Journal of Athletic Training 2021;56(7):711–718
doi: 10.4085/1062-6050-724-20

www.natajournals.org

Epidemiology of Injuries in National Collegiate Athletic Association Women's Swimming and Diving: 2014–2015 Through 2018–2019

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Context: The number of women's swimming and diving teams sponsored by the National Collegiate Athletic Association has increased over the last 5 years.

Background: Routine examinations of women's swimming and diving injuries are important for identifying emerging temporal patterns.

Methods: Exposure and injury data collected in the National Collegiate Athletic Association Injury Surveillance Program during the 2014–2015 through 2018–2019 athletic seasons were analyzed. Injury counts, rates, and proportions were used to describe injury characteristics, and injury rate ratios were used to examine differences in injury rates.

Results: The overall injury rate was 1.78 per 1000 athlete-exposures in swimmers and 2.49 per 1000 AEs in divers. Shoulder (33.0%) injuries accounted for the largest proportion of all swimming injuries; most injuries were classified as overuse (51.3%). Head or face (29.4%) and trunk (20.2%) injuries accounted for the largest proportions of all diving injuries.

Summary: Findings indicated that shoulder and trunk injuries, as well as injuries resulting from overuse mechanisms, warrant further attention in swimming. Given the low in the National Collegiate Athletic Association Injury Surveillance Program observed across the study period, the need for greater participation in sports injury surveillance is also apparent.

Key Words: NCAA swimming and diving, female, injury surveillance, descriptive epidemiology

Key Points

- The overall injury rate was higher in women's diving than in women's swimming, and injury rates in both swimming and diving followed similar trajectories across the study period.
- Shoulder and trunk injuries accounted for the largest proportions of all reported women's swimming injuries, and most injuries in women's swimming were attributed to overuse and non-contact mechanisms.
- Injuries to the head/face and trunk accounted for the largest proportions of all reported women's diving injuries, and most injuries in women's diving were attributed to surface contact and overuse mechanisms.

Swimming and diving are among the most well-known summer Olympic sports.[1] In the United States, both swimming and diving are popular from the youth to National Collegiate Athletic Association (NCAA) level. In recent years, the number of participating athletes and NCAA-sponsored teams have steadily increased, with nearly 13 000 women's swimming and diving athletes competing in 2018–2019.[2] It is reasonable to suggest that this increasing participation has implications with regard to not only the competitive nature of the sport but also injury risk, given the larger pool of athletes at risk of injury. Despite these implications, few researchers have described the epidemiology of injuries in this population. Such reports can facilitate appraisal of the overall health of NCAA women's swimming and diving athletes, highlight specific areas for attention, and help to inform targeted interventions aimed at injury prevention.

The NCAA initiated an injury surveillance system to monitor injuries within collegiate athletics in 1982, which in its current form is known as the NCAA Injury Surveillance Program (ISP).[3,4] The NCAA ISP has collected data on women's swimming and diving since 2006-2007, and the most recent study using these data (captured during 2009-2010 through 2013-2014) identified the overall injury rate in women's swimming and diving as approximately 2 injuries per 1000 athlete-exposures (AEs).[5] It has also been noted that injury rates were higher in diving than in swimming (2.49 per 1000 AEs versus 1.63 per 1000 AEs, respectively).[5] Furthermore, it has been reported that most injuries among NCAA women's swimmers occur to the shoulder, whereas injuries among divers occur most commonly to the trunk.[5] In addition, it has been previously indicated that injuries among NCAA women's swimming

Authors Avinash Chandran and Sarah N. Morris have contributed equally to manuscript preparation. The articles in this issue are published as accepted and have not been edited.

and diving are most often classified as overuse and/or noncontact injuries.[5]

Frequent examination of injury incidence over time is necessary to assess health and safety issues, and to allow stakeholders to implement nuanced injury prevention strategies. Given the time elapsed since the previous epidemiological investigation of this population, it is important to examine recent patterns in injury incidence among these athletes. As such, the purpose of this study was to describe the epidemiology of sport-related injuries among women's swimming and diving student-athletes in a sample of NCAA teams during the 2014–2015 through 2018–2019 academic years.

METHODS

Study Data

Women's swimming and diving exposure and injury data collected in the NCAA ISP during the 2014–2015 through 2018–2019 athletic seasons were analyzed in this study. The ISP has been reviewed and approved as an exempt study by the NCAA Research Review Board. The methods of the surveillance program are described in detail in a separate manuscript within this special issue.[6] Briefly, athletic trainers (ATs) at participating institutions contributed exposure and injury data by using their clinical electronic medical record systems. A reportable injury was one that occurred due to participation in an organized intercollegiate practice or competition and required medical attention by a team AT or physician, regardless of time loss (TL). Scheduled team practices and competitions were considered reportable exposures for this analysis. Data from 8 (2% of membership with sponsored programs) participating programs in 2014–2015, 7 (1% of membership with sponsored programs) in 2015–2016, 10 (2% of membership with sponsored programs) in 2016–2017, 15 (3% of membership with sponsored programs) in 2017–2018, and 36 (6% of membership with sponsored programs) in 2018–2019 qualified for inclusion in analyses. Qualification criteria are detailed further in the aforementioned methods manuscript.[6]

Classifying Injuries and AEs by Swimming Versus Diving

Injured athletes were identified as either swimmers or divers when injury records were submitted by the AT. For injury records with an unknown athlete type, the injured athlete was assumed to be a swimmer if the corresponding activity at the time of injury was reported as backstroke, breaststroke, butterfly, freestyle, or medley; and the athlete was assumed a diver if the corresponding activity was reported as 1.0-m board, 1.0-m platform, 3.0-m board, 3.0-m platform, 5.0-m platform, 7.5-m platform, or 10.0-m platform. Records for which athlete type was not identifiable (either by AT report or activity, as noted above) were not retained in the analysis (n = 10). Combined AEs were collected for swimming and diving teams in the NCAA ISP. Previous researchers in this population determined that, on average, 87% of athletes on swimming and diving team rosters are swimmers, whereas 13% are divers.[5] Injury rates were calculated using the appropriate distribution of AEs for each athlete type.

Statistical Analysis

Injury counts and rates per 1000 AEs for each athlete type (swimmers or divers) were examined by event type (practice or competition) and TL (TL or non-TL [NTL]). An AE was defined as 1 athlete participating in 1 exposure event. Weighted and unweighted rates were estimated; however, results were presented in terms of unweighted rates (unless otherwise specified) due to low frequencies of injury observations across levels of certain explanatory variables. Temporal trends in injury rates (pooled for practices and competitions) across the study period were described using rate profile plots stratified by athlete type. Injury counts and proportions were examined by body part injured, mechanism of injury, injury diagnosis, and activity at the time of injury. Respiratory infections (n = 41) were not included in analyses due to reporting inconsistencies across the study period. Injury rate ratios (IRRs) were used to examine differential injury rates across event types. IRRs with associated 95% confidence intervals (CIs) excluding 1.00 were considered statistically significant. All analyses were conducted using SAS 9.4 (SAS Institute).

RESULTS

A total of 630 women's swimming and diving injuries (swimmers: 521; divers: 109) from 336851 AEs (swimmers: 293060; divers: 43,791) were reported to the NCAA ISP during the 2014–2015 through 2018–2019 athletic seasons (rate: swimmers = 1.78 per 1000 AEs; divers = 2.49 per 1000 AEs). This equated to a national estimate of 23 281 injuries overall (swimmers: 19 734; divers: 3548; Table 1). Practice and competition injury rates did not significantly differ in both swimming and diving. Injury rates in women's swimming remained relatively stable between 2014–2015 and 2015–2016, then increased through 2017–2018 before decreasing in the final year of the study (Figure). Injury rates in women's diving decreased notably between 2014–2015 and 2015–2016, and then steadily increased through 2017–2018 before decreasing in the final year of the study (Figure). Similarly, by inspecting injury incidence in diving, we found that the injury rate decreased notably between 2014–2015 and 2015–2016 and then steadily increased through 2017–2018 before decreasing in the final year of the study (Figure).

Time Loss

Original sentence: In both women's swimming and diving, NTL injuries represented a larger proportion of reported injuries than TL injuries (swimmers: NTL- 49.9%; TL- 28.6%; missing- 21.5%; divers: NTL- 45.0%; TL- 40.4%; missing- 14.7%). TL injuries accounted for a greater proportion of reported competition (43.1%) injuries than practice (27.0%) injuries in women's swimming. Conversely, TL injuries accounted for a greater proportion of reported practice (41.0%) injuries than competition (33.3%) injuries in women's diving.

Injury Characteristics

Injuries to the shoulder (33.0%) and trunk (15.6%) accounted for the largest proportions of all injuries reported in women's swimming during the study period (Table 2). Most swimming injuries were attributed to overuse (51.3%)

Table 1. Reported and National Estimates of Injuries, Athlete Exposure (AEs), and Rates per 1000 AEs by Athlete Type and Event Type[a]

	Overall		Practices		Competitions	
	Reported	National Estimate	Reported	National Estimate	Reported	National Estimate
Swimmers	521 293 060 1.78 (1.63, 1.93)	19 734 10 682 625 1.85 (1.69, 2.00)	470 267 041 1.76 (1.60, 1.92)	17 958 9 690 502 1.85 (1.69, 2.01)	51 26 019 1.96 (1.42, 2.50)	1776 992 123 1.79 (1.25, 2.33)
Divers	109 43 791 2.49 (2.02, 2.96)	3548 1 596 254 2.22 (1.76, 2.69)	100 39 903 2.51 (2.01, 3.00)	3319 1 448 006 2.29 (1.80, 2.78)	9 3888 2.31 (0.80, 3.83)	228 148 248 1.54 (0.03, 3.05)
Overall	630 336 851 1.87 (1.72, 2.02)	23 281 12 278 880 1.90 (1.75, 2.04)	570 306 944 1.86 (1.70, 2.01)	21 277 11 138 508 1.91 (1.76, 2.06)	60 29 907 2.01 (1.50, 2.51)	2,004 1 140 371 1.76 (1.25, 2.26)

Cell contents: Number / AEs / Rate per 1000 AEs (95% CI)

[a] Data presented in the order of reported number, followed by athlete exposures (AEs), estimated injury rates, and associated 95% Confidence Intervals (CIs). Data pooled association-wide are presented overall, and separately for practices and competitions. National estimates were produced using sampling weights estimated on the basis of sport, division, and year. All CIs were constructed using variance estimates calculated on the basis of reported data. A reportable injury was one that occurred due to participation in an organized intercollegiate practice or competition and required medical attention by a team Certified Athletic Trainer or physician (regardless of time loss). Only scheduled team practices and competitions were retained in this analysis.

and noncontact (18.0%) mechanisms. Overuse injuries accounted for a larger proportion of practice-related (52.6%) than competition-related (39.2%) women's swimming injuries. Noncontact injuries accounted for comparable proportions of practice- and competition-related injuries (Table 2). Most women's swimming injuries reported during 2014–2015 through 2018–2019 were categorized as inflammatory conditions (23.8%) and strains (12.9%). The most commonly reported specific injury diagnoses during the study period were shoulder impingement (8.6%; rate = 1.54 per 10 000 AEs), biceps tendonitis (shoulder) (7.9%; rate = 1.40 per 10 000 AEs), and rotator cuff tendonitis (5.4%; rate = 0.96 per 10 000 AEs).

Injuries to the head or face (29.4%) and trunk (20.2%) accounted for the largest proportions of all women's diving injuries reported during the study period (Table 3). Injuries were most commonly attributed to surface contact (31.2%) and overuse (23.9%) mechanisms. Women's diving injuries reported during the study period were distributed across several diagnostic classifications (Table 3). Concussions

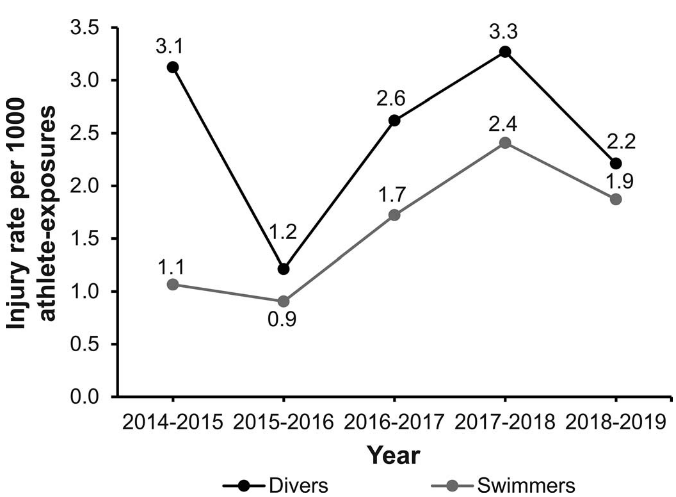

Figure. Temporal patterns in injury rates between 2014–2015 and 2018–2019. Depicts annual injury rates (per 1000 AEs) stratified by athlete type (swimmers versus divers).

accounted for 13.8% of all reported injuries in diving, although this result should be interpreted with caution given the low number of diving injuries reported across the study period.

Injuries by Swimming- and Diving-Specific Activities

Most women's swimming injuries from 2014–2015 through 2018–2019 occurred during freestyle stroke (47.2%) and conditioning (14.4%; Table 4). Freestyle stroke in particular accounted for 60.9% of all reported shoulder injuries and 44.4% of all trunk injuries in swimming. Most women's diving injuries during the study period occurred in unspecified diving activities (30.3%) and 3.0-m board (24.8%).

SUMMARY

We aimed to describe the epidemiology of NCAA women's swimming- and diving-related injuries reported to the NCAA ISP during the 2014–2015 through 2018–2019 academic years. Injury rates in women's swimming remained relatively low during 2014–2015 to 2015–2016, as compared with the latter years of the study period. The overall women's swimming injury rate observed in the present study was consistent with previous findings in this population.[5] Furthermore, there were no differences between practice- and competition-related injury rates in women's swimming, a finding also consistent with previous reports.[5] Although these findings appear to indicate stability in injury incidence among NCAA women's swimming athletes across 2 time periods, it is necessary to note that in the context of injury surveillance, these inferences are drawn on the basis of relatively small numbers of injury observations. Furthermore, we only examined temporal trends in overall injury incidence (and not by event type), which was also the case in previous reports. Given that competition exposures account for a smaller proportion of all reported exposures than practice exposures, it is perhaps unsurprising that few competition injuries were captured during the present study period. The low number of

Table 2. Distribution of Swimmer Injuries by Body Part, Mechanism, and Injury Diagnosis; Stratified by Event Type[a]

	Overall		Competitions		Practices	
	Injuries Reported (%)	National Estimate (%)	Injuries Reported (%)	National Estimate (%)	Injuries Reported (%)	National Estimate (%)
Body part						
Head/face	50 (9.60)	1510 (7.65)	6 (11.76)	184 (10.36)	44 (9.36)	1326 (7.38)
Neck	13 (2.50)	526 (2.67)	1 (1.96)	37 (2.08)	12 (2.55)	490 (2.73)
Shoulder	172 (33.01)	7006 (35.50)	9 (17.65)	264 (14.86)	163 (34.68)	6742 (37.54)
Arm/elbow	23 (4.41)	813 (4.12)	7 (13.73)	233 (13.12)	16 (3.40)	580 (3.23)
Hand/wrist	15 (2.88)	504 (2.55)	4 (7.84)	97 (5.46)	11 (2.34)	407 (2.27)
Trunk	81 (15.55)	4065 (20.60)	9 (17.65)	387 (21.79)	72 (15.32)	3678 (20.48)
Hip/groin	26 (4.99)	975 (4.94)	5 (9.80)	232 (13.06)	21 (4.47)	742 (4.13)
Thigh	13 (2.50)	259 (1.31)	2 (3.92)	53 (2.98)	11 (2.34)	206 (1.15)
Knee	40 (7.68)	1411 (7.15)	4 (7.84)	202 (11.37)	36 (7.66)	1209 (6.73)
Lower leg	12 (2.30)	415 (2.10)	0 (0.0)	0 (0.0)	12 (2.55)	415 (2.31)
Ankle	6 (1.15)	115 (0.58)	1 (1.96)	18 (1.01)	5 (1.06)	97 (0.54)
Foot	23 (4.41)	781 (3.96)	0 (0.0)	0 (0.0)	23 (4.89)	781 (4.35)
Other	47 (9.02)	1354 (6.86)	3 (5.88)	68 (3.83)	44 (9.36)	1286 (7.16)
Mechanism						
Player contact	26 (4.99)	907 (4.60)	2 (3.92)	33 (1.86)	24 (5.11)	873 (4.86)
Surface contact	48 (9.21)	1799 (9.12)	9 (17.65)	428 (24.10)	39 (8.30)	1371 (7.63)
Water	17 (3.26)	623 (3.16)	0 (0.0)	0 (0.0)	17 (3.62)	623 (3.47)
Deck	27 (5.18)	1031 (5.22)	9 (17.65)	428 (24.10)	18 (3.83)	603 (3.36)
Other	4 (0.77)	145 (0.73)	0 (0.0)	0 (0.0)	4 (0.85)	145 (0.81)
Other apparatus contact	11 (2.11)	376 (1.91)	5 (9.80)	148 (8.33)	6 (1.28)	228 (1.27)
Out-of-bounds contact	1 (0.19)	12 (0.06)	0 (0.0)	0 (0.0)	1 (0.21)	12 (0.07)
Noncontact	94 (18.04)	3126 (15.84)	11 (21.57)	481 (27.08)	83 (17.66)	2645 (14.73)
Overuse	267 (51.25)	11 279 (57.16)	20 (39.22)	599 (33.73)	247 (52.55)	10 680 (59.47)
Other/unknown	74 (14.20)	2235 (11.33)	4 (7.84)	87 (4.90)	70 (14.89)	2149 (11.97)
Diagnosis						
Concussion	27 (5.18)	827 (4.19)	4 (7.84)	129 (7.26)	23 (4.89)	698 (3.89)
Contusion	9 (1.73)	215 (1.09)	1 (1.96)	12 (0.68)	8 (1.70)	203 (1.13)
Dislocation/subluxation	16 (3.07)	843 (4.27)	1 (1.96)	59 (3.32)	15 (3.19)	784 (4.37)
Entrapment/impingement	46 (8.83)	1840 (9.32)	3 (5.88)	87 (4.90)	43 (9.15)	1754 (9.77)
Fracture	6 (1.15)	174 (0.88)	0 (0.0)	0 (0.0)	6 (1.28)	174 (0.97)
Illness/infection	17 (3.26)	499 (2.53)	0 (0.0)	0 (0.0)	17 (3.62)	499 (2.78)
Inflammatory condition	124 (23.80)	4385 (22.22)	10 (19.61)	254 (14.30)	114 (24.26)	4131 (23.00)
Spasm	27 (5.18)	995 (5.04)	5 (9.80)	142 (8.00)	22 (4.68)	853 (4.75)
Sprain	21 (4.03)	769 (3.90)	8 (15.69)	356 (20.05)	13 (2.77)	413 (2.30)
Strain	67 (12.86)	2497 (12.65)	8 (15.69)	311 (17.51)	59 (12.55)	2186 (12.17)
Other	161 (30.90)	6689 (33.90)	11 (21.57)	427 (24.04)	150 (31.91)	6262 (34.87)

[a] Data presented in the order of reported number, followed by the proportion of all injuries attributable to a given category. Data pooled across event types are presented overall, and separately for practices and competitions. National estimates were produced using sampling weights estimated on the basis of sport, division, and year. A reportable injury was one that occurred due to participation in an organized intercollegiate practice or competition and required medical attention by a team Certified Athletic Trainer or physician (regardless of time loss). Only scheduled team practices and competitions were retained in this analysis.

observed competition injuries also precluded juxtapositions of differential injury distributions between event types for several explanatory variables of interest (eg, comparisons of injury distributions by activity across event types). As such, future researchers may not only examine temporal patterns in injury incidence with more granularity (by event type, for instance), but also target the distribution of competition-related injuries for further attention. Such examinations will not only help elucidate factors in the sport that contributed to the burden of injury among NCAA women's swimming athletes, but also highlight areas for directing injury prevention efforts in this population.

Nearly one-half of all reported injuries in women's swimming were NTL injuries. Notably, the prevalence of TL injuries was higher among reported competition injuries than practice injuries. Furthermore, more than 60% of competition injuries were attributed to noncontact and overuse mechanisms. Although the low number of competition injuries reported across the study period restrict the inferential capacity of these injury distributions (ie, the extent to which these findings represent true distributions), it is important to consider that overuse and noncontact injuries also accounted for a large proportion (~70%) of all reported practice injuries. Together, with these findings, we indicate the need to further examine the complex injury etiology associated with muscular and connective tissue breakdown during high-intensity repetitive movements inherent to swimming,[7] which occur similarly during practice and competition events and may not be attributed to a discrete point in time. It is reasonable to suggest that injury prevention efforts in women's swimming may target commonly injured body parts, such as the shoulder and trunk, for further attention and targeted care in protecting against chronic workloads that may

Table 3. Distribution of Diver Injuries by Body Part, Mechanism, and Injury Diagnosis; Stratified by Event Type[a]

	Overall		Competitions		Practices	
	Injuries Reported (%)	National Estimate (%)	Injuries Reported (%)	National Estimate (%)	Injuries Reported (%)	National Estimate (%)
Body part						
Head/face	32 (29.36)	967 (27.25)	3 (33.33)	92 (40.35)	29 (29.00)	875 (26.36)
Neck	4 (3.67)	118 (3.33)	0 (0.0)	0 (0.0)	4 (4.00)	118 (3.56)
Shoulder	9 (8.26)	222 (6.26)	1 (11.11)	18 (7.89)	8 (8.00)	203 (6.12)
Arm/elbow	1 (0.92)	18 (0.51)	1 (11.11)	18 (7.89)	0 (0.0)	0 (0.0)
Hand/wrist	5 (4.59)	181 (5.10)	1 (11.11)	32 (14.04)	4 (4.00)	149 (4.49)
Trunk	22 (20.18)	681 (19.19)	1 (11.11)	32 (14.04)	21 (21.00)	650 (19.58)
Hip/groin	5 (4.59)	95 (2.68)	1 (11.11)	18 (7.89)	4 (4.00)	77 (2.32)
Thigh	1 (0.92)	32 (0.90)	0 (0.0)	0 (0.0)	1 (1.00)	32 (0.96)
Knee	10 (9.17)	662 (18.66)	0 (0.0)	0 (0.0)	10 (10.00)	662 (19.95)
Lower leg	4 (3.67)	87 (2.45)	0 (0.0)	0 (0.0)	4 (4.00)	87 (2.62)
Ankle	3 (2.75)	99 (2.79)	1 (11.11)	18 (7.89)	2 (2.00)	81 (2.44)
Foot	4 (3.67)	85 (2.40)	0 (0.0)	0 (0.0)	4 (4.00)	85 (2.56)
Other	9 (8.26)	301 (8.48)	0 (0.0)	0 (0.0)	9 (9.00)	301 (9.07)
Mechanism						
Surface contact	34 (31.19)	959 (27.03)	4 (44.44)	87 (38.16)	30 (30.00)	873 (26.30)
Water	31 (28.44)	868 (24.46)	3 (33.33)	68 (29.82)	28 (28.00)	800 (24.10)
Other	3 (2.75)	92 (2.59)	1 (11.11)	18 (7.89)	2 (2.00)	73 (2.20)
Other apparatus contact	13 (11.93)	394 (11.10)	3 (33.33)	105 (46.05)	10 (10.00)	289 (8.71)
Noncontact	16 (14.68)	544 (15.33)	0 (0.0)	0 (0.0)	16 (16.00)	544 (16.39)
Overuse	26 (23.85)	828 (23.34)	1 (11.11)	18 (7.89)	25 (25.00)	809 (24.37)
Other/unknown	20 (18.35)	822 (23.17)	1 (11.11)	18 (7.89)	19 (19.00)	804 (24.22)
Diagnosis						
Abrasion/laceration	3 (2.75)	92 (2.59)	1 (11.11)	37 (16.23)	2 (2.00)	55 (1.66)
Concussion	15 (13.76)	458 (12.91)	1 (11.11)	37 (16.23)	14 (14.00)	422 (12.71)
Contusion	7 (6.42)	174 (4.90)	1 (11.11)	32 (14.04)	6 (6.00)	143 (4.31)
Dislocation/subluxation	2 (1.83)	55 (1.55)	0 (0.0)	0 (0.0)	2 (2.00)	55 (1.66)
Entrapment/impingement	3 (2.75)	68 (1.92)	0 (0.0)	0 (0.0)	3 (3.00)	68 (2.05)
Fracture	4 (3.67)	108 (3.04)	0 (0.0)	0 (0.0)	4 (4.00)	108 (3.25)
Illness/infection	12 (11.01)	370 (10.43)	1 (11.11)	18 (7.89)	11 (11.00)	352 (10.61)
Inflammatory condition	5 (4.59)	130 (3.66)	0 (0.0)	0 (0.0)	5 (5.00)	130 (3.92)
Spasm	5 (4.59)	134 (3.78)	2 (22.22)	50 (21.93)	3 (3.00)	84 (2.53)
Sprain	6 (5.50)	186 (5.24)	2 (22.22)	37 (16.23)	4 (4.00)	149 (4.49)
Strain	7 (6.42)	562 (15.84)	1 (11.11)	18 (7.89)	6 (6.00)	544 (16.39)
Other	40 (36.70)	1209 (34.08)	0 (0.0)	0 (0.0)	40 (40.00)	1209 (36.43)

[a] Data presented in the order of reported number, followed by the proportion of all injuries attributable to a given category. Data pooled across event types are presented overall, and separately for practices and competitions. National estimates were produced using sampling weights estimated on the basis of sport, division, and year. A reportable injury was one that occurred due to participation in an organized intercollegiate practice or competition and required medical attention by a team Certified Athletic Trainer or physician (regardless of time loss). Only scheduled team practices and competitions were retained in this analysis.

contribute to overuse injuries.[8,9] Future researchers may also aim to better understand the etiology of workload accumulation in women's swimming athletes that may be unspecific to a particular event type and rather inherent to the sport. The physiologic strain on the shoulder during all swimming motions requires muscular endurance, excellent technique, and a large range of motion.[10,11] This may be particularly salient with regard to injuries attributed to the freestyle stroke, which was most prevalently associated with reported injuries in the present study, and also accounted for large proportions of shoulder and trunk injuries. With that said, the observed prevalence of injuries attributed to freestyle stroke may be unsurprising given the frequent use of the freestyle stroke among practices and competitions.[12] The freestyle stroke consists of a complex series of muscle activation with antagonistic activity in the biceps and triceps brachii to maintain joint stability during the early pull-through phase, the pectoralis major and latissimus dorsi during the underwater phase, and the rotator cuff throughout the stroke.[13,14] The trunk also serves an integral role as a stable base that allows for a transfer of force from the core to the extremities.[15–17] A breakdown in this force transfer has been previously shown to predispose overhead athletes to shoulder injury.[18] Such findings suggesting a related injury risk in these body parts in other overhead-concentrated sports indicate that this kinetic link warrants further attention in women's swimming athletes.

The overall women's diving injury rate in the present study was comparable to that in previous reports in this population.[5] Due to the limitations in stratifying diving injuries by explanatory variables of interest, it is difficult to contextualize these findings for the reasons described in subsequent sections. Most women's diving injuries occurred to the head/face and trunk. Coupled with the observed prevalence of knee and shoulder injuries, these findings are arguably consistent with expectations given the nature of the sport. For instance, head/face injuries were most often attributed to surface contact mechanisms

Table 4. Distribution of Injuries by Injury Activity; Stratified by Athlete Type and Event Type[a]

	Activity	Overall Injuries Reported (%)	Overall National Estimate (%)	Competitions Injuries Reported (%)	Competitions National Estimate (%)	Practices Injuries Reported (%)	Practices National Estimate (%)
Swimmers	Swim, backstroke	32 (6.14)	1245 (6.31)	9 (17.65)	345 (19.43)	23 (4.89)	900 (5.01)
	Swim, breaststroke	50 (9.60)	1974 (10.00)	4 (7.84)	331 (18.64)	46 (9.79)	1643 (9.15)
	Swim, butterfly	33 (6.33)	1477 (7.48)	2 (3.92)	30 (1.69)	31 (6.60)	1447 (8.06)
	Swim, freestyle	246 (47.22)	8960 (45.40)	24 (47.06)	748 (42.12)	222 (47.23)	8212 (45.73)
	Swim, medley	18 (3.45)	568 (2.88)	4 (7.84)	116 (6.53)	14 (2.98)	452 (2.52)
	Diving, not specified	1 (0.19)	32 (0.16)	0 (0.0)	0 (0.0)	1 (0.21)	32 (0.18)
	Conditioning	75 (14.40)	3019 (15.30)	1 (1.96)	37 (2.08)	7 (13.73)	169 (9.52)
	Weights	6 (1.15)	219 (1.11)	0 (0.0)	0 (0.0)	6 (1.28)	219 (1.22)
	Other/unknown	60 (11.52)	2240 (11.35)	7 (13.73)	169 (9.52)	53 (11.28)	2072 (11.54)
Divers	Dive, 1-m board	16 (14.68)	514 (14.49)	1 (11.11)	18 (7.89)	15 (15.00)	496 (14.94)
	Dive, 3-m board	27 (24.77)	761 (21.45)	6 (66.67)	173 (75.88)	21 (21.00)	587 (17.69)
	Dive, 3-m platform	4 (3.67)	132 (3.72)	0 (0.0)	0 (0.0)	4 (4.00)	132 (3.98)
	Dive, 5-m platform	1 (0.92)	32 (0.90)	0 (0.0)	0 (0.0)	1 (1.00)	32 (0.96)
	Dive, 10-m platform	4 (3.67)	87 (2.45)	0 (0.0)	0 (0.0)	4 (4.00)	87 (2.62)
	Diving, not specified	33 (30.28)	998 (28.13)	1 (11.11)	18 (7.89)	32 (32.00)	979 (29.50)
	Swim, freestyle	1 (0.92)	59 (1.66)	0 (0.0)	0 (0.0)	1 (1.00)	59 (1.78)
	Conditioning	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
	Weights	2 (1.83)	43 (1.21)	0 (0.0)	0 (0.0)	2 (2.00)	43 (1.30)
	Other or unknown	21 (19.27)	923 (26.01)	1 (11.11)	18 (7.89)	20 (20.00)	905 (27.27)

[a] Data presented in the order of reported number, followed by the proportion of all injuries attributable to a given category. Data pooled across event types are presented overall, and separately for practices and competitions. National estimates were produced using sampling weights estimated on the basis of sport, division, and year. A reportable injury was one that occurred due to participation in an organized intercollegiate practice or competition and required medical attention by a team Certified Athletic Trainer or physician (regardless of time loss). Only scheduled team practices and competitions were retained in this analysis.

(particularly with water) in the present study; this result is unsurprising given that diving athletes often break the surface tension of water at high velocities.[19,20] Furthermore, the biomechanical nuances of diving align with the prevalence of trunk, shoulder, and knee injuries observed in the present study. The sequence of diving begins with "take-off" from a stable (or unstable) surface in the form of a handstand or jump that requires considerable neuromuscular control of the lower extremity and trunk, followed by flight and entry, for which athletes perform complex maneuvers that demand precise proprioception.[21] The entry has been measured at 7.58 m/s on average in the 1.0-m (springboard) dive and 9.54 m/s on average in the 3.0-m (springboard) dive into the water, which may particularly affect the hand or wrist, arm or elbow, shoulder, trunk, and head or face.[20–22] Each phase of a dive predisposes the athlete to various risks of injury across the kinetic chain that may be accumulated over a series of dives that may vary in difficulty as athletes work to develop new skills. With the findings of the present study (in particular, the observed prevalence of shoulder, trunk, and knee injuries), we indicate that injuries in women's diving are distributed across the kinetic chain[23] and suggest that future researchers may leverage this rationale in directing research efforts. However, given the low number of diving injuries observed in this study, it is important not only to exercise caution in drawing inferences from the observed results but also to acknowledge that future studies regarding the etiology of injuries across the kinetic chain in this population are needed to inform injury prevention efforts.

Although the results of the present study extend the existing literature surrounding injury incidence in NCAA women's swimming and diving, it is important to consider the limitations that warrant further attention in examining these results. To begin with, participation in the NCAA ISP among women's swimming and diving programs was low across the study period, which limited the analytical scope of the present study, as well as the overall external validity of findings. More specifically, and as alluded to above, low participation precluded several cross-tabulations in this particular analysis. As a corollary to this point, sports injury surveillance is often leveraged to closely monitor temporal patterns in injury incidence; however, robust participation in surveillance is also critical for securing the requisite volume of data to support such investigations. Therefore, as future researchers consider studying this population, it is concurrently important to emphasize the continued surveillance and strong participation in surveillance programs. Furthermore, while considering the estimates of injury incidence presented here, it is important to acknowledge that there exist 2 fundamental compromises involved in their estimation. First, the representation of at-risk exposure time by using AEs may be particularly imprecise for swimming and diving. Given the individualized nature of swimming and diving activities, at-risk exposure time captured as AEs may not appropriately represent true differences in exposure time between athletes irrespective of their position or event (swimming or diving). Second, although swimming and diving are typically unified as a single sport within member institutions, swimming and diving exposures, including the likelihood and nature of contact, are inherently different due to the differences in activities and training routines between swimming and diving athletes.[24] Swimmers typically repeat comparable movements at high volumes, whereas divers perform highly technical maneuvers at comparatively lower volumes. The consolidation of swimming and diving as a single sport, coupled with the current structure of the NCAA ISP, precludes precise estimations of position-specific at-risk exposure time. Although separating exposure time on the basis of roster size (as seen here) is a practical solution, this strategy is understandably not ideal. As such, it is critical that future researchers studying this population not only consider methods for more precisely capturing at-risk exposure time in swimming and diving athletes but also measure exposure time for swimming and diving separately. Athlete-level measurements using dedicated data recorders or wearable technology may be effective alternative strategies for exposure time ascertainment in this population.[19,25,26] Such strategies may also allow researchers to capture more detailed exposure data, such as swim distance, type and number of dives, and exertional metrics, in this group. Although the NCAA ISP is unable to accommodate all of these measurement advancements in its current form, researchers may conduct targeted studies to pilot their feasibility and ultimately refine them for large-scale implementation.

Injury surveillance in NCAA women's swimming and diving facilitates the identification of emerging injury-related patterns in this population, and healthy participation in surveillance programs is critical to support meaningful inferences. With the findings of the present study, we direct attention toward potential areas for further monitoring in this athlete population, such as the incidence of shoulder and trunk injuries, as well as overuse injuries. We also highlight meaningful differences in injury incidence between swimming and diving athletes. In addition, in the discussions above, we offer important study design considerations for future research in this population. Together, the findings and discussions presented here will be critical for informing future work that will profoundly affect injury prevention in this population.

ACKNOWLEDGMENTS

The NCAA Injury Surveillance Program was funded by the NCAA. The Datalys Center is an independent nonprofit organization that manages the operations of the NCAA ISP. The content of this report is solely the responsibility of the authors and does not necessarily represent the official views of the funding organization. We thank the many ATs who have volunteered their time and efforts to submit data to the NCAA-ISP. Their efforts are greatly appreciated and have had a tremendously positive effect on the safety of collegiate student-athletes.

REFERENCES

1. Billings AC, Angelini JR. Packaging the Games for viewer consumption: gender, ethnicity, and nationality in NBC's coverage of the 2004 Summer Olympics. *Commun Q*. 2007;55(1):95–111. doi:10.1080/01463370600998731
2. NCAA sports sponsorship and participation rates database. National Collegeiate Athletic Association. Published 2020. Accessed July 3, 2020. http://www.ncaa.org/about/resources/research/ncaa-sports-sponsorship-and-participation-rates-database
3. Kerr ZY, Comstock RD, Dompier TP, Marshall SW. The first decade of web-based sports injury surveillance (2004–2005 through 2013–2014): methods of the National Collegiate Athletic Association Injury Surveillance Program and High School Reporting Information Online. *J Athl Train*. 2018;53(8):729–737. doi:10.4085/1062-6050-143-17
4. Dick R, Agel J, Marshall S. National Collegiate Athletic Association Injury Surveillance System commentaries: introduction and methods. *J Athl Train*. 2007;42(2):173–182.
5. Kerr ZY, Baugh CM, Hibberd EE, Snook EM, Hayden R, Dompier TP. Epidemiology of National Collegiate Athletic Association men's and women's swimming and diving injuries from 2009/10 to 2013/14. *Br J Sports Med*. 2015;49(7):465–471. doi:10.1136/bjsports-2014-094423
6. Chandran A, Morris SN, Wasserman EB, Boltz A, Collins CL. Methods of the National Collegiate Athletic Association Injury Surveillance Program, 2014–2015 Through 2018–2019. *J Athl Train*. 2021;56(7):616–621.
7. Edwards WB. Modeling overuse injuries in sport as a mechanical fatigue phenomenon. *Exerc Sport Sci Rev*. 2018;46(4):224–231. doi:10.1249/JES.0000000000000163
8. Peterson MD, Rhea MR, Alvar BA. Maximizing strength development in athletes: a meta-analysis to determine the dose-response relationship. *J Strength Cond Res*. 2004;18(2):377–382. doi:10.1519/R-12842.1
9. Lauersen JB, Andersen TE, Andersen LB. Strength training as superior, dose-dependent and safe prevention of acute and overuse sports injuries: a systematic review, qualitative analysis and meta-analysis. *Br J Sports Med*. 2018;52(24):1557–1563. doi:10.1136/bjsports-2018-099078
10. Funai Y, Matsunami M, Taba S. Physiological responses and swimming technique during upper limb critical stroke rate training in competitive swimmers. *J Hum Kinet*. 2019;70(1):61–68. doi:10.2478/hukin-2019-0026
11. Martens J, Figueiredo P, Daly D. Electromyography in the four competitive swimming strokes: a systematic review. *J Electromyogr Kinesiol*. 2015;25(2):273–291. doi:10.1016/j.jelekin.2014.12.003
12. Lockard G. NCAA men's and women's swimming and diving rules 2019-20 and 2020-21 rules book. August 2019. Accessed February 9, 2021. http://www.ncaapublications.com/productdownloads/SW20.pdf.
13. Pink M, Perry J, Browne A, Scovazzo ML, Kerrigan J. The normal shoulder during freestyle swimming: an electromyographic and cinematographic analysis of twelve musclse. *Am J Sports Med*. 1991;19(6):569–576. doi:10.1177/036354659101900603
14. Rouard AH, Clarys JP. Cocontraction in the elbow and shoulder muscles during rapid cyclic movements in an aquatic environment. *J Electromyogr Kinesiol*. 1995;5(3):177–183. doi:10.1016/1050-6411(95)00008-N
15. Yamauchi T, Hasegawa S, Matsumura A, Nakamura M, Ibuki S, Ichihashi N. The effect of trunk rotation during shoulder exercises on the activity of the scapular muscle and scapular kinematics. *J Shoulder Elbow Surg*. 2015;24(6):955–964. doi:10.1016/j.jse.2014.10.010
16. Krause DA, Dueffert LG, Postma JL, Vogler ET, Walsh AJ, Hollman JH. Influence of body position on shoulder and trunk muscle activation during resisted isometric shoulder external rotation. *Sports Health*. 2018;10(4):355–360. doi:10.1177/1941738118769845
17. Kibler WB, Press J, Sciascia A. The role of core stability in athletic function. *Sports Med*. 2006;36(3):189–198. doi:10.2165/00007256-200636030-00001
18. Pogetti LS, Nakagawa TH, Conteçote GP, Camargo PR. Core stability, shoulder peak torque and function in throwing athletes with and without shoulder pain. *Phys Ther Sport*. 2018;34:36–42. doi:10.1016/j.ptsp.2018.08.008
19. Harrison S, Cohen RCZ, Cleary PW, Barris S, Rose G. Forces on the body during elite competitive platform diving. Presented at: 9th International Conference on Computational Fluid Dynamics in the Minerals and Process Industries. Conf CFD Miner Process Ind.; December 10–12, 2012; Melbourne, Australia.

20. Zillmer EA. The neuropsychology of repeated 1- and 3-meter springboard diving among college athletes. *Appl Neuropsychol*. 2003;10(1):23–30. doi:10.1207/S15324826AN1001_4
21. Rubin BD. The basics of competitive diving and its injuries. *Clin Sports Med*. 1999;18(2):293–303. doi:10.1016/S0278-5919(05)70145-9
22. Baranto A, Hellström M, Nyman R, Lundin O, Swärd L. Back pain and degenerative abnormalities in the spine of young elite divers: a 5-year follow-up magnetic resonance imaging study. *Knee Surg Sports Traumatol Arthrosc*. 2006;14(9):907–914. doi:10.1007/s00167-005-0032-3
23. Welbeck AN, Amilo NR, Le DT, et al. Examining the link between thoracic rotation and scapular dyskinesis and shoulder pain amongst college swimmers. *Phys Ther Sport*. 2019;40:78–84. doi:10.1016/j.ptsp.2019.08.013
24. Rice SG, American Academy of Pediatrics Council on Sports Medicine and Fitness. Medical conditions affecting sports participation. *Pediatrics*. 2008;121(4):841–848. doi:10.1542/peds.2008-0080
25. Kidman EM, D'Souza MJA, Singh SPN. A wearable device with inertial motion tracking and vibro-tactile feedback for aesthetic sport athletes Diving Coach Monitor. Presented at: 10th International Conference on Signal Processing and Communication Systems; December 19–21, 2016; Surfers Paradise, Australia. doi:10.1109/ICSPCS.2016.7843371
26. Barker L, Burnstein B, Mercer J. Acceleration profile of an acrobatic act during training and shows using wearable technology. *Sports Biomech*. 2020;19(2):201–211. doi:10.1080/14763141.2018.1460394

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