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Anterior Cruciate Ligament Injuries in Female Athletes

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Over the past decade, sports physicians, orthopaedic surgeons, trainers, and female athletes have recognized that deceleration, noncontact injuries have produced anterior cruciate ligament injuries at an alarming rate in high school and college female athletes. A review of the NCAA Injury Surveillance System supports the notion that there are different injury rates by sex (Fig. 1). Men's and women's sports cannot be compared exactly because of differences in the rules (men's lacrosse is contact, women's lacrosse is not) and type of activity (women's and men's gymnastics share only the vault and floor exercise). Yet where males and females play on similar surfaces, with similar rules and activity levels, as in basketball and soccer, there exists a higher percentage of anterior cruciate ligament injuries in females. The NCAA with the aid of the PAC 10, Big Ten, and ACC has compiled statistics that underscore the concern[1] (Fig. 2).

Figure 1. National Collegiate Athletic Association Frequency Data Anterior Cruciate Ligament Injuries

	1988-1989	**1989-1990**	**Total**
Women	50	34	84
Men	7	12	29

Figure 2. Total Injury and Knee Injury Summary for Basketball (1989-1993)

Factor	**Men's Basketball**	**Women's Basketball**
Teams submitting data (ave./year)	531 (107)	676 (116)
All injuries	4,116	3,303
Knee injuries (% of all injuries)	503 (12%)	615 (19%)
Athlete exposures	736,076	639,898
Knee injury rate(per 1,000 exposures)	0.70	1.0

Females have been shown to have a higher incidence of anterior cruciate ligament injuries in skiing, gymnastics, handball, volleyball, basketball and soccer than their male counterparts.

Research has suggested that females have a multi-factorial reason for their injury pattern[2] (Figs. 3-6). Certainly, contact injuries in men produce cruciate ligament injuries. It has been suggested that 72% of football players with knee injuries were hypermobile. This 1970 Nicholas[3] study has never been substantiated in the female athlete. Furthermore, detailed studies in females with bilateral injuries have not shown any conclusive relationship between hypermobility in general and laxity of the knee and

anterior cruciate ligament as was demonstrated in the males in the study.
Some current areas of research are worthy of discussion. They include:

1. The femoral notch width or condyle size.
2. Shoe and surface interface.
3. Deficiencies in training with regard to skill level, proprioception, coordination, muscular balance, and recruitment.
4. Lower extremity malalignment.
5. The crucial effect of estrogen on ligament laxity.

In 1993, a study of more than 900 male and female high school athletes correlated that noncontact cruciate ligament injuries occurred in athletes with a smaller notch-width index than in athletes whose cruciate ligaments tore in contact activities. LaPrade et al,[4] correlated intercondylar notch stenosis and anterior cruciate injuries in a prospective study and found that no conclusive evidence referable to female anterior cruciate ligament tears could be made. This study recorded no evidence of the role of notch width index or notch width in anterior cruciate ligament injuries. However, studies relating width to width, that is, width of the notch to width of the anterior cruciate ligament, have led Japanese literature to postulate that, if all anterior cruciate ligaments are the same size, a smaller notch is more likely to cause impingement on a normal sized ligament.[5]

Figure 3. Prevalence of Anterior Cruciate Injuriesin the Big Ten Conference (10 Institutions)

	Men	**Women**
Number of participants	145	140
Documented ACL injuries	3	27
Prevalence of ACL injuries	2.1%	19.3%

Figure 4. Prevalence of Anterior Cruciate LigamentInjuries in the Pacific Ten Conference (10 Institutions)

	Men	**Women**
Number of participants	138	130
Documented ACL injuries	1	16
Prevalence of ACL injuries	0.7%	12.9%

Figure 5. Prevalence of Anterior Cruciate Ligament Injuries in the Atlantic Coast Conference (9 Institutions)

	Men	**Women**
Number of participants	119	115
Documented ACL injuries	5	19
Prevalence of ACL injuries	4.2%	16.5%

Figure 6. Prevalence of Anterior Cruciate Ligament Injuries Combined Date (29 Institutions)

	Men	**Women**
Number of participants	402	385
Documented ACL injuries	9	62
Prevalence of ACL injuries	2.2%	16.1%

Shoe and surface interface have also been reviewed in the literature. Basketball sneakers and cleated soccer shoes are all similar at a high performance level. They do not perform the same, however, on male and female feet. Norwegian investigators studying three upper divisions of female handball players postulated a relationship of sneakers with a higher friction rate to anterior cruciate ligament injuries after a review of high incidence of injuries.[6] The female foot differs from the male. It has a narrow heel, small heel cord, and is narrower relative to overall length than the male foot. Leg length is 51% of female body height compared to 56% in males. Female's feet strike the ground more often to cover an equal distance and also have more ground reaction forces. It is entirely possible that females simply have more opportunities to injure the cruciate ligament.

In many sports, the female shoe is a smaller version of the shoe worn by men. In the shoe industry, this is referred to as scaling. The problem worsens for women with a shoe size of 8 or greater. Straighter lasts to correct female pronation are desirable, yet width adjustment to correct the last is only accomplished by tighter lacing of the sneaker. The average athletic size is a D width for males and a C width for females. A compromise in design must be met to enhance performance and protect the athlete. With increasing amounts of ankle resistance, as in the use of high top athletic shoes for basketball, movement is restricted in the frontal plane. In an effort to reduce ankle inversion injuries, knee strain is increased in a manner similar to that of ski boots. Still, the question remains whether it is surface to surface friction or foot imbalance at the time of pronated foot strike that causes cruciate ligament injuries.

Skill level appears to have a multifaceted influence at the cellular level in cruciate ligament injuries. Females mature at an earlier age than males. Does the slower onset of puberty in males play an important role in preventing injury? A Ball State study of muscle biopsies in male and female track athletes demonstrated that the two groups were similar in terms of muscle fiber composition and selected enzymatic activities. There were, however, notable differences in muscle enzymes and in slow twitch fiber characteristics in males and females competing in and training for similar sports. Male athletes presented with larger fiber areas. These slow twitch fibers seemed essential for speed and endurance in track and field events. Does a difference between glycolitic and oxidated enzyme activities correlate to performance, speed, endurance, and strength? It has been suggested that performance, in part, reflected genetic endowment. Was there a demonstrated physiologic difference between males and females shown in lower extremity strength, endurance, muscle reaction time, muscle recruitment order, and joint laxity? The Wojtys7 study suggests yes. The anterior cruciate ligament is clearly a primarily static restraint, but the lower extremity muscles, particularly the hamstrings, are dynamic balancers, preventing anterior translation of the tibia.

The quadriceps muscle is an anterior cruciate ligament antagonist. In females, the order of muscle recruitment is different than in males. A study conducted by Wojtys et al,[7] demonstrated that 31% of the female athletes recruited the quadriceps first whereas only 17% of the males did. In these athletes, the quadriceps contraction placed an increased strain on the anterior cruciate ligament due to tibial translation anteriorly. In addition, peak muscle reaction time appeared delayed in the female athletes. As these studies were conducted on elite collegiate female athletes at the University of Michigan, inadequate conditioning should not have been a factor in the results. Anterior translation is greater in female than male athletes, perhaps playing a role in the increase in female injuries. Intuitively, the dynamic restraints of the musculoskeletal system should prevent or lessen injury during physical activity. Fatigue and lack of endurance decrease the effectiveness of this dynamic system, and contribute to the increased injury rate.

Contact sports show decreased anterior cruciate ligament injury with increased agility drills for males. Not surprising, when rehabilitating a patient after anterior cruciate ligament repair, therapy includes agility drills and plyometrics to strengthen the knee.

Lower extremity alignment has been dismissed by many examiners as having no role in anterior cruciate ligament injuries. Clearly, however, the miserable triad of hip anteversion, increased external tibial torsion, and pro-nated feet, characteristic of females, alters patello-femoral biomechanics. Meister et al[8] recently studied lower extremity malalignment and its relationship to anterior cruciate ligament injuries, finding that there was a greater correlation to injury and external tibial rotation than had previously been thought. The same malalignment as studied by Hughston[9] noted a compensatory external rotation, producing a greater pronated forefoot contact and an even greater rotation of the tibia during running or jumping activities. Although obviously leading to patellofemoral problems, the link to anterior cruciate ligament injury has not been widely accepted.

Do hormonal differences predispose athletes to injury? It is well known that female hormones effect the composition and structure of a variety of tissues. Estrogen has a significant effect on the development of bone, muscle, and connective tissue. Clearly, fluctuations in hormonal concentrations may influence the structure and composition of the anterior cruciate ligament. Expression of the estrogen and progesterone receptor proteins in target cells is a prerequisite for hormonal action. Nuclear localization of these receptors has recently been demonstrated in all cells that respond to female steroid hormones. As recently as April 1995, Liu et al,[10,11] localized both estrogen and progesterone receptor cells in the anterior cruciate ligament in ten human tissue specimens. With demonstration of these receptors in the synovium and the accompanying immunohistological localization in stromal cells in the blood vessels of the anterior cruciate ligament, these findings suggest that either directly or indirectly female hormones do indeed effect the structure of the anterior cruciate ligament.

Administration of estrogen to laboratory rats acutely decreased total tendon and fascial collagen. Long-term estrogen administration resulted in a decrease in the total amount of collagen in the joint capsules. Acute fluctuations in the serum estrogen concentration may induce changes in metabolism resulting in alterations in amount, type, and cross linkage of collagen fibers in the anterior cruciate ligament. An additional finding of this study was an increase in elastin in the aorta and hip joint capsule. During delivery of a human infant, a female in the breech position shows estrogen and relaxin hormonal changes that often produce laxity in the developmental hip. It is not difficult to conclude that the menstrual cycle and its accompanying hormonal fluctuations may definitively change the elasticity of the anterior cruciate ligament. The luteal phase of the menstrual cycle is characterized by high estrogen and relaxin levels, which may contribute to laxity of the ligament. Not surprisingly, in a Swedish study of 108 female soccer players in 1988, Moller-Neilson and Hammer[12] were able to demonstrate that players were more susceptible to injury in the premenstrual and menstrual phase of their cycles. An interesting finding of this study was a reduction in the number of injuries in the group using oral contraceptives. The implications of this study are still unclear.

It has been over 80 years since female divers were introduced into the Olympics. It has been 28 years since the introduction of Title IX collegiate programs. Medicine has made advances in treating anterior cruciate ligament injuries but is still struggling with the vulnerability of female athletes. It has defined multifactorial relationships between ground contact, limb alignment, muscle recruitment, and time to reduce anterior translation by muscle contraction. The recent recognition of hormonal influence on the anterior cruciate may be a significant factor in determining what causes anterior cruciate ligament disruption at a greater rate in female athletes.

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