external tibial rotation. Moul's (1998) study measured Q-angle at 30 degrees in females and found that the external rotation was increased placing added stress on the ACL. Moul (1998) also found that the greatest magnitude of force was incurred by the ACL at 30 degrees of knee flexion.
Another lower extremity alignment factor that might increase an athlete’s chances for injury is excessive foot pronation or hyperpronation. This specifically focuses on the subtalar joint (STJ) which is a single axis joint that acts as a hinge between the talus and the calcaneus. This joint is the most important joint of the foot and ankle as it affects the performance of the distal articulations and modifies the forces imposed on the skeletal and soft tissues transmitted upward through the ankle, knee, hip joint, pelvis and spine all the way up through the body. Excessive motion of the STJ can lead to poor shock absorption and increased tibial internal rotation. The ACL tightens with tibial internal rotation. Therefore excessive motion of the STJ or hyperpronation can cause the tibia to rotate internally causing more stress and loading on the ACL. This excessive pronation can be measured by the navicular drop test. Woodford-Rogers et al (1994) measured navicular drop on 22 ACL injured subjects and found that they had greater navicular drop which suggests increased pronation. Allen and Glasoe (2000) used a Metrecom, which is an electromechanical three-dimensional digitizer, to measure the amount of navicular drop on 18 subjects with
previous ACL injury. This study showed a mean statistic of 10.5 mm in movement. Healthy, normal subjects are reported to have a drop of six to nine millimeters of movement. Smith, Szczerba, Arnold, Martin, and Perrin's (1997) study of 28 subjects, 14 with ACL injuries and 14 with no ACL injuries, were examined using the navicular drop test and the tests did not distinguish a difference between the two groups. This study hypothesized that the reason for these results may be that females have smaller drop values, or that the sampling size was too small (Smith et al, 1997). One reason might be that this study was conducted by hand and did not use the Metrecom machine, and that possible human error was involved. Excessive pronation has been linked to overuse injuries of knee, and studies have shown that there is a link between ACL injured athletes and excessive pronation.

An additional risk factor involving lower extremity alignment is genu recurvatum, or knee hyperextension. This is usually a structural abnormality either acquired from repetitive and chronic stress of the soft tissue or is genetic and can be seen by hyperextension of other joints.
such as the fingers, elbows and abduction of the thumb to reach the forearm, which generally indicates joint laxity.

**Joint Laxity.** In the past some authors have tried to relate "loose-jointed" knees as being more susceptible to injury but subsequent analysis has yet to prove that this theory is true especially as it relates to gender differences (Arendt & Dick, 1995). In a study by Woodford-Rogers, Cyphert, and Denegar (1994), 14 ACL injured males and eight ACL injured females were examined and compared with 14 non-injured males and eight non-injured females and compared anterior knee joint laxity using a KT-1000 instrument. Their study revealed anterior knee laxity in the ACL injured athlete's noninvolved limb versus the non-injured athletes. No comparison was made in relation to possible gender difference. This study was also too small to show a true relationship between anterior knee joint laxity and ACL injuries as well as no further research has shown this relationship to be true.

What has been well documented is the effect of exercise in increasing anterior-posterior (AP) laxity in knees and the relationship to ACL intact knees as well as ACL deficient knees (Arendt & Dick, 1995). It has been
shown that all knees show some AP laxity after exercise but not necessarily related to gender differences. This laxity could be inherent to the genetic make up of the ligament, probably physiologic, and an integral part of connective tissue function (Arendt & Dick, 1995).

Anatomically and biomechanically researchers can verify the roles that lower extremity alignment and Q-angle play on regards to a female’s body, and can infer the implications they play on the ACL, but, there has yet to be any studies that prove that a correlation between the limb alignment and ACL injuries exist. Further research needs to be done to clarify the influence that limb alignment plays in regards to ACL injury rates. With regards to limb flexibility, laxity, or hyperextension research has shown no relationship between these factors and injury.

Ligament Size. Another proposed risk factor for ACL injuries is the size of the AC ligament. Differences in ACL size (length, cross-sectional, and volume) have been reported in a cadaveric study using a 3-D imaging system by ChandraShekar, Slauterbeck, and Hashemi (2005); in an in vivo study using MRI measurements' by Anderson, Dome, Gautam, Awh, and Rennirt (2001); and in a cadaveric study
using a molding technique by Muneta, Takakuda, and Yamamoto (1997). All three studies reported a smaller female ACL size. Assuming that the tensile properties of the ACL are independent of sex, race, weight, it is reasonable to believe that a smaller ACL would be more prone to injury during similar load levels. The real test is to investigate if the female ACL’s structural properties are different or lower in quality than a male’s ACL. A study by Chandrashekar, Mansouri, Slauterbeck, and Hashemi (2005), took 20 cadaveric ACL’s to investigate whether the male ACL possess better material properties, in terms of mechanical and structural. After examination Chandrashekar et al (2005) discovered that indeed the female ACL is lower in structural qualities and that not only are female ACL’s smaller in size but there are differences in material. This is significant as it not only indicates that females have smaller ACL’s but the material is of lesser quality and both are possible factors in the difference in gender injury rates.

Intercondylar Notch. Impingement of the ACL against the intercondylar notch has been the latest proposal that has received the most attention for its role as a possible
contributing factor to the increased injury rates for female athletes as it relates to ACL injuries. Females have a narrower intercondylar notch, where the ACL is housed, in the femur than males (Good, Odensten, & Gillquist, 1991). According to Norwood and Cross's (1977) study, athletes with a notch width index less than 17mm are at a higher risk of incurring an ACL injury, due to the possibility of the ligament being impinged in the notch causing the ligament to shred or tear. It has been demonstrated in cadavers that the ACL contacts the anterior intercondylar notch when the knee is in full extension (Norwood & Cross, 1977). However the majority of ACL injuries occur with the knee partially flexed and only a limited percentage are during knee hyperextension. In addition, the localization of ligament rupture is usually more proximal to the potential site of impingement.

**Biomechanical Considerations**

**Neuromuscular.** Recent research has centered on neuromuscular characteristics and the role they play as a factor of gender implications in relation to ACL injuries. Neuromuscular control of the knee involves a complex interplay between the neurologic system and the muscles
that cross the knee joint (Huston & Wojtys, 1996). Perhaps in noncontact ACL injury, expected motor recruitment patterns that control the knee are altered, which leads to injury. This may result in a faulty or delayed neurologic signal to the knee instead of a protective muscle response. When Huston and Wojtys (1996) evaluated neuromuscular response to anterior tibial translation in male and female athletes, they found that female athletes relied more on their quadriceps muscles and took significantly longer to generate maximum hamstring muscle torque after anterior tibial force is applied. Though understanding of neuromuscular characteristics of the knee is in its infancy, any alteration in the dynamic control of the knee that favors the quadriceps over the hamstrings may predispose an athlete to a noncontact ACL injury.

**Muscular Imbalances.** It has been found that the ratio of quadriceps strength to hamstring strength has an effect on ACL Strain (Renstrom, Arms & Stanwyck, 1986). Moul (1998) found that there was a significant difference in ratios between genders, and that females had a smaller ratio when comparing eccentric hamstring strength to eccentric quadriceps strength. The data suggested that the
activation of the quadriceps muscle had the most pronounced effect on ACL strain, especially in angles greater than 70 degrees in knee flexion. It also indicated that hamstring contraction decreases anterior tibial translation and internal tibial rotation and reduces tension in the ACL between 15 and 45 degrees of knee flexion. The hamstrings therefore, act as protagonists to the ACL in controlling tibial movement. Additionally Baretta et al (1998) suggested that an individual with hypertrophied quadriceps without complementary hamstring strength is predisposed to an ACL injury. The hamstrings contract eccentrically to stabilize the hip while the quadriceps contracts eccentrically to stabilize the knee when decelerating the horizontal velocity of the body when stopping, slowing down or cutting. The quadriceps are ACL agonists or "stress shielders", therefore, any weakness, increased flexibility, or delayed motor signal to the hamstrings may increase the susceptibility of an ACL injury.
CHAPTER FIVE

EXTRINSIC FACTORS

Introduction

There are other factors that may contribute to the higher incidence of females tearing their ACL’s. These factors are extrinsic, or environmental, or external in nature. Extrinsic factors lack the substantial research that has been devoted to the intrinsic factors as it relates to gender differences. Yet, these factors are the most controllable and can be addressed in a positive manner to help female athletes minimize the risk associated with playing a sport. Some extrinsic factors that have been addressed are the shoe-surface interface, body posture and movement, and skill level and conditioning.

Shoe-Surface Interface

One such extrinsic factor, the shoe-surface interface, particularly those with high coefficients of friction, has been suggested as a cause of higher ACL injury rates. For instance, basketball courts and basketball shoes are both designed for traction and not slipping. Most ACL’s are torn when the foot is planted and the player attempts to make a
move in another direction and the foot stays planted. This increased shoe-to-surface interface ratio increases the chances of an athlete tearing their ACL. Another instance is on the soccer field where the athlete's cleats or studs insert into the ground to increase traction. This traction does not allow for movement and the foot will get stuck in the ground while the knee continues to move. Longer size studs on a shoe will create an increased amount of traction increasing the chances of injuries. Basketball programs today teach females how to run, stop, and pivot correctly to minimize the risks of a knee injury, more specifically an ACL injury. With advances in technology, these conditions have improved. There has not been any research on the role that the shoe to surface interface plays on gender differences. However, understanding all the factors involved is important in understanding the impact they have on ACL tears.

Body Posture and Movement

Another extrinsic factor that may contribute to the higher rates of ACL injuries is the gender variations in athletic body posture and movement. Videotape analysis of male versus female athletes revealed that females tend to
play sports in a more erect position (Huston & Wojtys, 1996). A more upright position amplifies ground reaction forces that increase the load transmitted to the knee and maximizes anterior shear forces from the quadriceps (Huston & Wojtys, 1996). Also females tend to land from a jump with their center of gravity behind the knee in a more upright position of the hip and knee, with increased trunk extension and flat footed (Devita & Skelly 1992). A videotaped analysis by Teitz (2001) showed that landing a jump or stopping a run with the center of gravity behind the knee was associated with two-thirds of the injuries. Ground contact in the flat footed position was noted in two-thirds of the injured females and all injured males.

More research needs to be conducted on the gender differences of body posture and movement but most prevention programs and coaches have focused their attention on teaching females the proper techniques of landing and cutting to help decrease the chances of injury. **Skill Level and Conditioning**

Conditioning and experience may also be a variable involved in gender differences in ACL injuries. Research on the sport of soccer suggests that the demands of the game
for females are similar to those placed on males including distance covered, exercise intensity, and physical and physiological characteristics (Arendt & Dick, 1995). The number of NCAA female soccer programs has increased almost 50% (compared with 9% for males) since 1989 (Arendt & Dick, 1995). The rapid increase in new programs may introduce players that are less experienced into the rigors of collegiate soccer. As a result, these new participants may be more susceptible to ACL injuries.

In the early 1990s the idea of females having a lack of skill and conditioning to compete was a factor addressed by researchers concerning the increased incidence of ACL injuries among females. Over the past decade it was hypothesized that the injury rate gap would decrease due to the skill level and conditioning increasing and also due to the wide spread knowledge of gender differences in ACL injuries. As Arendt et al (1999) revisited and reviewed the data submitted to the NCAA Injury Surveillance System, as they did in 1995, they expected to see lower rates among female athletes in regards to ACL injuries but instead saw that the rates were the same or had increased. Arendt et al (1999) believed that the skill level, conditioning, and
experience would increase due to earlier participation of females in sports and would in turn decrease the injury rates. Over time this has shown to be false and other factors need to be of greater concern.
CHAPTER SIX
PREVENTION PROGRAMS

Introduction

Current trends focus on the implementation of prevention programs that emphasize neuromuscular control, strengthening of lower extremity muscles, and changing the techniques involved with maneuvering and landing. A comprehensive neuromuscular training program designed for the prevention of lower extremity injuries can provide simultaneous improvements in athletic performance and movement biomechanics in female athletes (Myer, Ford, Palumbo, & Hewett, 2005).

Prevention Programs

A study by Hewett, Stroupe, Nance, & Noyes (1996) showed that male athletes activate their knee flexors at three times the level of female athletes when landing from a jump. This study also demonstrated that jump training corrects hamstring and quadriceps imbalances, decreases impact forces, and increases lower extremity strength and jump height. A 20% decrease in impact forces at landing is possible following training. Another study by Hewett,
Riccobene, & Lindenfeld (2001) implemented by the Cincinnati Sportsmetrics Training Program suggested that a training program that combined stretching, plyometrics and weight training could possibly be an effective prevention strategy for knee ligament injuries. The Cincinnati Sportsmetrics Training Program used a six week, three component program to evaluate the effect of neuromuscular training on serious knee injury rates in female athletes. The program frequency was three times per week, and was comprised of a program with 20 to 25 minutes of careful stretching, a plyometrics training program lasting 30 minutes per session, and 30 minutes of progressive resistance of upper and lower extremity weight training exercises.

Griffin (2001) reviewed a program developed by Chuck Henning, Orthopaedist, which used video tape analysis and injury data to develop an ACL injury prevention program. The Henning Program had athletes change the plant-and-cut maneuver to an accelerated rounded turn, the straight-knee landing to a bent knee landing, and the one-step stop with knees straight or hyperextended to a three-step stop with knees bent. Because the study was not continued after
Henning’s death in 1991, the population tested was small. Although Henning’s principles seem logical, this program needs to be further tested on larger number of athletes. Nonetheless, these results are encouraging and are not inconsistent with the improved injury rates seen with the recent neuromuscular training program introduced by Hewett et al (1999). Commonalities exist between these programs. Both programs teach the athlete to land with the hip flexed, knee flexed, and the trunk balanced over the lower extremity. The data suggest that a training program combining stretching, plyometrics, and weight training can be an effective prevention strategy for knee ligament injuries in the female athlete.

The Sportsmetrics program focused more on increasing neuromuscular strength to lesson the chances of a serious knee injury while the Henning program focused more on changing the techniques involved in maneuvering. The combination of programs, presumably, would decrease the chances for a major knee injury. It would be of interest to see a program that included changing the basic maneuvering techniques and incorporated the Sportsmetrics program and
then using this new program study the implications it had across a larger population.
CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

Summary

The increased risk of ACL injuries among females is likely multifactoral, with no single structural, anatomical, or biomechanical feature solely responsible. Contributing factors may include intrinsic factors such as hormones, anatomical differences, biomechanical considerations, and extrinsic factors that include shoe-surface interface, body posture and movement, and skill and conditioning. Although sex differences have been confirmed, the risk of injury is relatively infrequent in the college environment. For example, assuming 20 athletes participated in a soccer practice or game session, the ACL injury rate for this sport translated to one ACL injury every 385-activity sessions (practice or game) in male soccer and one ACL injury every 161-activity sessions in female soccer (Arendt & Dick 1995). Both males and females are nine times more likely to experience an ACL injury in a game as compared with practice (Arendt & Dick 1995). With the incorporation of prevention programs into preseason
workouts, athletic programs may be able to decrease the number of injuries.

Conclusions

Anterior Cruciate Ligament injuries are considered to be one of the worst injuries that occur to an athlete. Not only is an ACL injury a season ending injury, but the athlete usually requires surgery, and the rehabilitation process is painful, exhausting and long. Even with the proven fact that there are many different plausible causes of an ACL injury, it does not negate the fact that athletes with these same intrinsic and extrinsic factors are playing everyday, performing the same motions that are commonly the mechanism of injury, and yet there is no injury. Also, even with all the knowledge we have about possible causes of females incurring more ACL injuries there is nothing that can be done outside of neuromuscular prevention programs that emphasize neuromuscular control and strengthening. Even though some studies have suggested that some female athletes with predisposing factors not be allowed to participate. However, this suggestion is impractical. It would be nearly impossible to measure every female’s Q-angle, intercondylar notch, anterior tibial translation,
muscular strength or monitoring a female’s menstrual cycle. Not only does this require too much time but also most programs do not have the personnel, money or equipment to do so. Even if they did, do they tell the athlete that they cannot play because they have more than one of the risk factors associated with a possible ACL injury. The female athlete is just as competitive as the male athlete and has a mental drive to not let the “what if’s” stand in their way. Upon returning to competition after ACL reconstruction, a University of Tennessee female basketball player stated that she would do anything to win a national championship including tearing her ACL.

**Future Research and Recommendations**

More research needs to be conducted as it relates to the correlation of lower extremity alignment and ACL injuries. Anatomical knowledge and small testing populations do not account for why some female athletes with predisposing factors do not incur an ACL injury while playing and why some other females athletes do tear their ACL. Also more research needs to be conducted to see if there is a relationship in gender difference in ACL injuries due to shoe-surface interface. One can postulate
based upon biomechanical knowledge of the differences in how females cut versus males, how females land, or how female muscular imbalances might cause a different coefficient of traction and friction as it relates to shoe-surface interface but no study to this author’s knowledge has shown empirical data demonstrating the direct relationship of the two.
REFERENCES


