

Incidence and Prevention of Injury of the Anterior Cruciate Ligament in Females

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Abstract

According to the American College of Sports Medicine, women are two to eight times more likely to sustain an anterior cruciate ligament injury than men at the same level of performance. This high incidence of women with an ACL injury is thought to be due to a number of gender differences. This study examines the research that has been conducted to determine the reason for the disproportionate incidence of anterior cruciate ligament in female population. The study encompasses anatomical structure of the knee joint, structural differences in the male and female knee, hormonal influences, biomechanical influences, neuromuscular influences, and strategies for prevention. If intrinsic and extrinsic risk factors for women can be determined and altered, then steps can be taken to reduce the risk of an anterior cruciate ligament injury in women.

Incidence and Prevention of Injury of the Anterior Cruciate

Ligament in Females

It is estimated that about 80,000 people in the United States sustain an anterior cruciate ligament (ACL) injury every year. An injury may result in a tear that is partial or complete. The majority of this type of injury occurs in people aged 15 to 45, and 70% of injuries are sports related injuries. More men than women sustain an ACL injury every year; however, this is only because there are a greater number of men than women who participate in athletic activities. According to the American College of Sports Medicine, women are two to eight times more likely to sustain an ACL injury than men at the same level of performance (Halpern, 2003). Female ACL injuries are especially common in sports such as basketball, volleyball, and soccer. The higher incidence of female versus male ACL injury is thought to be due to a number of gender differences including differences in anatomical structure, hormonal levels, neuromuscular control, and biomechanical differences. With the high occurrence of ACL injuries among female athletes, it is important for researchers to determine which causes of this injury are valid in order to better predict and prevent ACL injuries in women. If intrinsic and extrinsic risk factors for women can be determined and altered, then steps can be taken to reduce the risk of an anterior cruciate ligament. The purpose of this study is to determine the differences between male and female structural, physiological, and biomechanical components of the knee, and to examine literature regarding possible risk factors for ACL injuries. In addition this study aims to increase knowledge of techniques for injury prevention.

Anatomical Structure of the Knee

In order to study and determine the structural differences between males and females it is first important to have a thorough understanding of the anatomy of the knee. The knee, while seemingly simple, is one of the most complicated structures of the human body. The complex interaction between the bones, muscles, ligaments, and cartilage of the knee allows this unique joint to bear loads greater than four times a person's body weight. In order to better understand the anatomical structure of this joint, the articulation and movement, bone structure, muscular structure, ligamentous structure, cartilage, and synovium of the knee will be closely examined.

Articulation and Movement

The knee is the joint connecting the femur to the tibia and fibula, and is the largest joint, or articulation, in the body (Turek, 1984). It operates as a ginglymus, or hinge joint which is an articulation that primarily moves in a single plane of motion. This means that the knee performs flexion and extension movements, and only has slight rotational or pivoting ability. The knee is in fact composed of three joints: the patello-femoral, the medial tibio-femoral, and the lateral tibio-femoral (Monk, 1985). The patello-femoral joint is a sliding joint between the lower end of the femur and the patella. The tibio-femoral joints are gliding joints. The medial tibio-femoral joint has a greater antero-posterior diameter than the lateral. In addition to extension and flexion, the primary movements of the knee, some minor rotation of the femur on the tibia occurs at the end of extension (Monk, 1985).

It is only beyond twenty degrees of flexion that the knee possesses the slight axial rotational capability. In this position the supporting ligaments of the knee are relaxed and allow gliding and axial rotation. In the fully extended position, the knee has no rotational capabilities, as tautness of the ligaments prevents any rotary motion. This locking of the knee is caused by contraction in the quadriceps which produces a medial rotation of the femur on the tibia. This movement is known as the screw home mechanism (Turek, 1984).

Bone Structure

The femur is the longest bone in the body and extends from the pelvis to the knee. Located at the end of the femur are two round knobs, the medial and lateral condyles. The space in between the condyles is known as the intercondylar notch, and this is where the Anterior cruciate ligament is housed (Halpern, 2003). The primary purpose of the femur is to distribute the weight of the upper body to the tibia. The patella is a sesamoid bone which is a bone that forms within a tendon (Martini, 2009). The patella lies within the quadriceps tendon, and it functions as a pulley, which increases the efficiency and the mechanical advantage of the quadriceps muscles. The patella slides in a groove in the femur between the two condyles; this groove is known as the trochlear groove. Because the bone structure does not provide the necessary support, the knee must rely on the surrounding musculature and ligaments for stability (Turek, 1984).

Muscular Structure

The quadriceps femoris consists of four muscles that are located on the anterior aspect of the femur superior to the knee and is the main extensor of the knee. It consists

of the vastus medialis, vastus lateralis, vastus intermedius, and the rectus femoris. It inserts into the tibia by means of the patellar tendon (Monk, 1985). The hamstrings, a large muscle group on the posterior aspect of the femur, are comprised of three muscles: the biceps femoris, which consists of a short and long head, the semitendinosus, and the semimembranosus. These muscles are the primary flexors of the knee. Flexion is also aided by the gastrocnemius, the major calf muscle, and the popliteus, a small muscle posterior to the knee (Halpern, 2003).

Stability of the knee in the extended position is attained by the quadriceps anteriorly and the gastrocnemius and the popliteus posteriorly (Turek, 1984). The strength of the muscular groups surrounding the knee is essential to knee health and stability. When there is more support from the muscular structure, there is less strain on the joint itself (Halpern, 2003).

Ligamentous Structure

In addition to the surrounding muscles, the knee is supported by four major ligaments. A ligament is a connective tissue consisting of collagen, a strong, fibrous protein, which connects bones to other bones. The four major ligaments in the knee are the lateral collateral ligament, the medial collateral ligament, the posterior cruciate ligament, and the anterior cruciate ligament. The collateral ligaments extend vertically on either side of the joint. The lateral collateral ligament attaches the femur to the fibula and the medial collateral ligament attaches the femur to the tibia. These serve to keep the knee from moving too far to one side or the other (Halpern, 2003). The posterior cruciate ligament and the anterior cruciate ligament cross in the center of the joint capsule and

prevent the tibia from moving too far anteriorly (ACL) or posteriorly (PCL), as well as maintaining the alignment of the femoral and tibial condyles (Martini, 2009). The ACL originates anteriorly on the tibial condyle, crosses anterior to the PCL (see Figure 1), and inserts posteriorly on the femur. Likewise the PCL originates posteriorly on the tibial condyle and inserts anteriorly on the femur.

At full extension, a slight lateral rotation of the tibia tightens the ACL and compresses the lateral meniscus between the tibia and the femur (Martini, 2009).

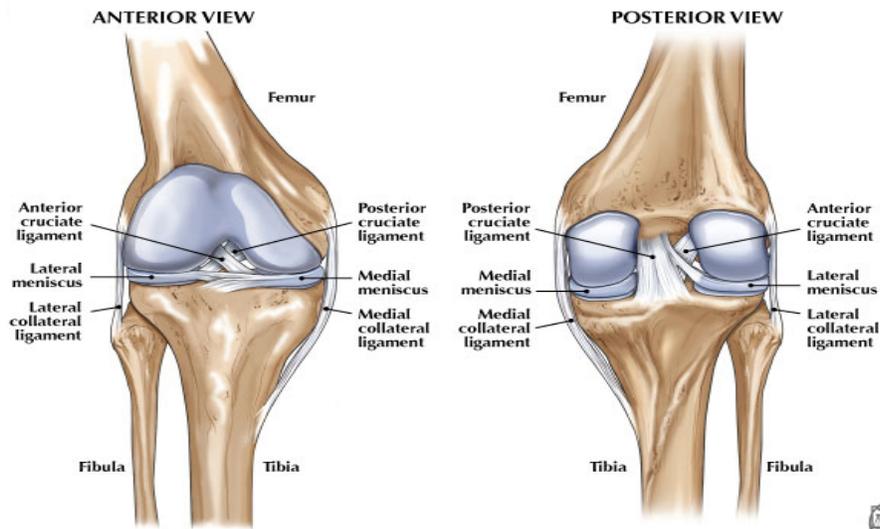


Figure 1: Anatomical Structure of the Knee (Trialsight Medical Media, 2008)

Cartilage

The bones of the knee are cushioned by cartilage, a spongy connective tissue. The two types of cartilage found in the knee are hyaline articular cartilage and fibrous cartilage. The articular cartilage covers the ends of bones. It protects the bone, provides a cushion to absorb shock, and creates a smooth surface for movement facilitation. The second type of cartilage found in the knee is the fibrous cartilage (Halpern, 2003). This is

specialized to form the lateral and medial menisci. The menisci are two semi-circular shaped pads (see Figure 2) that lie between the femoral and tibial surfaces. They provide a cushion for the bones from ground reaction forces, as well as prevent bone to bone grinding of the femur and the tibia. The menisci are also able to conform to the shape of the articulating surfaces as the femur changes position. Lastly, the menisci act as stabilizers for the knee, distributing weight and absorbing shock (Martini, 2009).

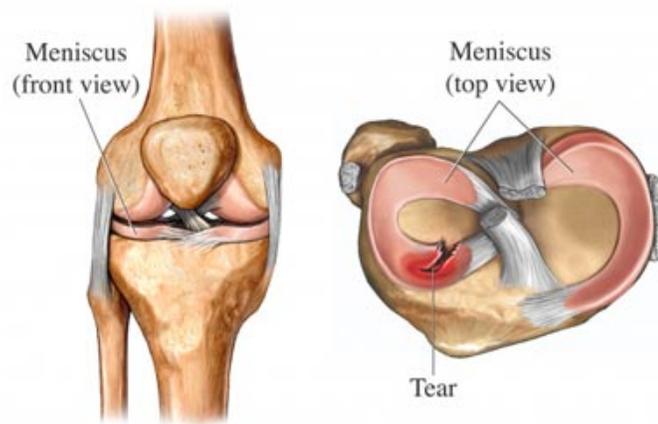


Figure 2: Meniscus (Smith, 2011)

Synovium

The knee, like many other freely movable joints in the body, is enclosed in a joint capsule. The joint capsule is lined with a synovial membrane which secretes a synovial fluid. Synovial fluid is a lubricant and thus greatly reduces the friction between the articular surfaces of the knee. Also, synovial fluid is important for nutrient distribution and waste removal within the joint capsule. Lastly, synovial fluid, along with other structures previously mentioned, aids in shock absorption by distributing pressure evenly across the articular surfaces (Martini, 2009).

Structural Differences in the Male and Female knee

Anatomical Structure plays a major role in the higher incidence of female versus male anterior cruciate ligament injuries. It is important for females, especially athletes, to understand these differences and recognize if they possess any of the bodily characteristics that may increase risk of an ACL injury. While bodily structure cannot be altered, recognizing the risk factors can help identify individuals who may be more susceptible to injury, and thus avoid or modify higher risk biomechanical movements which are described in detail in later sections. Structural characteristics that place the ACL at risk that tend to be more prominent in females include a wide quadriceps angle, malalignment of the lower extremities, smaller intercondylar notch, and increased joint laxity.

Quadriceps Angle

The Quadriceps angle (Q-angle) is the measure of alignment between the pelvis and the knee. The Q-angle is measured by drawing a line vertically through the tibial tuberosity and the patella for the first side of the angle. The second side of the angle is drawn from the patella to the anterior superior iliac spine (see Figure 3). Women tend to have a greater Q-angle than men because women are more inclined to have a wider pelvis. A normal quadriceps angle for a female typically ranges between fifteen and twenty degrees, whereas a typical male quadriceps angle is between ten and fifteen degrees. This increase in joint angle places excess rotational forces on the knee during a sudden deceleration at the joint, particularly the ACL. This increased strain on the ACL increases the chances of an ACL injury in a female doing the same movement that a male would do without injury (Halpern, 2003).

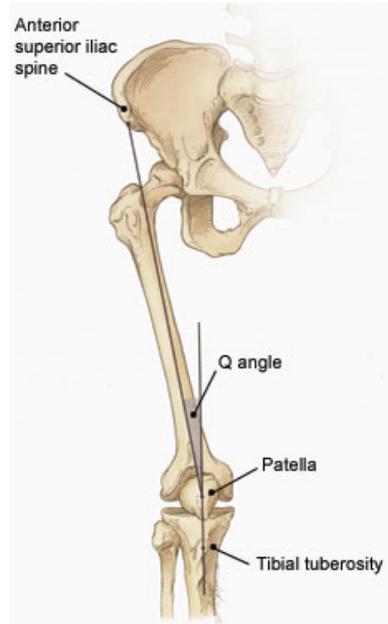


Figure 3: Q- angle (Calmbach, 2003)

Malalignment of the Lower Extremities

Several malalignments of the lower extremity can contribute to increased risk of ACL injury in females. These include foot pronation, knee valgus, and femoral anteversion. Higher quadriceps angle contributes to increased foot pronation in females. This malalignment causes the foot and ankle to rotate inward. The pronation of the foot creates excessive internal rotation forces on the knee, thus increasing the load on the medial aspect of the knee. Knee valgus, or knock-kneed, is another malalignment of the lower extremity. This is when the knees are situated closely together in a normal standing position. Malinzak conducted a study that has shown that the load on the ACL when the knee was in a 5° valgus position could be up to six times that when the knee was aligned in the frontal plane (Malinzak, 2001). Incidence of valgus is higher in women than in men, and therefore may contribute to the excess loading of the knees that lead to injury.

The last common malalignment of the leg is femoral anteversion. This is when there is excessive medial rotation of the femur resulting in in-toeing. This is common in females, and when present, creates malalignment of the other joints of the lower leg such as the knees and ankles.

Intercondylar Notch

Alignment is not the only structural difference between males and females that could contribute to the incidence of ACL injury in females. Research has indicated that females tend to have a smaller femoral notch, the space where the ACL is located, than men. A study conducted by K. Donald Shelbourne, Thorp J. Davis, and Thomas E. Klootwyk (1998) examined “The Relationship Between Intercondylar Notch Width of the Femur and the Incidence of Anterior cruciate ligament Tears.” In the study, 714 consecutive patients who underwent autogenous patellar tendon graft anterior cruciate ligament reconstructions had their intercondylar notch width. intraoperatively measured. The mean notch width was 13.9 ± 2.2 mm for women and 15.9 ± 2.5 mm for men. Analysis showed that, with height and weight as covariates, women had statistically significantly narrower notches than men. Thus, women have, on average, smaller notches, even when they are the same height as men. The overall results of the study showed that patients with narrower notches have a higher incidence of tearing their anterior cruciate ligament (Shelbourne, 1998). It is unknown why a smaller intercondylar notch is correlated to a higher incidence of ACL injury. It could be due to a shearing effect of the intercondylar notch against the ACL. The study conducted by Shelbourne et al. also suggests that it could be because a smaller intercondylar notch is indicative of a

smaller ACL. Some researchers believe that a smaller ACL may be weaker than normal, and thus less able to withstand high impact forces.

Joint Laxity

Compared to men, women are also more prone to increased joint laxity and muscular flexibility than men. Joint laxity is increased flexibility of the ligaments and articular structure. It is debatable why this is the case, but one possible explanation is hormonal influences which are discussed more thoroughly in the next section. A study conducted by R. Ramesh et al. (2005) suggests that higher joint laxity and knee hyperextension are contributing factors to ACL injury. This study compared joint laxity and knee hyperextension in persons with a symptomatic ACL injury with an uninjured control group. Joint laxity was measured using Beighton, Solomon and Soskilne's method (Ramesh, 2005). The Beighton score ranges from 0 to 9 and is derived by assigning one point each for hyperextension of the metacarpophalangeal joint of each little finger beyond 90°, the ability to touch the volar surface of each forearm with the thumb, hyperextension of each elbow, hyperextension of each knee, and the ability to place the palm of both hands flat on the ground by forward flexion with knees straight. A score of greater than 6 would indicate hypermobility and increased joint laxity. Hyperextension in the uninjured knee was assessed using a goniometer, which is a device used to measure joint axis and range of motion. Values of more than 10° were taken to represent hyperextension. The prevalence of generalized joint laxity in those with and ACL injury was 42.6%. The prevalence of generalized joint laxity in the control group was 21.5%. This difference was found to be statistically significant. The prevalence of

hyperextension of the knee in those with an injured ACL was 78.7% and the prevalence of hyperextension of the knee in the control group was only 37% (Ramesh, 2005). This difference was also found to be significant. The results of this study indicate that increased joint mobility and hyperextension of the knee may be contributing factors in ACL injuries. This study proposed a theory as to why a hypermobile knee may be more predisposed to an ACL injury:

[When] the back is straight without a lumbar lordosis, the trunk leans backwards with the hip and knee slightly flexed and the foot lands flat on the ground with the centre of gravity behind the knee. This pre-positioning of the trunk initiates events that may lead to an inevitable ligament injury. When there is a change in the sequence of movements in order to regain control, there is an excessive, eccentric contraction of the quadriceps. These events lead to hyperextension of the knee with increased anterior translation of the tibia. [...] This anterior translation force is greatest when the quadriceps is activated at higher acceleration and with small knee flexion angles. Therefore, when there is pre-existing excessive hyperextension, the knee moves through further in its final arc and generates greater anterior translatory forces. This continued momentum locks the knee into hyperextension and allows the ACL to hit the notch and guillotine itself. (Ramesh, 2005)

Sufficient evidence suggests that increased joint laxity is a contributing factor to joint and ligament injuries, particularly the anterior cruciate ligament. Since joint laxity is

more common in women than men, it is considered a contributing factor to the higher incidence of ACL injury in Females.

Hormonal Influences

Many recent studies such as those conducted by Wojtys, Liu, and Sarwar (2002) have shown that hormones could play a significant role in joint laxity, particularly in that of the knee. As previously stated, joint hypermobility is a contributing factor in injuries of the anterior cruciate ligament. While it is debatable what causes the prevalence of joint laxity in women, hormonal influences and the effects of estrogen and progesterone on collagen extensibility offer one explanation.

Description of the Menstrual Cycle and Accompanying Hormonal Fluctuations

The menstrual cycle and its accompanying hormonal fluctuations is one of the most basic differences between men and women. Therefore, it has been hypothesized that injuries to the ACL may be more likely during different times of the menstrual cycle because of the varying hormonal influence. There are many ways of classifying the stages of the menstrual cycle, but the most common system separates the cycle into three main phases: follicular, ovulatory, and luteal (Wojtys, 2002). The follicular phase, which begins on the first day of menstruation, has a mean length of 9 days. In this phase a follicle begins to develop with follicle growth increasing dramatically by the end of the phase. During the development of the follicle, the concentration of luteinizing hormone rises. A surge of luteinizing hormone begins 24 hours before ovulation. Associated with this surge is a sharp peak in estrogen, which occurs during or before the surge in gonadotropins. The ovulatory phase extends over a period of about 5 days. During the

last phase, known as the luteal phase, the follicle collapses and the corpus luteum is formed if pregnancy does not occur. This phase lasts approximately 14 days. A rise in progesterone is seen during the middle of this luteal phase. The abrupt cessation of progesterone release induces the onset of menstruation (Wojtys, 2002).

Distribution of ACL Injuries during Menstrual Cycle

A study conducted by E.M. Wojtys et al. (2002) found a significant association between the distribution of ACL injuries and the phase of the menstrual cycle. The researchers studied sixty-five women over a 2-year period who sustained acute noncontact ACL injuries. Each subject provided two urine samples: one within 24 hours of injury and the second sample within 24 hours of the first day of her next menstrual cycle. Each sample was analyzed for total estrogen, progesterone, and luteinizing hormone. As stated, a significant association was found between the distribution of ACL injuries and the phase of the menstrual cycle. This association was determined by hormonal identification of the cycle phase within twenty four hours of the injury. Overall, ACL injuries were more common during ovulation than during the luteal phase (Wojtys, 2002).

Influenced Composition of the ACL

While research has demonstrated that hormones do play a significant role in the incidence of ACL injury, it remains unclear how the ACL is influenced specifically. It could be that hormones are directly affecting collagen metabolism in the ACL itself. A study conducted by S. H. Liu et al. (1997) researched the effects of estrogen, particularly 17β -estradiol, on the cellular growth and collagen synthesis of fibroblasts derived from

the rabbit anterior cruciate ligament. The study found that collagen synthesis was significantly reduced with increasing estrogen concentrations. A significant reduction of fibroblast growth was also observed with increasing estrogen concentrations. Thus, alterations in anterior cruciate ligament cellular metabolism caused by estrogen fluctuations may change the composition of the ligament, rendering it more susceptible to injury (Liu, 1997).

Effected Neuromuscular Response during Ovulation

Besides having a possible direct effect on the ACL, hormones may influence the injury distribution during the monthly cycle by affecting the neuromuscular system. In general, women tend to have reduced neuromuscular response to impending injury as compared to men as assessed later in this study. In addition to the existing discrepancy, research has shown that women experience varying degrees of neuromuscular control during the menstrual cycle. One study conducted by Sarwar et al. reported significant changes in skeletal muscle function during ovulation. The researchers found that the ability to contract and relax the quadriceps muscle was altered. This difference in neuromuscular function could play a part in the increased incidence of anterior cruciate ligament injury during ovulation (Wojtys, 2002).

Pregnancy

During pregnancy, especially during the later stages, the hormone relaxin is released. This hormone causes the ligaments in the body to loosen in anticipation of labor. This places the ACL at increased risk. As a woman gains weight, the center of gravity changes and excess loads are placed on the already compromised ligaments of

the knee. Because of these hormonal influences, the anterior cruciate ligament is at a greater risk of rupture, and therefore exercise and athletics during pregnancy should be closely monitored (Halpern, 2003).

Oral Contraceptives

The Wojtys' study (2002) also examined women who were taking oral contraceptives in comparison to women who did not. Among women who were taking oral contraceptives no correlation was found between the menstrual cycle and ACL injury distribution. Oral contraceptives inhibit pituitary production of follicle-stimulating hormone and luteinizing hormone by providing synthetic estrogen and progesterone to the user. This stabilizing effect of the hormones and inhibition of the estrogen spike during ovulation may help to prevent or reduce hormone related anterior cruciate ligament injuries. It is clear from the study that oral contraceptive use diminishes the disproportionate distribution of ACL injuries during the menstrual cycle (Wojtys, 2002).

Neuromuscular Factors

Most injuries to the ACL are non-contact injuries, meaning the injury is not caused by impact with another person or object. Instead, most ACL injuries result from a cutting or sidestepping action, when the knee experiences a rapid deceleration or change in direction (Hewett, 2000). The strength of supporting muscles such as those of the hip girdle, quadriceps and lower back, have an impact on the health and stability of the knee. If these muscles are weak, then the knee needs to rely more on the ligaments for support. This excess strain over time can lead to weakening and injury of the ACL. Also, having unevenly distributed muscle strength can lead to knee injury. When the muscles on one

side of the leg are stronger than the ones on the other side, the muscles pull unevenly on the knee. This imbalance of tension causes excess strain on the joint and the ligaments. Neuromuscular factors such as imbalanced muscular strength, imbalanced muscular recruitment, and cultural influences contribute to incidence of anterior cruciate ligament in females.

Imbalanced Muscular Strength

The hamstring muscles are important to the stabilization of the knee joint. They function to restrain anterior motion of the tibia. This functions to decrease anterior shear forces, and greatly reduces the load on the ACL, which is the primary passive restraint to anterior tibial motion. Female athletes may demonstrate an imbalance between hamstrings and quadriceps strength and dominant versus non-dominant side hamstrings strength prior to training. There is an increased risk of ligamentous damage in athletes with strength imbalances between the quadriceps and hamstrings.

Imbalances in hamstrings to quadriceps strength in moderate to high speed isokinetic tests and side to side hamstrings strength in which the dominant leg flexor is fifteen percent stronger than non-dominant leg flexor have been correlated to greater incidence of lower extremity injury in female collegiate athletes (Hewett, 2000). In addition, a dominant hip extensor which is fifteen percent more flexible than the non-dominant side has also been reported to be predictive of injury. This evidence demonstrates a direct connection between relative hamstrings strength and flexibility and the incidence of knee injury. Young female athletes have been shown to have significantly lower hamstrings to quadriceps strength ratios than males during high speed

isokinetic tests and the non-dominant hamstrings were also significantly weaker than the dominant side (Hewett, 2000).

Imbalanced Muscular Recruitment

Evaluation of muscle activation patterns using electromyography (EMG) suggests that females demonstrate greater quadriceps and less hamstring activity than males during cutting which is a rapid change in direction and acceleration. In a study conducted by G. D. Myer et al. females demonstrated a decreased ratio of medial quadriceps to lateral quadriceps recruitment compared to males. In this study, electromyography measurements of muscle recruitment were taken while subjects performed side stepping and cutting exercises. Subjects were asked to perform these exercises in a position such that the knees were close to full extension with the tibia externally rotated and center of gravity behind the knee. This is a position usually associated with non-contact ACL injury when under conditions of high velocity and high loads. This type of dynamic body alignment can be present in both males and females during jumping and cutting sports, however, women tend to have an increased knee valgus in this position which places the ACL at greater risk. This study concluded that repeated performance of the high-risk maneuvers with insufficient neuromuscular control and dynamic valgus may lead to the valgus collapse and ACL rupture (Myer, 2005).

Cultural Influences

Males tend to have better neuromuscular recruitment than females. This factor is extrinsic in nature, and does not seem to stem from anatomical or hormonal differences. Cultural influences may offer a better source for these differences. Historically, females

in the United States were not expected or encouraged to participate in high levels of physical activities, and thus did not learn at a young age proper jump and landing techniques. In 1972, Title IX of the United States Educational Assistance Act was enacted. The legislation required that institutions receiving federal funding provide equal access for women to funding of extracurricular activities. This federal law has contributed to a several-fold increase in the number of female athletes participating at the junior high school, high school, collegiate and professional levels (Hewett, 2000). However, these cultural influences continue today. Boys are expected to be athletic and involved in sports from a very young age, whereas many girls do not begin participation in athletics until middle or high school. This may explain why males seem to be inherently better at proper neuromuscular recruitment than females.

Biomechanical factors

The knee is not only subjected to weight bearing forces, but it also acts as a shock absorber for movements such as walking, running and jumping, often bearing loads up to four times normal body weight. This, combined with its ability to move only in one plane, makes the knee vulnerable to traumatic injuries. As discussed, females have been shown to perform athletic maneuvers with decreased quadriceps activation and knee valgus. In addition to this, females tend to perform lower extremity athletic movements with decreased hip and knee flexion. Thus, females tend to rely more on the ligaments, which are the passive restraints of the lower extremity, to decelerate the body center of mass. Increased frontal plane loading at the knee is of particular concern as knee valgus angles and adductor moments have been found to be predictive of ACL injury

(Sigward, 2006). This comparative weakness of the flexors and extensors leaves females to be more ligament dependent during athletic movements, whereas males tend to be more muscle dependent.

Jump Landing Position

The anterior shear force applied on the tibia by the quadriceps muscles increases as the knee flexion angle decreases. This increase in force tends to translate the tibia forward and thus to increase the load on the ACL. A study conducted by Pollard et al. researched the biomechanics of drop landing techniques in females. It was found that women who have limited sagittal plane movement, that is they demonstrated a low hip and knee flexion landing pattern, experience greater frontal plane loading during the jump landing task. This means that these women needed to rely more heavily on the adduction movement of knee valgus to decelerate the body mass from the jump (see figure 4). Women who exhibit this landing pattern must rely on the passive restraints in the knee, particularly that of the ACL to control the landing (Pollard, 2010).

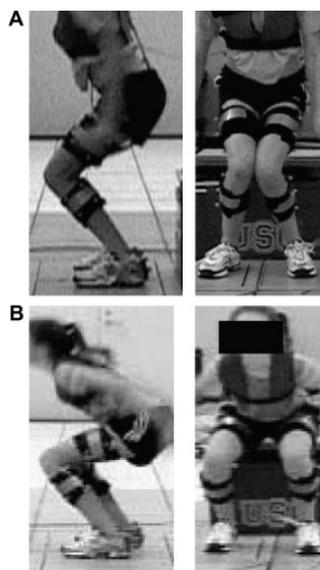


Figure 4: A) low flexion landing vs. B) high flexion landing (Pollard, 2010)

Although females exhibit sagittal and frontal plane mechanics that are thought to contribute to ACL injury, the underlying reasons for this movement pattern are not known. It has been hypothesized that because of poor strength of the muscles that perform flexion and extension movements, females limit the amount of knee and hip flexion during dynamic tasks. If the hip extensors are too weak to share control of the body center of mass during landing, individuals may compensate by adopting an over-reliance on their quadriceps. According to the Pollard study, Individuals who were able to limit frontal plane knee loading did so by engaging their hip extensors. Thus, strength and activation of muscle groups such as the hamstrings and gluteus maximus may help achieve a high flexion landing strategy (Pollard, 2010).

Prevention

Upon examination of the research it is very clear that no one factor can be identified as the cause of an anterior cruciate ligament injury. The high incidence of ACL injuries among females stems from a variety of factors including the anatomy of the female knee, hormonal influences, neuromuscular factors, and biomechanical factors. Once these risk factors have been properly identified, preventative measures can begin. When investigating prevention strategies it is important note the differences between intrinsic and extrinsic risk factors.

Intrinsic Risk Factors

Intrinsic risk factors include inherent characteristics that cannot be changed. This includes structural risk factors and hormonal influences. While these cannot be altered, they are useful in identifying females who would be in the highest risk category.

Awareness of increased risk is the first step toward prevention of an injury. For example, women who exemplify high risk structural characteristics such as lower extremity malalignment, small intercondylar notch, or a wide quadriceps angle should take extra precaution when participating in activities that involve rapid deceleration and direction change movements. Women should be examined prior to athletic participation so that their trainers and coaches will know when to take extra precautions, as well as implement training program to focus on correcting extrinsic risk factors.

The other major intrinsic risk factor is hormonal influences. While hormone levels are able to be altered with the use of oral contraceptives, there is not enough support to say that oral contraceptives can be used as a preventative measure. Therefore it is important to understand how hormone levels affect joint laxity and ACL risk. As discussed, research has shown that there is a significant increase in female ACL injuries during the ovulation phase of the menstrual cycle. Thus, in order to prevent unnecessary injury, women athletes could avoid or reduce activities that compromise the ACL during that time frame. Being aware of these intrinsic risk factors could help to reduce the occurrence of anterior cruciate ligament injuries in females.

Extrinsic Risk Factors

Extrinsic risk factors include neuromuscular and biomechanical factors. These are characteristics that can be altered in order to reduce the number of ACL injuries in females. A study conducted by Hewett et al. (1999) researched the effects of neuromuscular training on knee injury in female athletes involved in high-risk sports. A total of 366 female athletes participated in a neuromuscular training program in which

they were instructed in jumping and landing techniques designed to increase vertical height and increase strength before sports participation. The six week program consisted of three phases. The first was the technique phase in which when proper jump technique was demonstrated and drilled. The second phase was the fundamental phase in which participants concentrated on building a base of strength, power, and agility. The final phase was the performance phase focused on achieving maximum vertical jump height. Throughout the training sessions, the participants were encouraged to do as many jumps as possible using proper technique. The women were then monitored for injury during a playing season and compared to a group of 463 women who did not participate in the neuromuscular training. The study found that the incidence of serious knee injury was 2.4 to 3.6 times higher in the untrained group than in the trained group. These results indicate that neuromuscular training may decrease injury risk in female athletes. The decreased injury incidence in trained athletes might be due to increased dynamic stability of the knee joint after training (Hewett, 1999). While this does not eliminate the other risk factors, this study has shown that training may be able to override the effects of a number of these factors. Therefore, preventive measures, such as neuromuscular training, should be undertaken with the female athlete to decrease the incidence of serious knee injury in this high-risk population.

Conclusions

Many structural and anatomical differences exist between the male and the female knee. In order for women to achieve the same level of athlete performance as men, excess strain has been placed on the anterior cruciate ligament resulting in a disproportionate

amount of ACL injuries in the female population. No single factor is responsible for this high incidence of injury. Numerous research studies have revealed the intrinsic and extrinsic risk factors that female athletes face. Now that they have been identified, awareness and prevention of injury can follow. It has been shown that neuromuscular training can help overcome anatomical disadvantages of the female knee, and it is imperative that trainers and coaches to consider implementing proper neuromuscular conditioning to reduce the prevalence of female anterior cruciate ligament injury.

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