Sex-Based Differences in Anterior Cruciate Ligament Injuries Among United States High School Soccer Players

An Epidemiological Study

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Background: Anterior cruciate ligament (ACL) tears are common among high school athletes, with sex-based differences accounting for higher injury rates in girls. Previous epidemiological studies on ACL injuries focusing on adolescent athletes have looked at injuries across multiple sports, but few have analyzed ACL tears in solely high school soccer athletes.

Purpose: To examine sex-based differences in the epidemiology of ACL injuries among high school soccer players in the United States (US).

Study Design: Descriptive epidemiological study.

Methods: ACL injury data for US high school soccer players were obtained from the internet-based National High School Sports-Related Injury Surveillance Study’s High School RIO (Reporting Information Online) system. Athletic trainers from a random sample of 100 high schools from 8 strata based on US Census geographic region reported data for athlete-exposures (AEs) (practice or competition) and ACL injuries from 2007 through 2017. Injury rates were calculated as the number of ACL injuries per 100,000 AEs. Subgroup differences were evaluated with rate ratios (RRs) or injury proportion ratios (IPRs) and 95% CIs. Statistical differences in demographics between groups were examined using independent t tests. Comparisons of categorical data (ie, level of play) were performed using the Wald chi-square test.

Results: The reported number of ACL injuries corresponded to weighted national estimates of 41,025 (95% CI, 33,321-48,730) ACL injuries in boys’ soccer and 110,028 (95% CI, 95,349-124,709) in girls’ soccer during the study period. The rate of injuries was higher in girls’ soccer (13.23/100,000 AEs) than boys’ soccer (4.35/100,000 AEs) (RR, 3.04 [95% CI, 2.35-3.98]). The rate of ACL injuries was higher in competition compared with practice for girls (RR, 14.77 [95% CI, 9.85-22.15]) and boys (RR, 8.69 [95% CI, 5.01-15.08]). Overall, a smaller proportion of ACL injuries were caused by player-player contact for girls (30.1%) compared with boys (48.6%) (IPR, 0.62 [95% CI, 0.41-0.93]).

Conclusion: ACL injury rates and patterns in high school soccer players differed between sex, type of exposure (practice vs competition), and mechanism of injury.

Keywords: anterior cruciate ligament; football (soccer); pediatric sports medicine; knee; epidemiology

Anterior cruciate ligament (ACL) injuries are common among adolescent athletes, with soccer being the most frequent sport implicated. Of the approximately 7.8 million student-athletes in the United States, soccer is the fifth most popular boys’ program and fourth most popular girls’ program, with a combined total of 808,250 student-athletes. A recent study in high school athletes found that 53.2% of girls’ ACL injuries and 17.2% of boys’ injuries were sustained while playing soccer. Additionally, girls were 2 times as likely to sustain an ACL injury while playing soccer than any other girls’ sport. With increasing student participation in high school athletics over the past decade, such injuries continue to be more prevalent. Furthermore, ACL injury rates are rising, with increased participation in higher level athletics at earlier ages, increased awareness of the injury in youth, and improved diagnostic methods.

Girls are more likely than boys to sustain an ACL injury, with some reports estimating up to an 8 times greater
incidence of ACL tears in girls compared with boys. The many risk factors contributing to ACL injuries in this population add complexity to understanding the epidemiology of these injuries. Such sex-based differences that may account for the increased ACL injury risk in girls compared with boys include anatomic, biomechanical, neuromuscular, and hormonal differences. The current literature demonstrates that sagittal-plane biomechanical factors, such as decreased knee flexion angles and increased posterior ground-reaction forces and quadriceps muscle forces, are the major ACL loading mechanisms. Knee valgus forces and compressive anterior forces of the quadriceps contribute by lowering the force threshold required for ligament disruption. In addition, there are numerous anatomic factors that increase loading on the ACL during an injury, including lower extremity malalignment, a narrower intercondylar notch, an increased tibial tubercle–trochlear groove distance, and an increased medial posterior tibial slope.

The current literature on ACL injuries, while extensive, lacks a comprehensive soccer-specific study that describes the epidemiology of ACL injuries in US high school student-athletes. Previous epidemiological studies on ACL injuries focusing on high school athletes have looked at injuries across multiple sports. The objective of this study was to examine sex-based differences in the epidemiology of ACL injuries among high school soccer players in the US. We hypothesized that ACL injury rates and patterns in high school soccer players differ between sex, field position, mechanism, type of exposure (practice vs game), and year in school.

METHODS
Data Collection
Exemption from institutional review board approval was obtained for this descriptive epidemiological study. ACL data for US high school soccer players were obtained from the internet-based National High School Sports-Related Injury Surveillance Study’s High School RIO (Reporting Information Online) system. The methodology of this surveillance system has been reported on extensively. Briefly, high schools with ≥1 National Athletic Trainers’ Association (NATA)–affiliated certified athletic trainer (AT) with a valid email address were invited to participate. Responding high schools were categorized into 8 strata based on US Census geographic region and school size (enrollment ≤1000 or >1000). Schools from each of the 8 strata were randomly chosen to participate in the nationally representative sample of 100 schools reporting for 9 sports (boys’ football, soccer, basketball, wrestling, and baseball; girls’ soccer, volleyball, basketball, and softball). If a school dropped out during the study, it was replaced by another randomly selected school from the same stratum to maintain the 100-school study population. Certified ATs from participating high schools reported injury and athlete-exposure (AE) information on the High School RIO website weekly throughout the academic year. Injury and exposure data used in this study were collected from school years 2007-2008 through 2016-2017.

Definition of Injury and Exposure
An AE was defined as 1 athlete participating in 1 school-sanctioned practice or competition. A reportable injury was one that (1) occurred as a result of participation in an organized practice or competition, (2) required medical attention by an AT or physician, and (3) resulted in a restriction of the athlete’s participation for ≥1 day after the day of injury (except for fractures, concussions, heat illnesses, or dental injuries, which were captured regardless of time loss). For this study, only ACL injuries that occurred during boys’ or girls’ soccer were included. For each injury, the AT submitted a detailed injury report on the injured athlete (age, height, weight, etc), the injury (side of body, diagnosis, severity, etc), and the injury event (activity, mechanism, etc). Throughout the study, ATs were able to view all previously submitted information and update reports as needed.

Statistical Analysis
Injury rates were calculated as the number of ACL injuries per 100,000 AEs. Subgroup differences were evaluated with rate ratios (RRs) or injury proportion ratios (IPRs) and corresponding 95% CIs. The following is an example of the RR

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calculation for comparing ACL injuries in practices with ACL injuries in games:

$$RR = \frac{\text{total No. of competition ACL injuries}}{\text{total No. of competition soccer AEs}} \div \frac{\text{total No. of practice ACL injuries}}{\text{total No. of practice soccer AEs}}$$

IPRs were used to compare patterns of injuries. Unless otherwise stated, all comparisons are made with male sex as the reference category. The following is an example of the IPR calculation comparing the proportion of female ACL injuries resulting in surgery to male ACL injuries resulting in surgery:

$$IPR = \frac{\text{(No. of female ACL surgeries}}{\text{total No. of female ACL injuries}} \div \frac{\text{(No. of male ACL surgeries}}{\text{total No. of male ACL injuries}}$$

Apart from the calculation of rates, all data are analyzed using weighted national estimates and weighted survey procedures. Weighting factors used in calculating national estimates of ACL injuries reflect the inverse probability of a school’s selection into the study (based on the 8 strata representing school size and geographic region). Means and standard deviations were calculated for demographic variables (ie, age). Statistical differences in demographics between groups were examined with independent t tests. Comparisons of categorical data (eg, level of play) were performed using the Wald chi-square test or IPRs. 95% CIs not containing 1.00 and P values <.05 were considered statistically significant. Ordinary linear regression was used for time trend analysis. Data were analyzed using SAS software (Version 9.4; SAS Institute).

RESULTS

General Findings

Table 1 shows the frequencies, national estimates, and ACL injury rates for girls’ soccer and boys’ soccer. From 2007-2008 through 2016-2017, a total of 277 ACL injuries were reported in girls’ (n = 201) and boys’ (n = 76) soccer. The reported number of ACL injuries corresponds to weighted national estimates of 110,028 (95% CI, 95,349-124,709) in girls’ soccer and 41,025 (95% CI, 33,321-48,730) ACL injuries in boys’ soccer during the study period. Injury rates were higher in girls’ soccer (13.23/100,000 AEs) than boys’ soccer (4.35/100,000 AEs) (RR, 3.04 [95% CI, 2.35-3.98]). ACL injury rates did not change significantly over the study period for girls (15.54/100,000 AEs in 2007-2008; 12.92/100,000 AEs in 2016-2017; P = .89) but declined significantly for boys (5.92/100,000 AEs in 2007-2008; 2.43/100,000 AEs in 2016-2017; P = .04) (Figure 1).
On average, female athletes were aged 16.2 ± 1.1 years, and male athletes were aged 16.2 ± 1.2 years at the time of injury (P = .93). Injured players were most commonly seniors (girls, 31.8%; boys, 37.4%; P = .78), and the majority of injured athletes played at the varsity level (girls, 78.5%; boys, 72.9%; P = .86) (Table 1). To confirm the diagnosis, 93% of boys and 83% of girls underwent magnetic resonance imaging after the injury, and most injuries were initially evaluated by an orthopaedic surgeon (78% vs 80%, respectively).

**Exposure Type and Time in Season**

Competitions accounted for 87.3% of injuries among girls and 79.1% of injuries among boys. ACL injury rates were higher among girls compared with boys for both competition (RR, 3.31 [95% CI, 2.48-4.47]) and practice (RR, 1.95 [95% CI, 1.50-3.76]). ACL injury rates were higher in competition compared with practice for both girls (RR, 14.77 [95% CI, 9.85-22.15]) and boys (RR, 8.69 [95% CI, 5.01-15.08]). The timing of injury during competition was similar for girls and boys: 54.7% of ACL injuries among girls and 49.6% among boys occurred in the first half of the game (IPR, 1.10 [95% CI, 0.72-1.68]). For practices, although the difference was not statistically significant, 56.2% of girls sustained their injury >1 hour into practice compared with 37.2% of boys (IPR, 1.51 [95% CI, 0.61-3.76]). Moreover, most ACL injuries occurred later in practice—24.7% among girls and 13.1% among boys occurred during the first half hour (IPR, 1.88 [95% CI, 0.24-15.01]). Most ACL injuries occurred during the regular season for girls (81.1%) and boys (82.1%) (IPR, 0.98 [95% CI, 0.86-1.12]). The preseason accounted for 13.4% of ACL injuries in girls and 15.5% in boys (IPR, 0.95 [95% CI, 0.48-1.88]).

**Injury Mechanism and Activity**

The most common injury mechanism was noncontact for girls (52.7%), while player-player contact was the most common for boys (48.6%). Overall, a smaller proportion of ACL injuries were caused by player-player contact for girls (30.1%) compared with boys (48.6%) (IPR, 0.62 [95% CI, 0.41-0.93]). A greater proportion were noncontact for girls (52.7%) compared with boys (35.2%) (IPR, 1.50 [95% CI, 0.98-2.32]), although this relationship was not statistically significant.

Figure 2 shows the general injury mechanism by sex and exposure type. During competitions, a smaller proportion of ACL injuries were caused by player-player contact for girls (29.7%) compared with boys (53.7%) (IPR, 0.55 [95% CI, 0.36-0.84]), while a greater proportion of girls’ injuries were noncontact (57.3%) compared with boys (28.1%) (IPR, 1.91 [95% CI, 1.09-3.35]). However, during practices, there were no significant differences between sexes sustaining injuries due to player-player contact (girls, 33.2%; boys, 28.3%; IPR, 1.17 [95% CI, 0.33-4.23]) or noncontact mechanisms (girls, 45.2%; boys, 61.0%; IPR, 0.74 [95% CI, 0.36-1.51]).

Table 2 compares specific injury mechanisms and activities by sex. Rotation around a planted foot was the most common injury mechanism for both girls (48.9%) and boys (42.6%), followed by player-player contact excluding slide tackling (girls, 28.3%; boys, 26.7%). A smaller proportion of girls sustained ACL injuries due to slide tackling (1.3%) compared with boys (6.2%) (IPR, 0.21 [95% CI, 0.05-0.89]). The most common activities for both sexes were general play (girls, 24.0%; boys, 16.7%), chasing a loose ball (girls, 22.1%; boys, 18.0%), and defending (girls, 21.3%; boys, 16.3%). There were no statistically significant differences in activity at the time of injury between sexes (see Table 2 for IPRs).

**Position and Playing Surface**

Position played during the time of injury was similar between girls and boys. Midfielders sustained the greatest proportion of injuries (girls, 42.7%; boys, 35.4%; IPR, 1.21 [95% CI, 0.80-1.91]), followed by forwards (girls, 27.5%; boys, 25.9%; IPR, 1.06 [95% CI, 0.59-1.89]), defenders (girls, 23.8%; boys, 32.0%; IPR, 0.74 [95% CI, 0.43-1.30]), and goalkeepers (girls, 6.0%; boys, 5.2%; IPR, 1.15 [95% CI, 0.25-5.23]). Table 3 shows the injury mechanism and activity during the time of injury by position and sex. Because of small sample sizes, no statistical comparisons were made. The proportion of ACL injuries sustained on grass compared with artificial turf was also similar for boys and girls. Most ACL injuries occurred on grass (girls, 61.4%; boys, 64.0%; IPR, 0.96 [95% CI, 0.74-1.25]), with the remainder occurring on artificial turf.

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Figure 1. Anterior cruciate ligament injury rates over time by sex and exposure type among soccer players, National High School Sports Injury Surveillance Study, 2007-2008 through 2016-2017. AE, athlete-exposure.
Recurrence and Outcomes

Figure 3 shows recurrence and outcomes by sex. There were no significant differences between sexes in injury recurrence, time loss, or surgical repair. Most ACL injuries to both sexes were primary injuries as opposed to recurrent (girls, 91.1%; boys, 86.5%; IPR, 1.05 [95% CI, 0.94-1.18]). In girls, 8.2% were recurrent from the prior academic year, while 0.5% were sustained during the same season. In boys, 10.6% were recurrent from the prior academic year, while 2.9% had been sustained earlier in the same season. Almost half of ACL injuries resulted in medical disqualification of the athlete for the remainder of the season or for the athlete’s career for girls (46.4%) and boys (49.6%) (IPR, 1.07 [95% CI, 0.74-1.54]). For many athletes, the season ended before they were able to return to play (girls, 37.7%; boys, 29.7%; IPR, 1.26 [95% CI, 0.76-2.07]). Most ACL injuries resulted in surgical treatment for girls (77.7%) and boys (83.5%) (IPR, 0.93 [95% CI, 0.80-1.09]).

DISCUSSION

This study provides the largest and most comprehensive analysis to date of ACL injuries among a large national sample of high school soccer athletes during the 10 academic years from 2007-2008 through 2016-2017. Our findings revealed sex-based differences in ACL injury rates and patterns including type of exposure (practice vs competition) and injury mechanism. The overall rate of ACL injuries in high school soccer was higher in girls (13.23/100,000 AEs) than boys (4.35/100,000 AEs). While the rate of ACL...
TABLE 3
Most Common Injury Mechanisms and Activities During Injury by Position and Sex*

| Girls | | | |
|---|---|---|---|
| Midfielder (n = 40,923) | Forward (n = 27,755) | Defense (n = 24,076) | Goalkeeper (n = 6065) |
| **Most common general mechanisms** | | | |
| First | Noncontact (56.0%) | Noncontact (51.8%) | Player-player contact (41.4%) | Noncontact (63.0%) |
| Second | Player-player contact (25.8%) | Player-player contact (34.5%) | Noncontact (41.0%) | Contact with playing surface (27.8%) |
| **Most common specific mechanisms** | | | |
| First | Rotation around planted foot (45.9%) | Rotation around planted foot (56.1%) | Rotation around planted foot (38.4%) | Rotation around planted foot (48.4%) |
| Second | Player-player contact (other than slide tackle) (28.7%) | Player-player contact (other than slide tackle) (33.5%) | Player-player contact (other than slide tackle) (33.5%) | Other** (26.4%) |
| **Most common specific activities** | | | |
| First | Chasing loose ball (33.9%) | General play (35.9%) | Defending (55.7%) | Goal tending (46.3%) |
| Second | General play (21.2%) | Chasing loose ball (22.8%) | General play (17.8%) | Blocking shot (35.3%) |
| | | | | |
| Boys | | | |
| Midfielder (n = 14,371) | Forward (n = 10,526) | Defense (n = 12,970) | Goalkeeper (n = N/A) |
| **Most common general mechanisms** | | | |
| First | Player-player contact (47.5%) | Noncontact (34.4%) | Player-player contact (66.1%) | N/A |
| Second | Noncontact (43.0%) | Player-player contact (34.3%) | Noncontact (28.2%) | N/A |
| **Most common specific mechanisms** | | | |
| First | Rotation around planted foot (39.7%) | Rotation around planted foot (50.9%) | Player-player contact (other than slide tackle) (33.6%) | N/A |
| Second | Player-player contact (other than slide tackle) (30.8%) | Stepped on/fallen on/kicked (20.6%) | Rotation around planted foot (27.0%) | N/A |
| **Most common specific activities** | | | |
| First | General play (26.1%) | Passing (34.1%) | Defending (41.9%) | N/A |
| Second | Chasing loose ball (22.2%) | General play (20.0%) | Chasing loose ball (16.8%) | N/A |

*Percentages are calculated from weighted national estimates, which may not equal those in Table 1 because of missing responses. N/A, not applicable.
**Mechanism of injury was listed as “other.”
National estimates were not calculated for unweighted counts of <5.

Figure 3. Recurrence and outcomes by sex, National High School Sports-Related Injury Surveillance Study, 2007-2008 through 2016-2017. No significant differences were observed between sexes.
injuries declined for boys over the study duration, the rate of injuries did not change significantly over time for girls. A greater proportion of ACL injuries were caused by player-player contact in boys (48.6%) compared with girls (30.1%). This difference may have been driven in part by fewer girls sustaining their injuries due to slide tackling compared with boys (1.3% vs 6.2%, respectively; IPR, 0.21 [95% CI, 0.05-0.89]) and possibly by being stepped on/fallen on/kicked less frequently (3.3% vs 10.3%, respectively; IPR, 0.32 [95% CI, 0.09-1.16]). As girls’ soccer is the fourth most popular high school program with nearly 400,000 students participating during the 2014-2015 school year,14 the findings of our study can be helpful in developing injury prevention strategies in this high-risk population.

Previous studies have similarly described higher injury rates in girls than boys, although reported rates are highly variable in comparison with our findings, evaluating both high school and collegiate athletes (11-49/100,000 AEs and 8-39/100,000 AEs in girls and boys, respectively).8,17,20 Our study also revealed that girls were 3 times more likely than boys to sustain ACL injuries in practice or competition (RR, 3.04 [95% CI, 2.35-3.98]). Dick et al11 reported similar results with a female-to-male tear incidence ratio of 2.67 for collegiate and indoor soccer athletes.

Our study showed that girls had no statistically significant decrease in the number of ACL injuries over the 10-year data collection period. In contrast, boys’ ACL injuries demonstrated a statistically significant decrease over the duration of the study. This contrasts with a previous report in the literature that demonstrated no significant decrease over time in collegiate players.1 Similarly, Yard et al22 demonstrated a decline in injury rates in high school boys collected over a 3-year period. Since then, stricter player-to-player contact rules have been implemented as well as an increased emphasis on enforcing these changes at all levels of competitive and intramural soccer, which could account for the decrease in the incidence of ACL injuries in boys seen in our study.14

When comparing our injury rates in competition versus practice in the current study, girls were 15 times more likely to sustain injuries during competition, while boys were 9 times as likely. These findings are in contrast to collegiate soccer players in which prior studies found that both men and women were 6 times more likely to sustain ACL tears during games than practices.1,4 The authors reported a rate of 100 and 19 ACL injuries per 100,000 AEs in collegiate women’s and men’s soccer competition, respectively. Alternatively, ACL injury rates during practice were reported as 10 and 4 injuries per 100,000 AEs for women and men, respectively.1,4 Our study similarly reported 38 versus 3 ACL injuries per 100,000 AEs in competition versus practice in girls and 11 versus 1 ACL injury per 100,000 AEs in competition versus practice in boys. The higher incidence seen in both men and women at the collegiate level is likely because of the level of play. This is exhibited by the similar results seen at different levels of play in our athletes in which 77% of all injuries occurred at the varsity level. The reason for higher rates of injuries during games is likely multifactorial. During games, players may be more likely to run faster, cut or pivot more forcefully, or make contact with another player by either chasing down loose balls or suffering a misdirected slide tackle. Our data also showed an increase in the injury rate as the level of play increased, although this was not statistically significant. The presence of college and professional scouts, particularly at the varsity soccer level, may also motivate athletes to participate in riskier behaviors that would otherwise not be undertaken in practice. Because of these motivations, coaches and staff should exhibit a higher index of suspicion for knee injuries during competition and at more advanced levels of play.

Previous literature has reported similar percentages of contact and noncontact injuries in boys and girls, with girls more commonly sustaining noncontact injuries and boys more commonly sustaining contact injuries at high school and collegiate levels.1,4,10 In our study, the most common injury mechanism for girls was a noncontact injury to the knee (52.7%), while injuries in boys most commonly occurred because of contact injuries (48.6%). The second most common injury mechanism in boys was a noncontact injury (35.2%). Boys and girls both exhibited primarily noncontact injuries during practices. During games, a smaller proportion of ACL injuries were due to player-player contact for girls (29.7%) compared with boys, while a greater proportion of girls’ injuries were noncontact (53.7%) compared with boys.

This study reported data on position-dependent injuries, with the midfield position most susceptible to ACL injuries, regardless of sex. In contrast, a study of 113 consecutive ACL injuries by Faune and Wulff Jakobsen5 reported on high school athletes and found no influence of player position on ACL injuries, with all field players showing no statistically significant difference. Many factors may play into the higher number of midfield injuries in our study. The coach may choose to play in a formation that allows for a larger proportion of midfield positions than other positions. Additionally, during practices, athletes may have been performing drills when they sustained their injury rather than in a scrimmage. The AT may also have reported the position as midfield when there was no true position being played.

The increased risk of ACL injuries in girls in this study may substantiate the routine utilization of ACL injury prevention programs into high school soccer. Hewett et al8 reported a relative risk of 3.6 for ACL tears in girls who did not participate in injury prevention programs versus girls who participated. In a meta-analysis of injury prevention programs, Noyes and Barber-Westin15 recognized 3 specific injury prevention programs (Sportsmetrics, Prevent Injury and Enhance Performance [PEP], and Knee Injury Prevention Program [KIPP]) that significantly reduced the number of noncontact ACL injuries in female adolescent athletes. The authors reported that 70 to 98 athletes were needed to train to prevent 1 ACL injury.15 A relative risk reduction of 75% to 100% was achieved using these programs, although variability existed in the frequency and duration of the training programs. The Sportsmetrics program was implemented during the preseason, while PEP and KIPP were utilized during the regular season. All were performed 3 times a week for 6 to 15 weeks. The implementation of these programs on a regular basis during
preseason and in-season high school practices may help to prevent ACL injuries in adolescent soccer players.\textsuperscript{18}

Limitations

There are several limitations to this study associated with the restrictions of the surveillance system that supplied the data set. First, schools participating in this study were limited to those with NATA-affiliated ATs, which may not be an accurate representation of all US high schools. However, reporting performed by highly trained sports medicine clinicians likely improves the quality and consistency of the data. ATs were also not asked to report on injuries that did not result in time lost from practice, which may have artificially inflated the incidence of ACL injuries in our study and could be the cause of higher injury rates in both games and practices compared with previous reports. Second, reporting of the injury mechanism was left to the discretion of the AT based on the history given by the player. The injury could have resulted from more than 1 mechanism (eg, rotation around a planted foot on an uneven playing surface), which may lead to undervaluing one mechanism over another. A majority of players underwent surgery after injury (77.7% of girls and 83.5% of boys). These numbers reflect only surgery performed during the academic year of injury and reported by the AT, thus possibly underestimating the total number of athletes requiring surgical procedures. Last, this database does not provide an understanding of the surgical risk, assess outcomes of injured players, or provide information on the athletes’ level of return to play after an ACL tear. Despite these limitations, this study provides important data on the epidemiological characteristics of US high school soccer players sustaining ACL injuries.

CONCLUSION

ACL injury rates and patterns in high school soccer players differed between sex, type of exposure (practice vs competition), and injury mechanism. This study suggests several areas for targeted injury prevention programs, particularly in girls, who were more than 3 times more likely to sustain ACL injuries than their male counterparts.

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