Journal of Athletic Training 2013;48(6):810–817
doi: 10.4085/1062-6050-48.6.03

original research

A Multisport Epidemiologic Comparison of Anterior Cruciate Ligament Injuries in High School Athletics

Allan M. Joseph*; Christy L. Collins, MA*; Natalie M. Henke, BS*; Ellen E. Yard, PhD*; Sarah K. Fields, JD, PhD†; R. Dawn Comstock, PhD*‡

*Center for Injury Research and Policy, The Research Institute at Nationwide Children's Hospital, Columbus, OH; †The Ohio State University, School of Physical Activity and Educational Services, Columbus; ‡The Ohio State University, College of Medicine, Department of Pediatrics and College of Public Health, Division of Epidemiology, Columbus. Dr Fields is now at the Department of Communication, University of Colorado, Denver. Dr Comstock is now at the School of Medicine, Pediatric Injury Prevention, Education, and Research (PIPER) program, and Colorado School of Public Health, Department of Epidemiology, University of Colorado, Denver.

Background: The knee joint is the second most commonly injured body site after the ankle and the leading cause of sport-related surgeries. Knee injuries, especially of the anterior cruciate ligament (ACL), are among the most economically costly sport injuries, frequently requiring expensive surgery and rehabilitation.

Objective: To investigate the epidemiology of ACL injuries among high school athletes by sport and sex.

Design: Descriptive epidemiology study.

Main Outcome Measure(s): Using an Internet-based data-collection tool, Reporting Information Online (RIO), certified athletic trainers from 100 nationally representative US high schools reported athlete-exposure and injury data for athletes from 9 sports during the 2007/08–2011/12 academic years. The outcome of interest in this study was ACL injuries.

Results: During the study period, 617 ACL injuries were reported during 9 452 180 athlete exposures (AEs), for an injury rate of 6.5 per 100 000 AEs. Nationally, in the 9 sports studied, an estimated 215 628 ACL injuries occurred during the study period. The injury rate was higher in competition (17.6) than practice (2.4; rate ratio [RR] = 7.3, 95% confidence interval [CI] = 6.08, 8.68). Girls' soccer had the highest injury rate (12.2) followed by boys' football (11.1), with boys' basketball (2.3) and boys' baseball (0.7) having the lowest rates. In sex-comparable sports, girls had a higher rate (8.9) than boys (2.6; RR = 3.4, 95% CI = 2.64, 4.47). Overall, 76.6% of ACL injuries resulted in surgery. The most common mechanisms of injury were player-to-player contact (42.8%) and no contact (37.9%).

Conclusions: Anterior cruciate ligament injury rates vary by sport, sex, and type of exposure. Recognizing such differences is important when evaluating the effectiveness of evidence-based, targeted prevention efforts.

Key Words: sports, surveillance, knee

Key Points

- Anterior cruciate ligament (ACL) injuries are generally regarded as a particular concern for female athletes. However, of the 9 sports studied, football had the largest number of ACL injuries and the highest competition-related ACL injury rate.
- Athletes were 7 times more likely to sustain ACL injuries in competition than in practice.
- Overall, 76.6% of all ACL injuries resulted in surgery. However, 29.2% of the ACL injuries assessed by an athletic trainer and a general physician and 12.8% of those assessed by an athletic trainer and an orthopaedic physician did not result in surgical repair.
- The ACL injury rates and mechanisms varied by sport and sex, indicating that targeted prevention efforts will likely be most effective.

More than half of all high school students participate in some form of athletics, making sports one of the most popular extracurricular activities among high school-aged youth.[1] Athletic participation has been demonstrated to increase physical competency, decrease health risks, decrease body mass index, and promote social interaction.[2] Although the benefits of increased physical activity are well documented, athletes risk injury.[3,4] Injuries can exact emotional, physical, social, and economic tolls on athletes. Knee injuries are among the most common serious injuries, accounting for 60% of high school sport-related surgeries.[5,6]

Anterior cruciate ligament (ACL) injuries account for 50% or more of all knee injuries,[7] making this ligament especially important in any discussion of knee injuries. Anterior cruciate ligament injuries often require surgical repair followed by extensive long-term rehabilitation.[7,8] An estimated $1 billion is spent annually for ACL reconstructions in the United States.[9] Factors contributing to these costs include inpatient versus outpatient surgery, length of stay, treatment at off-site surgical centers versus main hospitals, etc.[8] Additionally, prevention is important because an ACL tear can mean the end of an athlete's competitive career and, possibly, permanently affect physical activity.[10,11] Furthermore, ACL injuries place a patient at risk for early osteoarthritis and chronic pain 10 to 20 years after the injury.[12,13]

The current literature on ACL injuries, though extensive, lacks a comprehensive multisport study that captures the epidemiology of ACL injuries in US high school athletes. Prior studies focus largely on sex, causation, and specific populations. Many studies[10,14–16] have focused specifically on the higher rate of knee injuries in female athletes, because female athletes have been reported to be 4 to 6 times more likely to sustain a major knee injury.[17] The majority of ACL injuries have been described as occurring without athlete-athlete contact: often they involve landing, jumping, or pivoting.[5,14,18–20] The vulnerability of female knees, which has been discussed extensively in the literature, has variously been attributed to a number of risk factors including anatomical, environmental, hormonal, neuromuscular, and biomechanical differences.[5,10,14,21] Some studies on ACL injuries have focused on specific populations (eg, collegiate athletes, specific sports, females),[10,15,18,22–26] and the only studies that exclusively focused on high school athletes looked at knee injuries as a whole[5] or are more than a decade old.[27]

The goal of our study was to explore the epidemiology of ACL injuries across 9 boys' and girls' high school sports in a large, nationally representative sample. We are the first to focus specifically on ACL injuries across multiple sports at this level. Our objective was to describe the rates and patterns of ACL injuries in high school athletes by sport, sex, and exposure type.

METHODS

All high schools with 1 or more National Athletic Trainers' Association–affiliated high school certified athletic trainers (ATs) with a valid e-mail address were invited to participate in the National High School Sports-Related Injury Surveillance Study using the High School Reporting Information Online (RIO, The Research Institute at Nationwide Children's Hospital, Columbus, OH) program. Schools agreeing to participate were categorized into 8 sampling strata based on US census geographic region and school size (enrollment $\leq$1000 and $>$1000 students). A simple random sample was then used to select schools from each sampling stratum to achieve a nationally representative sample of 100 schools. Schools and ATs that left the study for various reasons (including personal issues and loss of funding for the AT position) were replaced by another randomly selected school from the same stratum.

Athletic trainers from participating schools reported injury and exposure data for 9 high school sports using High School RIO, during the 2007/08–2011/12 academic years. These consisted of 5 boys' (football, soccer, basketball, baseball, and wrestling) and 4 girls' (soccer, volleyball, basketball, and softball) sports. Athletic trainers from participating schools weekly logged onto the High School RIO Web site using a unique study ID to report athlete-exposure (AE) and injury data. An *A-E*, defined as 1 athlete participating in 1 practice or competition, measured athlete time at risk of injury. Criteria for a reportable injury were threefold: occurring during an organized practice or competition, requiring attention by an AT or physician, and resulting in a restriction of the athlete's practice or competition participation for at least 1 day. For each injury, the AT reported various data for the athlete (age, height, weight, etc), the injury (severity in terms of time lost from play, need for surgery, etc), and the injury event (mechanisms, sport-specific activity, etc). Mechanism of injury was categorized as player-player contact, player-playing surface contact, player-playing apparatus contact (ball, base, goalpost, etc), no contact (rotation around a planted foot, etc), and other. All reported information could be viewed and edited by the AT throughout the academic year. This study dataset includes only the final injury report after any required revisions and updates were completed.

All ACL injuries captured by High School RIO were included in this study. This surveillance system captures all athletes with injuries presenting in the high school athletic training setting who are diagnosed and managed by the AT as well as all athletes with injuries who either presented to or were referred to physicians' offices, sports medicine clinics, emergency departments (EDs), etc, and were reported to the AT. Thus, this surveillance system captures a broader spectrum of high school sport-related injuries than clinic- or ED-based surveillance systems, including athletes with injuries so minor that they were not referred to a physician.

Data were analyzed using SPSS (version 19.0; SPSS Inc, Chicago, IL) and Epi Info (version 6.0; Centers for Disease Control and Prevention, Atlanta, GA). All rate calculations and rate comparisons used unweighted injury counts. Additional analyses used a weighting factor to produce national estimates, with the standard errors for comparison among sports and between sexes adjusted for the High School RIO sampling plan using the SPSS Complex Samples module. This weighting factor was based on the inverse probability of selection into the study sample, taking into account the total number of US schools by sampling stratum. Rate ratios (RRs) and injury proportion ratios (IPRs) were used to determine the magnitude of associations. The following is an example of the RR calculation comparing the rate of competition ACL injuries to the rate of practice ACL injuries:

$$\begin{aligned}\text{Rate ratio}\\ &= [(\text{No. competition ACL injuries}/\text{No. competition AEs}) \\ &\quad \times 100\,000] \\ &\quad \div [(\text{No. practice ACL injuries}/\text{No. practice AEs}) \\ &\qquad \times 100\,000].\end{aligned}$$

The following is an example of the IPR calculation comparing the overall proportion of player-player contact-related ACL injuries between boys and girls:

$$\begin{aligned}\text{Injury proportion ratio}\\ &= (\text{No. boys' contact ACL injuries} \\ &\quad \div \text{Total no. boys' ACL injuries}) \\ &\quad \div (\text{No. girls' contact ACL injuries} \\ &\qquad \div \text{Total no. girls' ACL injuries}).\end{aligned}$$

Statistical significance was evaluated using 95% confidence intervals (CIs), with those not containing 1.0

Table 1. Anterior Cruciate Ligament (ACL) Injury Rates per 100 000 Athlete-Exposures, High School Sports-Related Injury Surveillance Study, United States, 2007/2008–2011/2012[a]

	ACL Injuries			AEs			Rate per 100 000 AEs			
	Competition	Practice	Total	Competition	Practice	Total	Competition	Practice	Total	Rate Ratio (95% CI)[b]
Sport										
Football	198	88	286	423 874	2 156 763	2 580 637	46.7	4.1	11.1	**11.5 (8.91, 14.72)**
Boys' soccer	35	9	44	271 345	643 206	914 551	12.9	1.4	4.8	**9.2 (4.43, 19.18)**
Girls' soccer	83	13	96	235 938	550 355	786 293	35.2	2.4	12.2	**14.9 (8.30, 26.72)**
Volleyball	15	5	20	284 625	556 983	841 608	5.3	0.9	2.4	**5.9 (2.13, 16.15)**
Boys' basketball	18	7	25	328 264	777 796	1 106 060	5.5	0.9	2.3	**6.1 (2.55, 14.59)**
Girls' basketball	71	21	92	267 297	627 094	894 391	26.6	3.3	10.3	**7.9 (4.88, 12.91)**
Wrestling	14	13	27	215 378	594 052	809 430	6.5	2.2	3.3	**3.0 (1.40, 6.32)**
Baseball[c]	3	3	6	304 200	557 764	861 964	1.0	0.5	0.7	1.8 (0.37, 9.08)
Softball	13	8	21	226 111	431 135	657 246	5.7	1.9	3.2	**3.1 (1.28, 7.48)**
Sex Comparable[d]										
Boys	**56**	**19**	**75**	**903 809**	**1 978 766**	**2 882 575**	**6.2**	**1.0**	**2.6**	**6.5 (3.84, 10.86)**
Girls	**167**	**42**	**209**	**729 346**	**1 608 584**	**2 337 930**	**22.9**	**2.6**	**8.9**	**8.8 (6.25, 12.30)**
Total	**450**	**167**	**617**	**2 557 032**	**6 895 148**	**9 452 180**	**17.6**	**2.4**	**6.5**	**7.3 (6.08, 8.68)**
Boys	**268**	**120**	**388**	**1 543 061**	**4 729 581**	**6 272 642**	**17.4**	**2.5**	**6.2**	**6.9 (5.52, 8.50)**
Girls	**182**	**47**	**229**	**1 013 971**	**2 165 567**	**3 179 538**	**17.9**	**2.2**	**7.2**	**8.3 (6.00, 11.40)**

Abbreviations: AE, athlete-exposure; CI, confidence interval. Bold represents significant rate ratios.

[a] Table 1 represents unweighted data in order to calculate rates. All other tables and figures represent nationally representative weighted data.

[b] Calculated with practice as referent group.

[c] Caution should be used when interpreting results for sports with fewer than 10 total injuries such as baseball.

[d] Sex comparable sports included soccer, basketball, and baseball or softball.

considered statistically significant. This study was approved by the Human Subjects Board of Nationwide Children's Hospital.

RESULTS

Overall

During the study period, ATs reported 617 ACL injuries occurring in 9 452 180 AEs, for an overall rate of 6.5 ACL injuries per 100 000 AEs (Table 1). Anterior cruciate ligament injuries accounted for 20.5% of all knee injuries (n = 3012) and 3.0% of all injuries (n = 20 567) captured by this surveillance system during the study period (Figure 1). Overall, 459 (74.4% unweighted; 76.6% weighted) of the ACL injuries resulted in surgery, for a rate of 4.9 per 100 000 AEs. For boys, 388 total ACL injuries were reported, of which 287 resulted in surgery (6.2 and 4.6 per 100 000 AEs, respectively). For girls, 229 total ACL injuries were reported, of which 172 resulted in surgery (7.2 and 5.4 per 100 000 AEs, respectively). Nationally, an estimated 124 626 ACL injuries in boys and 91 002 ACL injuries in girls occurred in athletes participating in the 9 sports during the study period. Competition accounted for 74.9% of ACL injuries and injury rates were higher in competition (17.6) than practice (2.4; RR = 7.3; 95% CI = 6.08, 8.68; Table 1).

Overall, girls (7.2) and boys (6.2) had similar rates of ACL injury (RR = 1.2; 95% CI = 0.99, 1.37). The highest rates of ACL injury per 100 000 AEs were reported for girls' soccer (12.2), football (11.1), and girls' basketball (10.3), whereas the lowest ACL injury rates were seen in boys' basketball (2.3) and baseball (0.7). Most boys' ACL injuries were sustained while playing football (71.2% of boys' ACL injuries), followed by soccer (17.2%), basketball (5.5%), wrestling (4.1%), and baseball (2.0%). Girls most often injured their ACLs while playing soccer (53.2% of girls' ACL injuries), followed by basketball (26.5%), softball (11.4%), and volleyball (8.8%).

Of all ACL injuries, 87.6% were new, whereas 2.1% were recurrences from an injury sustained in the same academic year but from which the athlete had returned to play, and 7.9% were recurrences from an injury sustained in a previous academic year but from which the athlete had returned to play (2.4% were other/unknown). Of those injuries in which the outcome was reported (97.0%), 46.4% of ACL injuries resulted in a medical disqualification for the season, and 15.4% required a 3-week or longer recovery period before the athlete could return to activity (Figure 2). Of the ACL injuries requiring less than a 3-week recovery time (12.3%), 83.2% did not result in surgery, whereas 11.7% resulted in surgery, but the surgery was postponed to enable the athlete to continue to play (another 0.5% resulted in surgery, but timing of the surgery was unknown as these data were not captured during the 2007/2008 academic year). Overall, nationally, 76.6% of all ACL injuries resulted in surgery. However, the percentage of ACL injuries resulting in surgery varied by sport, ranging from 96.3% in boys' basketball to 54.9% in baseball (Figure 3).

Anterior cruciate ligament injury was assessed primarily by an AT in conjunction with a general physician or an orthopaedic physician (or both), using several diagnostic methods (Table 2). More specifically, 47.7% of injuries were assessed by an AT and orthopaedic physician; 19.0% by an AT and general physician; 18.6% by an AT, general physician, and orthopaedic physician; 6.9% by an AT alone; and 7.7% by general physicians and/or orthopaedic physicians alone (0.1% of injuries were assessed by only an

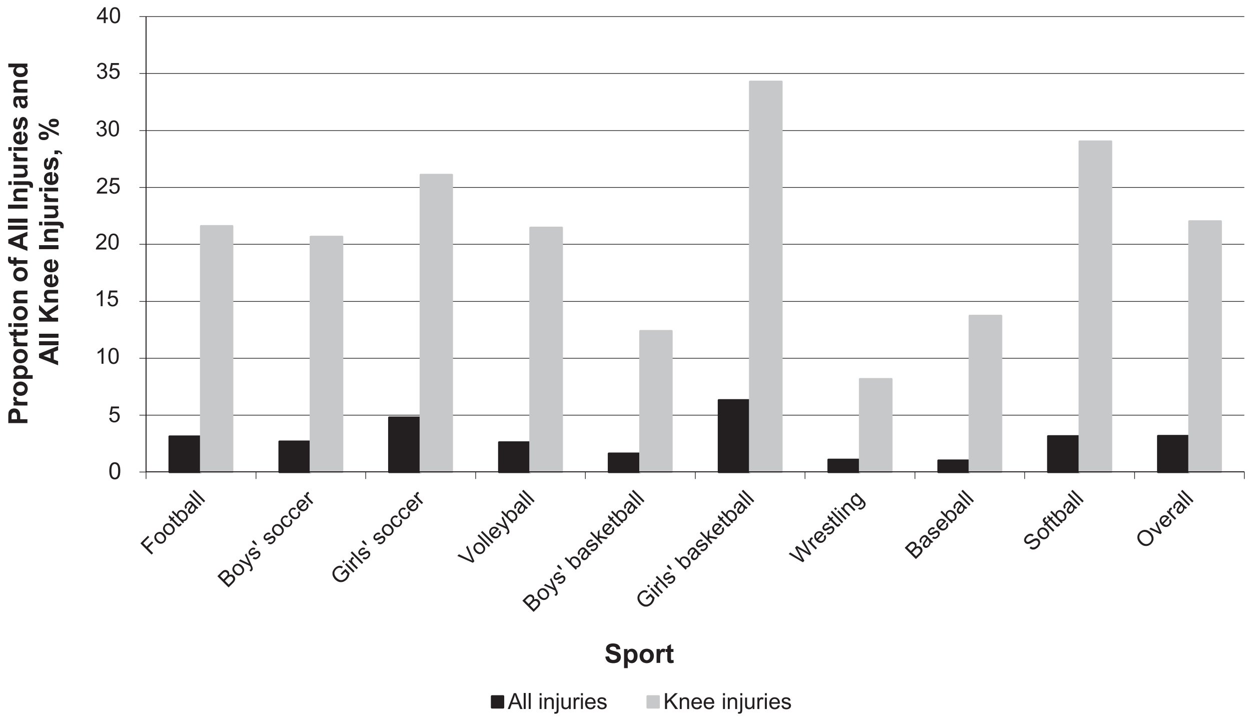

Figure 1. Anterior cruciate ligament injuries as a proportion of all injuries and all knee injuries, High School Sports-Related Injury Surveillance Study, United States, 2007/2008–2011/2012.

emergency medical technician). Anterior cruciate ligament injuries assessed by a physician were more likely to require surgery (80.5%) than those assessed by the AT alone (25.8%; IPR = 2.9; 95% CI = 1.52,5.70). Additionally, patients with ACL injuries assessed by the AT alone were more likely to return to play within 3 weeks (52.3%) compared with those assessed by a physician (8.9%; IPR = 5.9; 95% CI = 3.96, 10.13). Player-player contact was the most common mechanism of ACL injury (42.8%), followed by no contact (37.9%), player-surface contact (13.6%),

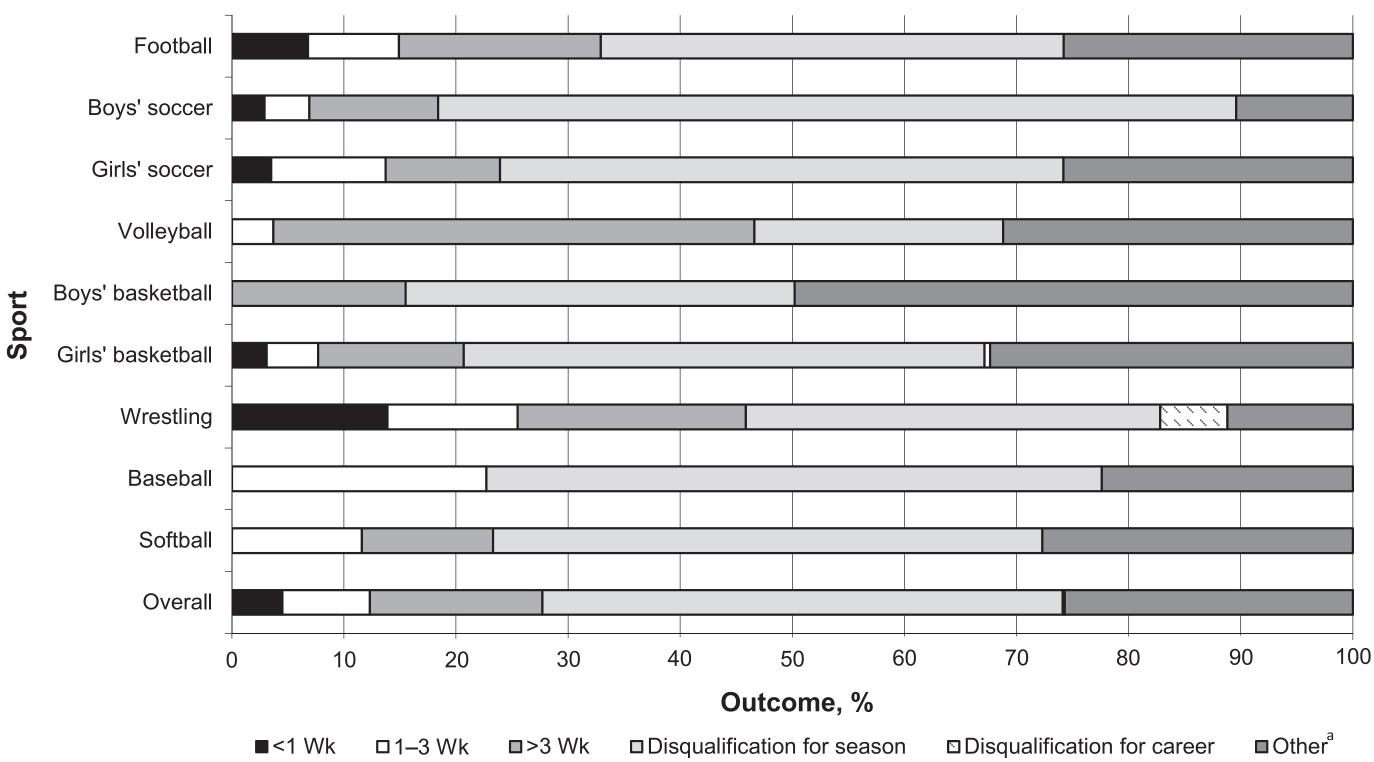

Figure 2. Outcome of anterior cruciate ligament injury in terms of time loss by sport, High School Sports-Related Injury Surveillance Study, United States, 2007/2008–2011/2012. [a] *Other* category consists of season ended before athlete returned to play, athlete chose not to continue, and athlete released from team for nonmedical reason.

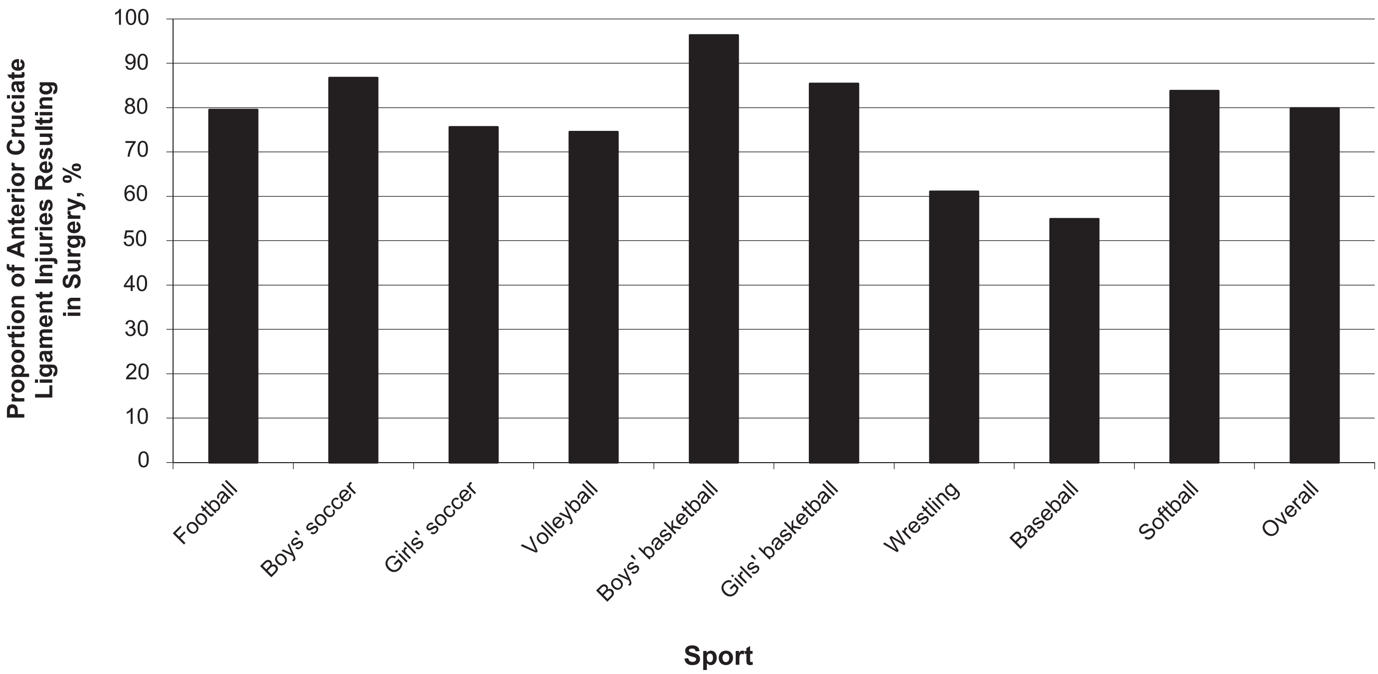

Figure 3. Proportion of anterior cruciate ligament injuries resulting in surgery by sport, High School Sports-Related Injury Surveillance Study, United States, 2007/2008–2011/2012.

Table 2. Anterior Cruciate Ligament (ACL) Injury Assessor[a] by Diagnostic Methods, Surgery and Time Loss, High School Sports-Related Injury Surveillance Study, United States, 2007/2008–2011/2012, %

	AT/Ortho, n = 102 874	AT/GP, n = 40 924	AT/Ortho/GP, n = 40 205	AT Only, n = 14 969	GP/Ortho, n = 16 511	Total,[b,c] n = 215 628
Diagnostic method						
Evaluation	95.6	98.3	99.7	87.6	94.8	96.3
X-ray	63.4	78.5	93.7	6.6	63.2	67.9
MRI	88.2	87.2	95.0	20.3	94.3	85.0
CT scan	0.0	0.3	0.0	0.0	0.0	0.1
Surgery	8.2	9.5	10.3	0.7	6.9	8.2
Total[b]	100	100	100	100	100	100
Surgery						
Yes	82.2	67.3	85.2	25.8	90.5	76.6
No	12.8	29.2	13.0	65.2	8.8	19.3
Not reported	5.0	3.5	1.8	9.0	0.7	4.1
Total	100	100	100	100	100	100
Time Loss						
<1 week	3.6	1.8	1.3	22.7	5.7	4.5
1–3 weeks	6.9	9.1	2.3	29.6	0.9	7.8
>3 weeks	11.7	19.1	18.5	13.2	18.4	15.4
Medical DQ for season	44.3	53.7	47.8	5.4	56.9	46.4
Medical DQ for career	0.4					0.2
Athlete chooses not to continue	0.7	1.6	2.6	5.1	0.0	1.5
Athlete released from team	0.0	0.0	0.0	3.8	0.0	0.3
Season ended before athlete returned	29.1	7.7	22.3	10.6	18.2	22.3
Other/unknown	3.3	7.1	5.2	9.5	0.0	1.6
Total	100	100	100	100	100	100

Abbreviations: AT, athletic trainer; CT, computed tomography; DQ, disqualification; GP, general physician; MRI, magnetic resonance imaging; Ortho, orthopaedic physician.

[a] One unweighted injury was assessed by only an emergency medical technician.

[b] Category containing diagnostic method does not sum to 100% because data were captured on all clinicians seen, and multiple responses were allowed.

[c] 10.9% of ACL injuries were assessed by others (ie, physician assistant, physical therapist) in conjunction with ATs, GPs, and/or Orthos.

Table 3. Anterior Cruciate Ligament Injury Mechanisms (%) by Sport, High School Sports-Related Injury Surveillance Study, United States, 2007/2008–2011/2012

Sport	Player-Player Contact	Player-Surface Contact	Player-Playing Apparatus Contact[a]	No Contact	Other
Football	61.2	7.8	0.3	30.4	0.4
Boys' soccer	40.4	21.6	1.9	34.8	1.3
Girls' soccer	39.1	7.5	3.2	45.6	4.6
Volleyball	16.2	52.9	0.0	30.9	0.0
Boys' basketball	31.7	17.6	0.0	50.8	0.0
Girls' basketball	17.2	24.2	0.0	46.0	12.5
Wrestling	41.6	27.7	12.7	18.0	0.0
Baseball	0.0	0.0	40.7	59.3	0.0
Softball	5.8	13.1	13.1	57.4	10.6
Total	42.8	13.6	2.4	37.9	3.3

[a] Playing apparatus included items such as the ball, base, goalpost, etc.

player-playing apparatus contact (2.4%), and other (3.3%; Table 3).

Sport and Sex Differences

Although there was no sex difference in ACL injury rates overall, in sex-comparable sports (soccer, basketball, and baseball or softball), girls sustained more ACL injuries than boys (209 versus 75, respectively), and girls had a higher injury rate than boys (8.9 and 2.6 per 100 000 AE, respectively; RR = 3.4; 95% CI = 2.64, 4.47; Table 1). Certain sports placed athletes at higher risk for ACL injuries than others. Boys were 4 times as likely to sustain an ACL injury while playing football as any other boys' sport (RR = 4.0; 95% CI = 3.20, 5.03). Girls were 2 times as likely to sustain an ACL injury playing soccer than any other girls' sport (RR = 2.2; 95% CI = 1.69, 2.86), and girls were 4 times as likely to sustain an ACL injury playing either soccer or basketball compared to volleyball or softball (RR = 4.1; 95% CI = 2.92, 5.73).

In both basketball and soccer, a higher proportion of ACL injuries among boys resulted in surgery compared with girls; however, this difference was not significant (96.3% versus 85.4%, IPR = 1.1; 95% CI = 0.996, 1.28 and 86.7% versus 75.6%, IPR = 1.2; 95% CI = 0.938, 1.40, respectively; Figure 3). Patterns of injury differed by sport and sex (Table 3). In sex-comparable sports, a higher proportion of girls (47.2%) than boys (40.5%) sustained an ACL injury by no contact (IPR = 1.2; 95% CI = 0.76, 1.79), however, the difference was not significant. In soccer, boys sustained 21.6% of injuries due to player-surface contact, compared with 7.5% of girls' (IPR = 2.9; 95% CI = 0.84, 9.87).

DISCUSSION

This study, the first of its kind to describe the epidemiology of ACL injuries across multiple high school sports in a large national sample, revealed that ACL injury rates and patterns varied by sport, sex, and type of exposure (competition versus practice). Anterior cruciate ligament injuries accounted for 20.5% of all knee injuries in this study, which is less than the 50% or more of all knee injuries reported in prior studies.[6,7] Although this evidence of a potential decrease is encouraging, ACL injuries still represent an important burden to high school athletes as they often require surgical repair followed by extensive long-term rehabilitation[7,27]; they can mean the end of an athlete's competitive career[10,28]; and they have been linked with negative long-term outcomes including chronic pain and osteoarthritis.[12,13] Thus, reducing the incidence and severity of ACL injuries continues to be an important goal.

Anterior cruciate ligament injuries are generally regarded as a particular concern for female athletes, with multiple previous studies, including those by Agel et al[22] and Arendt et al,[17] who reported higher rates of injury among females. Unfortunately, the plethora of such studies has led to a common belief that ACL injury is a problem for female athletes only. For example, Chappell et al[19] claimed simply that female athletes have a higher risk of ACL injuries than male athletes. This assertion has been perpetuated because so few researchers have evaluated the overall incidence of ACL injuries and ACL injury rates across large numbers of sports. As shown in Table 1, football, a male sport, had the largest number of ACL injuries and also the highest competition-related ACL injury rate of the 9 sports we studied. In fact, we found no significant sex difference in ACL injury rates when all 9 sports were considered, only seeing a significantly higher rate in females when limiting analyses to sex-comparable sports (soccer, basketball, and baseball or softball). This is consistent with Mountcastle et al,[20] who similarly found no sex difference between overall rates of ACL injury. Rates, however, are only one way to evaluate burden; incidence should also be considered. The high incidence of ACL injuries in football compared with other sports also demonstrates that ACL injuries are not limited to female athletes. In fact, given the large number of US high school football players relative to the number of girls' basketball and soccer players,[1] in terms of numbers of patients treated, sports medicine clinicians are more likely to treat a male high school athlete with an ACL injury than a female high school athlete with an ACL injury. Thus, in terms of sex, the burden of ACL injury is relative to the clinical or research question being asked. Although effective injury-prevention programs may need to be sex specific, given the large numbers of male athletes sustaining ACL injuries, efforts to create effective programs should not be solely targeted to female athletes.

Targeted injury-prevention programs should be focused on those athletes at highest risk of ACL injury.[29] For example, boys playing football were 4 times as likely to sustain an ACL injury as boys playing other sports. Similarly, girls were nearly 4 times as likely to sustain an ACL injury playing soccer and basketball compared with volleyball or softball. Some ACL injury-prevention programs have shown great promise,[30–32] but our understanding of the effectiveness of available ACL intervention programs is still limited.[29,33] Effective targeted prevention programs must be evidence based to address modifiable risk factors. However, we still lack a complete understanding of the modifiable risk factors for ACL injury. That said, coaches and ATs in sports with high rates of ACL injury should take special care to teach sport-specific skills (eg, planting and changing direction, jumping and landing) and address potential deficits in the neuromuscular strength and coordination of the stabilizing muscles about the knee joint through stretching, plyometrics, and strength training drills.[34] Additionally, screening tools have been developed in an attempt to identify athletes at increased risk of ACL injury. For example, although some researchers have questioned the reliability of this tool, according to Meyer et al and Hewett et al,[35,36] the tuck-jump exercise may be used to identify lower extremity technical flaws during plyometric activity that may indicate a higher risk of ACL injury. Identifying modifiable sport-specific risk factors for ACL injury is crucial to the development of effective, targeted injury-prevention efforts.[29]

Player-player contact is an example of one potentially modifiable risk factor that requires further study. In our study, 42.8% of ACL injuries were caused by player-player contact, which is higher than reports from previous studies. Boden et al[22] found only 28.0% of ACL injuries were contact injuries. Griffin et al[18] noted 30.0% were caused by contact. A sample from Agel et al[5] had 23.9% contact injuries, and Krosshaug et al[18] ascribed 28.2% of their injuries to contact. One possible reason for this discrepancy is the age and sport specificity of our study's population in comparison with others', which generally focus on collegiate athletes, sex-comparable sports only, or single sports. Potential explanations for the observed differences could include the fact that collegiate athletes generally have more body control and are more skilled at their sports, the pace and style of high school level play may leave athletes at higher risk of a contact injury, or athletes predisposed to ACL injury may be self-selected or medically selected out of sports before college. Additionally, the variety in study designs, data sources, and definitions of player-player contact may explain differences among studies. Another possible explanation is that, compared with prior studies, our data are skewed by the high frequency of football ACL injuries, which were predominantly caused by contact. Although further research is needed to fully understand contact-related ACL injuries, because player-player contact is a risk factor that can be reduced via rule changes, enforcement of existing rules, increased emphasis on sportsmanship, and teaching proper sport-specific skills, efforts should be made to reduce the risk of player-player contact-related ACL injuries without affecting the underlying purpose or culture of individual sports.

Another finding of note in this study was that athletes were 7 times more likely to sustain ACL injuries in competition than in practice. In comparison, a previous group[37] reported knee injuries were 3 times as likely in competition; whereas athletes in another study were 2.7 times as likely to sustain injury in competition compared with practice.[6] Further, the most common mechanism of ACL injury in our study was player-player contact, which occurs more frequently in competition than in practice. However, as more than 50% of ACL injuries in this study were not caused by player-player contact, additional research is needed to fully explain the observed difference between competition and practice. Higher rates of injury from competition exposures than practice exposures (presumably because of the increased intensity of play) have been well documented, and yet they persist. Competition ACL injury rates are higher than practice rates, so successful injury-prevention programs aimed at reducing competition-related ACL injuries could have a large effect.

LIMITATIONS

This study had several limitations. First, only schools with National Athletic Trainers' Association-affiliated, certified ATs with valid e-mail addresses were able to participate, potentially limiting the national generalizability of our study. However, ATs provide more accurate injury data than coaches or athletes.[38] Second, a specific definition of ACL injury was not used, which raises the possibility that some of the reported injuries may have been misclassified by the AT, particularly those that did not result in surgery and those from which the athlete returned to play quickly. However, only 6.9% of the ACL injuries included in this study were assessed by an AT alone. Additionally, 29.2% of the ACL injuries assessed by an AT and a general physician and 12.8% of those assessed by an AT and an orthopaedic physician did not result in surgical repair (Table 2). Also, although there is debate on this issue,[39] at least 1 recent study[40] found no clear evidence that ACL reconstruction improves the long-term symptomatic outcome, raising the question of how many ACL injuries could be successfully treated by more conservative rehabilitation programs rather than with surgery. Third, an AE was an event-based rather than a time-based measurement because measuring practice and game minutes for all athletes in 9 sports is not feasible for high school ATs. Finally, because the high school AT's role includes triaging injuries and diagnosing, managing, and treating less severe injuries that do not need to be referred to physicians, the patients with ACL injuries captured by the High School RIO surveillance system should be expected to represent a broader severity spectrum than those patients presenting to physicians' offices, sports medicine clinics, EDs, etc. Thus, caution should be used when comparing findings from this study with findings from studies based on those types of clinical settings. Note again, however, that more than 90% of the patients with ACL injuries in this study were evaluated by a physician. Although this study has limitations, it is the only study of ACL injuries across multiple sports at the high school level in a large national sample.

CONCLUSION

Anterior cruciate ligament injuries are among the most devastating injuries a young athlete can sustain, given the frequent need for surgical repair and extensive rehabilitation, as well as the potential for long-term health problems such as osteoarthritis. Although frequently thought of as a concern for female athletes, ACL injuries are not limited to female athletes. A certain endemic level of ACL injury will always be associated with sports, yet an increased commitment should be made to reduce the incidence and severity of ACL injuries sustained by high school athletes. Future investigators should focus on the modifiable sport-specific risk factors for ACL injuries in order to drive the development of effective, evidence-based, targeted ACL injury-prevention efforts. Until such programs are developed, the incidence of ACL injuries should be expected to continue to rise with the increasing number of youths participating in sports.

REFERENCES

1. National Federation of State High School Associations. *2007–08 High School Athletics Participation Survey*. http://www.nfhs.org/core/contentmanager/uploads/2007_08NFHSparticipationsurvey.pdf. Accessed May 15, 2012.
2. Centers for Disease Control and Prevention. Guidelines for school and community programs to promote lifelong physical activity among young people. *MMWR Recomm Rep*. 1997;46(RR-6):1–36.
3. Centers for Disease Control and Prevention. Sports-related injuries among high school athletes—United States, 2005–06 school year. *MMWR Morb Mortal Wkly Rep*. 2006;55(38):1037–1040.
4. Elkins WL, Cohen DA, Koralewicz LM, Taylor SN. After school activities, overweight, and obesity among inner city youth. *J Adolesc*. 2004;27(2):181–189.
5. Ingram JG, Fields SK, Yard EE, Comstock RD. Epidemiology of knee injuries among boys and girls in US high school athletics. *Am J Sports Med*. 2008;36(6):1116–1122.
6. Powell JW, Barber-Foss KD. Injury patterns in selected high school sports: a review of the 1995–1997 seasons. *J Athl Train*. 1999;34(3): 277–284.
7. Risberg MA, Lewek M, Snyder-Mackler L. A systematic review of evidence for anterior cruciate ligament rehabilitation: how much and what type? *Phys Ther Sport*. 2004;5(3):125–145.
8. Cimino F, Volk BS, Setter D. Anterior cruciate ligament injury: diagnosis, management, and prevention. *Am Fam Physician*. 2010; 82(8):917–922.
9. Centers for Disease Control and Prevention A, GA. *Preventing Injuries in Sports, Recreation, and Exercise*. Atlanta, GA, 2006.
10. Giugliano DN, Solomon JL. ACL tears in female athletes. *Phys Med Rehabil Clin N Am*. 2007;18(3):417–438, viii.
11. Mansson O, Kartus J, Sernert N. Health-related quality of life after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2011;19(3):479–487.
12. Lohmander LS, Englund PM, Dahl LL, Roos EM. The long-term consequence of anterior cruciate ligament and meniscus injuries: osteoarthritis. *Am J Sports Med*. 2007;35(10):1756–1769.
13. Fleming BC, Hulstyn MJ, Oksendahl HL, Fadale PD. Ligament injury, reconstruction and osteoarthritis. *Curr Opin Orthop*. 2005; 16(5):354–362.
14. Gehring D, Melnyk M, Gollhofer A. Gender and fatigue have influence on knee joint control strategies during landing. *Clin Biomech (Bristol, Avon)*. 2009;24(1):82–87.
15. Toth AP, Cordasco FA. Anterior cruciate ligament injuries in the female athlete. *J Gend Specif Med*. 2001;4(4):25–34.
16. Sarafrazi S, Tan Bt Abdulah RT, Amiri-Khorasani M. Kinematics analysis of hip and knee angles during landing after imagery in female athletes. *J Strength Cond Res*. 2012;26(9):2356–2363.
17. Arendt EA. Anterior cruciate ligament injuries. *Curr Womens Health Rep*. 2001;1(3):211–217.
18. Krosshaug T, Nakamae A, Boden BP, et al. Mechanisms of anterior cruciate ligament injury in basketball: video analysis of 39 cases. *Am J Sports Med*. 2007;35(3):359–367.
19. Chappell JD, Herman DC, Knight BS, Kirkendall DT, Garrett WE, Yu B. Effect of fatigue on knee kinetics and kinematics in stop-jump tasks. *Am J Sports Med*. 2005;33(7):1022–1029.
20. Mountcastle SB, Posner M, Kragh JF Jr., Taylor DC. Gender differences in anterior cruciate ligament injury vary with activity: epidemiology of anterior cruciate ligament injuries in a young, athletic population. *Am J Sports Med*. 2007;35(10):1635–1642.
21. Benjaminse A, Otten E. ACL injury prevention, more effective with a different way of motor learning? *Knee Surg Sports Traumatol Arthrosc*. 2011;19(4):622–627.
22. Agel J, Arendt EA, Bershadsky B. Anterior cruciate ligament injury in national collegiate athletic association basketball and soccer: a 13-year review. *Am J Sports Med*. 2005;33(4):524–530.
23. Arendt EA, Agel J, Dick R. Anterior cruciate ligament injury patterns among collegiate men and women. *J Athl Train*. 1999;34(2):86–92.
24. Bjordal JM, Arnly F, Hannestad B, Strand T. Epidemiology of anterior cruciate ligament injuries in soccer. *Am J Sports Med*. 1997; 25(3):341–345.
25. Freedman KB, Glasgow MT, Glasgow SG, Bernstein J. Anterior cruciate ligament injury and reconstruction among university students. *Clin Orthop Relat Res*. 1998;356:208–212.
26. Ireland ML. Anterior cruciate ligament injury in female athletes: epidemiology. *J Athl Train*. 1999;34(2):150–154.
27. de Loes M, Dahlstedt LJ, Thomee R. A 7-year study on risks and costs of knee injuries in male and female youth participants in 12 sports. *Scand J Med Sci Sports*. 2000;10(2):90–97.
28. Hewett TE, Lindenfeld TN, Riccobene JV, Noyes FR. The effect of neuromuscular training on the incidence of knee injury in female athletes: a prospective study. *Am J Sports Med*. 1999;27(6):699–706.
29. Griffin LY, Agel J, Albohm MJ, et al. Noncontact anterior cruciate ligament injuries: risk factors and prevention strategies. *J Am Acad Orthop Surg*. 2000;8(3):141–150.
30. Shultz SJ, Schmitz RJ, Nguyen AD, et al. ACL Research Retreat V: an update on ACL injury risk and prevention, March 25–27, 2010, Greensboro, NC. *J Athl Train*. 2010;45(5):499–508.
31. DiStefano LJ, Padua DA, DiStefano MJ, Marshall SW. Influence of age, sex, technique, and exercise program on movement patterns after an anterior cruciate ligament injury prevention program in youth soccer players. *Am J Sports Med*. 2009;37(3):495–505.
32. Gilchrist J, Mandelbaum BR, Melancon H, et al. A randomized controlled trial to prevent noncontact anterior cruciate ligament injury in female collegiate soccer players. *Am J Sports Med*. 2008; 36(8):1476–1483.
33. DiStefano LJ, Clark MA, Padua DA. Evidence supporting balance training in healthy individuals: a systemic review. *J Strength Cond Res*. 2009;23(9):2718–2731.
34. Boden BP, Dean GS, Feagin JA Jr, Garrett WE Jr. Mechanisms of anterior cruciate ligament injury. *Orthopedics*. 2000;23(6):573–578.
35. Myer GD, Ford KR, Hewett TE. Rationale and clinical techniques for anterior cruciate ligament injury prevention among female athletes. *J Athl Train*. 2004;39(4):352–364.
36. Hewett TE, Ford KR, Hoogenboom BJ, Myer GD. Understanding and preventing ACL injuries: current biomechanical and epidemiologic considerations—update 2010. *N Am J Sports Phys Ther*. 2010; 5(4):234–251.
37. Hutchinson MR, Ireland ML. Knee injuries in female athletes. *Sports Med*. 1995;19(4):288–302.
38. Yard EE, Collins CL, Comstock RD. A comparison of high school sports injury surveillance data reporting by certified athletic trainers and coaches. *J Athl Train*. 2009;44(6):645–652.
39. Vavken P, Murray MM. The potential for primary repair of the ACL. *Sports Med Arthrosc*. 2011;19(1):44–49.
40. Streich NA, Zimmermann D, Bode G, Schmitt H. Reconstructive versus non-reconstructive treatment of anterior cruciate ligament insufficiency: a retrospective matched-pair long-term follow-up. *Int Orthop*. 2011;35(4):607–613.

Address correspondence to Christy L. Collins, MA, The Research Institute at Nationwide Children's Hospital, Center for Injury Research and Policy, 700 Children's Drive, Columbus, OH 43205. Address e-mail to christy.collins@nationwidechildrens.org.