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original research

The Epidemiology of Stress Fractures in Collegiate Student-Athletes, 2004–2005 Through 2013–2014 Academic Years

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Context: Stress fractures are injuries caused by cumulative, repetitive stress that leads to abnormal bone remodeling. Specific populations, including female athletes and endurance athletes, are at higher risk than the general athletic population. Whereas more than 460 000 individuals participate in collegiate athletics in the United States, no large study has been conducted to determine the incidence of stress fractures in collegiate athletes.

Objective: To assess the incidence of stress fractures in National Collegiate Athletic Association (NCAA) athletes and investigate rates and patterns overall and by sport.

Design: Descriptive epidemiology study.

Setting: National Collegiate Athletic Association institutions.

Patients or Other Participants: National Collegiate Athletic Association athletes.

Main Outcome Measure(s): Data were analyzed from the NCAA Injury Surveillance Program for the academic years 2004–2005 through 2013–2014. We calculated rates and rate ratios (RRs) with 95% confidence intervals (CIs).

Results: A total of 671 stress fractures were reported over 11 778 145 athlete-exposures (AEs) for an overall injury rate of 5.70 per 100 000 AEs. The sports with the highest rates of stress fractures were women's cross-country (28.59/100 000 AEs), women's gymnastics (25.58/100 000 AEs), and women's outdoor track (22.26/100 000 AEs). Among sex-comparable sports (baseball/softball, basketball, cross-country, ice hockey, lacrosse, soccer, swimming and diving, tennis, indoor track, and outdoor track), stress fracture rates were higher in women (9.13/100 000 AEs) than in men (4.44/100 000 AEs; RR = 2.06; 95% CI = 1.71, 2.47). Overall, stress fracture rates for these NCAA athletes were higher in the preseason (7.30/100 000 AEs) than in the regular season (5.12/100 000 AEs; RR = 1.43; 95% CI = 1.22, 1.67). The metatarsals (n = 254, 37.9%), tibia (n = 147, 21.9%), and lower back/lumbar spine/pelvis (n = 81, 12.1%) were the most common locations of injury. Overall, 21.5% (n = 144) of stress fractures were recurrent injuries, and 20.7% (n = 139) were season-ending injuries.

Conclusions: Women experienced stress fractures at higher rates than men, more often in the preseason, and predominantly in the foot and lower leg. Researchers should continue to investigate biological and biomechanical risk factors for these injuries as well as prevention interventions.

Key Words: injury incidence, overuse injuries, bone remodeling

Key Points

- Stress fracture rates were highest among endurance sports and higher in female than in male collegiate athletes.
- Among female athletes, stress fracture rates were highest in basketball, cross-country, soccer, indoor track, and outdoor track.
- The rate of recurrent stress fracture was 21.5% and of season-ending injury was 20.7%.

Stress fractures, defined as microfractures of cortical bone tissue, affect thousands of athletes per year.[1–3] Certain subpopulations, including runners, gymnasts, and female athletes, are known to exhibit higher rates of stress fractures.[4–9]

These injuries affect a young athlete's health and sport participation in the short term and potentially also in the long term. They result from abnormal bone remodeling in the presence of repetitive stresses or impacts.[10,11] Bone remodeling is regulated through hormonal signals. A negative energy balance, caused by inadequate caloric intake relative to energy expenditure, can disrupt this process.[12,13] In the short term, stress fractures often require a minimum of several weeks of recovery[14] and may necessitate removal from sport participation. If left untreated, a stress fracture can progress to a complete fracture of a bone, which may require surgical fixation.[15] In addition, factors contributing to stress fractures increase the risk for osteoporosis,[16] a substantial long-term health concern.

Currently, more than 460 000 athletes participate in National Collegiate Athletic Association (NCAA) sports in the United States,[17] but limited stress fracture research has been conducted on this population. Much of our epidemiologic knowledge about stress fractures has been informed by research on military recruits[5,6] and high school athletes.[9] Studies involving collegiate athletes have been focused solely on endurance athletes, with results limited by cross-sectional designs and small sample sizes.[1,12,18,19] Therefore, the purpose of our study was to assess the incidence of stress fractures in NCAA athletes and investigate trends in specific subpopulations. By examining rates among athletes in 25 sports over a 10-year period, we sought to provide a more comprehensive understanding of the epidemiology of stress fractures to inform future research and prevention efforts.

METHODS

Data from the NCAA Injury Surveillance Program (NCAA-ISP) were analyzed. The methods of the NCAA-ISP during the 2004–2005 through 2013–2014 academic years have been described[20] and are briefly summarized here. The NCAA-ISP was initiated in 1982 as a paper-based data-collection system to obtain information from colleges on sport-related injuries in their athletes. Since 2004, data collection has been conducted via electronic medical records. Currently, information about the type of injury, location, activity during injury, and time missed due to injury is collected from athletes in 25 sports. The number of individual programs providing data varies by sport and year.

For our study, data from the 2004–2005 through 2013–2014 academic years were limited to injuries with a reported diagnosis of stress fracture. The study was approved by the Research Review Board of the NCAA.

Data Collection

Athletic trainers (ATs) voluntarily reported injuries and provided information on general illnesses, medical conditions, heat illnesses, and dermatologic conditions. Information provided for each injury included the type of injury, body part injured, and mechanism of injury. Time in season (preseason, regular season, or postseason) and number of participation days missed due to the injury were also noted. Throughout the season, ATs updated injury data, including when the student-athlete returned to full sport participation. Injuries that were recurrences of previous injuries were logged in the electronic medical record system. The ATs also collected exposure information by recording the number of student-athletes participating in each school-sanctioned practice and competition. Student-athlete participation during individual weight-training and conditioning sessions was not included in these analyses.

Data were deidentified and encrypted before being uploaded to the central aggregate database. Quality-control staff reviewed the data, and ATs were contacted and queried about invalid values. Verified data were included in the aggregate research dataset.

Operational Definitions

Injury. In this study, a reportable *injury* was defined as an injury that (1) occurred due to participation in a school-sanctioned practice or competition, (2) required attention from an AT or physician, (3) resulted in at least 24 hours of time missed from participation, and (4) had a reported diagnosis of stress fracture. *Season-ending injuries* (ie, injuries that resulted in the student-athlete prematurely ending his or her season) were noted. As did previous researchers,[9,21] we relied on the expertise of team medical staff to properly diagnose stress fractures. Whereas radiologic confirmation may have been used to aid or confirm diagnosis, the NCAA-ISP does not record data with that level of granularity.

Recurrence. The ATs identified recurrent injuries. We defined *recurrent injury* as a recurrence of the same injury sustained either earlier in the current academic year or in the previous academic year. As for the initial diagnosis, we relied on the expertise of the team medical staff to properly diagnose a stress fracture as recurrent.

Athlete-Exposure. A reportable *athlete-exposure* (AE) was defined in an earlier study[20] as "1 student-athlete participating in 1 NCAA-sanctioned practice or competition in which he or she was exposed to the possibility of athletic injury, regardless of the time associated with that participation." Only athletes with actual playing time in a competition, including warm-ups, were included in competition exposures.[20]

Location. The ATs identified the area where the stress fracture occurred. *Location* was categorized for analysis as lower back/lumbar spine/pelvis; femur; tibia; navicular; metatarsal; and other, including the upper limb, ankle, calcaneus, cuboid, cuneiform, and sesamoid.

Time in Season. We defined *time in season* as the specific season segment (ie, preseason, regular season, or postseason) in which the injury was reported to have occurred.

Participation-Restriction Time. Injuries were categorized by the number of days of participation restriction, which was calculated by subtracting the date of injury from the date of return. *Participation-restriction time* was categorized as 1 to 6 days; 7 to 21 days; more than 21 days; or season ending, which described a student-athlete prematurely ending the season for medical or nonmedical reasons associated with the injury or medical professionals requiring the student-athlete to prematurely end the season.[20]

Statistical Analysis

Data were analyzed to assess the rate and distribution of stress fractures sustained during collegiate sport participation during the 2004–2005 through 2013–2014 academic years. Stress fracture injury rates were calculated overall and by season. Rate ratios (RRs) compared rates within sports and seasons. They were also used to compare rates between the preseason and regular season; the postseason was excluded from analysis due to low numbers of stress fractures. They also compared rates among sex-comparable sports (baseball/softball, basketball, cross-country, ice hockey, lacrosse, soccer, swimming and diving, tennis, indoor track, and outdoor track). The following is an example of an RR comparing stress fracture rates in men and women:

$$\mathrm{RR} = \frac{\left(\frac{\sum \text{Stress fractures in men}}{\sum \text{Athlete-exposures in men}}\right)}{\left(\frac{\sum \text{Stress fractures in women}}{\sum \text{Athlete-exposures in women}}\right)}.$$

Distributions of injuries by body part, participation-restriction time, and recurrence were examined. For sex-comparable sports, injury proportion ratios (IPRs) were used to examine sex differences. The following is an example of an IPR comparing the proportion of stress fractures to the femur in men and women:

$$\mathrm{IPR} = \frac{\left(\frac{\sum \text{Stress fractures to the femur in men}}{\sum \text{Total stress fractures in men}}\right)}{\left(\frac{\sum \text{Stress fractures to the femur in women}}{\sum \text{Total stress fractures in women}}\right)}.$$

All 95% confidence intervals (CIs) that did not include 1.0 were considered different. Data were analyzed using SAS Enterprise Guide software (version 4.3; SAS Institute Inc, Cary, NC).

RESULTS

Overall

During the 2004–2005 through 2013–2004 academic years, 671 stress fractures resulting in at least 24 hours of time missed from participation were reported during 11 778 145 AEs, for an overall rate of 5.70/100 000 AEs (95% CI = 5.27, 6.13; Table 1). The sports with the highest rates were women's cross-country (28.59/100 000 AEs), women's gymnastics (25.58/100 000 AEs), and women's outdoor track (22.26/100 000 AEs). The men's sport with the highest stress fracture rate was cross-country (16.14/100 000 AEs). Among sex-comparable sports, the stress fracture rate was higher in women than in men for basketball, cross-country, soccer, indoor track, and outdoor track, as well as total sex-comparable sports (9.13/100 000 AEs versus 4.44/100 000 AEs, respectively; RR = 2.06; 95% CI = 1.71, 2.47).

Location

The most common stress fracture locations were the metatarsals (n = 254, 37.9%), tibia (n = 147, 21.9%), and lower back/lumbar spine/pelvis (n = 81, 12.1%; Table 2). Among sex-comparable sports, the proportion of stress fractures occurring in the lower back/lumbar spine/pelvis was higher in men (n = 23, 12.8%) than in women (n = 22, 6.9%; IPR = 1.85; 95% CI = 1.06, 3.23). In contrast, the proportion of stress fractures occurring in the femur was higher in women (n = 39, 12.2%) than in men (n = 8, 4.4%; IPR = 2.75; 95% CI = 1.31, 5.76).

Time in Season

Most stress fractures occurred during the regular season (n = 400, 59.6%; Table 3). However, the rate of stress fracture was higher in the preseason (7.30/100 000 AEs) than in the regular season (5.12/100 000 AEs; RR = 1.43; 95% CI = 1.22, 1.67). Individual sports that had higher stress fracture rates in the preseason than in the regular season were football (RR = 1.92; 95% CI = 1.28, 2.89) and men's outdoor track (RR = 5.16; 95% CI = 1.51, 17.61). The metatarsals were the most common location of stress fractures regardless of time in season (preseason = 38.3% [n = 92]; regular season = 38.3% [n = 153]; postseason = 29.0% [n = 9]).

Participation-Restriction Time

Overall, 8.8% (n = 59) of stress fractures resulted in participation-restriction time of 1 to 6 days; 19.2% (n = 129), 7 to 21 days; 46.8% (n = 314), more than 21 days; and 20.7% (n = 139) of stress fractures were season ending (Figure 1). The sports with the largest proportion of stress fractures that were season-ending injuries were men's outdoor track (n = 6, 46.2%), women's cross-country (n = 15, 37.5%), men's lacrosse (n = 6, 37.5%), women's outdoor track (n = 14, 36.8%), and women's lacrosse (n = 8, 36.4%). Among sex-comparable sports, the proportion of stress fractures that were season-ending injuries did not differ between men (n = 29, 16.1%) and women (n = 64, 20.1%; IPR = 0.80; 95% CI = 0.54, 1.20). Most season-ending stress fractures affected the metatarsals (n = 36, 25.9%), tibia (n = 25, 18.0%), and lower back/lumbar spine/pelvis (n = 23, 16.5%).

Recurrence

Almost one-quarter of stress fractures were recurrent (n = 144, 21.5%; Figure 2). The sports with the highest proportion of recurrent stress fractures were women's field hockey (n = 4, 36.4%), women's gymnastics (n = 9, 34.6%), men's football (n = 26, 27.7%), and women's outdoor track (n = 10, 26.3%). Among sex-comparable sports, the proportion of stress fractures that were recurrent did not differ between men (n = 31, 17.2%) and women (n = 64, 20.1%; IPR = 0.86; 95% CI = 0.58, 1.27). The locations with the largest proportion of stress fractures that were recurrent were the metatarsals (n = 42, 29.2%), lower back/lumbar spine/pelvis (n = 32, 22.2%), and tibia (n = 28, 19.4%).

DISCUSSION

In our study of 25 NCAA sports, we found that stress fractures affected athletes across a wide range of sports and, as reported by Nattiv et al,[14] caused athletes to miss weeks of participation in their sports. The severity of these stress fractures indicates a burden to the athletes, as well as a challenge to the sports medicine professionals who treat them.

Overall, the stress fracture rates among the collegiate athletes in our study were higher than recent epidemiologic data on stress fractures among high school athletes from High School Reporting Information Online (RIO),[9] with 5.70 versus 1.54 per 100 000 AEs, respectively, and for all sports included in both the NCAA-ISP[20] and High School RIO except men's swimming and diving, in which only 1 stress fracture was reported in both studies. Such findings may indicate that collegiate athletes are at greater risk of stress fracture than high school athletes. This may be due to higher training-intensity levels in collegiate participation, as Roos et al[21] suggested in an

Table 1. **Stress Fracture Counts and Rates per 100 000 Athlete-Exposures in 25 National Collegiate Athletic Association Sports, 2004–2005 Through 2013–2014**

Sport	Count	Athlete-Exposures[a]	Injury Rate per 100 000 Athlete-Exposures (95% CI)	Rate Ratio (95% CI) Comparing Sex-Comparable Sports[b]
Men's football	94	3 121 476	3.01 (2.40, 3.62)	Not computed
Men's wrestling	7	257 297	2.72 (0.71, 4.74)	Not computed
Women's field hockey	11	185 984	5.91 (2.42, 9.41)	Not computed
Women's gymnastics	26	101 636	25.58 (15.75, 35.41)	Not computed
Women's volleyball	34	563 845	6.03 (4.00, 8.06)	Not computed
Baseball/softball				
Men	14	804 737	1.74 (0.83, 2.65)	1.00
Women	15	579 553	2.59 (1.28, 3.90)	1.49 (0.72, 3.08)
Basketball				
Men	72	868 631	8.29 (6.37, 10.20)	1.00
Women	110	783 600	14.04 (11.41, 16.66)	1.69 (1.26, 2.28)
Cross-country				
Men	22	136 289	16.14 (9.40, 22.89)	1.00
Women	40	139 918	28.59 (19.73, 37.45)	1.77 (1.05, 2.98)
Ice hockey				
Men	2	552 642	0.36 (0.00, 0.86)	Not computed
Women	1	232 051	0.43 (0.00, 1.28)	Not computed
Lacrosse				
Men	16	390 029	4.10 (2.09, 6.11)	1.00
Women	22	287 856	7.64 (4.45, 10.84)	1.86 (0.98, 3.55)
Soccer				
Men	30	686 918	4.37 (2.80, 5.93)	1.00
Women	57	772 048	7.38 (5.47, 9.30)	1.69 (1.09, 2.63)
Swimming and diving				
Men	1	172 960	0.58 (0.00, 1.71)	Not computed
Women	4	240 313	1.66 (0.03, 3.30)	Not computed
Tennis				
Men	1	66 224	1.51 (0.00, 4.47)	Not computed
Women	7	72 492	9.66 (2.50, 16.81)	Not computed
Indoor track				
Men	9	195 562	4.60 (1.60, 7.61)	1.00
Women	25	214 920	11.63 (7.07, 16.19)	2.53 (1.18, 5.42)
Outdoor track				
Men	13	180 466	7.20 (3.29, 11.12)	1.00
Women	38	170 699	22.26 (15.18, 29.34)	3.09 (1.65, 5.80)
Sports total[c]				
Men	180	4 054 457	4.44 (3.79, 5.09)	1.00
Women	319	3 493 450	9.13 (8.13, 10.13)	2.06 (1.71, 2.47)
Overall total	671	11 778 145	5.70 (5.27, 6.13)	Not computed

Abbreviation: CI, confidence interval.

[a] Defined as 1 student-athlete participating in 1 practice or 1 competition.

[b] Rate ratios were not computed for non–sex-comparable sports (men's football and wrestling and women's field hockey, gymnastics, and volleyball) or sex-comparable sports with stress fracture counts $<$10 (ie, ice hockey, swimming and diving, and tennis).

[c] Includes only sports in which both sexes participated (ie, baseball/softball, basketball, cross-country, ice hockey, lacrosse, soccer, swimming and diving, tennis, indoor track, and outdoor track).

examination of injuries resulting from overuse mechanisms. Further research should be conducted to determine whether the factors associated with additional years of cumulative training (eg, years of participation; level of participation; history of stress fractures, nonstress fractures, and other injuries; and training load) increase the incidence of stress fractures in collegiate athletes.

Sport Differences

We assessed stress fractures across athletes in 25 sports, whereas the authors[1,12,18,19] of most studies at the collegiate level primarily assessed endurance athletes. Consistent with the previous literature,[4–9] we found the highest rates of stress fractures in gymnastics, cross-country, and track athletes. This is thought to be due to the nature of training

Table 2. Stress Fracture Counts and Distributions by Location in 25 National Collegiate Athletic Association Sports, 2004–2005 Through 2013–2014

Sports	Area Injured, n (%)[a]							
	Lower Back/ Lumbar Spine/Pelvis	Femur	Tibia	Fibula	Navicular	Metatarsal	Other[b]	Total
Men's football	20 (21.3)	2 (2.1)	8 (8.5)	7 (7.4)	3 (3.2)	50 (53.2)	4 (4.3)	94 (100.0)
Men's wrestling	6 (85.7)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (14.3)	7 (100.0)
Women's gymnastics	4 (15.4)	0 (0.0)	2 (7.7)	7 (26.9)	3 (11.5)	7 (26.9)	3 (11.5)	26 (100.0)
Women's volleyball	5 (14.7)	0 (0.0)	7 (20.6)	6 (17.6)	0 (0.0)	13 (38.2)	3 (8.8)	34 (100.0)
Baseball/softball								
Men	5 (35.7)	0 (0.0)	5 (35.7)	2 (14.3)	0 (0.0)	1 (7.1)	1 (7.1)	14 (100.0)
Women	1 (6.7)	2 (13.3)	6 (40.0)	0 (0.0)	0 (0.0)	5 (33.3)	1 (6.7)	15 (100.0)
Basketball								
Men	6 (8.3)	2 (2.8)	9 (12.5)	6 (8.3)	3 (4.2)	43 (59.7)	3 (4.2)	72 (100.0)
Women	5 (4.5)	8 (7.3)	23 (20.9)	12 (10.9)	6 (5.5)	51 (46.4)	5 (4.5)	110 (100.0)
Cross-country								
Men	0 (0.0)	3 (13.6)	12 (54.5)	0 (0.0)	0 (0.0)	5 (22.7)	2 (9.1)	22 (100.0)
Women	2 (5.0)	10 (25.0)	13 (32.5)	2 (5.0)	2 (5.0)	9 (22.5)	2 (5.0)	40 (100.0)
Ice hockey								
Men	2 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	2 (100.0)
Women	1 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (100.0)
Lacrosse								
Men	5 (31.3)	0 (0.0)	4 (25.0)	2 (12.5)	0 (0.0)	5 (31.3)	0 (0.0)	16 (100.0)
Women	2 (9.1)	4 (18.2)	5 (22.7)	1 (4.5)	1 (4.5)	8 (36.4)	1 (4.5)	22 (100.0)
Soccer								
Men	4 (13.3)	2 (6.7)	5 (16.7)	3 (10.0)	2 (6.7)	13 (43.3)	1 (3.3)	30 (100.0)
Women	1 (1.8)	8 (14.0)	18 (31.6)	6 (10.5)	4 (7.0)	14 (24.6)	6 (10.5)	57 (100.0)
Swimming and diving								
Men	0 (0.0)	1 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (100.0)
Women	2 (50.0)	0 (0.0)	0 (0.0)	1 (25.0)	0 (0.0)	0 (0.0)	1 (25.0)	4 (100.0)
Tennis								
Men	0 (0.0)	0 (0.0)	1 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (100.0)
Women	2 (28.6)	0 (0.0)	1 (14.3)	0 (0.0)	0 (0.0)	4 (57.1)	0 (0.0)	7 (100.0)
Indoor track								
Men	0 (0.0)	0 (0.0)	3 (33.3)	0 (0.0)	0 (0.0)	3 (33.3)	3 (33.3)	9 (100.0)
Women	4 (16.0)	3 (12.0)	5 (20.0)	2 (8.0)	3 (12.0)	8 (32.0)	0 (0.0)	25 (100.0)
Outdoor track								
Men	1 (7.7)	0 (0.0)	3 (23.1)	2 (15.4)	4 (30.8)	3 (23.1)	0 (0.0)	13 (100.0)
Women	2 (5.3)	4 (10.5)	12 (31.6)	6 (15.8)	3 (7.9)	8 (21.1)	3 (7.9)	38 (100.0)
Sports total[c]								
Men	23 (12.8)	8 (4.4)	42 (23.3)	15 (8.3)	9 (5.0)	73 (40.6)	10 (5.6)	180 (100.0)
Women	22 (6.9)	39 (12.2)	83 (26.0)	30 (9.4)	19 (6.0)	107 (33.5)	19 (6.0)	319 (100.0)
Overall total	81 (12.1)	49 (7.3)	147 (21.9)	65 (9.7)	5 (5.2)	254 (37.9)	40 (6.0)	671 (100.0)

[a] Some percentages were rounded.
[b] Includes the arm (n = 1), ankle (n = 10), calcaneus (n = 11), cuboid (n = 6), cuneiform (n = 7), and sesamoid (n = 5).
[c] Includes only sports in which both sexes participated (ie, baseball/softball, basketball, cross-country, ice hockey, lacrosse, soccer, swimming and diving, tennis, indoor track, and outdoor track).

for these sports, which exposes the athlete's lower extremities to high loads of repetitive impact.[22] Cross-training regimens, such as strength and resistance training, have been found to protect against overtraining injuries and improve performance in endurance athletes.[23–25] Such regimens should be investigated further for their potential to reduce stress fractures in collegiate endurance athletes and other collegiate athletes, such as gymnasts, whose sport training is also repetitive.

Sex Differences

Our results also supported previous findings[4–7,9,21] that stress fractures occurred at higher rates in female than in male athletes. An important addition to the existing body of knowledge is our observation that female athletes across all sex-comparable sports experienced stress fractures at higher rates than their male counterparts. Traditionally, much of the attention has been focused on female endurance athletes, but our results indicated that female

Table 3. Stress Fracture Counts and Rates per 100 000 Athlete-Exposures by Time in Season in 25 National Collegiate Athletic Association Sports, 2004–2005 Through 2013–2014

	Preseason		Regular Season		Postseason		
Sport	Count	Injury Rate per 100 000 Athlete-Exposures[a] (95% CI)	Count	Injury Rate per 100 000 Athlete-Exposures[a] (95% CI)	Count	Injury Rate per 100 000 Athlete-Exposures[a] (95% CI)	Preseason Versus Regular Season Rate Ratio (95% CI)[b]
Men's football	45	4.52 (3.20, 5.84)	47	2.35 (1.68, 3.03)	2	1.57 (0.00, 3.74)	1.92 (1.28, 2.89)
Men's wrestling	5	6.84 (0.84, 12.84)	2	1.22 (0.00, 2.90)	0	0.00	Not computed
Women's gymnastics	12	22.91 (9.95, 35.87)	10	24.57 (9.34, 39.8)	4	46.75 (0.94, 92.57)	0.93 (0.40, 2.16)
Women's volleyball	5	3.41 (0.42, 6.41)	27	6.88 (4.29, 9.48)	2	7.95 (0.00, 18.97)	0.50 (0.19, 1.29)
Baseball/softball							
Men	6	2.33 (0.47, 4.20)	8	1.55 (0.48, 2.63)	0	0.00	1.50 (0.52, 4.33)
Women	3	1.50 (0.00, 3.21)	12	2.50 (1.09, 3.92)	0	0.00	0.72 (0.20, 2.57)
Basketball							
Men	24	11.55 (6.93, 16.16)	47	7.58 (5.41, 9.74)	1	2.48 (0.00, 7.34)	1.52 (0.93, 2.49)
Women	33	18.01 (11.86, 24.15)	74	13.15 (10.16, 16.15)	3	7.94 (0.00, 16.92)	1.37 (0.91, 2.06)
Cross-country							
Men	5	17.12 (2.11, 32.13)	14	16.58 (7.90, 25.27)	3	13.24 (0.00, 28.22)	1.03 (0.37, 2.87)
Women	4	13.99 (0.28, 27.71)	28	31.79 (20.02, 43.57)	8	34.39 (10.56, 58.21)	0.44 (0.15, 1.25)
Ice hockey							
Men	1	1.57 (0.00, 4.64)	1	0.22 (0.00, 0.66)	0	0.00	Not computed
Women	0	0.00	1	0.54 (0.00, 1.60)	0	0.00	Not computed
Lacrosse							
Men	8	6.24 (1.92, 10.57)	8	3.41 (1.05, 5.77)	0	0.00	1.83 (0.69, 4.88)
Women	9	9.47 (3.28, 15.65)	13	7.56 (3.45, 11.67)	0	0.00	1.25 (0.54, 2.93)
Soccer							
Men	11	5.86 (2.40, 9.33)	17	3.77 (1.98, 5.56)	2	4.14 (0.00, 9.87)	1.56 (0.73, 3.32)
Women	23	13.68 (8.09, 19.27)	31	7.13 (4.62, 9.64)	3	9.79 (0.00, 20.88)	1.60 (0.93, 2.74)
Swimming and diving							
Men	1	2.39 (0.00, 7.07)	0	0.00	0	0.00	Not computed
Women	1	1.69 (0.00, 5.00)	3	1.89 (0.00, 4.04)	0	0.00	Not computed
Tennis							
Men	0	0.00	1	2.09 (0.00, 6.18)	0	0.00	Not computed
Women	1	7.66 (0.00, 22.68)	6	11.10 (2.22, 19.99)	0	0.00	Not computed
Indoor track							
Men	4	4.62 (0.09, 9.15)	5	5.07 (0.63, 9.52)	0	0.00	Not computed
Women	13	13.87 (6.33, 21.42)	12	11.07 (4.81, 17.33)	0	0.00	1.25 (0.57, 2.75)
Outdoor track							
Men	7	16.62 (4.31, 28.93)	4	3.22 (0.06, 6.38)	2	14.00 (0.00, 33.40)	5.16 (1.51, 17.61)
Women	15	37.09 (18.32, 55.86)	22	19.41 (11.30, 27.52)	1	5.91 (0.00, 17.51)	1.91 (0.99, 3.68)
Sports total[c]							
Men	67	6.34 (4.82, 7.85)	105	3.83 (3.10, 4.57)	8	3.09 (0.95, 5.23)	1.65 (1.22, 2.25)
Women	102	11.17 (9.00, 13.34)	202	8.57 (7.39, 9.76)	15	6.69 (3.31, 10.08)	1.30 (1.03, 1.65)
Total	240	7.30 (6.38, 8.23)	400	5.12 (4.62, 5.62)	31	4.57 (2.96, 6.18)	1.43 (1.22, 1.67)

Abbreviation: CI, confidence interval.
[a] Defined as 1 student-athlete participating in 1 practice or 1 competition.
[b] Rate ratios were not computed for sports with stress fracture counts <10 (ie, men's wrestling, ice hockey, swimming and diving, tennis, and indoor track and women's ice hockey, swimming and diving, and tennis).
[c] Includes only sports in which both sexes participated (ie, baseball/softball, basketball, cross-country, ice hockey, lacrosse, soccer, swimming and diving, tennis, indoor track, and outdoor track).

athletes, in general, should be considered at higher risk for stress fracture.

Stress fractures in female athletes have been associated with the *female athlete triad*,[2,5,26] which is defined as low energy availability (inadequate caloric intake relative to energy expenditure) leading to diversion of energy away from the hypothalamic-pituitary-gonadal axis in order to conserve energy for more vital processes. In women, this leads to menstrual abnormalities, including oligomenorrhea, and other neuroendocrine changes that occur in energy-restricted states and have deleterious effects on bone. Therefore, to understand sex differences related to stress fractures, further research into the female athlete triad is necessary.

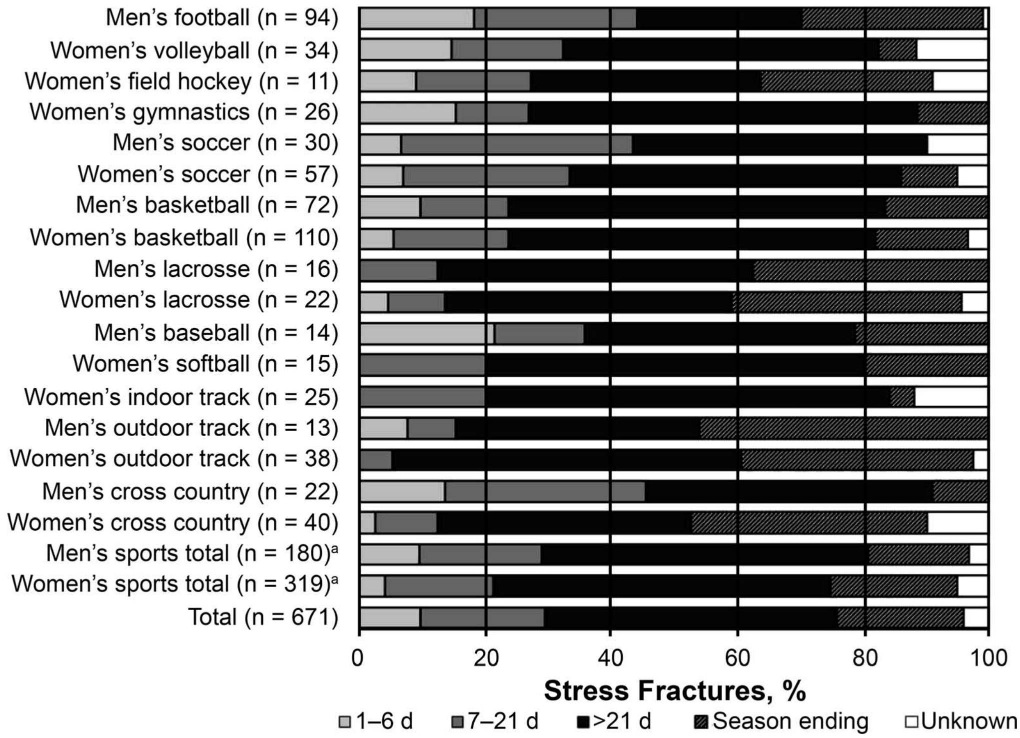

Figure 1. Participation-restriction time after stress fractures, by sport, in 25 National Collegiate Athletic Association sports, 2004–2005 through 2013–2014. Sports with stress fracture counts <10 were excluded from this figure (ie, men's wrestling, ice hockey, swimming and diving, tennis, and indoor track and women's ice hockey, swimming and diving, and tennis). [a] Includes only sports in which both sexes participated (ie, baseball/softball, basketball, cross-country, ice hockey, lacrosse, soccer, swimming and diving, tennis, indoor track, and outdoor track).

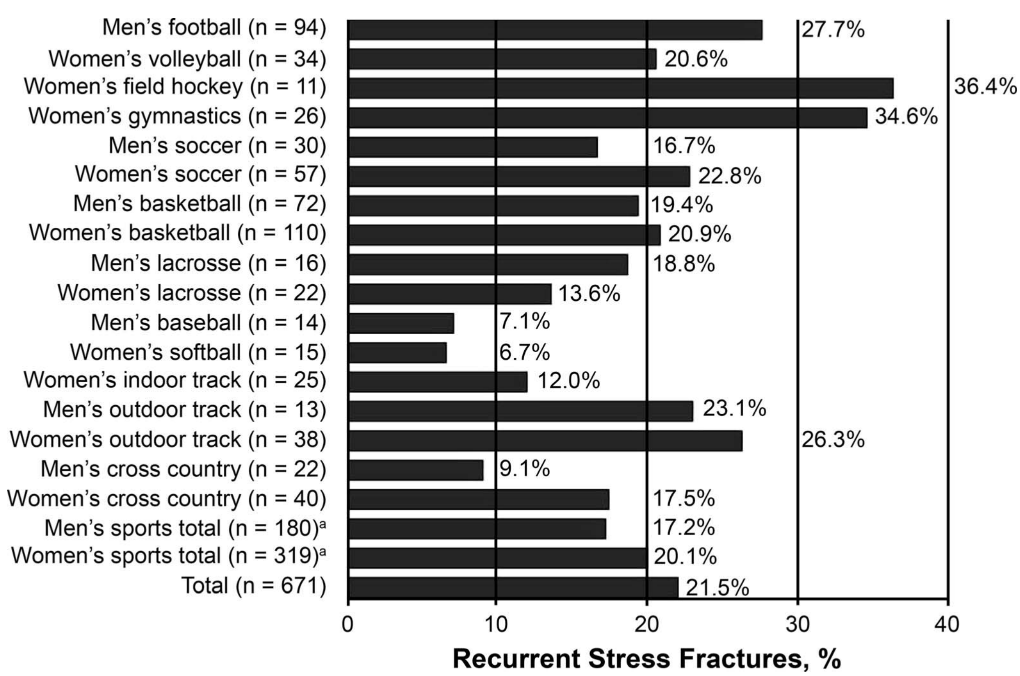

Figure 2. Proportion of stress fractures that were recurrent, by sport, in 25 National Collegiate Athletic Association sports, 2004–2005 through 2013–2014. Sports with stress fracture counts <10 were excluded from this figure (ie, men's wrestling and ice hockey and women's ice hockey, swimming and diving, tennis, and indoor track). [a] Includes only sports in which both sexes participated (ie, baseball/softball, basketball, cross-country, ice hockey, lacrosse, soccer, swimming and diving, tennis, indoor track, and outdoor track).

The risk may predate participation in collegiate athletics, especially in light of increasingly higher training loads imposed on young athletes in many sports.[3] During adolescence, boys develop long bones with greater diameter and cortical thickness than girls, possibly offering greater resistance to injury.[27] Female athletes have higher rates of low energy availability,[11] lower rates of bone-mass gains after menarche, and hormonal abnormalities that negatively affect bone remodeling.[27] Given that surveillance data typically do not examine risk factors, future cohort investigations focused on these known differences are warranted.

Despite the known higher incidence of stress fractures among females, recent screening protocols for the female athlete triad[28] and Relative Energy Deficiency in Sport[29] emphasize the need to better detect both male and female student-athletes at risk for stress fractures. Decreased energy availability places female and male athletes at risk,[30] possibly through similar mechanisms of hormonal dysregulation leading to abnormal bone turnover. Whereas the relationship between decreased energy availability and stress fractures in males is less well elucidated, one theory is that perhaps a lower energy availability threshold for negative bone effects exists for males versus females.[31] Therefore, we recommend that researchers examine risk factors for both male and female collegiate athletes.

Time in Season

Rates of stress fracture were greater in the preseason than in the regular season. Although researchers[32,33] have shown that overall sport-related injuries in collegiate athletes occur at higher rates in the preseason than in the regular season, few authors have examined how the incidence of stress fracture may differ by time of year. One exception is a study of 42 figure skaters, in which Pecina et al[34] reported similar numbers of stress fractures occurring in the preseason and regular season. Collegiate athletes preparing for competitions in the regular season are expected to participate in off-season and preseason conditioning exercises and drills. However, such preparation may be detrimental if student-athletes do not allow for sufficient recovery time between preseason workouts and the initiation of the regular season.[35] Our data did not include granularity of individuals' and teams' training loads in the off-season, so we cannot draw additional conclusions from our findings. Further study is needed to understand the effects of training regimen and recovery time on stress fracture risk.

Preparticipation examinations are used to screen athletes for a history of injuries, medical conditions, and risk factors for injury.[36] Screening for risk factors pertinent to stress fracture development via preparticipation examinations is lacking in either consistency[37,38] or effectiveness in detecting these factors.[39] Future efforts should focus on implementing uniform screening for collegiate athletes using validated methods to obtain information about an individual's risk.

Injury Location

The metatarsals and tibia were the most common locations for stress fractures in our study, consistent with previous research.[6,9,26] Sex differences were also noted, with larger proportions of stress fractures to the femur in women and the lower back/lumbar spine/pelvis in men. Given that the stress fracture counts were low for many sports with multiple positions played and the fact that AEs were not collected by position, we were unable to examine rate differences by position. Such research with larger samples would help to better identify specific risk factors associated with stress fractures in particular locations.

Recurrence and Season-Ending Injuries

Twenty-two percent of stress fractures were recurrent, and 20% resulted in season-ending injuries. The proportion of stress fractures that were recurrent was higher in sports involving greater, more repetitive impacts, such as gymnastics, and lower in sports that involve less running, such as baseball and softball. We observed no differences in recurrence of or season-ending stress fractures between male and female athletes. Given the long-term health implications and potentially dramatic effects on sport participation, our findings suggest the need for further examination of ways to mitigate the risk of both season-ending and recurrent stress fractures.

Limitations

Our study had limitations. The NCAA-ISP relies on the medical expertise and reporting consistency of ATs. This may be of particular concern when evaluating stress fractures, which are often diagnosed via imaging studies (eg, bone scan, magnetic resonance imaging). The NCAA-ISP does not require information about whether such imaging was performed, which studies were chosen, or the specific radiologic findings. Therefore, it is possible that cases were misclassified (eg, tendinitis misclassified as a stress fracture). Recurrent injuries could have been incompletely healed fractures, which is another source of misclassification.[40] The NCAA-ISP includes data reported by a convenience sample of collegiate sports programs; the findings may not be generalizable to nonparticipating programs or programs outside the NCAA (eg, junior colleges). A stress fracture is a cumulative injury that may not have an immediate and clear identification point of injury onset; therefore, time in season may have been misclassified (eg, injury onset was in the preseason, but the pain was not severe enough for a diagnosis of stress fracture until the regular season), and the participation-restriction time from injury may have been inaccurate.

CONCLUSIONS

We examined the epidemiology of stress fractures among collegiate athletes in 25 sports across 10 years. Our study is the most comprehensive evaluation of stress fractures in collegiate athletes to date. The rate of stress fracture was highest among endurance sports and higher in women than in men. Higher rates among female athletes were found not only in cross-country athletes, and indoor and outdoor track athletes but also in basketball and soccer athletes. Nearly 22% of stress fractures were recurrent, and 21% resulted in season-ending injuries. Therefore, whereas stress fractures may be less common than other sport-related injuries, the considerable effect they have on athletes' sport participation justifies the need for additional research regarding prevention.

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