Trends in Recurrent Anterior Cruciate Ligament Injuries Differ From New Anterior Cruciate Ligament Injuries in College and High School Sports

2009-2010 Through 2016-2017

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Background: Knee injuries are common and result in extended time missed from sports participation. Little is known regarding the comparative characteristics of recurrent versus first-time anterior cruciate ligament (ACL) injuries sustained during athletic events and how they are influenced by sex, sports participation level, and game-time features.

Purpose: To evaluate the characteristics (sex, sports level, and game timing [ie, early vs late in the game]) of recurrent ACL injury in National Collegiate Athletic Association (NCAA) and high school athletes compared with first-time ACL injury.

Study Design: Descriptive epidemiology study.

Methods: Athletic trainers reported ACL injury occurrences and characteristics for collegiate athletes during the 2009-2010 through 2016-2017 academic years and for high school athletes during the 2011-2012 through 2013-2014 academic years. Logistic regression was used to estimate odds ratios (ORs) and 95% CIs for recurrent versus first-time ACL injury. The number of ACL injuries, proportions, and ORs were calculated by sex, competition level, and time in game played. Results were also classified according to injury mechanism: noncontact, overuse, or surface contact.

Results: A total of 705 ACL injuries were reported, including 644 first-time injures and 61 recurrent injuries. When restricting to noncontact ACL injuries, 416 were reported (373 first-time injuries and 43 recurrent injuries). The odds of a recurrent versus new ACL injury in NCAA student-athletes were 4.6 times that of high school student-athletes (95% CI, 1.41-15.24; $P = .01$). When restricting to noncontact ACL injuries, the odds of a recurrent versus new ACL injury during postseason and preseason were 4.5 and 2.8 times that during the regular season, respectively. Athletes in limited-contact and noncontact sports had greater odds of a recurrent versus new ACL injury compared with athletes playing football and other contact and collision sports. There was no significant difference in the odds of a recurrent ACL injury by sex or time in game.

Conclusion: Based on the current study, the odds of recurrent ACL injuries are associated with the level of competition but not associated with sex or timing of game play. Determinants of reinjury after primary ACL reconstruction will help advance care for young injured athletes who continue to participate in competitive sports.

Keywords: knee; ACL; recurrent; injury; high school; college; injury surveillance

Knee injuries are the most commonly reported injury resulting in extended time loss from activity in both high school and college athletes.[8,22] Anterior cruciate ligament (ACL) rupture is the most common sports-related knee injury,[29] with an annual incidence of up to 200,000 instances.[1] The ACL injury rate is highest in younger athletes, especially in those who participate in high-risk sports that involve cutting and pivoting, such as basketball, football, skiing, and soccer.[2] Young athletes commonly elect to have a surgical reconstruction of a torn ACL to restore stability, with the goal of returning to preinjury level of activity or sports.

Within the first 2 years after reconstruction and return to athletics is when young active patients have the highest risk for reinjury, both to the ipsilateral/reconstructed knee and to the contralateral knee. Athletes younger than 25

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years who return to sports exhibit a reinjury rate of 23%[43] and are at 6 times greater risk for subsequent knee injury compared with uninjured athletes.[31,32] Young age, exposure to risk via high activity level, and use of allograft all contribute to the risk of subsequent injury after an initial ACL reconstruction.[17] In young athletes, prevention of secondary injury is paramount, especially in those who are exposed to continued risk because of competitive sports. Revision ACL reconstruction for patients with failed primary reconstruction results exhibit even worse functional outcomes,[7,12,16,35] especially in adolescent patients.[5]

Prior research has aimed to understand the risk of primary[40] and secondary[4,43] ACL injuries in young competitive athletes. Population-based studies using the National Collegiate Athletic Association (NCAA) Injury Surveillance Program (ISP) and National Athletic Treatment Injury and Outcomes Network (NATION) databases have been instrumental in describing the distribution and potential determinants of lower extremity injury in adolescents and young adults, leveraging the existing infrastructure for injury and exposure tracking in high school and college athletes.[6,37] The purpose of the study was to compare the factors associated with recurrent and new ACL injuries for collegiate and high school athletes in American high school and NCAA schools. We hypothesized that the factors associated with recurrent injuries will differ from those associated with first-time injuries.

METHODS

This study described and compared recurrent versus new ACL injuries captured in the data from the NCAA ISP from 2009-2010 through 2016-2017 and the NATION from 2011-2012 through 2013-2014. The methods for the NCAA ISP[23] and NATION[10] have been described elsewhere. Both the NCAA ISP and NATION are prospective ISPs using a convenience sample of varsity teams from 25 NCAA championship sports and 27 secondary school sports, respectively. The NCAA ISP data collection was approved by the research review board of the NCAA, and the NATION data collection was approved by the Western Institutional Review Board.

Data Collection

Athletic trainers (ATs) recorded injury and exposure data via their preferred electronic medical record system. They completed a report on injury circumstances, including circumstances that may be associated with recurrence status: sex, competition level (NCAA or high school), sports, season (preseason, regular season, or postseason), mechanism of injury, event type (competition vs practice), and stage in the competition when the injury occurred. ATs also reported information about the injury itself, including whether it was a recurrent injury. Common injury and exposure data elements from the electronic medical record systems were stripped of any identifiable information and exported to a verification engine specific to the ISP. Automatic and manual checks were performed to ensure high-quality data.

Definitions

A *reportable injury* in both the NCAA ISP and the NATION was defined as an injury that occurred because of participation in an organized collegiate or high school practice or competition and that required attention from an AT or physician. Only injuries during team-sanctioned practices and competitions were included; individual weight lifting and conditioning sessions were excluded. This study included all injuries for which the diagnosis was recorded as "Anterior Cruciate Ligament (ACL) Tear – Partial Or Complete" and resulted in time loss of at least 7 days, regardless of the surgery status.

A *recurrent injury* was one in which the AT selected that the injury was "recurrence of an injury earlier in the current academic year" or "recurrence of an injury from a previous academic year." Data on whether the injury was contralateral or ipsilateral were not collected.

A *first-time injury* was one in which the AT selected that it was a "new injury."

Sports contact level was based on the American Academy of Pediatrics sports contact level classifications.[34] Sports were categorized into 3 groups: football, all other collision and contact sports, and limited/noncontact.

Time in competition was dichotomized into "early" in the competition (warm-up, halftime or earlier, preliminaries, game/set 1 or 2, innings 1-3, or first period) and "late" in the competition (after halftime, finals, game/set 3-5, innings 4-9, second period, third period, overtime, or cool down), based on the sport the student-athlete was playing at the time of the injury. This information was available only about injuries occurring during competitions; the NCAA ISP and NATION do not collect time in practice in which an injury occurred and do not collect individual time-based exposure data.

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Ethical approval for this study was waived by the Western Institutional Review Board and the National Collegiate Athletic Association Research Review Board.

Statistical Analyses

We calculated the number and proportion of new and recurrent ACL injuries with variables that may be associated with recurrence risk (described above). Logistic regression was used to estimate the odds ratios (ORs) and 95% CIs for recurrent versus first-time ACL injury, and the data were analyzed according to injury mechanism: noncontact, overuse, or surface contact. Additional analyses compared the odds of recurrent injury between "early" and "late" in the competition. Owing to the large number of football injuries in the data set, we ran sensitivity analyses excluding football in order to evaluate whether football injuries influenced the results. The alpha level was set at $P < .05$.

RESULTS

A total of 705 ACL injuries were reported: 644 first-time injures (91.3%) and 61 (8.7%) recurrent injuries. The majority of first-time injuries were in male athletes, whereas the majority of recurrent injuries were in female athletes; the majority of first-time injuries were during competition, whereas the majority of recurrent injuries were during practices (Table 1). However, the odds of sustaining a recurrent injury were not significantly different when comparing event type (competition vs practice) (OR = 0.64; 95% CI, 0.32-1.27; $P = .83$). Figures 1 and 2 summarize the ORs calculated from multivariate regression analyses.

When examining the factors using multivariable logistic regression, the only characteristic that was statistically significantly associated with recurrent versus first-time injury was competition level: The odds of recurrent injury in NCAA student-athletes were 4.6 times that of high school student-athletes (OR, 4.63; 95% CI, 1.41-15.24; $P = .01$) (Figure 1). Sex, sports contact level, playing season, mechanism of injury, and event type were not statistically significantly associated with odds of sustaining a recurrent injury compared with a first-time injury.

When restricting to only injuries due to noncontact mechanisms, the competition level ($P = .02$), sports contact level ($P = .01$), and playing season ($P = .02$) were all associated with the odds of sustaining a recurrent versus new injury (Figure 2). Regarding competition level, the odds of recurrent injury in NCAA student-athletes were 11 times that of high school student-athletes (OR, 10.76; 95% CI 1.42-81.43). When examining sports contact level, the odds of recurrent injury in student-athletes playing football were 88% less (OR, 0.12; 95% CI, 0.03-0.45) and the odds for student-athletes in other contact/collision sports were 65% less (OR, 0.35; 95% CI, 0.15-0.82) than the odds for student-athletes playing limited-contact or noncontact sports. Finally, regarding playing season, the odds of recurrent injury in the postseason were 4.5 times the odds in the regular season (OR, 4.45; 95% CI, 1.04-19.03), and the odds of recurrent injury in the preseason were 2.8 times the odds in the regular season (OR, 2.79; 95% CI, 1.09-7.18). Sex and event type (ie, competition vs practice) were not associated with odds of sustaining a recurrent versus first-time injury.

When restricting to competitions only (ie, removing injuries during practices), no factors were associated with recurrent versus first-time injury. When restricting to only injuries because of noncontact, surface contact, or overuse mechanisms during competition, there were also no factors associated with recurrent versus first-time injury. Sensitivity analyses excluding football slightly changed the ORs but did not affect significance.

DISCUSSION

The purpose of this study was to compare recurrent to first-time ACL injuries based on sex, athletics level, and game time. As a descriptive study, the goal was to summarize patterns of recurrent ACL injuries compared with first-time injuries. Of the ACL injuries reported, 8.7% were recurrent injuries; however, when restricted to noncontact, surface contact, and overuse mechanisms, 12.2% were recurrent injuries. These injuries were reported by athletic training staff as recurrent injuries; therefore, we assumed that these injuries described graft failures in the ipsilateral limb. The recurrent injury proportions reported in this study are greater than reinjury rates previously reported[18,42,44]; however, the proportions were similar to the reported pooled ipsilateral reinjury rate for patients younger than 25 years.[42] Young athletes, both in high school and college, tend to have better strength and patient-reported outcomes at 6 months postoperatively compared with the general, noncompetitive athlete ACL reconstruction (ACLR) population.[26]

The high rate of reinjury in young athletes may be attributed to risk exposure and the timing from index surgical procedure to the point where the athlete is released to unrestricted sports activity. The high rate of graft failures also increases the risk of posttraumatic osteoarthritis,[14] suggesting that sports medicine professionals working with youth athletes after primary ACLR should use caution when returning an athlete back to sports to minimize the risk of secondary injury and long-term consequences such as the development of osteoarthritis. It may be advantageous for athletes to continue rehabilitation and delay return to sports beyond satisfactory patient-reported outcomes and strength measures.[30]

Activity level has been previously identified as a risk factor in primary ACL injuries, with higher activity level associated with increased risk of injury.[3,21] Activity level was also identified as a risk factor in the current study; NCAA athletes had 4.6 times the odds of the ACL injury being recurrent rather than new compared with high school athletes. This may be for a variety of factors, including age of primary injury and increased exposures. Most primary ACL injuries occur when athletes are between 15 and 18 years old,[39] suggesting that if a primary injury occurs during high school, athletes who return to sports after 6-12+ months of rehabilitation may have graduated from high school and can only play at the collegiate level. Increased exposures in college sports may also be associated with increased risk of injury; however, greater

TABLE 1
Number of New and Recurrent Anterior Cruciate Ligament Injuries Reported Based on Sex, Event Type, Sports, Contact Level, Time in Game, Season, Competition Level, and Mechanism in Collegiate (2009-2017) and High School (2011-2014) Athletics[a]

	All Injuries		Injuries Due to Noncontact Mechanisms	
	New Injury (n = 644)	Recurrent Injury (n = 61)	New Injury (n = 373)	Recurrent Injury (n = 43)
Sex				
Male	373 (57.9)	29 (47.5)	185 (49.6)	17 (39.5)
Female	271 (42.1)	32 (52.5)	188 (50.4)	26 (60.5)
Event type				
Competition	387 (60.1)	26 (42.6)	209 (56.0)	18 (41.9)
Practice	257 (39.9)	35 (57.4)	164 (44.0)	25 (58.1)
Sports				
Baseball/softball	14 (2.2)	4 (6.6)	10 (2.7)	4 (9.3)
Basketball	88 (13.7)	11 (18.0)	57 (15.3)	9 (20.9)
Football	253 (39.3)	16 (26.2)	122 (32.7)	8 (18.6)
Field hockey	6 (0.9)	0 (0.0)	3 (0.8)	0 (0.0)
Women/girls Gymnastics	12 (1.9)	3 (4.9)	11 (3.0)	3 (7.0)
Ice hockey	21 (3.3)	2 (3.3)	2 (0.5)	0 (0.0)
Lacrosse	72 (11.2)	3 (4.9)	58 (15.6)	3 (7.0)
Soccer	129 (20.0)	13 (21.3)	78 (20.9)	8 (18.6)
Tennis	0 (0.0)	1 (1.6)	0 (0.0)	1 (2.3)
Track/cross-country	3 (0.5)	1 (1.6)	1 (0.3)	1 (2.3)
Women/girls Volleyball	34 (5.3)	6 (9.8)	28 (7.5)	6 (14.0)
Wrestling	12 (1.9)	1 (1.6)	3 (0.8)	0 (0.0)
Sports contact level[b]				
Football	253 (39.3)	16 (26.2)	122 (32.7)	8 (18.6)
Other contact/collision	340 (52.8)	33 (54.1)	212 (56.8)	23 (53.5)
Limited contact/noncontact	51 (7.9)	12 (19.7)	39 (10.5)	12 (27.9)
Time in game[c]				
Early	191 (52.6)	16 (66.7)	114 (57.9)	11 (61.1)
Late	172 (47.4)	8 (33.3)	83 (42.1)	7 (38.9)
Season				
Preseason	131 (20.3)	21 (34.4)	86 (23.1)	18 (41.9)
Regular season	490 (76.1)	36 (59.0)	276 (74.0)	22 (51.2)
Postseason	23 (3.6)	4 (6.6)	11 (3.0)	3 (7.0)
Competition level				
High school	137 (21.3)	3 (4.9)	81 (21.7)	1 (2.3)
NCAA	507 (78.7)	58 (95.1)	292 (78.3)	42 (97.7)
Mechanism of injury				
Contact with another person	239 (37.1)	13 (21.3)	0 (0.0)	0 (0.0)
Surface contact	71 (11.0)	13 (21.3)	71 (19.0)	13 (30.2)
Noncontact/overuse	302 (46.9)	30 (49.2)	302 (81.0)	30 (69.8)
Unknown/other[d]	32 (5.0)	5 (8.2)	0 (0.0)	0 (0.0)

[a]Data are expressed as n (%). NCAA, National Collegiate Athletic Association.
[b]Based on American Academy of Pediatrics definitions.[34]
[c]Only includes injuries that occurred during a game for which it was known when the injury occurred (24 recurrent injuries; 197 new injuries due to noncontact mechanisms; 18 recurrent injuries due to noncontact mechanisms). "Early" = warm-up, halftime or earlier, preliminaries, game/set 1, game/set 2, innings 1-3, first period; "Late" = after halftime, finals, game/set 3, game/set 4, game/set 5, innings 4-9, second period, third period, overtime, cool down.
[d]Includes contact with out-of-bounds object, contact with playing apparatus (eg, goal), unknown, and other.

athlete-exposures have been reported in high school athletes compared with college athletes, which is likely because of the greater number of athletes in the high school setting.[3,36] Therefore, if exposures were the only factor in injury rates, we would assume that high school athletes would have higher odds of recurrent injury compared with college athletes.

Along with increased competition level, female sex has been identified as a main risk factor for primary noncontact ACL injury.[3,37] After injury and subsequent reconstruction, female patients tend to have worse outcomes compared with male patients.[24,38] Despite decreased patient-reported outcomes and inability to return to sports for many women after ACLR, there was no sex-based difference in recurrent injuries

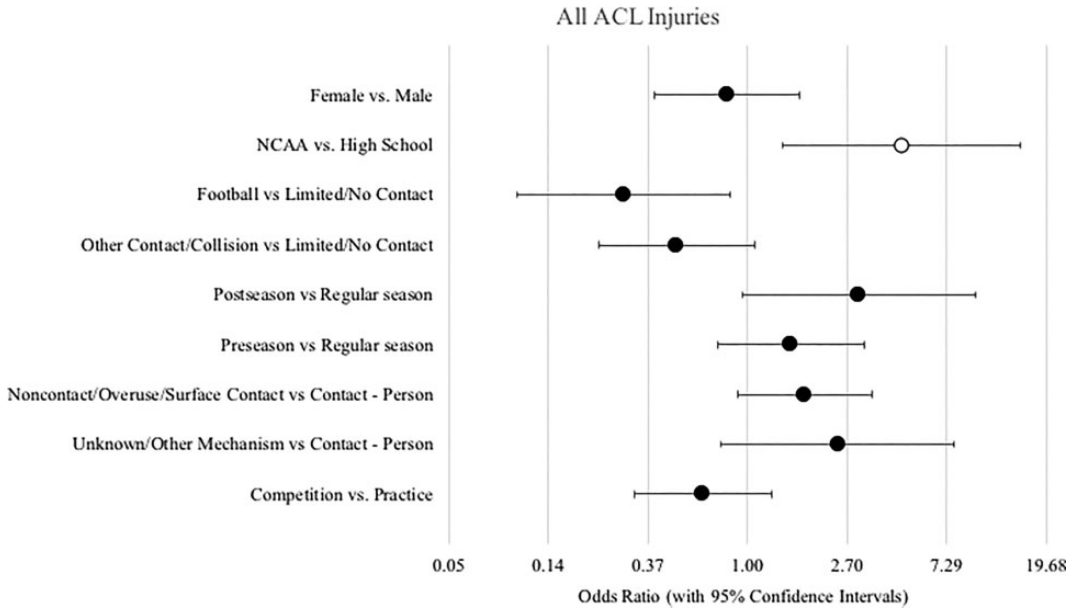

Figure 1. Odds ratios and 95% CIs for recurrent versus first-time anterior cruciate ligament (ACL) injury for all injuries reported in National Collegiate Athletic Association (NCAA) and high school athletics. An odds ratio of 1.0 indicates the event is equally likely to occur in both groups, while an odds ratio greater than 1.0 indicates that the variable is more likely to lead to recurrent injury. Significant odds ratios ($P < .05$) are noted with open circles.

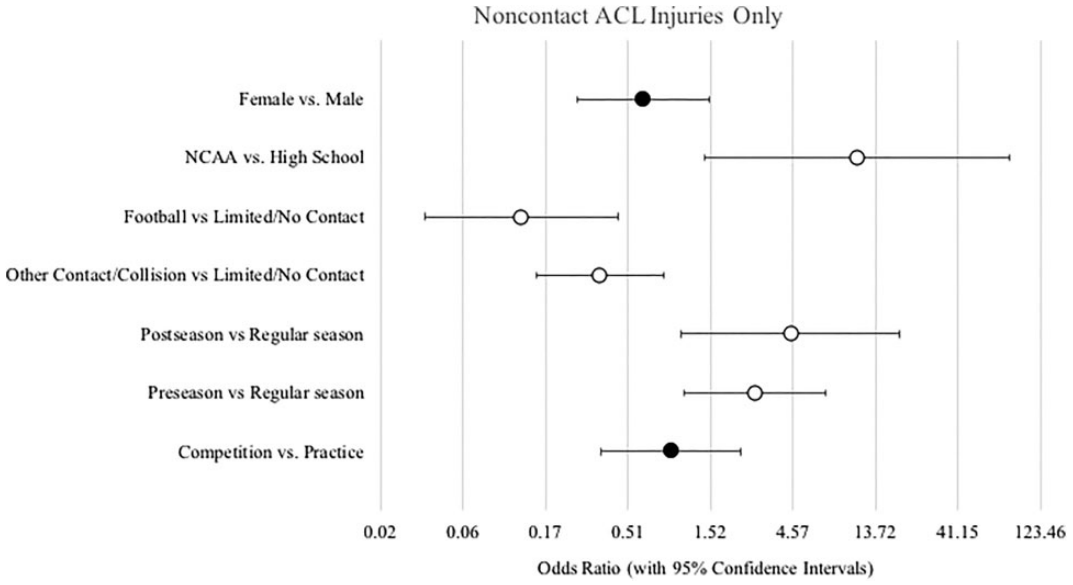

Figure 2. Odds ratios and 95% CIs for recurrent versus first-time anterior cruciate ligament (ACL) injury for only noncontact injuries reported in National Collegiate Athletic Association (NCAA) and high school athletics. Significant odds ratios ($P < .05$) are noted with open circles.

compared with new injuries in the current study. Although women are at increased risk of primary injury, our results suggest that this risk is no different for recurrent when compared with new ACL injuries. Sports medicine professionals working with college athletes should therefore consider injury history as the predominant risk factor when designing neuromuscular training and rehabilitation programs.

Event type (competition vs practice) was not associated with significantly different odds of sustaining recurrent compared with new injuries in this data set, despite a trend toward more first-time injuries occurring during competition (60.1%) and more recurrent injuries occurring during practice (57.4%). This may be because of the overall small number of recurrent injuries (n = 61). This finding may

pave the way for an area for future research with a larger database of recurrent injuries, ideally a database with individual-based exposure time so that rates of recurrent versus new injuries could be compared rather than odds.

Fatigue is often considered a risk factor for ACL injuries during games.[9,33] There are a plethora of data to support that neuromuscular control and mechanics change with fatigue; however, these changes may not necessarily increase the risk of ACL injury. Although video analyses of ACL injuries have confirmed that reduced knee flexion and valgus stress are typical mechanisms of injury,[15,19] injuries tend to mostly occur early in games,[15] suggesting that these altered mechanics are largely unrelated to fatigue. The findings in the current study suggest a similar trend in recurrent injuries, with 67% of all reported recurrent injuries occurring early in games. However, only 24 of the 61 recurrent injuries in the database included the time in the game when the injury occurred, limiting our ability to analyze this variable. Additionally, the surveillance programs do not track individual time-based exposure, so these analyses assume that student-athletes who have not had a previous ACL injury have similar exposure to student-athletes who have had a previous ACL injury.

Along with the trend for more recurrent injuries to occur early during a game, for injuries due to noncontact, surface contact, or overuse mechanisms, the odds of recurrent injury compared with new injury during preseason were 2.8 times that of regular season. This could be because of several reasons, including inadequate physical preparation at the beginning of the season, increased training load during preseason without recovery, and reduced or asymmetrical strength and flexibility at the beginning of the season.[25] Implementing neuromuscular training during the preseason and encouraging dynamic warm-ups before games may reduce the risk of injury early in season and during games.[13,27]

The odds of recurrent injury compared with new injury for injuries because of noncontact, surface contact, or overuse mechanisms were higher during postseason compared with regular season (OR = 4.45). To our knowledge, this is the first study to compare recurrent injury risk during 3 separate times of the season (preseason, regular season, and postseason) rather than combining the regular and postseason.[11] Increased risk of recurrent injury during postseason implies slightly different risk factors for recurrent injuries compared with primary injuries, which occur most often during regular season across all collegiate divisions.[20] Postseason often requires a different type of play, such as increased number of minutes played[41] and increased perceptual strain during similar work,[28] which may heighten the risk of recurrent ACL injury. Sports performance and medical staff may need to consider injury history during postseason.

Although these data represent a large sample from a wide range of schools across the country, enabling collection of outcomes that may be considered an infrequent injury at a single site, there are a few limitations in the current study. All injury mechanisms and sports were included in primary analysis, which was weighted heavily with football injuries, which may have influenced the results, although our sensitivity analysis excluding football did not affect significance. Another limitation was the small sample of recurrent injuries in this database. These databases are limited to participating high schools and colleges and are limited to programs with ATs. Future investigations examining sex differences in the injury rate and sports participation level should be examined over a longer period to include more recurrent injuries. Because these surveillance systems are not traditional longitudinal studies, many of the recurrent injuries were in different student-athletes than the new injuries. Therefore, our conclusions about factors associated with recurrent injury are limited to comparisons against the characteristics of new injuries.

These databases also do not allow for contralateral and ipsilateral comparisons; however, we assumed that the recurrent injuries reported in this study are largely ipsilateral graft failures because of being labeled a "recurrent" injury by ATs, while an ACL injury to the contralateral side may be labeled as "new." We cannot guarantee that the injuries reported in this study were not a mixture of ipsilateral and contralateral injuries. It may be beneficial to improve clarity in the databases in the future for ATs to identify which limb was injured. We also cannot assume that all recurrent injuries were surgical. We controlled for included injuries the best we could by excluding all injuries with less than 7 days of lost activity time. Last, the injuries in these data likely represent a range of surgical techniques and rehabilitation protocols. Although we do not have information regarding graft type or rehabilitation length and compliance, the participants included in this study represent a specific group of patients who returned back to a high level of sports after ACLR, which is the primary goal of a rehabilitation program regardless of the length or the program design.

CONCLUSION

NCAA athletes had 4.5 times the odds of recurrent injury compared with high school athletes; however, there were no differences between sex and time of injury (late vs early in the game) despite a trend toward more recurrent injuries early in the game. These data suggest that factors associated with recurrent ACL injury differ from those associated with new ACL injury.

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