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Anterior Cruciate Ligament Injury in Female Athletes: Epidemiology

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Objective: To present epidemiologic studies on anterior cruciate ligament (ACL) injuries in female athletes.

Data Sources: MEDLINE was searched from 1978 to 1998 with the terms "anterior cruciate ligament" and "female athlete," among others. Additional sources were knowledge base and oral, didactic, and video presentations.

Data Synthesis: Epidemiologic studies have focused on level of participation, specific sports, sex differences and contributing factors, injury mechanism, prevention programs, and outcomes studies. Female athletes have a significantly increased risk of noncontact ACL injuries over male athletes in soccer and basketball.

Conclusions/Recommendations: I believe that appropriate intervention programs can reduce these alarming rates of ACL injuries.

Key Words: mechanism of injury, position of no return, outcomes studies, prevention programs

Although the medial collateral ligament is the most commonly injured ligament, the anterior cruciate ligament (ACL) is the most frequently injured single ligament associated with limited range of motion.[1–3] In 1985, it was estimated that 50000 knee surgeries were performed each year in the United States.[4] One study showed an incidence of 60 knee ligament injuries per 100000 health members per plan year.[1] Males accounted for 72% and females for 28%; 65% of the injuries occurred during sports activities.

The true incidence of noncontact ACL injuries and the actual numbers of athletes affected are difficult to determine; determination would require following a large number of athletes participating on different levels over several seasons. In studying the incidence of this injury, the numerator is the number of ACL tears, and the denominator can be, for example, the number of athletic exposures (ie, number of hours of practices and games) or the number of participants. For valid comparisons of statistically significant numbers, epidemiologic studies must involve a large number of subjects over an appropriate number of years.

Epidemiologic studies have focused on level of participation,[5–23] specific sports,* sex differences and contributing factors, injury mechanism, prevention programs,[26–34] and outcomes studies.[3,35–49] A significantly increased risk of noncontact ACL injury has been noted in female soccer and basketball athletes when compared with male athletes in the same sports.[13,19] I believe that appropriate intervention programs can reduce these alarming rates and allow female athletes to participate with less risk of ACL injury. In this paper, the results of these studies will be addressed and suggestions for preventing ACL injuries will be made.

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*References 8, 10, 13, 14, 17, 18, 20, 23–25.

LEVEL OF PARTICIPATION

College Level

In 1982, the National Collegiate Athletic Association instituted the Injury Surveillance System, which collects injury information from athletic trainers at a geographic cross-section of Division I, II, and III institutions.[19] In 1997–1998, data on 15 sports (football, men's and women's soccer, field hockey, women's volleyball, men's and women's gymnastics, wrestling, ice hockey, men's and women's basketball, spring football, softball, and men's and women's lacrosse) were collected.[19] From 1990–1991 through 1997–1998, 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. All mechanisms of injury (noncontact, contact and collision, surface contact, and ball contact) were considered together.

As the years have passed, females have continued to experience more injuries than males, but injury rates within the sexes have not changed. That is, even though the female athletes are starting to play earlier and may now have better coaching and improved skills, their injury rate has not declined.

Female basketball players received an average of 0.68 ACL injuries in games versus 0.10 in practices, while the rates for male basketball players were 0.14 (games) and 0.05 (practices).[50] Similarly, female soccer players incurred an average of 1.12 injuries in games and 0.09 in practices, while the rates for males were 0.45 (games) and 0.06

(practices). Corresponding data for 1985–1993 also reflected greater ACL injury rates in females: 2.9 times greater in basketball players and 2.3 times greater in soccer players.[1] The rate of noncontact ACL injuries was 0.21 in female and 0.04 in male basketball players and 0.17 in female and 0.05 in male soccer players. Contact ACL injury rates were 0.05 in female and 0.02 in male basketball players and 0.10 in female and 0.05 in male soccer players.

Noncontact basketball ACL injuries were studied at 29 colleges in 3 conferences (Atlantic Coast, Big Ten, and Pacific Ten) during the 1988–1989 and 1989–1990 seasons.[18] Women athletes were 6.1 times more likely to sustain an ACL injury. Exposure hours were similar for the 194 men and 182 women, and 95% of injuries occurred in games, with ankle injuries being most common. The incidence of knee sprains was 5% for both females and males.[51] At 14 New Jersey colleges, females had a highly significant risk for knee injuries (2.21:1), ACL injuries (6.23:1), season-ending injuries (5.07:1), and injuries requiring orthopaedic surgery (7.61:1).[52]

High School Level

In studies of Texas high school football and girls' and boys' basketball injuries,[6,8,11] knee injuries were most common in girls' basketball, with a 2.1 times greater risk of knee injury per hour of exposure in females. Males had more injuries (543 injuries/973 participants) than females (436 injuries/890 participants) for injury rates of 0.55 in males and 0.49 in females. Compared with the males, female basketball athletes sustained 3.75 times more ACL injuries per exposure hour. The risk of injury in both males and females was greater during games than during practices.

When New Jersey high school basketball athlete injury patterns were compared,[16,52] females had a greater number of total and season-ending knee injuries, and ACL injuries occurred 3.52 times more often than in males. Both patellofemoral injuries and medial meniscal tears occurred more often in females than in males.

Other studies of high school sports injuries include one by Garrick and Requa.[7] In 870 participant seasons pairing 9 sports, the overall injury rates for noncontact injuries were similar in males and females. Zillmer, Powell, and Albright[10] noted a greater incidence of significant knee injuries in female basketball players, especially during games at the varsity level. Beachy et al[12] performed an 8-year prospective longitudinal study of injuries in Hawaiian high schools. Girls lost fewer days to knee injuries (0.31) than boys (0.39), but ACL injuries were not specifically investigated. By teams, females lost more days to injury than males (0.37 to 0.31) and more days per athlete per injury (0.34 to 0.24).

Further longitudinal prospective studies are needed. A National Athletic Trainers' Association-sponsored study directed by John Powell, which researched injuries over a 3-year period, is currently being presented. Data from this injury surveillance high school study will be presented in an upcoming issue of the *Journal of Athletic Training*.

Olympic Level

At the 1988 US Olympic trials, 80 males and 64 females participated.[20,53,54] A significant number of females sustained knee injuries requiring surgery when compared with males: 20 knee injuries requiring 25 surgeries, 8 of them ACL reconstructions, versus 6 knee injuries in the males, requiring 6 surgeries, 3 of them ACL reconstructions (Table 1).[20]

Military Level

When young female cadets first entered the military academies, they showed stress fracture rates that were increased over those of the male cadets.[22] As the training became more equalized, these rates also equalized.[21] At West Point, the incidence of complete ACL tears was not significantly different between male and female intramural and varsity athletes.[21] However, despite the lack of difference and the small number of subjects studied, there was a trend toward a higher incidence of ACL injuries in gymnasts and basketball players.[21] These findings are in contrast to findings at the US Naval Academy, where women midshipmen had a statistically significant increased incidence of ACL injuries, with a relative risk of 9.74 for military-related training; specifically, the obstacle course was associated with a 2.44 times greater risk of overall ACL injuries. The ACL injury rates for males and females in coeducational soccer, basketball, softball, and volleyball were not significantly different.[55] Further work is being conducted with military populations.

SPORT-SPECIFIC INJURIES

ACL injury incidences and patterns have been compiled for basketball,[8,10,13,18,20,23,24] soccer,[13,17,25] and volleyball.[14] Other studies have compared injuries in different sports.[7,9,19] Rates of noncontact ACL tears range from 2 to 4 times greater in female basketball and soccer athletes than in males playing the same sports.[13,19]

Table 1. Injuries Sustained During 1988 Olympic Basketball Trials*

Parameter	Males	Females	Total
Number of participants	80	64	144
Athletes with knee injuries	11†	34	45
ACL injuries	3	13	16
Number of athletes requiring surgery	6‡	20	26
Number of procedures	6	25	31
Type of procedure			
Arthroscopy	3	17	20
ACL reconstruction	3	8	11

* Reprinted with permission from Adis International Limited, Auckland, New Zealand. † and ‡ indicate a statistically significant difference between male and female athletes († = $P < .0001$; ‡ = $P < .0007$).

SEX DIFFERENCES AND CONTRIBUTING FACTORS

In order to reduce the rate of ACL injuries in the female athlete, we must focus on those factors that can be modified. These factors include playing style, preparation, and skill acquisition from a very young age. Contributing factors are intrinsic (not controllable), extrinsic (controllable), or both (partially controllable) (Table 2).

INJURY MECHANISM: NONCONTACT ACL, POSITION OF NO RETURN

By understanding the mechanisms of injury in sport, we can design intervention programs to reduce the risk of injury. Observations of ACL injury mechanisms in basketball show the athlete coming down in an uncontrolled landing, either catching the ball or trying not to go out at the baseline. A whiplike snap of the lower extremity is seen as the ACL tears. In visualizing this high-risk "position of no return," we comprehend the importance of a "get-down," knee-flexed, 2-footed balanced position. Figure 1 diagrammatically shows the position of no return and the safe position, from the joint positions of the back, hips, knee, and foot. In the no-return position, the hip abductors and extensors have shut down, and the pelvis and hip are uncontrolled. Muscle groups that would normally upright the individual are unable to perform this function due to their mechanical disadvantages and the lengthening of the muscle groups.

Noncontact injury patterns are similar in males and females. Figure 2 includes still photographs and line drawings of this mechanism of injury. Athletes injure their knees as they come down from a shot. Note the relatively extended knee initially; by the second frame, the ACL has failed. Hip and trunk-pelvis-hip control were previously lost, and lower extremity alignment was hip internal rotation and adduction, knee valgus, and tibial external rotation on a pronated, externally rotated foot. Figure 3 shows a left knee from the left and the back. The initially abducted hip goes into relative internal rotation and adduction on a pronated, externally rotated foot. At first, there is relatively little knee flexion; then the body weight goes forward as the body flexes over the legs, and, again, extreme valgus stress occurs after the ACL has failed. The hip and knee positions of rotation and less flexion are observed as the ACL fails. The gluteus maximus and hamstrings are unable to protect the ACL.

Table 2. Factors Contributing to ACL Injuries

Intrinsic	Extrinsic	Combined (partially controllable)
Alignment	Strength	Proprioception (position sense/balance)
Hyperextension	Conditioning	Neuromuscular activation patterns
Physiologic rotatory laxity	Shoes	Order of firing
ACL size	Motivation	Acquired skills
Notch size and shape		
Hormonal influences		
Inherited skills and coordination		

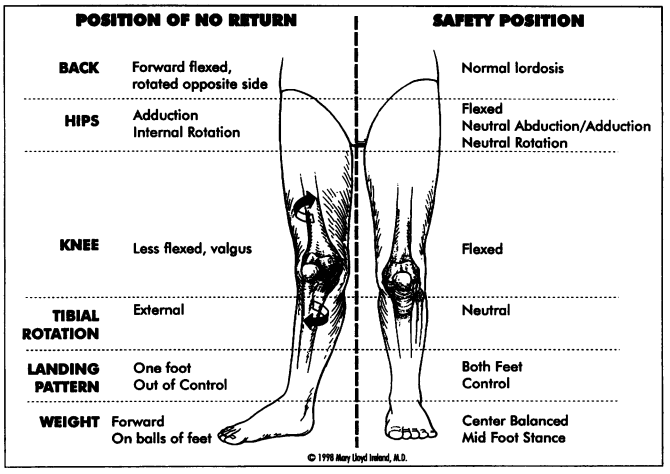

Figure 1. The position-of-no-return mechanism for ACL injury and the safe position.

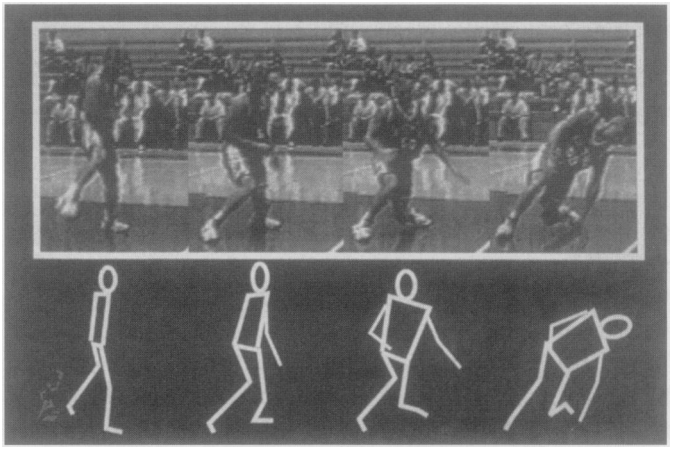

Figure 2. Sequence of body and lower extremity positions as this athlete tears his left ACL. By the second frame, the ACL has most likely torn. Note the planting of the foot, the adducted hip, the valgus knee, the externally rotated tibia, and the body falling forward to the opposite side.

PREVENTION PROGRAMS

The role of neuromuscular training in reducing the risk of serious knee injuries was studied in high school volleyball and basketball players.[26] A 6-week preseason training program to reduce landing forces and increase hamstring power using plyometrics was instituted.[26] After 1 season of tracking 1263 athletes, untrained females demonstrated a knee injury rate 3.7 times higher than that for trained females and 4.6 times higher than that for males. Based on the results of this study, neuromuscular training appears to reduce the risk of injury in female volleyball and basketball players.

A prospective, controlled study of proprioceptive training was conducted in 40 Italian semiprofessional and amateur soccer teams, which included 600 male players.[28] Over 3

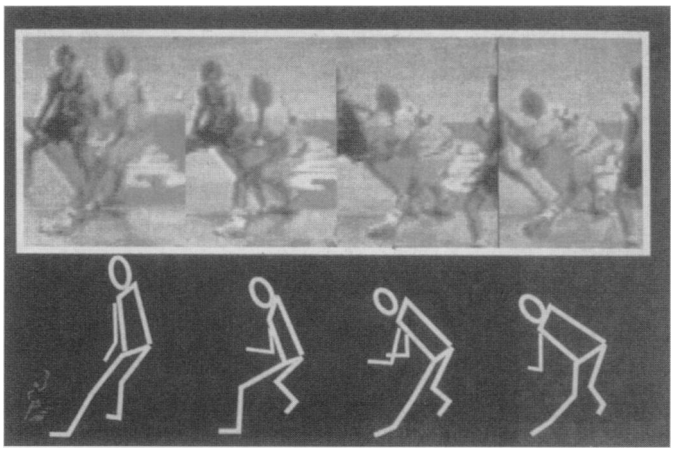

Figure 3. Injury to the left knee as observed from the back and left side of the athlete. She has just rebounded and stops to change direction to avoid the defending player. She lands in an upright position with less knee and hip flexion and forward-flexed lumbar spine. After the ACL fails, she falls forward, and knee valgus rotation and flexion increase. She is unable to upright herself and regain pelvis control to avoid ACL injury.

seasons, arthroscopically verified ACL injuries occurred in only 10 of the trained athletes and in 70 of the untrained athletes. In terms of injuries per team per season, the trained group's rate was 0.15, while the untrained group's rate was 1.15.

Injury prevention programs have been established for certain sports, such as skiing.[29,31] Equipment changes have had an impact on the reduction of tibial fractures and equipment-related lower extremity injuries.[32,33] Modern boots have a more proper fit with a rigid shell and fixed forward-lean angle, ski bindings have a low friction and standardized multidirectional release function, and skis have improved turning characteristics. Vermont skiing patrollers and instructors who underwent training to reduce the risk of ACL injuries showed a 62% drop in serious knee sprains when compared with a control group that received no such training.[29]

An injury prevention program for basketball was presented in 1989.[34] By focusing on improving technique with accelerated, rounded turns off the inside leg, flexed-knee landings, and 3-step stops with flexed knees, 2 Division I Kansas schools reduced the rate of ACL tears by 89% in 2 years. Video analysis of injury patterns in basketball has resulted in teaching programs to train athletes, coaches, and physicians.[30]

FUNCTIONAL OUTCOMES STUDIES

A well-designed, prospective outcomes study compared ACL-injured patients with and without reconstructions.[36] Patients who underwent ACL reconstructions had higher levels of arthrosis by radiographs and bone scans. Studies of autogenous, ipsilateral bone-patellar tendon-bone graft ACL reconstructions have shown that males and females do equally well,[35] even though females required more physical therapy visits.

Many knee rating scales have been developed, including Noyes (Cincinnati),[39] International Knee Society (presently being revised),[40,56] Mohtadi,[41] Irrgang et al (Pittsburgh),[42] Shapiro et al (SF-36),[43] Tegner and Lysholm,[44] and Lysholm and Gillquist.[45] Researchers[46–49] have also compared the various knee rating systems. Presently, studies are using several scales. No one scale has been shown to be the best.

CONCLUSIONS

A primary goal in treating athletes is prevention of the injury. We cannot restore an ACL-injured knee to normal with a reconstruction. Analyzing data collected from multiple centers and large numbers of athletes over time will allow us to identify high-risk individuals early and to institute appropriate intervention programs.

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