

# Epidemiology of Injuries Sustained in Boys' High School Contact and Collision Sports, 2008-2009 Through 2012-2013

Erin Hammer,<sup>\*†</sup> MD, MPH, M. Alison Brooks,<sup>†</sup> MD, MPH, Scott Hetzel,<sup>‡</sup> MS, Alan Arakkal,<sup>§</sup> BS, and R. Dawn Comstock,<sup>§</sup> PhD

*Investigation performed at the University of Wisconsin–Madison, Madison, Wisconsin, USA*

**Background:** Injury epidemiology for boys' high school contact and collision sport has been described in several overlapping but fragmented studies. Comprehensive comparisons of injuries sustained in boys' soccer, wrestling, football, ice hockey, and lacrosse are lacking.

**Purpose:** To describe patterns of injury by severity, body site, and diagnosis among high school boys' contact and collision sports in the United States.

**Study Design:** Descriptive epidemiology study.

**Methods:** Injury rates and rate ratios (RRs) were calculated for injuries sustained in boys' high school soccer, wrestling, football, ice hockey, and lacrosse through use of the High School RIO (Reporting Information Online) surveillance data from 2008-2009 through 2012-2013. Injury patterns were described by site, diagnosis, time loss, and severity. Severe injury was defined as an injury that resulted in 21 days or more of time loss from sport participation. Risk of sustaining a concussion was compared between sports.

**Results:** The risk of sustaining an injury was higher in competition compared with practice overall (RR, 4.01; 95% CI, 3.90-4.12); the same pattern was true for severe injuries (RR, 4.61; 95% CI, 4.34-4.90). Football players experienced the highest injury rate (3.87 per 1000 athlete-exposures [AEs]) and the highest severe injury rate (0.80 per 1000 AEs). Overall, the most commonly injured body site was the head/face (22.5%), and the most prevalent injury diagnosis was ligament sprain not requiring surgery (23.5%). The most frequently injured body site from severe injury was the knee (24.6%), and fracture or avulsion was the most prevalent severe injury diagnosis (37.0%). Football players had a significantly higher risk of sustaining a concussion compared with other contact or collision sport athletes ( $P < .05$ ).

**Conclusion:** Injuries rates were higher in competition than those in practice for boys' high school contact and collision athletes. Football players sustained the highest injury rate, the highest severe injury rate, and the highest concussion rate among the sports included in this analysis. Understanding these patterns of injury can generate policy and rule changes to make sports safer and maintain high levels of participation.

**Keywords:** injury; high school; sports; epidemiology; football; ice hockey; soccer; lacrosse; wrestling

Contact and collision sports such as soccer, wrestling, football, ice hockey, and lacrosse remain popular among boys' high school athletes in the United States (US).<sup>9</sup> Beyond enjoyment, participation in organized sports is associated with greater self-esteem, lower risky substance use, and lower rates of obesity.<sup>6,8,11</sup> However, participation in these sports incurs an inherent risk of injury.<sup>1,4,14</sup>

Previous epidemiologic studies using the High School RIO (Reporting Information Online) surveillance system have described injury patterns among boys' high school contact and collision sport athletes within narrow,

overlapping foci. For example, Rechel et al<sup>13</sup> found that the risk of injury in boys' football and wrestling was higher in competition than in practice, and Darrow et al<sup>4</sup> replicated these findings for severe injuries. Additionally, among boys' football, soccer, and wrestling, concussion rates increased from 2005 through 2014, resulting in an overall 2.3-fold increase in concussion rates over this period.<sup>14</sup> Concussions sustained among boys' football, ice hockey, soccer, and lacrosse athletes are most likely to be due to player-player contact and represent a higher proportion of total injuries compared with noncontact sports.<sup>7</sup> These studies cumulatively illuminate a patchwork of understanding about the nature of injuries in boys' contact and collision sports, but research on this topic is incomplete.

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Analyzing specific injury patterns in boys' high school contact and collision sports may allow for targeted interventions to reduce risk of injury. The purpose of this study was to assess patterns of injury by time loss, severity, body site, and diagnosis among participants in US high school boys' football, ice hockey, lacrosse, wrestling, and soccer.

## METHODS

### Data Collection

Injury and exposure data collected by High School RIO from 2008-2009 through 2012-2013 were used to assess injury rates among boys' soccer, wrestling, football, ice hockey, and lacrosse athletes. The specific methods used in this study has been reported elsewhere<sup>1,13,14</sup> and replicated widely. Commencing in the 2005-2006 season, US high schools with a National Athletic Trainers' Association-certified athletic trainer (AT) reported sport-related injuries and athlete-exposures (AEs) on a weekly basis. The schools were then categorized into 8 strata based on US Census geographic locations and school enrollment ( $\leq 1000$  or  $>1000$ ), and a nationally representative sample of 100 schools was randomly selected to participate. The High School RIO database initially consisted of 9 sports including boys' soccer, wrestling, and football. Subsequently, boys' ice hockey and lacrosse were added in 2008-2009, and concurrent to the randomly selected sample of 100 schools replicated annually, a convenience sample of eligible schools was enrolled to report data on these newer sports.

We chose to include football, ice hockey, lacrosse, wrestling, and soccer because contact and collision are inherent and incentivized within their rules. Contact with the ball or playing surface is also a major contributor to injuries in the sports we included, which is distinct from limited-contact sports. Other sports that entail limited contact, such as basketball, were not included in the analysis because they do not permit contact to the same degree as the sports we chose to include. Although they are surveilled in High School RIO, girls' sports were not included in this analysis because sex-based rule differences in high school collision sports alter injury risk and therefore invalidate comparisons that might be made. This study was approved by an institutional review board.

### Definition of Exposure and Injury

An AE was defined as 1 athlete participating in 1 school-sanctioned practice or competition in which there was a risk of injury. Sports-related injuries were required to meet the following criteria: (1) occurred as a result of an AE, (2) required medical attention from a physician or an AT, and (3) resulted in the athlete missing 1 or more days of participation.<sup>13</sup> In this study, a severe injury was defined as an injury that resulted in one of the following outcomes: 21 or more days of missed participation, medical disqualification for the season/career, fatality, or paralysis. For injuries in which the season ended prior to the athletes' return to play ( $n = 1678$ ), an AT's professional opinion on how long it would have taken the athlete to return to activity was used to categorize severity. Severe injuries were then categorized based on the nature of the event in which they occurred, injury site, diagnosis, and severity.

### Injuries With Indeterminate Time Lost

Time loss was indeterminable for injuries in which time loss data were missing ( $n = 834$ ), the athlete chose not to continue with the team ( $n = 294$ ) or was released from the team though not medically disqualified ( $n = 19$ ), if the AT was unable to render a decision about the athlete's ability to return to sport before the athlete returned to activity ( $n = 74$ ), or other ( $n = 186$ ). This left 1407 (6.8%) injuries with indeterminate time loss. Since exposure data in the High School RIO database are aggregate totals and not subject specific, the removal of these injuries would result in an underestimate of the rate ratios (RRs) for severe injuries. Therefore, we assigned the 1407 injuries with indeterminate time loss data into 1 of 3 categories:  $<1$  week, 1-3 weeks, or  $>3$  weeks. First, we assumed that all of these injuries entailed at least 1 day of time loss. Second, we calculated the time loss distribution for each injury type-by-sport combination (eg, dislocation/hyperextension in football was 36.0%  $<1$  week, 34.4% 1-3 weeks, and 29.6%  $>3$  weeks). Third, we imputed time loss through a random number generator such that the probability of assigning 1 of the 3 time loss categories would match the distribution of time loss in the collected data for the corresponding injury type-by-sport combination. For every combination, there was at least 5.8 times as much collected data compared with imputed data. Only 28 (0.1%) injuries were missing body

\*Address correspondence to Erin Hammer, MD, MPH, 1685 Highland Avenue, Madison, WI 53705, USA (email: ehammer@uwhealth.org) (Twitter: @HammerWisco).

<sup>†</sup>Department of Orthopedics and Rehabilitation, University of Wisconsin-Madison, Madison, Wisconsin, USA.

<sup>‡</sup>Department of Biostatistics and Medical Informatics, University of Wisconsin-Madison, Madison, Wisconsin, USA.

<sup>§</sup>Department of Epidemiology, Colorado School of Public Health, University of Colorado Anschutz, Aurora, Colorado, USA.

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Ethical approval for this study was obtained from the University of Wisconsin-Madison Health Sciences Institutional Review Board (study ID 2019-0769).

site data. Time loss data were not imputed for these injuries.

Statistical Analysis

Data were analyzed by use of R Version 3.3.1.<sup>12</sup> Actual/unweighted case counts were used for rate calculations of injuries sustained by boys' high school soccer, wrestling, football, ice hockey, and lacrosse athletes. Overall injury rates were calculated as the ratio of sports-related injuries per 1000 AEs. Similarly, severe injury rates were calculated as the ratio of severe injuries per 1000 AEs. RRs were calculated to compare differences in the rate of injuries sustained in competition versus practice, and comparisons of severe injuries sustained in competition versus practice were calculated in a similar fashion. An example of the RR calculation comparing severe wrestling injuries sustained in competition compared with severe wrestling injuries sustained in practice is demonstrated below:

$$RR = \frac{\left( \frac{\text{No. of severe wrestling injuries sustained in competition}}{\text{No. of wrestling competition AEs}} \right)}{\left( \frac{\text{No. of severe wrestling injuries sustained in practice}}{\text{No. of wrestling practice AEs}} \right)}$$

Prevalence of injury site, diagnosis, and time lost due to injury were reported for each sport and stratified by those injuries sustained during practice versus competition and between severe versus not severe injuries. These were calculated by dividing the relevant site, diagnosis, or severity by the total injuries for that sport.

Injury sites reported in the High School RIO surveillance system were combined as follows: knee, ankle, shoulder (including clavicle), hand (including wrist and finger), head/face (including eye, ear, nose, mouth, teeth, mouth/teeth), hip/leg (including lower leg, upper leg), foot/toe, arm (including upper arm and lower arm), spine (including neck/cervical spine, chest/thoracic spine, lumbar spine, and pelvis), and other (abdominal, genitalia). Injury diagnosis categories were combined as follows: fracture (including avulsion fracture), ligament sprain with surgery, ligament sprain without surgery (including separation), dislocation (including hyperextension and subluxation), concussion, contusion, muscle/tendon (including muscle strain, tendinitis, tendon strain), bone stress injury (including stress fracture, shin splints, spondylolysis, apophysitis), and other (bursitis, laceration, nerve injury, plantar fasciitis, other). Categories were combined with regard to similarities between sites or diagnoses with regard to typical mechanism of injury or injury process; this facilitated analysis. Additionally, risk of sustaining a concussion between each sport was calculated through use of 2-way risk ratios by comparing injury rates. We chose not to include concussions that were reported as having a duration less than 1 day (n = 52; 1.2% of total concussion).

RESULTS

During the 2008-2009 through 2012-2013 school years, 20,551 injuries were sustained in boys' soccer, lacrosse, wrestling, football, and ice hockey during 6,941,583 AEs, for a

TABLE 1  
Incidence and Rate of Injuries Sustained in Boys' High School Football, Soccer, Wrestling, Ice Hockey, and Lacrosse by Type of Exposure<sup>a</sup>

Sport	No. of Injuries	No. of AEs	Rate/1000 AEs	Rate Ratio (95% CI) <sup>b</sup>
Football				
Competition	7311	590,327	12.38	5.74 (5.55-5.93)
Practice	6343	2,938,463	2.16	
Total	13,654	3,528,790	3.87	
Soccer				
Competition	1443	406,788	3.55	4.03 (3.70-4.39)
Practice	839	953,517	0.88	
Total	2282	1,360,305	1.68	
Wrestling				
Competition	1107	318,415	3.48	1.90 (1.76-2.06)
Practice	1630	892,988	1.83	
Total	2737	1,211,403	2.26	
Ice hockey				
Competition	569	101,725	5.59	7.78 (6.51-9.31)
Practice	151	210,092	0.72	
Total	720	311,817	2.31	
Lacrosse				
Competition	706	163,878	4.31	3.48 (3.10-3.92)
Practice	452	365,390	1.24	
Total	1158	529,268	2.19	
All sports				
Competition	11,136	1,581,133	7.04	4.01 (3.90-4.12)
Practice	9415	5,360,450	1.76	
Total	20,551	6,941,583	2.96	

<sup>a</sup>AE, athlete-exposure.

<sup>b</sup>Practice is the referent group. All rate ratios were significant (P < .001).

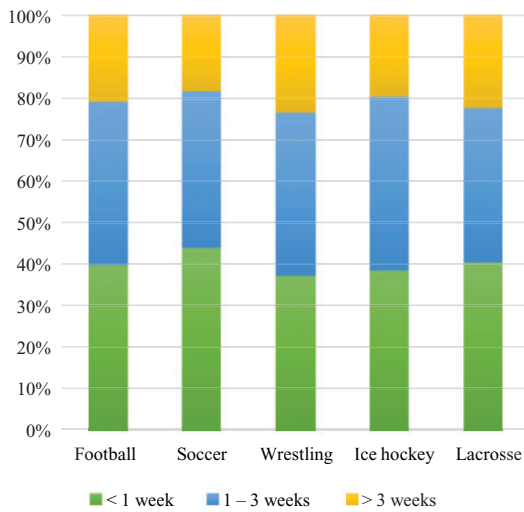
rate of 2.96 injuries per 1000 AEs (Table 1). Football players experienced the highest injury rate overall (3.87/1000 AEs), in competition (12.38/1000 AEs), and in practice (2.16/1000 AEs). We found that overall, 54% of injuries occurred during competition and 46% during practice. The risk of sustaining an injury was higher in competition overall (RR, 4.01; 95% CI, 3.90-4.12). This trend was true for football (RR, 5.74; 95% CI, 5.55-5.93), lacrosse (RR, 3.48; 95% CI, 3.10-3.92), soccer (RR, 4.03; 95% CI, 3.70-4.39), wrestling (RR, 1.90; 95% CI, 1.76-2.06), and ice hockey (RR, 7.78; 95% CI, 6.51-9.31).

Time Loss

The largest proportion of injured athletes in football (39.8%), soccer (44.1%), and lacrosse (40.5%) returned to activity within 1 week of sustaining an injury (Figure 1). Injuries in wrestling and ice hockey players followed a slightly different distribution, with the highest proportion of injuries (39.3% and 42.0%, respectively) lasting for 1 to 3 weeks.

Patterns of Injury by Severity

There were 4286 severe injuries, 57.6% sustained in competition and 42.4% in practice, with an overall severe injury



**Figure 1.** Football, soccer, wrestling, ice hockey, and lacrosse time loss after an injury.

rate of 0.62 injuries per 1000 AEs (Table 2). Football players experienced the highest severe injury rate overall (0.80/1000 AEs), in practice (0.42/1000 AEs), and in competition (2.72/1000 AEs). The risk of sustaining a severe injury was higher in competition overall (RR, 4.61; 95% CI, 4.34-4.90). This trend was true for football (RR, 6.48; 95% CI, 6.02-6.98), ice hockey (RR, 16.0; 95% CI, 9.51-26.9), lacrosse (RR, 4.02; 95% CI, 3.12-5.19), wrestling (RR, 2.17; 95% CI, 1.86-2.54), and soccer (RR, 5.97; 95% CI, 4.82-7.39).

**Patterns of Injury by Body Site**

Overall, the most commonly injured body site was the head/face (22.5%) (Table 3). This was true for football (22.0%), wrestling (22.5%), lacrosse (25.2%), and ice hockey (32.2%). In soccer, the most commonly injured body site was the hip/leg (25.3%). Overall, the body site most often injured severely was the knee (24.6%). This was true for football (26.6%), soccer (26.1%), lacrosse (23.3%), and wrestling (18.2%). The shoulder/clavicle was the site most often injured severely in ice hockey (30.7%).

**Patterns of Injury by Diagnosis**

Overall, 23.5% of injuries were due to ligament sprain not requiring surgery, the most common injury diagnosis (Table 4). This was the most prevalent injury diagnosis in football (24.8%), soccer (22.6%), and wrestling (22.1%). Concussion accounted for the highest proportion of injuries in ice hockey (27.8%) and lacrosse (22.3%). Fracture or avulsion fracture was the most common severe injury diagnosis overall (37.0%) and in all sports individually (football, 36.1%; soccer, 40.5%; wrestling, 33.7%; ice hockey, 51.4%; and lacrosse, 41.5%).

**Concussions**

Concussions were the second most prevalent injury overall in this cohort and accounted for the second highest

**TABLE 2**  
Incidence and Rate of Severe Injuries Sustained in Boys' High School Football, Soccer, Wrestling, Ice Hockey, and Lacrosse by Type of Exposure<sup>a</sup>

Sport	No. of Injuries	No. of AEs	Rate/1000 AEs	Rate Ratio (95% CI) <sup>b</sup>
<b>Football</b>				
Competition	1603	590,327	2.72	6.48 (6.02-6.98)
Practice	1231	2,938,463	0.42	
Total	2834	3,528,790	0.80	
<b>Soccer</b>				
Competition	298	406,788	0.73	5.97 (4.82-7.39)
Practice	117	953,517	0.12	
Total	415	1,360,305	0.31	
<b>Wrestling</b>				
Competition	279	318,415	0.88	2.17 (1.86-2.54)
Practice	360	892,988	0.40	
Total	639	1,211,403	0.53	
<b>Ice hockey</b>				
Competition	124	101,725	1.22	16.0 (9.51-26.9)
Practice	16	210,092	0.08	
Total	140	311,817	0.45	
<b>Lacrosse</b>				
Competition	166	163,878	1.01	4.02 (3.12-5.19)
Practice	92	365,390	0.25	
Total	258	529,268	0.49	
<b>All Sports</b>				
Competition	2470	1,581,133	1.56	4.61 (4.34-4.90)
Practice	1816	5,360,450	0.34	
Total	4286	6,941,583	0.62	

<sup>a</sup>AE, athlete-exposure.

<sup>b</sup>Practice is the referent group. All rate ratios were significant ( $P < .001$ ).

percentage of severe injuries after fracture/avulsion fracture (Table 4). Football players had the highest risk of sustaining a concussion overall and a 27% higher risk than ice hockey players (RR, 1.27; 95% CI, 1.10-1.46) (Table 5). Lacrosse players had the third highest risk of sustaining a concussion, followed by wrestlers and soccer players. Football players had a nearly 3 times higher risk of sustaining a concussion than soccer athletes (RR, 2.98; 95% CI, 2.68-3.32), 2.27 times higher risk than wrestlers (95% CI, 2.05-2.51), and 67% higher risk than lacrosse players (RR, 1.67; 95% CI, 1.47-1.89).

**DISCUSSION**

This study compared injury patterns by time loss, severity, body site, and diagnosis among US high school boys' football, soccer, wrestling, ice hockey, and lacrosse athletes. Although this topic has been investigated by other groups, our study adds to the literature by virtue of reclassification of injury sites and diagnoses to better describe these patterns and the statistical method we used to directly compare concussion rates between sports.

Given the intense interest and efforts to reduce injury rates in these sports, comprehensive epidemiologic

TABLE 3  
Percentages of All Injury and Severe Injury Body Sites Sustained  
in Boys' High School Football, Soccer, Wrestling, Ice Hockey, and Lacrosse<sup>a</sup>

All Injuries	Football (n = 13,642)	Soccer (n = 2280)	Wrestling (n = 2730)	Ice Hockey (n = 720)	Lacrosse (n = 1155)	All Sports (n = 20,527)
Knee	15.2	13.6	14.8	8.8	12.1	14.6
Ankle	12.2	17.5	6.4	3.9	10.6	11.6
Shoulder/clavicle	11.9	3.5	16.3	20.0	10.8	11.8
Hand/wrist	10.4	4.9	8.2	8.3	7.9	9.3
Head/face	22.0	21.3	22.5	32.2	25.2	22.5
Hip/leg	12.3	25.3	5.8	11.4	17.4	13.1
Foot	2.7	7.4	1.9	1.4	3.3	3.1
Spine	7.7	4.3	11.7	8.2	7.4	7.9
Arm/elbow	3.8	1.4	9.4	4.7	2.8	4.2
Other	1.9	0.9	3.0	1.1	2.6	2.0
Severe Injuries	Football (n = 2833)	Soccer (n = 414)	Wrestling (n = 639)	Ice Hockey (n = 140)	Lacrosse (n = 258)	All Sports (n = 4284)
Knee	26.6	26.1	18.2	11.4	23.3	24.6
Ankle	7.7	10.6	3.4	0.7	3.9	6.9
Shoulder/clavicle	14.5	8.0	17.8	30.7	17.8	15.1
Hand/wrist	12.6	6.0	16.9	15.7	15.1	12.9
Head/face	14.8	15.5	16.0	20.0	20.2	15.5
Hip/leg	9.9	19.1	4.4	7.9	8.5	9.8
Foot	3.2	8.0	2.5	2.1	1.6	3.4
Spine	4.0	2.7	6.1	1.4	3.5	4.1
Arm/elbow	5.7	3.6	13.5	8.6	3.9	6.6
Other	1.1	0.5	1.3	1.4	2.3	1.1

<sup>a</sup>All values are reported as percentages.

investigations of injuries in boys' high school contact and collision sports such as in the current study are paramount in providing accurate estimates of the burden of these injuries. Our study found that injuries overall and severe injuries in particular are more likely to occur during competition compared with practice. This trend has been noted previously in several other studies<sup>1,4,7,13</sup>; however, our study used contemporaneous injury data to allow for direct comparisons between sports. Football and ice hockey players were far more likely to sustain injuries in competition compared with practice (football: RR, 5.74; ice hockey: RR, 7.78). Perhaps this is attributable to the inherent risks due to collision in sports, which coaches attempt to limit during practice in favor of conditioning and skill development. The rate of injuries sustained during competition could be further lowered with increased attention paid to stricter adherence to the rules and disincentivizing illegal contact through more severe penalties. The low ratio of injuries sustained in competition compared with practice in wrestling is a notable outlier in our results. Compared with the other sports, in wrestling, there was near parity of injuries sustained in practice and competition overall (RR, 1.90) and among severe injuries (RR, 2.17). The factors contributing to this are largely unstudied and represent an opportunity for the sport to reflect upon how it can be made safer for its athletes.

Severe injuries—those that necessitate more than 3 weeks of recovery—accounted for 18% to 23% of injuries

in the 5 contact or collision sports included in this analysis. Although severe injuries were a minority of total injuries, the morbidity associated with severe injuries warrants in-depth investigation. Football players experienced the highest rate of severe injury of all sports (0.80 severe injuries per 1000 AEs). Compared with injuries overall, severe injuries occurred at much higher rates in competition versus practice. This was especially true in ice hockey, where severe injuries occurred at a ratio of 16 times higher than in practice (95% CI, 9.51-26.9). However, this is largely due to the fact that the rate of severe injuries sustained in ice hockey practice is minuscule compared with most of the other sports (ice hockey, 0.08 severe injuries/1000 AEs; football, 0.42 severe injuries/1000 AEs; wrestling, 0.40 severe injuries/1000 AEs; lacrosse, 0.25 severe injuries/1000 AEs; soccer, 0.12 severe injuries/1000 AEs).

With regard to specific injury site and diagnoses, head and face injuries were the most commonly injured body site overall (22.5%), despite the universal use of helmets and facemasks in sports such as football, ice hockey, and lacrosse. Knee injuries were the most prevalent severe injury site (24.6%). These results are consistent with previously published work.<sup>1,4</sup> Our study adds to this body of knowledge in that our results are categorized in a more specific manner compared with previous work. For example, Darrow et al<sup>4</sup> and Bartley et al<sup>1</sup> described injuries sustained in contact and collision sports by injury site and diagnosis but included an "other" category that contained

TABLE 4  
Percentages of All Injury and Severe Injury Diagnoses Sustained  
in Boys' High School Football, Soccer, Wrestling, Ice Hockey, and Lacrosse<sup>a</sup>

All Injuries	Football (n = 13,620)	Soccer (n = 2277)	Wrestling (n = 2732)	Ice Hockey (n = 717)	Lacrosse (n = 1155)	All Sports (n = 20,501)
Fracture	11.0	11.1	9.8	12.7	11.8	11.0
Ligament sprain with surgery	2.6	2.2	1.2	0.4	2.9	2.3
Ligament sprain without surgery	24.8	22.6	22.1	16.0	17.3	23.5
Dislocation/hyperextension	6.4	2.9	7.7	5.9	2.8	6.0
Concussion	21.1	16.2	15.9	27.8	22.3	20.1
Torn cartilage	1.6	1.0	3.0	1.4	1.1	1.7
Contusion	12.0	14.7	6.3	17.6	14.6	11.9
Muscle/tendon	13.4	21.3	15.1	10.6	17.7	14.6
Bone stress	0.4	1.4	0.2	0.1	1.1	0.5
Medical	2.1	1.0	13.0	1.0	1.6	3.3
Other	4.7	5.6	5.7	6.6	6.8	5.1
Severe Injuries	Football (n = 2833)	Soccer (n = 415)	Wrestling (n = 638)	Ice Hockey (n = 140)	Lacrosse (n = 258)	All Sports (n = 4284)
Fracture	36.1	40.5	33.7	51.4	41.5	37.0
Ligament sprain with surgery	10.9	11.6	4.1	1.4	12.0	9.7
Ligament sprain without surgery	15.0	14.2	16.9	9.3	5.4	14.5
Dislocation/hyperextension	9.0	3.4	13.5	10.0	3.5	8.8
Concussion	14.4	11.3	15.2	17.9	17.8	14.6
Torn cartilage	4.2	4.1	5.8	3.6	3.5	4.3
Contusion	1.6	2.9	1.4	2.1	1.6	1.7
Muscle/tendon	3.1	5.5	4.9	0.0	6.2	3.7
Bone stress	0.9	3.6	0.3	0.7	1.9	1.1
Medical	1.0	0.2	0.9	1.4	1.9	1.0
Other	3.7	2.7	3.3	2.1	4.7	3.6

<sup>a</sup>All values are reported as percentages.

TABLE 5  
Two-Way Risk Ratio and 95% CI for Concussion Sustained  
in Boys' High School Football, Soccer, Wrestling, Ice Hockey, and Lacrosse<sup>a</sup>

	Football	Soccer	Wrestling	Ice Hockey	Lacrosse
Football	1				
Soccer	2.98 (2.68-3.32)	1			
Wrestling	2.27 (2.05-2.51)	0.76 (0.66-0.87)	1		
Ice hockey	1.27 (1.10-1.46)	0.43 (0.36-0.50)	0.56 (0.47-0.66)	1	
Lacrosse	1.67 (1.47-1.89)	0.56 (0.48-0.65)	0.73 (0.63-0.86)	1.31 (1.09-1.58)	1

<sup>a</sup>Sport in the left column is the referent group. Significance was set to  $P = .05$ .

more than 20% of the injuries. The large proportion of injuries classified as "other" limits meaningful conclusions a reader can draw from these studies, because in many cases this category was larger than any other. We initially attempted to classify injuries in our study to match the method described in previous work but found that our results were also limited by a large "other" category. We chose to reclassify many of the injuries in the "other" category based on similarities between sites and diagnoses and based on typical mechanism of injury or injury process. For example, elbow and forearm were combined with the arm category and subluxation was combined with dislocation. This produced more discrete, meaningful results.

The most commonly injured body site overall was the head/face. Concussions accounted for a high proportion of injuries in all 5 sports and was the most prevalent injury diagnosis in ice hockey and lacrosse. These proportions can be misleading, however, because they do not account for injury rates per AE. The concussion risk ratios presented in this study allowed us to directly compare the rate of concussion injury between sports, a method not previously performed in epidemiologic studies of this kind. We found that football players have higher risk of sustaining a concussion than lacrosse, wrestling, ice hockey, or soccer players.

Football specifically has been intensely scrutinized regarding the long-term implications of injury, which is in

part due to the number of athletes who participate in football in the United States. More than 1 million boys' high school athletes participated in football in the 2016-2017 season compared with 450,000 soccer players, 245,000 wrestlers, 112,000 lacrosse players, and 35,000 ice hockey players.<sup>9</sup> The large number of participants and the high rate of injury perhaps warrant the more recent and increasing scrutiny of the sport by the media, parents, and governing athletic bodies.

Epidemiologic studies like ours can help to guide policy and rule changes to make sports safer and maintain high levels of participation. For example, a rule limiting contact in high school football practices resulted in 42% fewer head impacts,<sup>2</sup> which could significantly reduce the number of head injuries. Similarly, studies like that performed by Yard and Comstock,<sup>17</sup> which found that kickoff and punt return football players were particularly vulnerable to severe injuries and concussion, helped to pave the way for rule changes intended to improve player safety. Indeed, changes to the Ivy League kickoff rule, intended to increase touchbacks and reduce kick returns, were associated with a reduction in the rate of concussions.<sup>15</sup> Notably, recognition of the concussion injury rate and associated morbidity among high school athletes led to concussion legislation in all 50 US states and better care for injured athletes. The rate of concussion during this era continues to increase, which is largely attributed to increased recognition and thus treatment of these injuries, which had been previously underrecognized and underreported.<sup>14,16</sup>

Ice hockey players had the second highest injury rate and risk of sustaining a concussion in the current study. Although far fewer athletes participate in ice hockey than the other contact and collision sports included in this study, identifying and acknowledging the high risk of injury create an opportunity to make the sport safer. A systematic review published in 2013 examined the effectiveness of interventions to reduce aggression and injuries among ice hockey players and found that rule changes were associated with reductions of both measures.<sup>3</sup> Similarly, another systematic review addressing strategies to reduce concussion in all sports found that strict enforcement of established rules was associated with reduction in risk of concussion.<sup>5</sup>

Aggression is inherent in contact and collision sports; indeed, it is what attracts many players and fans. However, injuries sustained because of overzealous physicality can manifest severe and long-lasting effects. The National Federation of State High School Associations advocates student participation in sport as a way to promote respect, healthy lifestyles, and safe competition.<sup>10</sup> The value of sports such as football and ice hockey does not lie in highlight reels of the biggest hits; instead, safe participation in these sports can enhance the lives of athletes through developing teamwork, leadership, accountability, and lifelong physical fitness. Balancing the risks and benefits of sport participation starts with understanding the magnitude of risk, which this study comprehensively presents.

## Limitations

Although this study followed the heavily replicated methods of other analyses using the High School RIO surveillance system, it is not without limitations. First, the data for the High School RIO surveillance system were collected by ATs associated with high schools. Therefore, these results may not be generalizable to high schools without athletic training staff, as there might not be similar oversight and expertise in triaging and treating injuries. Second, capturing injuries in this database relies on recognizing them. Athletes might fail to perceive or report injuries, as in the case of concussion, which means that injury rates in this study are likely underestimated. Limiting this analysis to injuries that resulted in at least 1 day of time loss limits the impact of underreporting, because injuries of this magnitude are difficult to ignore. Third, although AE is the accepted denominator in calculating injury rates for large epidemiologic studies such as ours, it is not as precise of a unit of time as hours and minutes. However, it would not be feasible to ask ATs to measure and record exposure time to this level of precision given the vast number of athletes and sports for which ATs are responsible.

In many cases, we made decisions to present our results in the same convention as other studies that used this dataset. As such, we did not include age of the subjects at the time of injury in our analysis, although this could be an interesting approach in the future. Also, the dataset did not describe the number of injuries that required surgery, with the exception of injuries to the knee. Therefore, we were unable to comment on the rates of surgery as an important endpoint for many severe injuries. As noted in the Methods section, we chose not to include 1.2% of concussions that resulted in time loss of less than 1 day. We believed this was consistent with our injury definition, although it likely contributed to an underestimate of the true risk of concussion. Although the contemporary standard of care for concussions requires that athletes be removed from play, evaluated by a health care professional, and undergo a return-to-play protocol that takes several days, these safety measures were not in place in all areas during data collection for this study. Despite these limitations, analyses using the High School RIO surveillance system provide some of the most comprehensive injury data in the high school population.

## CONCLUSION

This study describes patterns of injury by time loss, severity, body site, and diagnosis among US high school boys' football, ice hockey, lacrosse, wrestling, and soccer athletes. Football players sustained the highest injury rate and the highest severe injury rate overall and had the highest risk of sustaining a concussion among the sports included in the analysis. Head and face injuries, concussion in particular, were common in these contact and collision sports, although ligament sprains not requiring surgery accounted for one-fourth of all injuries. Understanding these patterns



can generate policy and rule changes to make sports safer and maintain high levels of participation.

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