FEMALE ISSUES IN SPORT: RISK FACTORS AND PREVENTION OF ACL INJURIES

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KEY POINTS

- Anterior cruciate ligament (ACL) injuries are becoming more common and costly.
- The 15- to 45-year-old patient population is most likely to undergo an ACL reconstruction.
- The main function of the ACL is to limit anterior tibial translation on the femur.
- Although overall ACL injury rates for males and females are very similar, the rates do differ for specific sports. Studies have placed the rate of ACL injuries in female basketball players at 2.89 to 3.5 times higher than in males. The increased rate in female soccer players has been placed at 2.3 to 2.8 times that of males.
- Mechanics appear to contribute significantly to the ACL gender bias. Females generally exhibit greater knee valgus, femoral internal rotation, and femoral adduction on an externally rotated knee. Proximal instability from the trunk and hip results in greater knee valgus and knee external rotation, postures known to place increased strain on the ACL. Trunk instability, combined with limited knee flexion, further increases the risk of ACL injury because smaller knee flexion angle limits the hamstrings' ability to contract and prevent anterior tibial translation.
- Females with either a lower extremity or low back dysfunction have demonstrated greater side-to-side hip extension strength symmetry than males.
- Future studies should examine whether improvements in strength, proprioception, movement execution, or a specific combination of areas is most effective in preventing ACL injury. Those studies should also quantify the most appropriate time, duration, and intensity of participation in a prevention program relative to the competitive season.

Anterior cruciate ligament (ACL) injuries are one of the more serious injuries seen in sports medicine. Orthopaedic surgeons perform an estimated 100,000 ACL reconstructions (1) each year with an associated cost of approximately $1.7 billion (2). Furthermore, costs associated with conservative management of ACL injuries, postoperative rehabilitation, and long-term care of posttraumatic arthritis that may occur in certain situations further increase this financial burden. This has a huge economic impact. With today's current emphasis on staying fit, statistics suggest that these numbers will continue to rise in the future. Daniel and Fritschy (3) have reported ACL injury rates of one per 3,500 enrollees across a large managed care–insured population. The 15- to 45-year-old patient population, which encompasses nearly 47% of the entire U.S. population, is most likely to undergo an ACL reconstruction. Griffin et al. (4) have reported ACL injury projection rates specific to this population as one per 1,750.

Nearly 70% of all ACL injuries occur during sports participation (3). Typically, males sustain a higher absolute number of ACL injuries because of their greater sports participation (3). Since the passage of Title IX in 1972, the number of females competing in organized sports has increased. Surprisingly, overall ACL injury rates for males and females are very similar (implying no gender differences). However, these rates do differ when looking at specific sports (5). The National Collegiate Athletic Association (NCAA) (6) has reported that female basketball players sustained an ACL injury at a rate 2.89 times higher than male basketball players, and others (7–9) have reported injury rates as much as 3.5 times higher for female basketball players. Female soccer players have incurred similar rates of injury, with their reported injury rates ranging from 2.3 to 2.8 times greater than male players (7–9).

TABLE 55.1 Summary of Factors Contributing to ACL Injuries

Intrinsic	Extrinsic
ACL size	Kinetics
Intercondylar notch size	Kinematics
Structural alignment	Proprioception
Tibial plateau orientation	Muscular activation
Physiological laxity	Muscular strength
Hormonal influences	and endurance

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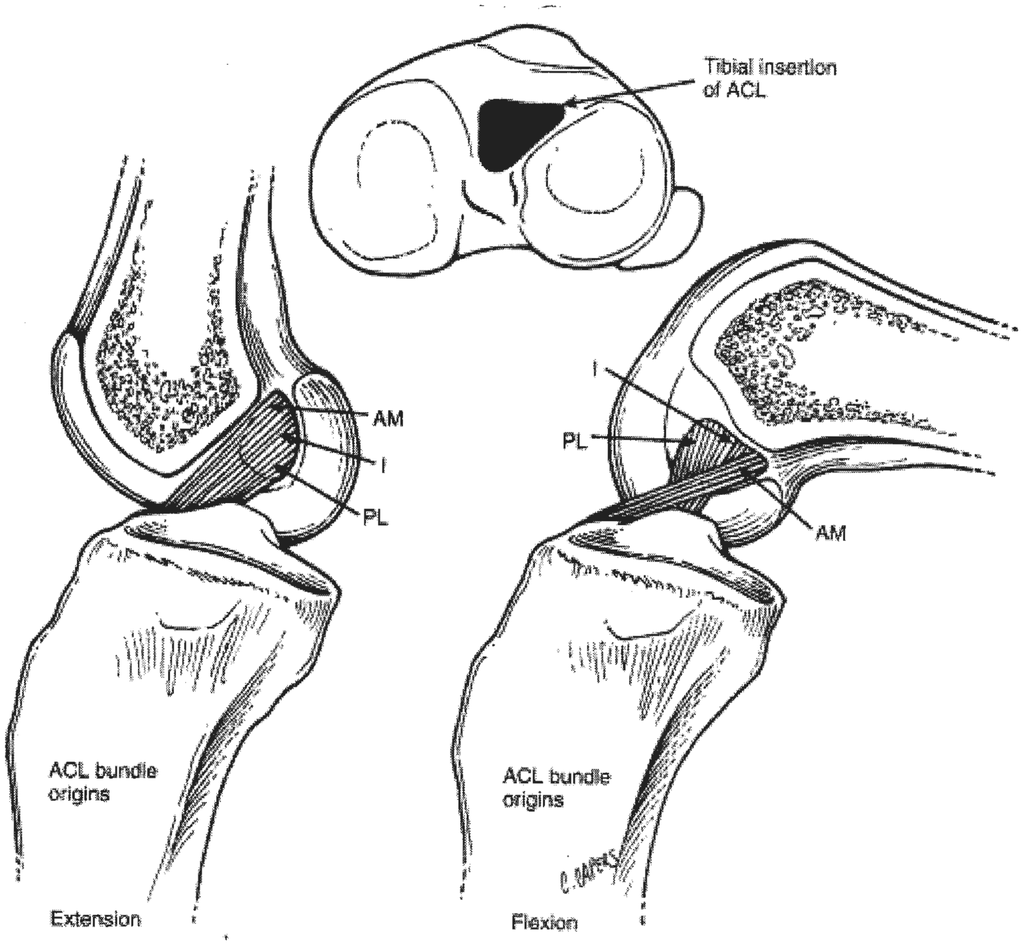

Fig 55-1. The anterior cruciate ligament (ACL) is divided into three bundles based on the tibial attachment: the anteromedial (AM), the intermediate (I), and the posterolateral (PL). With knee flexion, the posterior fibers loosen and the anteromedial fibers coil around the posterolateral ones. (From Baker CL, Flandry F, Henderson JM. *The Hughston Clinic Sports Medicine Book*. Baltimore: Williams & Wilkins; 1995.)

Basketball and soccer injuries usually result from a noncontact mechanism, which represents approximately 70% of all ACL injuries (4). Researchers (10) have described noncontact injuries occurring during two common movement patterns. First, injury may result during open cutting maneuvers. During the deceleration phase of a cutting maneuver, an athlete may exhibit an excessive knee valgus angle in combination with increased femoral internal rotation, resulting in an externally rotated knee. This combined loading has been shown to place a great amount of tension on the ACL that may lead to failure (11). ACL injury may also occur during the landing phase of a jumping maneuver in which the athlete is in a relatively upright position with minimal hip and knee flexion. In this position, greater quadriceps and less hamstring activation increases the forward translation of the tibia on the femur, which may result in an ACL injury (12).

Several factors may contribute to noncontact ACL injuries and can be classified as being intrinsic or extrinsic **(Table 55.1)** (13). Intrinsic factors are structural and physiological in nature, representing those features that clinicians cannot modify. They include the intercondylar notch width, ACL size, absolute pelvic width, femoral length, physiological laxity, and hormonal influences. Extrinsic factors are those that can be modified with therapeutic interventions and include biomechanical and neuromuscular influences. In this chapter, we will explain how all of these factors may lead to injury and present prevention program strategies that may decrease the risk of ACL injury in the female athlete.

ANATOMICAL OVERVIEW

The ACL is an intra-articular, extrasynovial ligament that primarily restrains anterior tibial translation on the femur. The ligament passes through the intercondylar notch from an anteromedial to a posterolateral direction. The ligament has attachments along the posteromedial wall of the lateral femoral condyle and just anterior to the medial tibial eminence. It consists of two distinct bands, although a third intermediate band has also been described (14). These bands are defined based on their tibial attachments and consist of anteromedial and posterolateral bundles **(Fig 55-1)**. As the knee moves, these bands provide differing stabilizing effects for the knee. When the knee is in full extension, the posterolateral bundle is tauter compared to the anteromedial bundle. As the knee flexes, the ACL assumes a relatively horizontal position. This position causes increased tightening of the anteromedial bundle and a loosening of the posterolateral bundle. One portion of the ACL remains under tension throughout the full range of motion, providing a continuous stabilizing effect for the knee.

INTRINSIC FACTORS

ACL and Intercondylar Notch Size

Since 1938, researchers (15) have theorized that a smaller intercondylar notch size may increase the risk of ACL injury. They believed that ACL injury results from an increased stretch over the inner margins of the femoral condyles, which may occur at positions near full knee extension where the ACL can abut the roof of the intercondylar notch. Therefore, athletes who have a smaller sized notch may be more susceptible to an ACL injury because of the decreased space available within the intercondylar notch. Based on this relationship, researchers have investigated the correlation between intercondylar notch stenosis and ACL injury using plain radiographs, computed tomography (CT), and magnetic resonance imaging (MRI).

Plain Radiographs

Historically, physicians have assessed intercondylar notch size using plain radiographs. In an attempt to normalize notch size for comparison among subjects, Souryal et al. (16) developed the notch width index (NWI). This is defined as the ratio of the width of the intercondylar notch to the width of the distal femur at the level of the popliteal grove as seen on a tunnel view. They reported that high school athletes who sustained a noncontact injury had an NWI of 0.189 compared to 0.233 for those who injured their ACL during a contact mechanism. In a related study, Ireland et al. (17) reported that individuals who sustained an ACL injury had both smaller NWI and absolute notch width measurements, regardless of gender, than those individuals who did not injure their ACL ligament.

Researchers (18,19) have challenged the usefulness of the NWI. Shelbourne et al. (18) found that femoral bicondylar width increased as absolute femur length increased and believed that absolute notch width may be a more appropriate radiographic measurement. They reported a mean notch width of 16.9 mm and 14.5 mm, respectively, for noninjured males and females of similar height. For patients with unilateral ACL tears, the mean notch width decreased to 15.8 mm in males and 13.8 mm in females. The notch size decreased even more in those having bilateral ACL tears. For this subject cohort, males and females had average notch widths of 15.3 mm and 12.8 mm, respectively. Based on these findings, Shelbourne et al. (18) concluded that subjects with narrower absolute notch widths might possess a higher risk of injury.

Alternatively, others (20–23) have not found a relationship between notch size and incidence of ACL injury. The controversy in the literature may be due to limitations associated with plain radiographs that may influence measurement precision. Such factors include overlap and shadowing associated with plain radiographs and variation in knee position during radiography. Finally, plain radiographs only provide a two-dimensional view. Therefore, plain films may not adequately depict the true shape of the intercondylar notch and true relationship between the intercondylar notch and ACL size.

CT and MRI

More recently, researchers have analyzed the three-dimensional features of the intercondylar notch using more advanced imaging technology. Anderson et al. (24) collected CT images of the distal femur, created composite drawings of the intercondylar notch, and consistently identified five general shapes. Shapes ranged from an inverted "U" to a crested wave–shaped notch with a flattened superior medial corner. The crested wave shape resulted in a more stenotic notch. Patients with this morphology had a higher incidence of ACL injury, regardless of gender.

MRI has also been used to study the size of the intercondylar notch and the ACL. Davis et al. (25) reported a positive correlation between absolute intercondylar notch and ACL width. They also found that males exhibited larger notch and ACL widths than females. Other researchers have also compared ACL cross-sectional area between genders (19,26). In these studies, they reported larger ligaments in male subjects. They inferred that a smaller ligament may be weaker and more vulnerable to forces generated during certain athletic maneuvers. Some researchers have examined the strength of different sized ACL specimens and reported that a 14-mm ligament may withstand loads of up to 2,900 newtons (N), whereas a 10-mm ligament can only withstand loads up to 2,070 N (27). Few studies have examined this relationship, and more are needed to establish the relationship between ACL size and ligamentous strength.

Structural Alignment

Studies have shown that females tend to perform running and cutting activities with greater valgus angles and external abduction moments of the knee compared to males. Fung and Zhang (11) have shown that these actions may place greater stain on the ACL, and researchers have studied gender differences related to structural alignment. They have theorized that the structural malalignment that contributes to these movement patterns may increase the risk of ACL injury in the female athlete.

Conventional wisdom suggests that females have wider pelvises, which may lead to coxa varum, genu valgus, and increased rotational forces at the tibiofemoral joint. However, a study by Horton and Hall (28) found that, in absolute terms, females had smaller pelvic widths compared to male subjects. Subsequently, Livingston and Gahagan (29) examined pelvic width by calculating a hip width to femoral length ratio for males and females. Although females had smaller absolute pelvic widths, their hip width to femoral length was greater than in males. These authors concluded that the shorter femur length associated with female subjects increased the hip adduction required to position the feet under the center of mass of the body. This, in turn, may increase the knee valgus angle and, perhaps, the strain on the ACL. Therefore, the pelvic width to femoral length ratio might be more predictive of ACL injury than absolute pelvic width alone.

Loudon et al. (30) studied static structural faults that may be predictive of ACL injury. They reported that knee hyperextension, excessive navicular drop, and excessive subtalar joint pronation discriminated between females with and without ACL injury. They also determined that the presence of two or more structural faults may be more predictive of ACL injury than any one alone. For example, knee hyperextension in combination with tibial internal rotation can stretch the ACL over the lateral femoral condyle. During weight-bearing activities, subtalar pronation is coupled with tibial internal rotation (31). Therefore, excessive pronation can impart additional strain to the ACL, making it more vulnerable to injury. However, this study was retrospective in nature; it is unknown if these factors conclusively caused the ACL injury.

Tibial Plateau Orientation

The posterior slope of the tibial plateau has been suggested to contribute to ACL injury risk. This angle is formed by the tibial plateau in relation to the long axis of the tibia. The normal posterior slope ranges from 10 to 12 degrees. However, a steeper posterior slope may increase anterior tibial translation by placing the femur in a more posteriorly directed position relative to the tibia. Dejour and Bonnin (32) measured tibial slope and anterior tibial translation, using the radiological Lachman test, for the involved and uninvolved knee in subjects having a unilateral chronic ACL rupture. They then used linear regression analysis to determine the relationship between anterior translation and tibial slope. This analysis showed a 3.5-mm increase of anterior tibial translation for every 10-degree increase in tibial slope, and it was thought that a higher tibial slope may contribute to ACL injury. However, Meister et al. (33) measured posterior tibial slope in subjects diagnosed with and without ACL injury. Their results did not find differences in tibial slope between groups and were unable to validate this as a risk factor associated with ACL injury. Because limited research exists in this area, future investigations are needed to establish the possible relationship between tibial plateau orientation and ACL injury.

Physiological Laxity

The main function of the ACL is to limit anterior translation of the tibia on the femur. Failure occurs when the anterior load exceeds the strength of the ligament. Some researchers (34,35) have suggested that increased joint laxity results in excessive anterior tibial translation and ACL injury. Therefore, there has been some focus on the influence of both generalized joint laxity and ligamentous laxity on ACL injury.

Nicholas (36) originally reported a relationship between generalized joint laxity and knee injury in male football players. These relationships have also been compared between males and females in the context of understanding the gender bias in ACL injuries. Both Ostenberg and Roos (37) and Soderman et al. (38) have found generalized joint laxity to be a significant factor in the gender bias for ACL injury.

The KT-1000 Ligament Arthrometer (Med-Metric, San Diego, CA) has been used to assess gender differences in ligamentous laxity. Prior work has shown that collegiate female athletes have greater anterior tibial translation than their male counterparts (39–41). Furthermore, Uhorchack et al. (42) reported that females who exhibited ligamentous laxity values of one or more standard deviations above the mean were 2.7 times more likely to sustain a noncontact ACL injury than those with less laxity. This ligamentous laxity, in combination with a decreased intercondylar notch size, may further increase the likelihood of sustaining an ACL injury.

Hormonal Influences

Hormonal differences may further contribute to the ACL injury gender bias. Many studies have evolved from the earlier work of Liu et al. (43), who identified estrogen and progesterone receptors in human ACL cells. Estrogen is thought to decrease fibroblastic and collagen production (44), whereas progesterone has opposite effects (45). It has been hypothesized that cyclic changes, absolute level, and rate of hormonal change of estrogen and progesterone may affect ligament strength.

The menstrual cycle can be divided into the follicular, ovulatory, and luteal phases. Estrogen levels rise dramatically during the ovulatory phase and remain elevated throughout the luteal phase; progesterone levels remain relatively low until the luteal phase. These fluctuations may place the female athlete at greater risk of injury just prior to ovulation when estrogen levels are at their highest. Some researchers (46,47) have reported an association between high estrogen levels, ligament laxity, and ACL injury. However, in contrast, others (48–50) have not found this relationship. A limitation of many studies has been a smaller sample size and reliance on subjective history regarding the phase of menstrual cycle at the time of injury. Although researchers have documented hormone level using saliva and blood samples, larger scale studies are needed to better understand this relationship. Future studies should use common time intervals to define the menstrual phases; determine hormone levels based on urine, saliva, and serum; and report these levels both at the time of injury and at the beginning of the next period (51). Such information will help clinicians better determine the phase of the menstrual cycle and the length of time within the cycle that an injury occurred (51).

Oral contraceptive use further complicates this issue. Moller-Neilson and Hammar (52) reported that females who took an oral contraceptive pill (OCP) sustained fewer overall injuries than females who did not. Martineau et al. (53) reported a significant decrease in knee laxity in women who took an OCP. In stark contrast to these studies, an NCAA surveillance revealed higher injury rates prior to or immediately following menses regardless of OCP use. Therefore, at this point, there is a lack of consensus regarding the association between menstrual cycle phase, OCP use, and ACL injury.

EXTRINSIC FACTORS

Although anatomical and hormonal factors may play a role in injury risk, they are generally not modifiable. However, there are factors thought to be related to injury risk that may be amenable to change. These include movement patterns and forces (biomechanical factors) as well as the control of muscular activity (neuromuscular factors). These factors will be discussed in the next sections.

Biomechanical Factors

Lower extremity kinematic differences between male and female athletes have been studied during many types of athletic maneuvers. Zeller et al. (54) examined gender differences during a single-legged squat and found that females demonstrated greater hip adduction and subtalar pronation compared to males. Females also maintained a valgus knee position throughout the task, while males remained in a more varus posture. These results showed that females moved toward knee valgus, a more risky knee position according to Hewett et al. (55), during a relatively low-demanding task **(Fig 55-2)**.

Malinzak et al. (56) evaluated gender differences in lower extremity kinematics during higher demanding activities of running, cross-cutting, and side-cutting. Compared to males, female athletes demonstrated greater knee valgus and less knee flexion angles during the stance phase of these maneuvers. Ferber et al. (57) conducted a study in recreational runners to identify gender differences in frontal- and transverse-plane knee and hip kinematics. As in the Malinzak et al. (56) study, females exhibited greater knee valgus angles, as well as greater hip adduction, hip internal rotation, and tibial external rotation angles compared to males.

Many noncontact ACL injuries occur during landing, and gender differences have been identified with these activities

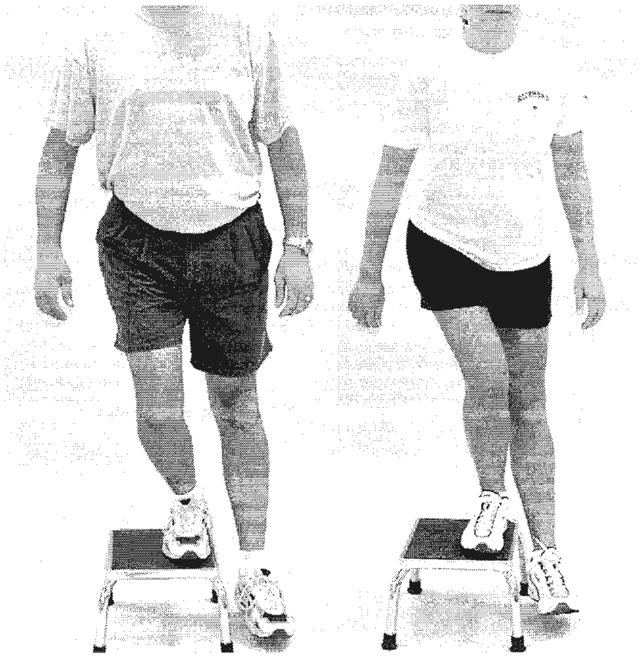

Fig 55-2. When instructed to do a minisquat, the male (left) demonstrates hip over knee over ankle alignment; the female (right) demonstrates femoral adduction and internal rotation and subsequent external rotation, valgus of the knee, and forefoot pronation. (Copyright 2001, M.L. Ireland.)

as well. Ford et al. (58) reported that high school female basketball players land in greater knee valgus than males during a drop vertical jump task. Lephart et al. (59) found that females performed landing activities with greater hip internal rotation, greater tibial external rotation, and less knee flexion than males. Fung and Zhang (11) have shown that combined tibial external rotation (that may result from increased femoral internal rotation) and knee valgus places high strain on the ACL.

Gender differences in kinetic variables have also been studied. Chappell et al. (60) showed that females generated greater external knee valgus moments during a vertical jump than males. More recently, Hewett et al. (61) assessed lower extremity kinetics in 205 healthy high school basketball, volleyball, and soccer athletes. They then followed them through two fall (soccer) and one winter (basketball) sports seasons and recorded any lower extremity injuries. They reported that females who went on to sustain an ACL injury exhibited 8-degree greater knee valgus angles than noninjured athletes. Injured athletes also had 2.5 times greater external knee abduction moments during landing and 20% higher ground reaction force during landing compared to noninjured females.

In general, females exhibit greater knee valgus, femoral internal rotation, and femoral adduction on an externally rotated knee, which Ireland (13) has described as the "position of no return." **(Fig 55-3).** compares optimal body alignment and muscle activity to this vulnerable position. A noteworthy point is that proximal instability (from the trunk and hip) results in greater knee valgus and knee external rotation, postures known to place increased strain on the ACL (11). This, in combination with limited knee flexion, further increases the risk of ACL injury because smaller knee flexion angles limit the hamstrings' ability to contract and prevent anterior tibial translation. In summary, mechanics appear to contribute significantly to the ACL gender bias.

Neuromuscular Factors

Although kinematic and kinetic patterns contribute to the ACL gender bias, neuromuscular factors are thought to also play a significant role. Studies have identified gender differences related to proprioception, muscular activation, and muscular strength and endurance. We believe that an understanding of these differences is paramount when developing and implementing ACL injury rehabilitation and prevention programs.

Proprioception

Proprioception, the recognition of joint motion and position during active and passive movements, is critical for normal joint function. The nervous system receives proprioceptive input from mechanoreceptors located in ligaments, such as the ACL. It uses this information to coordinate quadriceps

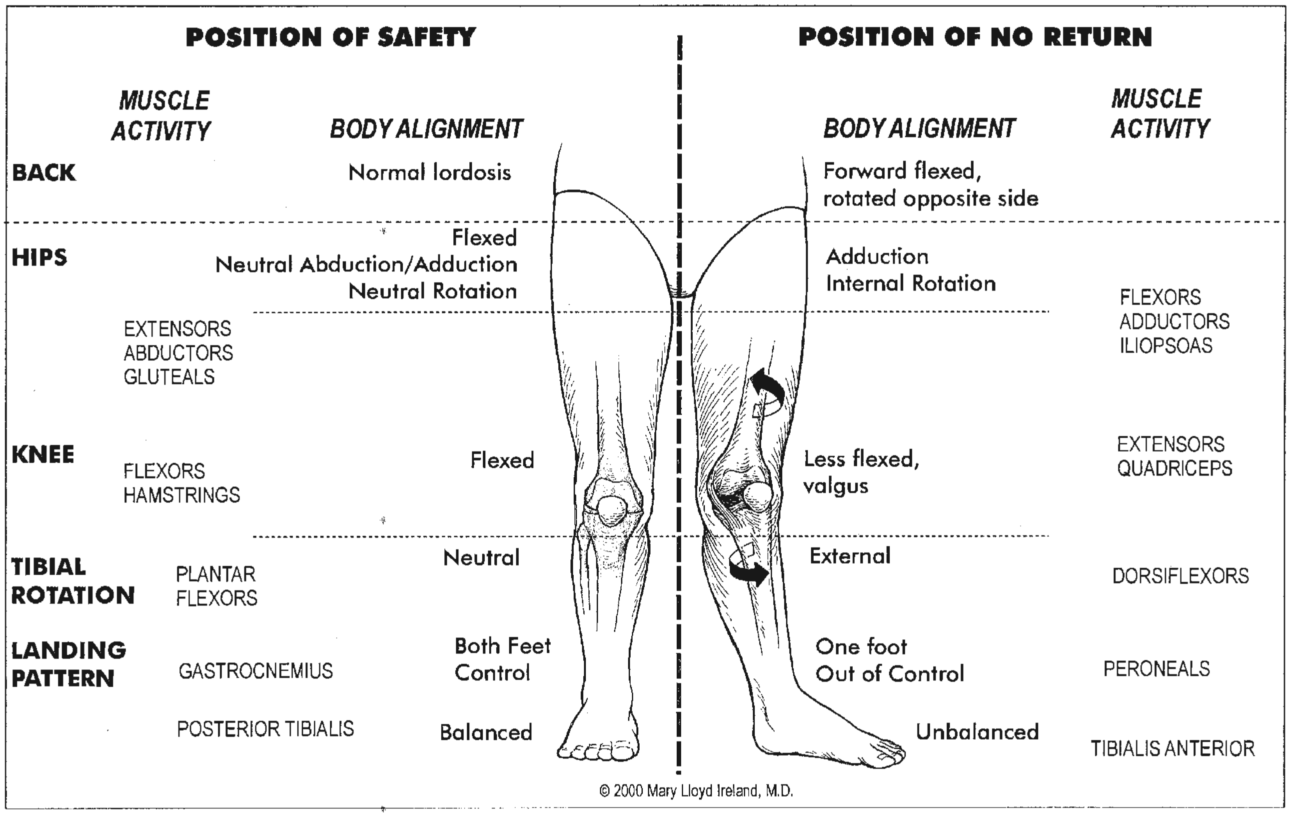

Fig 55-3. The position-of-no-return mechanism for ACL injury and the safe position. (Copyright 2002, M.L. Ireland.)

and hamstring co-contraction, which in effect stiffens and stabilizes the knee during dynamic activities. Therefore, diminished proprioception may alter knee musculature activation in such a way as to make the ACL more vulnerable to injury.

Gender differences may exist with respect to proprioception. Rozzi et al. (40) reported that females required longer time to detect motion during passive knee extension. This diminished proprioception suggests that the hamstring contraction required to counteract quadriceps activity may be delayed. Such a delay may be detrimental to the ACL because of the resultant anterior tibial shear force.

Muscular Activation

Regarding ACL injury risk, much attention has been focused on the balance between the quadriceps and hamstring activation. Hamstring activity helps prevent excessive anterior translation of the tibia. Wojtys et al. (62) reported that males can generate greater maximum isometric co-contraction of the quadriceps and hamstrings, resulting in significantly less anterior tibial translation, than females with similar knee laxity. During dynamic athletic maneuvers, it has been shown that males produce relatively higher peak flexor moments about the knee (2). However, females tend to perform landing maneuvers with predominant quadriceps activation, a pattern that may lead to excessive anterior tibial translation (12). Markolf et al. (63) found that an excessive quadriceps contraction causes increased tibial anterior translation during 0 to 30 degrees of knee flexion. As the knee approaches 45 degrees of flexion and beyond, the patella ligament's orientation changes and provides a posteriorly directed tibial force. Since females perform many demanding activities with limited knee flexion, they do not take advantage of the stabilizing influence knee flexion provides.

The focus of muscular activation in ACL injury has been on the knee. However, it is the hip musculature that has the greatest influence on frontal and transverse plane movements of the knee. Zeller et al. (54) were among the first researchers to examine gender differences in hip and knee muscle activity during a single-legged squat. They chose this activity because it simulated a common athletic position that required an individual to control body weight over a planted leg. As expected, in terms of kinematics, females performed a single-legged squat with greater hip adduction and knee valgus angles. With respect to electromyogram (EMG) activation, a multivariate analysis of variance for all muscle activity showed that females had higher overall activation than male subjects. When analyzing muscles separately, females demonstrated significantly greater rectus femoris amplitudes.

Studies for patellofemoral pain syndrome have shown that subjects with apparent quadriceps weakness require greater motor unit recruitment (higher activation) during stair climbing (64) and knee extension exercise (65). With respect to the Zeller et al. (54) study, greater hip activation demonstrated by females may reflect proximal weakness and account for greater hip adduction and internal rotation (as discussed in Biomechanical Factors). Combined hip adduction and internal rotation can increase knee valgus which, when combined with rectus femoris activation, can impart a strong anterior tibial force on the knee and strain on the ACL. Additional studies are warranted to conclusively support the relationship between hip control and ACL injury.

Muscular Strength

Adequate quadriceps and hamstring muscle strength is required for normal knee function. Together, co-contraction of the knee musculature not only stiffens the knee but also attenuates ground reaction forces imparted through the lower extremity. Although male athletes exhibit overall greater knee strength than females (66), this bias does not occur until after puberty (55,67). During the adolescent growth spurt, males show dramatic increases in strength, power, and coordination, which is not similarly achieved by females (9,10,55). As a result, this difference may account for the increase in the postpubescent female ACL injury rates during this developmental stage. These findings support the importance of knee strength and its stabilizing effects.

Strength has also been significantly correlated with endurance, which, when decreased, results in early fatigue. Fatigue has been shown to lead to faulty movement patterns (68) and altered proprioception (69). Nyland et al. (70) evaluated the effect of fatigue on muscle activation in female basketball and volleyball athletes. As these athletes fatigued, they had delayed recruitment of the quadriceps and hamstring musculature and an acceleration of maximal knee flexion during running and rapid stopping maneuvers. Chappell et al. (71) examined the effect of lower extremity fatigue on knee kinematics and kinetics. They found that females demonstrated significantly higher peak proximal tibial anterior shear forces and external valgus moments and smaller knee flexion angles during landing from three stop-jump tasks. Based on these studies, it can be inferred that knee musculature fatigue may predispose the female athlete to knee injury.

The quadriceps and hamstrings are important knee stabilizers in the sagittal plane, but they play less of a role controlling frontal and transverse plane motion. Fortunately, the lumbopelvic musculature, referred to as the core, can influence these planes of motion. For example, the hip abductors control femoral adduction, and the hip external rotators control femoral internal rotation. Together, hip abductor and external rotator muscle strength may limit the amount of valgus strain placed on the knee.

As seen in the knee musculature, there appears to be a gender difference related to core strength. Females with either a lower extremity or low back dysfunction have demonstrated greater side-to-side hip extension strength asymmetry than males (72). Cahalan et al. (73) reported a 39% deficit in hip external rotation torque in females compared to males. Recently, Ireland et al. (74) have shown that females with anterior knee pain had significant hip abductor and external rotator muscle weakness. However, this study was cross-sectional in nature and was unable to assess cause and effect. To address this limitation, Leetun et al. (75) prospectively examined the association between core strength, endurance measures, and lower extremity injury in male and female collegiate athletes. Females generally exhibited lower measures of hip abduction, hip external rotation, and side bridging function. In addition, they were slightly weaker in their abdominal muscles. Over an entire competitive season, they found that athletes with weaker core muscles were more likely to incur a lower extremity injury. To date, limited literature exists regarding this association between core endurance and lower extremity injury. More prospective studies are needed to establish this relationship.

PREVENTION PROGRAMS

As the mechanisms of ACL injuries are being revealed, prevention programs are being developed. Some have stressed proper mechanics (76,77) and proprioception (77,78), whereas others have emphasized strengthening (2), conditioning (79), and neuromuscular training (2,80). Although each intervention has a primary focus and reported significant success, much overlap exists among programs, making it difficult to ascertain the most important factor. Based on the current state of knowledge, a prevention program should include all areas related to the neuromuscular, kinematic, and kinetic factors that are believed to increase the risk of ACL injury.

Beginning at the postpubescent developmental phase, females should engage in an aggressive knee and core neuromuscular rehabilitation program. Quadriceps and hamstring strength is needed to adequately support the knee and attenuate forces generated during high-demand activities. Core strength appears to be critical for proper hip and knee alignment. Proprioceptive training may further protect the female from injury because it allows her to anticipate external forces or loads applied to the knee. This anticipation, referred to as the feedforward mechanism, can help the athlete preactivate her muscles and develop movement patterns to protect the knee. Studies have shown that proprioception programs can significantly reduce the incidence of ACL injury (77,78,80).

Addressing these neuromuscular factors may help females develop proper kinematic and kinetic patterns during landing and cutting techniques. Henning and Griffis (81) have reported a significant reduction in ACL injury by training athletes to increase knee flexion during landing, avoiding a planted foot pivot, and using a three-step stop-deceleration. Furthermore, Hewett et al. (76) have shown that emphasis on minimizing knee varus and valgus alignment during these maneuvers can reduce injury. They also train their athletes to land softly to minimize external moments applied to the knee.

Clinicians can use both verbal and visual feedback to instruct the athlete on proper landing and cutting techniques. Hewett et al. (76) successfully used a prevention program that encouraged females to perform as many repetitions of plyometric drills as long as they used proper technique. However, the athletes were stopped when they exhibited signs of fatigue. Myklebust et al. (77) also implemented a training program where athletes were paired and provided each other with visual feedback on proper biomechanics. Using augmented feedback, Onate et al. (82) trained athletes to generate less ground reaction forces during a vertical jump. Together, these studies have found that feedback is an important component of an effective prevention program.

Finally, a prevention program should address sport-specific tasks. This component is very important because it will help train the female athlete to maintain optimal lower extremity alignment during more demanding activities. They should participate in a plyometric program that emphasizes landing in a more varus, flexed knee position **(Fig 55-4).** Sport-specific agility drills may also be used to improve proprioception and biomechanics **(Figs 55-5 to 55-7)** (83). Finally, we cannot overemphasize that the female athlete

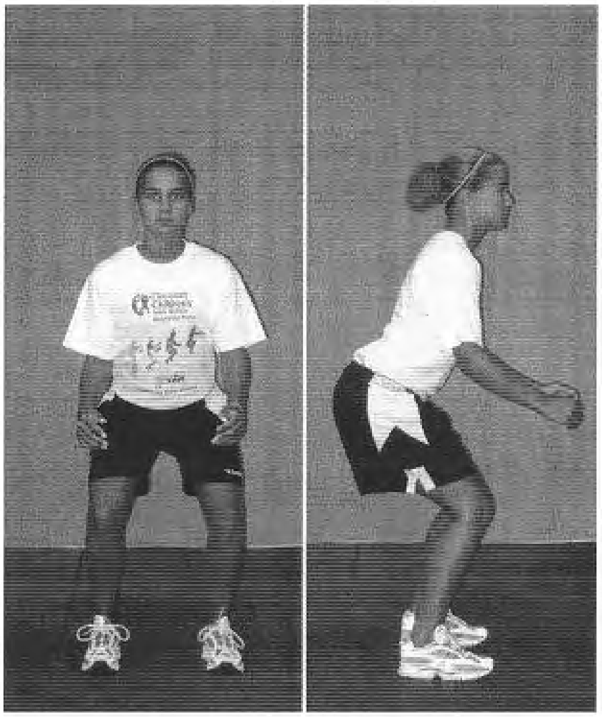

Fig 55-4. The athletic position is a functionally stable position with the knees comfortably flexed, shoulders back, eyes up, feet approximately shoulder width apart, and body mass balanced over the balls of the feet. The knees should be over the balls of the feet, and the chest should be over the knees. The athlete-ready position is the starting and finishing position for most of the training exercises. During some exercises, the finishing position is exaggerated with deeper knee flexion in order to emphasize the correction of certain biomechanical deficiencies. (From Myer GD, Ford KR, Hewett TE. Rationale and clinical techniques for anterior cruciate ligament injury prevention among female athletes. *J Athl Train*. 2004;39:352–364; permission pending.)

Fig 55-5. Single-leg hop and hold. The starting position is a semi-crouched position on a single leg. The athlete's arm should be fully extended behind her at the shoulder. She initiates the jump by swinging the arms forward while simultaneously extending at the hip and knee. The jump should carry the athlete up at an angle of approximately 45 degrees and attain maximal distance for a single-leg landing. She is instructed to land on the jumping leg with deep knee flexion (to 90 degrees) and to hold the landing for at least 3 seconds. Coach this jump with care to protect the athlete from injury. Start her with a submaximal effort on the single-leg broad jump so she can experience the level of difficulty. Continue to increase the distance of the broad hop as the athlete improves her ability to "stick" and hold the final landing. Have the athlete keep her visual focus away from the feet to help prevent too much forward lean at the waist. (From Myer GD, Ford KR, Hewett TE. Rationale and clinical techniques for anterior cruciate ligament injury prevention among female athletes. *J Athl Train*. 2004;39:352–364; permission pending.)

Fig 55-6. Single-leg balance. The balance drills are performed on a balance device that provides an unstable surface. The athlete begins on a device with a two-legged stance with feet shoulder width apart, in athletic position. As she improves, the training drills can incorporate ball catches and single-leg balance drills. Encourage the athlete to maintain deep knee flexion when performing all balance drills. (From Myer GD, Ford KR, Hewett TE. Rationale and clinical techniques for anterior cruciate ligament injury prevention among female athletes. *J Athl Train*. 2004; 39:352–364; permission pending.)

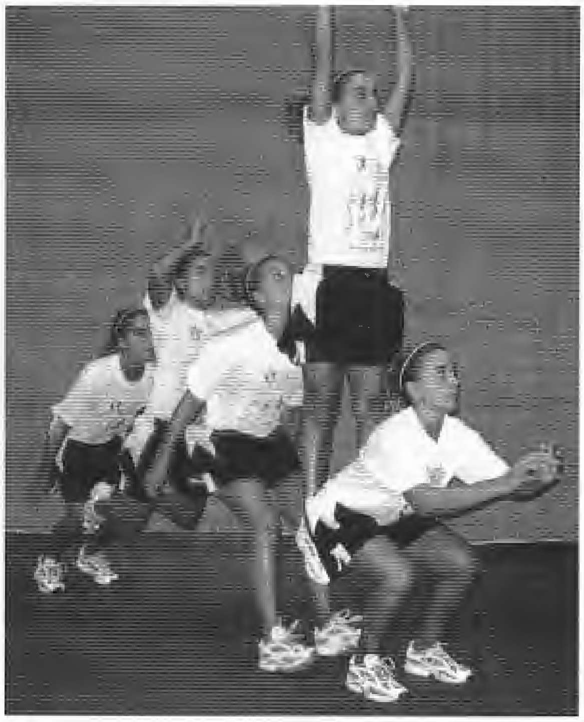

Fig 55-7. Jump, jump, jump, vertical jump. The athlete performs three successive broad jumps and immediately progresses into a maximum-effort vertical jump. The three consecutive broad jumps should be performed as quickly as possible and attain maximal horizontal distance. The third broad jump should be used as a preparatory jump that will allow horizontal momentum to be quickly and efficiently transferred into vertical power. Encourage the athlete to provide minimal braking on the third and final broad jump to ensure that maximum energy is transferred to the vertical jump. Coach the athlete to go directly vertical on the fourth jump and not move horizontally. Use full arm extension to achieve maximum vertical height. (From Myer GD, Ford KR, Hewett TE. Rationale and clinical techniques for anterior cruciate ligament injury prevention among female athletes. *J Athl Train*. 2004;39:352–364; permission pending.)

should practice proper deceleration techniques and prevent pivoting on a fixed foot (84).

In conclusion, recent studies have shown promising results with prevention programs. However, because the risk factors have not been clearly identified, additional prospective studies are required to determine the most critical aspect of a specific program. Additional information on prevention programs can be accessed at www.aclprevent.com and www.sportsmetrics.net.

CONCLUSION AND FUTURE DIRECTIONS

Females are known to be at higher risk than males for noncontact ACL injury in sports like basketball and soccer. Historically, research has focused on anatomic, physiological, and hormonal influences independent of each other. A review of the recent literature has not conclusively supported a single intrinsic factor responsible for injury. Future studies should examine the interdependence of these measures because a multifactorial approach may better explain the role of intrinsic factors on the ACL gender bias (85).

Fortunately, recent investigations have suggested that extrinsic factors might contribute more to the ACL gender bias. Studies on prevention programs have demonstrated that extrinsic factors are amenable to change and can reduce injury. Although these programs have had promising outcomes, it is inconclusive what specific changes they impart on the overall system. Future studies should examine whether improvement in strength, proprioception, movement execution, or a specific combination of areas is most effective in preventing ACL injury. Future investigations should also quantify the most appropriate time, duration, and intensity of participation in a prevention program relative to the competitive season (85).

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