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original research

Epidemiology of Quadriceps Strains in National Collegiate Athletic Association Athletes, 2009–2010 Through 2014–2015

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Context: Few researchers have examined the rates and patterns of quadriceps strains in student-athletes in the National Collegiate Athletic Association (NCAA).

Objective: To describe the epidemiology of quadriceps strains in 25 NCAA sports during the 2009–2010 through 2014–2015 academic years.

Design: Descriptive epidemiology study.

Setting: Convenience sample of NCAA programs from 25 sports during the 2009–2010 through 2014–2015 academic years.

Patients or Other Particpants: Collegiate student-athletes participating in men's and women's NCAA athletics during the 2009–2010 through 2014–2015 academic years.

Main Outcome Measure(s): Aggregate quadriceps strain injury and exposure data from the NCAA Injury Surveillance Program during the 2009–2010 through 2014–2015 academic years were analyzed. Quadriceps strain injury rates and injury rate ratios (IRRs) were reported with 95% confidence intervals (CIs).

Results: Overall, 517 quadriceps strains were reported, resulting in an injury rate of 1.07/10 000 athlete-exposures (AEs). The sports with the highest overall quadriceps strain rates were women's soccer (5.61/10 000 AEs), men's soccer (2.52/10 000 AEs), women's indoor track (2.24/10 000 AEs), and women's softball (2.15/10 000 AEs). Across sex-comparable sports, women had a higher rate of quadriceps strains than men overall (1.97 versus 0.65/10 000 AEs; IRR = 3.03; 95% CI = 2.45, 3.76). The majority of quadriceps strains were sustained during practice (77.8%). However, the quadriceps strain rate was higher during competition than during practice (1.29 versus 1.02/10 000 AEs; IRR = 1.27; 95% CI = 1.03, 1.56). Most quadriceps strains occurred in the preseason (57.8%), and rates were higher during the preseason compared with the regular season (2.29 versus 0.63/10 000 AEs; IRR = 3.60; 95% CI = 3.02, 4.30). Common injury mechanisms were noncontact (63.2%) and overuse (21.9%). Most quadriceps strains restricted participation by less than 1 week (79.3%).

Conclusions: Across 25 sports, higher quadriceps strain rates were found in women versus men, in competitions versus practices, and in the preseason versus the regular season. Most quadriceps strains were minor in severity, although further surveillance is needed to better examine the risk factors associated with incidence and severity.

Key Words: injury surveillance, injury prevention, collegiate sports

Key Points

- The highest rates of quadriceps strains were found in women's and men's soccer.
- Rates of quadriceps strains were higher in women versus men (in sex-comparable sports), in competitions versus practices, and in the preseason versus regular season.

Lower extremity muscle strains are common in athletes.[1–4] Players with strains incur significant participation-restriction time, as they often require extensive rehabilitation and are at high risk for reinjury.[5–8] The quadriceps muscle group, made up of 4 muscles in the anterior thigh, is at particular risk for strains in events that involve explosive movements and require forceful eccentric contractions to decelerate knee-flexion and hip-extension motions.[5,9–11] The rectus femoris is the most commonly strained quadriceps muscle, likely due to the fact that it is the sole biarticular muscle in the group, capable of both knee extension and hip flexion.[9] This role requires the rectus femoris to provide forceful eccentric contractions across both the hip and knee during rapid deceleration movements, increasing its vulnerability to strain.[9]

Few researchers have examined the rates and patterns of quadriceps strains in student-athletes in the National Collegiate Athletic Association (NCAA). The available data are almost exclusively from elite-level soccer players.[1,12] Furthermore, these data typically do not account for non–time-loss (NTL) injuries, that is, injuries resulting in participation-restriction time of less than 24 hours. The purpose of our study was to describe the epidemiology of quadriceps strains in 25 NCAA championship sports over 6 recent academic years (ie, 2009–2010 through 2014–2015).

METHODS

The NCAA Injury Surveillance Program (NCAA-ISP) is a prospective injury-surveillance program managed by the

Datalys Center for Sports Injury Research and Prevention, Inc (hereafter known as the Datalys Center), an independent, nonprofit research organization. Data used in this study originated from the 2009–2010 through 2014–2015 academic years. This study was approved by the Research Review Board of the NCAA. The methods of the NCAA-ISP during the 2009–2010 through 2014–2015 academic years have been previously described[13] but are briefly summarized here.

Data Collection

The NCAA-ISP used a convenience sample of NCAA varsity teams from 25 sports with athletic trainers (ATs) reporting injury data. These 25 sports were men's football; men's wrestling; women's field hockey; women's gymnastics; women's volleyball; men's baseball; women's softball; and men's and women's basketball, cross-country, ice hockey, lacrosse, soccer, swimming and diving, tennis, indoor track, and outdoor track. The number of programs providing data varied by sport and year.[13]

The ATs who worked with these participating teams attended school-sanctioned events (ie, practices [including team conditioning sessions] and competitions) and logged the number of student-athletes participating in each event. Injuries were reported in real time through the electronic health record application used by the team medical staff throughout the academic year. This allowed ATs to document injuries normally as part of their daily clinical practice, as opposed to having to separately report injuries for the ISP. Data were from varsity-level practices and competitions. Individual weight-lifting and conditioning sessions were excluded.

The ATs completed detailed event reports on each injury or condition. After initially entering injury data, the ATs could return to view and update the data as needed over the course of a season, such as when the student-athlete returned to sport participation or a diagnosis was differentiated through imaging or other procedures. Deidentified common data elements were extracted from the certified electronic health record applications.[13] Exported data passed through an automated verification process that involved a series of range and consistency checks. Data that passed the verification process were then placed into the aggregate research dataset.

Definitions

Injury. A reportable *injury* occurred as a result of participation in an NCAA-sanctioned practice or competition and required attention from an AT or physician. All injuries reported as *quadriceps strains* were included. No specific definition for quadriceps strain was provided aside from the general injury definition. Instead, we relied on the training and expertise of the ATs collecting data, as well as the other members of the team medical staff with whom they work, to accurately identify and diagnose all athletes. Quadriceps contusions were excluded from this study as they are a separate reportable diagnosis in the NCAA-ISP.

Athlete-Exposure. A reportable *athlete-exposure* (AE) was defined 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 student-athletes with actual playing time in a competition were included in competition exposures.

Event Type. *Event type* was the specific event (ie, practice [including team conditioning sessions], competition) in which the injury was reported to have occurred.

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

Injury Mechanism. *Injury mechanism* was defined as the manner in which the student-athlete sustained the injury. In the NCAA-ISP, ATs selected from a preset list of options: player contact, surface contact, equipment contact, contact with out-of-bounds object, noncontact, overuse, illness, infection, and other/unknown. Given the rarity or lack of quadriceps strains being due to contact with an out-of-bounds object, illness, or infection, these 3 mechanisms were grouped into the *other/unknown* category.

Recurrence. A *recurrent injury* was a recurrence of the same injury that was sustained either earlier in the current academic year or prior.

Participation-Restriction Time. Injuries were categorized by the number of days of participation restriction (ie, date of return minus the date of injury). The NTL injuries resulted in participation restriction of less than 24 hours. Severe injuries[14] resulted in participation restriction of more than 3 weeks, the student-athlete choosing to prematurely end the season (for medical or nonmedical reasons associated with the injury), or a medical professional requiring the student-athlete to prematurely end the season.

Statistical Analysis

Data were analyzed to assess rates and patterns of quadriceps strains sustained during collegiate sports. We first calculated *quadriceps strain rates*, defined as the number of injuries divided by the number of AEs. The rates are reported per 10 000 AEs overall (ie, competitions and practices combined) and within competitions and practices separately. We then examined the distributions of injuries by injury mechanism, recurrence, and participation-restriction time (eg, NTL, severe). Injury rate ratios (IRRs) compared rates within sports by event type (ie, competition or practice) and time in season (ie, preseason versus regular season). Due to the low counts, time-in-season analyses did not include the postseason. The IRRs also compared overall rates by sex among sex-comparable sports (ie, baseball/softball, basketball, cross-country, ice hockey, lacrosse, soccer, swimming and diving, tennis, indoor track, and outdoor track). We also used injury proportion ratios (IPRs) to examine sex differences in distributions of injury mechanism, recurrence, and participation-restriction time.

The following is an example of an IRR comparing competition and practice quadriceps strain rates:

$$\mathrm{IRR} = \frac{\left(\frac{\sum \text{competition quadriceps strains}}{\sum \text{competition athlete-exposures}}\right)}{\left(\frac{\sum \text{practice quadriceps strains}}{\sum \text{practice athlete-exposures}}\right)}$$

Table 1. Quadriceps Strain Counts and Rates Among Student-Athletes in 25 Sports by Event Type, National Collegiate Athletic Association Injury Surveillance Program, 2009–2010 Through 2014–2015 Academic Years

Sport	Quadriceps Strains in Sample, No.			Rate per 10 000 Athlete-Exposures[a] (95% CI)			Competition Versus Practice Rate Ratio (95% CI)
	Competition	Practice	Overall	Competition	Practice	Overall	
Men's football	10	53	63	0.91 (0.35, 1.48)	0.52 (0.38, 0.66)	0.56 (0.42, 0.70)	1.75 (0.89, 3.43)
Men's wrestling	2	0	2	1.88 (0.00, 4.48)	0.00	0.20 (0.00, 0.48)	NA
Women's field hockey	1	6	7	0.88 (0.00, 2.60)	1.66 (0.33, 2.99)	1.47 (0.38, 2.57)	0.53 (0.06, 4.38)
Women's gymnastics	0	3	3	0.00	0.58 (0.00, 1.24)	0.53 (0.00, 1.13)	NA
Women's volleyball	3	25	28	0.53 (0.00, 1.12)	1.77 (1.07, 2.46)	1.41 (0.89, 1.93)	0.30 (0.09, 0.99)
Men's baseball	5	5	10	0.60 (0.07, 1.13)	0.35 (0.04, 0.67)	0.45 (0.17, 0.72)	1.69 (0.49, 5.84)
Women's softball	11	34	45	1.40 (0.57, 2.22)	2.60 (1.73, 3.48)	2.15 (1.52, 2.78)	0.54 (0.27, 1.06)
Men's basketball	4	9	13	0.65 (0.01, 1.29)	0.41 (0.14, 0.67)	0.45 (0.17, 0.72)	1.61 (0.50, 5.22)
Women's basketball	2	18	20	0.36 (0.00, 0.85)	0.98 (0.53, 1.43)	0.83 (0.47, 1.20)	0.36 (0.08, 1.56)
Men's cross-country	1	4	5	1.99 (0.00, 5.90)	0.76 (0.02, 1.50)	0.86 (0.11, 1.62)	2.64 (0.29, 23.58)
Women's cross-country	0	7	7	0.00	1.40 (0.36, 2.43)	1.28 (0.33, 2.23)	NA
Men's ice hockey	3	3	6	0.31 (0.00, 0.65)	0.10 (0.00, 0.21)	0.15 (0.03, 0.27)	3.11 (0.63, 15.43)
Women's ice hockey	3	2	5	0.76 (0.00, 1.62)	0.18 (0.00, 0.44)	0.34 (0.04, 0.63)	4.14 (0.69, 24.77)
Men's lacrosse	5	9	14	1.52 (0.19, 2.86)	0.54 (0.19, 0.89)	0.70 (0.33, 1.07)	2.82 (0.94, 8.41)
Women's lacrosse	7	12	19	2.58 (0.67, 4.49)	1.04 (0.45, 1.62)	1.33 (0.73, 1.93)	2.49 (0.98, 6.31)
Men's soccer	16	32	48	3.91 (1.99, 5.82)	2.14 (1.40, 2.88)	2.52 (1.80, 3.23)	1.83 (1.00, 3.33)
Women's soccer	27	123	150	4.18 (2.60, 5.75)	6.07 (4.99, 7.14)	5.61 (4.71, 6.51)	0.69 (0.45, 1.04)
Men's swimming and diving	0	0	0	0.00	0.00	0.00	NA
Women's swimming and diving	0	0	0	0.00	0.00	0.00	NA
Men's tennis	2	0	2	3.00 (0.00, 7.16)	0.00	0.63 (0.00, 1.50)	NA
Women's tennis	1	7	8	0.97 (0.00, 2.86)	1.99 (0.52, 3.47)	1.76 (0.54, 2.98)	0.48 (0.06, 3.94)
Men's indoor track	0	12	12	0.00	0.85 (0.37, 1.34)	0.77 (0.33, 1.21)	NA
Women's indoor track	5	30	35	3.64 (0.45, 6.82)	2.10 (1.35, 2.86)	2.24 (1.50, 2.98)	1.73 (0.67, 4.46)
Men's outdoor track	5	1	6	3.25 (0.40, 6.09)	0.11 (0.10, 0.33)	0.57 (0.11, 1.02)	29.45 (3.44, 252.10)
Women's outdoor track	2	7	9	1.31 (0.00, 3.13)	0.92 (0.24, 1.60)	0.98 (0.34, 1.63)	1.43 (0.30, 6.88)
Men's sports total[b]	41	75	116	1.11 (0.77, 1.45)	0.53 (0.41, 0.65)	0.65 (0.53, 0.77)	2.09 (1.43, 3.05)
Women's sports total[b]	58	240	298	1.79 (1.33, 2.25)	2.02 (1.77, 2.28)	1.97 (1.75, 2.19)	0.88 (0.66, 1.18)
Overall total	115	402	517	1.29 (1.06, 1.53)	1.02 (0.92, 1.12)	1.07 (0.98, 1.16)	1.27 (1.03, 1.56)

Abbreviations: CI, confidence interval; NA, not applicable.

[a] Athlete-exposure = 1 student-athlete participating in 1 practice or competition.

[b] Only includes 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 following is an example of an IPR comparing the proportions of severe quadriceps strains in men and women:

$$\text{IPR} = \frac{\left(\frac{\sum \text{severe quadriceps strains in men}}{\sum \text{total quadriceps strains in men}}\right)}{\left(\frac{\sum \text{severe quadriceps strains in women}}{\sum \text{total quadriceps strains in women}}\right)}$$

All 95% confidence intervals (CIs) not including 1.00 were considered statistically significant. Data were analyzed using SAS-Enterprise Guide software (version 5.1; SAS Institute Inc, Cary, NC).

RESULTS

Overall Frequencies and Rates

Overall, 517 quadriceps strains were reported to the NCAA-ISP during the 2009–2010 through 2014–2015 academic years (Table 1). This represents an overall injury rate of 1.07/10 000 AEs. The sports with the highest overall quadriceps strain rates were women's soccer (5.61/10 000 AEs), men's soccer (2.52/10 000 AEs), women's indoor track (2.24/10 000 AEs), and women's softball (2.15/10 000 AEs). Across sex-comparable sports, women had a higher rate of quadriceps strains than men overall (1.97 versus 0.65/10 000 AEs; IRR = 3.03; 95% CI = 2.45, 3.76).

Event Type

The majority of quadriceps strains were sustained during practice (n = 402, 77.8%). However, the quadriceps strain rate was higher during competition (1.29 versus 1.02/10 000 AEs; IRR = 1.27; 95% CI = 1.03, 1.56; Table 1). In addition, only 1 of the 25 sports had a higher competition than practice rate: men's outdoor track (3.25 versus 0.11/10 000 AEs; IRR = 28.45; 95% CI = 3.44, 252.10), although the numbers of quadriceps strains within each event type were low (competition n = 5, practice n = 1).

Across sex-comparable sports, women had a higher rate of quadriceps strains than men in competition (1.79 versus 1.11/10 000 AEs; IRR = 1.61; 95% CI = 1.08, 2.41) and practice (2.02 versus 0.53/10 000 AEs; IRR = 3.81; 95% CI = 2.94, 4.94; Table 2). In addition, within specific pairs of sex-comparable sports, differences in overall rates were found in baseball/softball, soccer, and indoor track;

Table 2. Comparison of Quadriceps Strain Rates Among Student-Athletes by Sex and Event Type, National Collegiate Athletic Association Injury Surveillance Program, 2009–2010 Through 2014–2015 Academic Years

Sport	Rate Ratio, Women Versus Men (95% Confidence Interval)		
	Competition	Practice	Overall
Baseball/softball	2.33 (0.81, 6.70)	7.34 (2.87, 18.77)	4.82 (2.43, 9.57)
Basketball	0.54 (0.10, 2.98)	2.42 (1.09, 5.38)	1.82 (0.90, 3.65)
Lacrosse	1.69 (0.54, 5.33)	1.92 (0.81, 4.55)	1.89 (0.95, 3.77)
Soccer	1.07 (0.58, 1.98)	2.84 (1.92, 4.19)	2.23 (1.61, 3.08)
Indoor track	Not applicable	2.47 (1.26, 4.82)	2.90 (1.51, 5.59)
Total[a]	1.61 (1.08, 2.41)	3.81 (2.94, 4.94)	3.03 (2.45, 3.76)

[a] Only includes sports in which both sexes participated (ie, baseball/softball, basketball, cross-country, ice hockey, lacrosse, soccer, indoor track, and outdoor track). Specific analyses for cross-country, ice hockey, swimming and diving, tennis, and outdoor track were not included due to low sample counts (<10).

differences in practice rates were present in baseball/softball, basketball, soccer, and indoor track. No sex differences were found in competition rates.

Time in Season

Most quadriceps strains occurred during the preseason (n = 299, 57.8%; Table 3). Rates were higher during the preseason compared with the regular season (2.29 versus 0.63/10 000 AEs; IRR = 3.60; 95% CI = 3.02, 4.30). Of the 25 sports, 8 had higher preseason rates. The sports with the largest preseason versus regular season IRRs were women's volleyball (IRR = 14.01; 95% CI = 5.33, 36.86), women's soccer (IRR = 7.37; 95% CI = 5.16, 10.54), women's field hockey (IRR = 6.84; 95% CI = 1.33, 35.27), and men's basketball (IRR = 6.62; 95% CI = 1.99, 21.98).

Across sex-comparable sports, women had a higher rate of quadriceps strains than men in the preseason (4.46 versus 1.03/10 000 AEs; IRR = 4.32; 95% CI = 3.12, 5.99) and the regular season (1.08 versus 0.53/10 000 AEs; IRR = 2.04; 95% CI = 1.51, 2.77; Table 4). In addition, within specific pairs of sex-comparable sports, differences in regular-

Table 3. Quadriceps Strain Counts and Rates Among National Collegiate Athletic Association Student-Athletes in 25 Sports by Time in Season, National Collegiate Athletic Association Injury Surveillance Program, 2009–2010 Through 2014–2015 Academic Years

Sport	Quadriceps Strains in Sample, No.			Rate per 10 000 Athlete-Exposures[a] (95% CI)			Preseason Versus Regular Season Rate Ratio (95% CI)
	Preseason	Regular Season	Postseason	Preseason	Regular Season	Postseason	
Men's football	41	21	1	1.20 (0.83, 1.56)	0.29 (0.16, 0.41)	0.21 (0.00, 0.61)	4.17 (2.46, 7.06)
Men's wrestling	0	2	0	0.00	0.31 (0.00, 0.73)	0.00	NA
Women's field hockey	5	2	0	4.30 (0.53, 8.07)	0.63 (0.00, 1.50)	0.00	6.84 (1.33, 35.27)
Women's gymnastics	3	0	0	0.96 (0.00, 2.04)	0.00	0.00	NA
Women's volleyball	23	5	0	4.85 (2.87, 6.83)	0.35 (0.04, 0.65)	0.00	14.01 (5.33, 36.86)
Men's baseball	5	5	0	0.67 (0.08, 1.26)	0.35 (0.04, 0.66)	0.00	1.92 (0.55, 6.62)
Women's softball	29	16	0	4.34 (2.76, 5.92)	1.19 (0.61, 1.78)	0.00	3.64 (1.98, 6.70)
Men's basketball	8	4	1	1.28 (0.39, 2.16)	0.19 (0.00, 0.38)	0.76 (0.00, 2.25)	6.62 (1.99, 21.98)
Women's basketball	11	8	1	2.09 (0.85, 3.32)	0.46 (0.14, 0.77)	0.86 (0.00, 2.55)	4.57 (1.84, 11.37)
Men's cross-country	1	4	0	0.87 (0.00, 2.56)	0.98 (0.02, 1.93)	0.00	0.89 (0.10, 7.93)
Women's cross-country	3	4	0	2.68 (0.00, 5.71)	1.02 (0.02, 2.02)	0.00	2.63 (0.59, 11.76)
Men's ice hockey	0	6	0	0.00	0.18 (0.04, 0.32)	0.00	NA
Women's ice hockey	2	3	0	1.09 (0.00, 2.61)	0.25 (0.00, 0.52)	0.00	4.45 (0.74, 26.62)
Men's lacrosse	6	8	0	0.98 (0.20, 1.76)	0.65 (0.20, 1.10)	0.00	1.50 (0.52, 4.32)
Women's lacrosse	7	11	1	1.53 (0.40, 2.66)	1.25 (0.51, 2.00)	1.07 (0.00, 3.16)	1.22 (0.47, 3.14)
Men's soccer	18	26	4	3.89 (2.09, 5.69)	2.00 (1.23, 2.77)	2.71 (0.00, 5.36)	1.94 (1.06, 3.54)
Women's soccer	106	42	2	16.44 (13.31, 19.56)	2.23 (1.55, 2.90)	1.38 (0.00, 3.29)	7.37 (5.16, 10.54)
Men's swimming and diving	0	0	0	0.00	0.00	0.00	NA
Women's swimming and diving	0	0	0	0.00	0.00	0.00	NA
Men's tennis	0	2	0	0.00	0.88 (0.00, 2.09)	0.00	NA
Women's tennis	4	4	0	3.74 (0.07, 7.40)	1.24 (0.02, 2.45)	0.00	3.02 (0.75, 12.07)
Men's indoor track	7	5	0	0.91 (0.24, 1.58)	0.69 (0.09, 1.29)	0.00	1.32 (0.42, 4.15)
Women's indoor track	18	17	0	2.43 (1.31, 3.55)	2.19 (1.15, 3.24)	0.00	1.11 (0.57, 2.15)
Men's outdoor track	0	6	0	0.00	0.80 (0.16, 1.45)	0.00	NA
Women's outdoor track	2	6	1	0.84 (0.00, 1.99)	0.97 (0.19, 1.75)	1.76 (0.00, 5.22)	0.86 (0.17, 4.27)
Men's sports total[b]	45	66	5	1.03 (0.73, 1.33)	0.53 (0.40, 0.66)	0.47 (0.06, 0.88)	1.94 (1.33, 2.83)
Women's sports total[b]	182	111	5	4.46 (3.81, 5.10)	1.08 (0.88, 1.29)	0.62 (0.08, 1.17)	4.11 (3.25, 5.20)
Overall total	299	207	11	2.29 (2.03, 2.55)	0.63 (0.55, 0.72)	0.43 (0.18, 0.68)	3.60 (3.02, 4.30)

Abbreviation: CI, confidence interval; NA, not applicable.

[a] Athlete-exposure = 1 student-athlete participating in 1 practice or competition.

[b] Only includes 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).

Table 4. **Quadriceps Strain Rates Among National Collegiate Athletic Association Student-Athletes, by Sex and Time in Season, National Collegiate Athletic Association Injury Surveillance Program, 2009–2010 Through 2014–2015 Academic Years**

Sport	Rate Ratio, Women Versus Men (95% Confidence Interval)	
	Preseason	Regular Season
Baseball/softball	6.47 (2.50, 16.71)	3.41 (1.25, 9.30)
Basketball	1.63 (0.66, 4.06)	2.36 (0.71, 7.85)
Lacrosse	1.56 (0.53, 4.65)	1.92 (0.77, 4.78)
Soccer	4.22 (2.56, 6.96)	1.11 (0.68, 1.81)
Indoor track	2.67 (1.12, 6.40)	3.18 (1.17, 8.62)
Total[a]	4.32 (3.12, 5.99)	2.04 (1.51, 2.77)

[a] Only includes 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). Specific analyses for cross-country, ice hockey, swimming and diving, tennis, and outdoor track were not included due to low sample counts (<10).

season rates were found in baseball/softball and indoor track.

Injury Mechanism

The majority of quadriceps strains were due to noncontact (n = 327, 63.2%) or overuse (n = 113, 21.9%) mechanisms overall and across all sports. No sex differences were found in the distribution of injury mechanism.

Recurrence

Overall, 7.5% (n = 39) of injuries were classified as recurrent (Figure 1). The sports with the highest incidence of recurrence included women's basketball (n = 4, 20.0%), women's soccer (n = 16, 10.7%), and men's football (n = 6, 9.5%). In sex-comparable sports, the proportion of quadriceps strains that were recurrent did not differ between men and women (n = 6, 5.2%, versus n = 27, 9.1%; IPR = 0.57; 95% CI = 0.24, 1.35).

Participation-Restriction Time

Participation-restriction time was limited to less than 1 week in 79.3% of athletes with quadriceps strains (n = 410; Figure 2). In particular, 236 of these quadriceps strains (45.6% of all cases) were NTL. Severe quadriceps strains accounted for 3.3% (n = 17). The sports with the largest proportion of severe quadriceps strains were men's football (n = 4, 6.3%), women's lacrosse (n = 1, 5.3%), and women's basketball (n = 1, 5.0%). In sex-comparable sports, the proportion of severe quadriceps strains did not differ between men and women (n = 6, 5.2%, versus n = 6, 2.0%; IPR = 2.57; 95% CI = 0.85, 7.80).

DISCUSSION

Muscle strains in the lower extremities are common in athletes[1–4] and result in extensive participation-restriction time, rehabilitation, and risk for reinjury.[5–8] However, few authors have specifically examined quadriceps strains. Our study is the first, to our knowledge, to examine the epidemiology of quadriceps strains among athletes in 25 NCAA sports. The inclusion of NTL injuries allows for a better understanding of the breadth of injuries diagnosed and managed by ATs in the collegiate sports setting.

Incidence

The overall incidence of quadriceps injuries in NCAA student-athletes in 25 sports during the surveillance period was relatively low. By comparison, hamstrings strains, the most commonly strained muscle group in athletes, had an injury rate nearly 3 times that of quadriceps strains among collegiate student-athletes examined over approximately the same time period.[15] The differences noted are likely due to the variations in muscle morphology and function between these muscle groups. Muscles that cross 2 joints

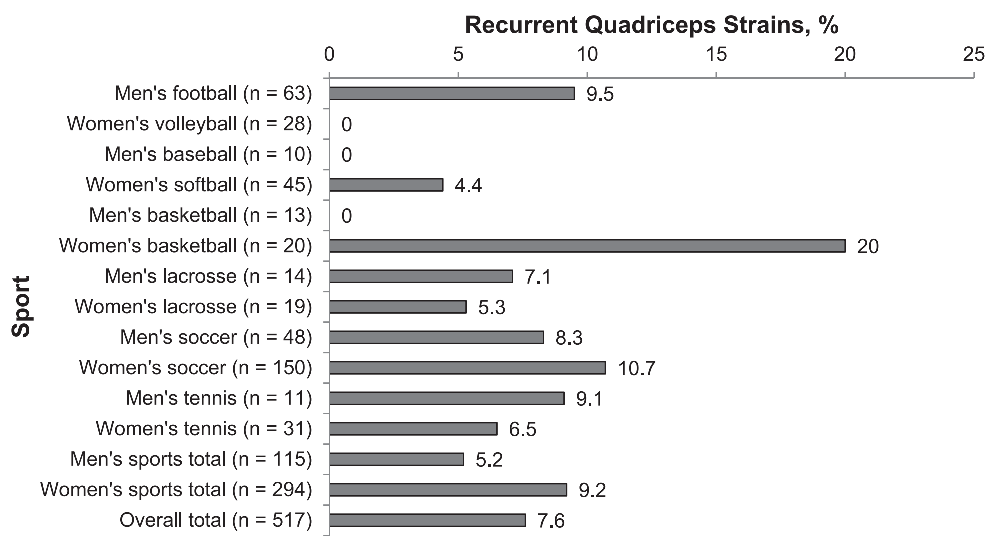

Figure 1. Proportion of quadriceps strains that were recurrent among student-athletes in 25 sports: National Collegiate Athletic Association Injury Surveillance Program, 2009–2010 through 2014–2015 academic years. Note: Sports with quadriceps strain counts <10 were excluded from figure (ie, men's and women's cross-country, ice hockey, swimming and diving, tennis, and outdoor track). Total includes 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).

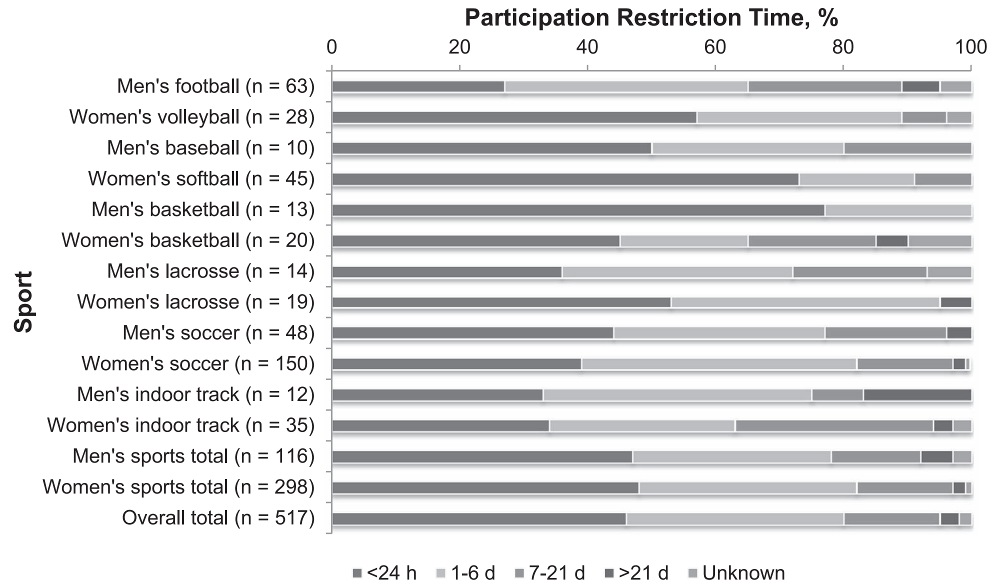

Figure 2. Participation-restriction time for quadriceps strains among student-athletes in 25 sports: National Collegiate Athletic Association Injury Surveillance Program, 2009–2010 through 2014–2015 academic years. Note: Sports with quadriceps strain counts <10 were excluded from figure (ie, men's and women's cross-country, ice hockey, swimming and diving, tennis, and outdoor track). Total includes 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).

are at increased risk of strain.[10,11] Compared with all 3 hamstrings muscles, only 1 of the 4 quadriceps muscles crosses both the hip and knee joints in its course. The hamstrings group may also have a higher injury rate due to strength imbalances in comparison with the quadriceps, which are often found in athletes.[2,16–18] Quadriceps strains occur at a higher incidence than calf muscle strains in professional soccer players[19] and hip-flexor strains (not including the rectus femoris) in professional basketball players.[20] Compared with the incidence of quadriceps strains in the NCAA-ISP data from 2009–2010 through 2014–2015, the incidence of calf muscle strains (including only those to the gastrocnemius-soleus) was lower, whereas the incidence of hip-flexor tears was similar (Datalys Center, unpublished data, 2016). Additional researchers need to further examine variations in the rates of lower extremity strains among athletes. However, our findings, in conjunction with previous findings, may highlight the quadriceps and hamstrings as the lower extremity areas experiencing the most strains.

Event Type

Across all sports, the quadriceps strain rate was higher in competition than in practice. A plausible explanation for this difference is that game play may occur at higher intensity during competitions than during practices.[4] Also, competition often features stronger muscle contractions coupled with greater fatigue relative to practice settings, thereby placing athletes at greater risk for muscle strains.[10,21] However, nearly 4 times as many quadriceps strains were reported in practices than in competitions, which is most likely the result of far larger numbers of practices than competitions across a season. In both practice and competition settings, athletes should take the time to perform an active warm-up before activity and conclude with postactivity stretching to decrease the risk of injury associated with stiffness and length asymmetries.[1,2,22–24]

Time in Season

The rate of quadriceps strains was higher in the preseason compared with the regular season. These findings are consistent with those for other muscle strains examined in NCAA student-athletes and may be due to student-athletes entering the preseason with lower levels of conditioning and decreased muscle flexibility.[15] As previously mentioned, muscle-length asymmetries and strength imbalances in the antagonist groups are associated with an increased risk of muscle strains.[1,2,16,22,23] These asymmetries and imbalances may be greatest during the preaseason as athletes exit a period of decreased activity levels and adherence to prophylactic therapeutic exercise programs. It is also common for athletes to experience the greatest total training volume during the preseason, which may cause fatigue that places athletes at greater risk for strains.[10,21]

Injury Mechanism

The most frequent mechanism of injury was noncontact, which suggests that many injuries were sustained from performance of explosive movements, such as sprints and jumps. Jumps are a high-risk activity for quadriceps strains due to the significant eccentric work that the quadriceps must perform to counter first, hip-extension moments that occur during upward propulsion, and second, knee-flexion moments during the absorption phases of jump landings. Jump-landing training that focuses on decreasing the activation ratio of the quadriceps to the hamstrings is already recommended to decrease the risk of injuries such as noncontact anterior cruciate ligament ruptures during jumping tasks, and it has the potential to decrease the risk of quadriceps strains as well.[25–27] Sprinting also requires the quadriceps to perform significant eccentric work, making them vulnerable to injury. To reduce the likelihood of injury during both sprinting and jumping, athletes should strengthen their quadriceps through resistance training that emphasizes eccentric work, which has been demonstrated to decrease the incidence of hamstrings strains.[28–30] Future investigators should seek data on the specific mechanism of injury for each patient. These data would help to drive the development of improved recommendations that are both sport and mechanism specific for the prevention and rehabilitation of quadriceps strains.

Participation-Restriction Time

The majority of quadriceps strains included in this study resulted in participation-restriction time of less than 1 week, with many being NTL. Only 3.3% were classified as severe, thus providing insufficient power to detect any sex differences. These findings parallel those reported by Dalton et al[15] regarding hamstrings injuries. Because we included quadriceps strains that were NTL, it is possible that some of the reported strains represented delayed-onset muscle soreness rather than a true muscle strain. However, the NCAA-ISP relies on the expertise and knowledge of the ATs and the team medical staff with whom they work to accurately detect and diagnose injuries. Still, future researchers may benefit from examining the manners of diagnosis to ensure the validity of the data.

Sex Differences

The rate of quadriceps strains was higher in women than in men for all sex-comparable sports combined and for 3 of the 5 examined sex-comparable sports (ie, baseball/softball, soccer, indoor track). However, these findings appeared to be largely influenced by practices, as all but 1 sex-comparable sport indicated a significantly higher rate in women than in men during practices. At the same time, a larger proportion of quadriceps strains were recurrent in women compared with men, although the finding was not significant. These results differ from those of previous authors[15,31] who observed higher rates and larger proportions of recurrent hamstrings strains in men. The contrasting findings may be due to muscle-activation differences between the sexes. Padua et al[25] noted that women demonstrated 46% greater quadriceps activity than men across two 2-legged–hopping conditions. This greater activation could translate into greater levels of fatigue, leaving women at higher risk for strain. Another explanation involves athlete height. Fousekis et al[1] determined that shorter male professional soccer players were at increased risk for quadriceps strains, but not for hamstrings strains, relative to their taller peers. This may help to explain the increased rate of quadriceps strains observed in female athletes, as they are often shorter than their male counterparts who play the same sport.[1] Because we did not collect demographic information, such as height, future researchers should examine the association between height and the risk of quadriceps strain. Future investigators should also seek to elucidate the reasons why female athletes appeared to incur a higher rate and greater chance of recurrence of quadriceps strains, whereas men experienced a higher overall rate and greater chance of recurrence of hamstrings strains.

LIMITATIONS

First, the NCAA-ISP represents a convenience sample of NCAA varsity sports programs that chose to participate in the program during the study period. Our findings may not be generalizable to other collegiate programs or levels of play. Second, the total number of quadriceps strains incurred within specific sports was low, making it difficult to conduct sport-specific analyses. Third, although we included NTL injuries, it is possible that some of these injuries actually represented delayed-onset muscle soreness, contusions, or other differential diagnoses. However, we relied on the expertise of the ATs providing the data, alongside the team medical staff with whom they worked, to accurately detect, diagnose, and manage quadriceps strains, which data support as the most reliable method of case identification in injury-surveillance studies.[32] Fourth, the NCAA-ISP did not collect information on team-specific attributes (eg, if teams implemented injury-prevention programs), athlete-specific risk factors (eg, complete injury and surgery history, leg dominance, bilateral strength, ratio of quadriceps to hamstrings muscle strength), or injury-specific characteristics (eg, grade of severity for injuries). In addition, to reduce the burden on the data collectors, the NCAA-ISP did not obtain information on more in-depth variables, such as the specific quadriceps muscles that were injured or mechanisms more specific than player contact, surface contact, and so on that led to injuries. Fifth, data collection aimed to acquire variables of interest while ensuring that the ATs collecting the data were not overburdened. For example, AEs were defined in independent units without controlling for duration, intensity, or type of exposure. Recording the actual number of minutes played by each student-athlete would provide a more accurate measure of exposure but would be more burdensome for data collectors. Finally, from the data collected, there was no way to determine which of the respective quadriceps muscles were injured in a strain. Although our data provide a large sample of quadriceps strains from athletes in 25 sports, these limitations highlight areas in which future researchers could build on the findings from the NCAA-ISP.

CONCLUSIONS

Across 25 NCAA sports during the 2009–2010 through 2014–2015 academic years, a higher quadriceps strain rate was found in women than in men, in competitions than in practices, and in the preseason than the regular season. Future authors should examine the potential reasons for such disparities in the incidence of quadriceps strains. However, most quadriceps strains were minor in nature, and further surveillance is needed to better examine the risk factors associated with injury incidence, mechanism, severity, and recurrence.

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