EPIDEMIOLOGY OF NECK INJURIES ACCOMPANYING SPORT CONCUSSIONS IN YOUTH OVER A 13-YEAR PERIOD IN A COMMUNITY-BASED HEALTHCARE SYSTEM

Joel P. Carmichael, BSc, DC¹

Elizabeth W. Staton, MSTC²

Patrick J. Blatchford, PhD³

Jennifer Stevens-Lapsley, MPT, PhD^{1,4}

ABSTRACT

Background: The same trauma that produces concussion may also produce neck injury. The signs of concussion and neck injury are similar, and symptoms after acceleration-deceleration trauma to the head-neck complex do not accurately discriminate between them. Research on the epidemiology of neck injury among sport-concussed youth is sparse.

Purpose: The purpose of this study was to investigate the epidemiology of diagnosed neck injury in non-sport-related concussion (Non-SRC) versus sport-related concussion (SRC) in youth by age, sex, and sport.

Study design: Cross-sectional epidemiologic study

Methods: De-identified data from community-based electronic health records over 13 years were extracted to analyze rates and characteristics of neck injuries among non-SRCs and SRCs in youth aged five to 21. Neck injury diagnosis prevalence rates and odds ratios were calculated to estimate risk of neck injury among concussed youth, comparing non-SRCs to SRCs by age and sex.

Results: Sixteen thousand, eight hundred eighty-five concussion records were extracted, of which 3,040 SRCs and 2,775 non-SRCs in youth aged five to 21 were identified by cross-filtering sport-related keywords (e.g., football, basketball, soccer, running, swimming, batting, horseback riding, skiing, etc.) with all ICD-9 and ICD-10 concussion codes. The prevalence of neck injuries diagnosed among SRCs (7.2%) was significantly different than the prevalence of neck injuries diagnosed among non-SRCs (12.1%, $p < 0.000$). Neck injury diagnoses were significantly more prevalent in females overall ($p < 0.000$) and among non-SRCs ($p < 0.000$). The prevalence of neck injury diagnoses was not significantly higher in concussed females versus concussed males with SRC ($p = 0.164$).

Among youth aged five to 21 exposed to concussions, non-SRCs were more likely to be accompanied by a neck injury diagnosis than SRCs (OR 1.66; 95% CI 1.39 to 1.98; $p < 0.000$). Similarly, female-to-male neck injury proportion ratios were significantly higher in females in non-SRCs compared to SRCs (IPR 1.90, 95% CI 1.60 to 2.25, $p < 0.000$).

Sports with highest prevalence of concussion differ from sports with highest prevalence of concussion-related neck injury in both sexes.

Conclusions: The overall prevalence of diagnosed neck injuries in youth was higher in non-SRCs compared to SRCs (12.1 vs. 7.2%, $p < 0.001$), with the highest prevalence at age 14 in both sexes. The risk of neck injury diagnosis accompanying concussion was significantly higher in females compared to males (6.1% difference; $p < 0.000$).

Key words: Cervical spine, concussion, epidemiology, movement system, neck injury, whiplash

¹ Physical Therapy Program, Department of Physical Medicine and Rehabilitation, University of Colorado, Aurora, CO, USA

² Department of Family Medicine, University of Colorado, Aurora, CO, USA

³ Department of Biostatistics and Informatics, Colorado School of Public Health, University of Colorado Anschutz Medical Campus, Aurora, CO, USA

⁴ Eastern Colorado Geriatric Research Education and Clinical Center, Aurora, CO, USA

Acknowledgement of financial and database support:

Supported by NIH/NCATS Colorado CTSA Grant Number UL1 TR001082 and by the Health Data Compass Data Warehouse project (healthdatacompass.org).

(NIH Disclaimer: The contents of this article are the authors' sole responsibility and do not necessarily represent official NIH views.)

Conflicts of interest: None.

CORRESPONDING AUTHOR

Dr. Joel Carmichael

Postal address: 13121 E 17th Ave, Mail Stop C244, Aurora, CO 80045-2581

E-mail: joel.carmichael@ucdenver.edu

Telephone: (303) 290-8342

INTRODUCTION

For over a decade, there has been increasing surveillance and earlier recognition of concussion at all levels of competition, from youth leagues to elite and professional sports.¹⁻⁷ The same acceleration-deceleration trauma that produces concussion may also produce a sprain, strain, or whiplash injury to the cervical spine.⁸⁻²⁰ Symptoms characterizing concussion may be produced by cervical/vestibular injury without concussion.⁸⁻¹⁶ Of symptoms listed in the commonly used 22-item Concussion-Related Symptom Scale component of the Sport Concussion Assessment Tool (SCAT),²¹ 19 are symptoms that fail to discriminate between concussion and cervical/vestibular injury.¹⁸ Several researchers have advocated for additional testing to distinguish between concussion and cervical/vestibular injury to be performed at initial clinical evaluation and in post-concussion syndrome to avoid misdiagnosis and delayed recovery.¹⁸⁻²⁰ These authors conclude that recognition of neck injuries mimicking or accompanying concussion will heighten awareness for early initiation of skilled cervical rehabilitation when indicated.

The first version of SCAT²¹ listed “cervical” or “neck” two times. The most recent version (SCAT 5)²² uses these terms seven times, indicating a greater awareness of the importance of concurrent neck injury among concussed athletes by concussion experts. Using the Delphi method, a recent consensus conference identified clinical assessments to differentiate cervicogenic from cerebrogenic dizziness in concussed athletes, including the cervical joint-reposition error test, smooth-pursuit neck-torsion test, and cervical flexion-rotation test.²³ These tests possess acceptable levels of sensitivity (range 82 – 90%) and specificity (range 91 – 92%).²⁰

The epidemiology of concussions and neck injuries in athletes have been reported separately in large national studies.²⁴⁻²⁷ A 10-year retrospective analysis of the National Electronic Injury Surveillance System (NEISS) database of participating emergency departments found 7.2 neck injuries per 10,000 American football participants.²⁴ An analysis of 19,802 exposure hours in elite soccer players reported an overall incidence of head/neck injuries of 12.5 per 1000 player hours.²⁵

According to Hootman,²⁸ apart from the small but valuable body of literature produced by the National Collegiate Athletic Association Injury Surveillance System (NCAA ISS) and the High School Reporting Information Online (RIO™) databases, little is known about sports and recreation injury in contexts apart from interscholastic and intercollegiate sports. Hootman cites the critical need for injury-surveillance data in community-based sports in both youth and adult populations.

There are no community-based studies examining the epidemiology of neck injury among sport-related and non-sport-related concussion in youth. Causes of non-sport concussion include motor vehicle trauma, domestic violence, accidental falls, horseplay, and other unexpected traumas and impacts. The purpose of this study was to investigate the epidemiology of diagnosed neck injury in non-sport-related concussion (Non-SRC) versus sport-related concussion (SRC) in youth by age, sex, and sport.

METHODS

De-identified encounters bearing at least one ICD-9 or ICD-10 concussion diagnosis code were extracted retrospectively from the electronic health records (EHR) of Colorado's two primary research hospitals (University of Colorado Health (UCH) and Children's Hospital Colorado (CHCO)) and their affiliated clinics and hospital emergency departments within Colorado over a 13-year period. Youth seeking care for acute head injury within these hospitals and community clinics were seen by a variety of health care professionals, including emergency room physicians, family medicine physicians, physical medicine and rehabilitation physicians, physical therapists, physician assistants, and nurses. These providers entered patient history and examination data, imaging findings, diagnostic impressions, and treatment plans into the EHR system.

The retrospective multi-year records extraction period yielded a convenience sample of 31,038 concussion encounters as indicated by one or more ICD-9 or ICD-10 concussion codes. Concussion encounters for youth aged five to 21 were retained, as well as sex, race and treatment facility data. Records were excluded if concurrent diagnoses included comorbidities such as fracture, spinal cord injury,

neoplasm, migraine headache, central nervous system disorders, depression, and anxiety.

Over the 13-year study period, the hospital networks installed new EHR software allowing data extraction. Since software implementation expanded gradually across the network, an increasing number of concussion cases were available each year of data collection.

Data collection

Extracted records that met the above selection criteria were searched for concurrent diagnoses indicating non-catastrophic neck injury (e.g., strain, sprain, or whiplash) and for keywords identifying individual competitive or recreational sports directly associated with the history of trauma. If an extracted concussion encounter was within 120 days of a prior encounter bearing a concussion diagnosis, the subsequent encounter was excluded under the presumption that this was a follow-up visit related to the prior concussion encounter. This was done to reduce the possibility of counting the same concussion episode twice. Sport-related keywords suggesting the same sport (e.g., soccer, header, kicking soccer ball) were consolidated under a singular sport heading. There was no distinction drawn between competitive and recreational sport in this study.

Statistical methods

Data were analyzed using Stata Software, V. 14.2 (StataCorp, College Station, Texas, USA) and SAS, V. 9.4 (SAS Institute Inc., Cary, North Carolina, USA). One concussion encounter was considered a concussion exposure (CE). Neck injuries per 100 CEs were calculated by multiplying the number of cervical injuries by 100 (numerator) and dividing by the total number of CEs (denominator), the resultant percentage reflecting the neck injury prevalence. Prevalence ratios, odds ratios, p-values, and 95% confidence intervals were calculated for observed neck injuries associated with both age and sex.

Data were categorized into four groups by age: 5-8 years, 9-12 years, 13-16 years, and 17-21 years. The non-SRC versus SRC probabilities of neck injury diagnoses were compared at each age group between sexes and sports by calculating the neck injury proportion ratio (IPR) with 95% confidence intervals

(CIs). As an example, for each age group the female-to-male IPRs were calculated as follows:

$$\begin{aligned} \text{IPR} &= \frac{(\text{Number of female neck injuries})}{(\text{total number of female concussions})} \\ &= \frac{(\text{Number of male neck injuries})}{(\text{total number of male concussions})} \end{aligned}$$

Male-to-female neck IPRs were also calculated for evaluation by sport. For all statistical analyses, confidence intervals not including 1.0 were considered statistically significant.

This study used fully de-identified patient data in conformity with the Helsinki Declaration and met criteria for exempt status with the Colorado Multiple Institutional Review Board. It was also formally approved by the Southern California University of Health Sciences Institutional Review Board.

RESULTS

Sample description

Sixteen thousand, eight hundred eighty-five concussion exposures (CEs) were extracted from January 1, 2003, through August 11, 2016, in youth aged five to 21. A total of 3,040 SRCs and 2,775 non-SRCs were identified by cross-filtering an extensive list of sport-related keywords (e.g., football, basketball, soccer, running, swimming, batting, horseback riding, skiing, etc.) with all first encounters bearing at least one ICD-9 or ICD-10 concussion code. Mean age was 13.5 ± 3.5 years; 41% were female and 59% were male. Prevalence data for overall and stratified participant groups are reported in Table 1. The EHR selection flow diagram is shown in Figure 1.

Overall prevalence of SRC- and Non-SRC-related neck injury diagnoses

Of the 16,885 total youth CE records extracted for analysis, 18.0% were SRCs, 16.4% were non-SRCs, and in 65.6% participation in sporting activity at concussion onset could not be determined by keyword analysis. The mean age of the total sample was significantly older than the 3,040 SRC group (difference 0.31 yrs; 95% CI 0.17 to 0.44; $p < 0.000$). More concussed girls than boys were diagnosed with neck injuries (971 female; 798 male; difference = 6.08%; 95%

Table 1. Demographic Information for Sport-Related Concussion Patients with documented Cervical Spine Injury.

	Concussions	NECK INJURY DIAGNOSIS = YES						
		Neck Injuries	Prevalence (%)	95%	CI	Mean Age	95%	CI
Total Sample	N = 16885	1769	10.48	10.02	10.95	13.5	13.4	13.5
Male	9983	798	7.99	7.48	8.54	13.2	13.2	13.3
Female	6902	971	14.07	13.27	14.91	13.9	13.8	14.0
Sport-concussed youth	N = 3040	220	7.24	6.34	8.22	13.2	13.1	13.3
Male	1972	133	6.74	53.79	66.75	13.0	12.9	13.1
Female	1068	87	8.15	6.58	99.51	13.7	13.5	13.8
Non-sport-concussed youth	N = 2775	335	12.07	10.88	13.34	13.3	13.1	13.5
Male	1492	135	9.05	7.64	10.62	12.9	12.6	13.1
Female	1283	200	15.59	13.65	17.69	13.8	13.6	14.0
University of Colorado Hospital	N = 4148	431	10.39	9.48	11.36	14.7	14.6	14.8
Male	2537	237	9.34	8.24	10.54	14.4	14.2	14.6
Female	1611	194	12.04	10.49	13.73	15.2	15.0	15.4
Childrens Hospital Colorado	N = 12737	1338	10.85	9.98	11.05	13.1	13.0	13.2
Male	7446	561	7.53	6.92	8.18	12.8	12.7	12.9
Female	5291	777	14.69	13.74	15.67	13.5	13.4	13.6
Ethnicity	N = 16885	1769	10.48	10.02	10.95	13.5	13.4	13.5
White or Caucasian	11417	1234	10.81	10.25	11.39	13.5	13.4	13.5
Hispanic	4325	417	9.64	8.80	10.56	13.5	13.4	13.6
Black or African American	865	87	10.06	8.22	12.25	13.7	13.4	13.9
Asian	184	25	13.59	9.32	19.40	13.8	13.3	14.2
Native Hawaiian/Pacific Islander	38	4	10.53	3.82	25.83	13.8	12.6	15.0
Native American/Alaska Native	56	2	3.57	0.86	13.71	13.0	11.9	14.0
<i>CI = Confidence Interval</i>								

CI 5.10 to 7.06; $p < 0.000$), even though fewer girls than boys sustained CEs (6902 female; 9983 male).

Prevalence of concussion and neck injury stratified by sport/non-sport participation

The mean age of the SRC group (13.2 yrs) did not differ significantly from the mean age of the non-SRC group (13.3 yrs; difference 0.05 yrs; 95% CI -0.15 to 0.25; $p = 0.302$). A significantly higher prevalence of neck injuries was observed among non-SRCs (12.1%) compared to SRCs (7.2%) (difference = 4.8%; 95% CI 3.31 to 6.35; $p < 0.000$) (Figure 2).

SRCs yielded a non-significant difference (1.41% difference; $p = 0.164$) in the prevalence of neck injuries between concussed females and males. By contrast, there was a significantly higher (6.54%) prevalence of neck injuries among concussed girls versus boys in the non-SRC group (95% CI 4.08 to 9.00; $p < 0.000$). Furthermore, for all other strata (total sample, healthcare facility, and ethnicity) where the

sexes were compared, a significantly greater prevalence of neck injury diagnosis was observed among concussed girls compared to concussed boys (2.7 – 7.2% difference; $p < 0.008$ for all strata).

Between-sport prevalence comparisons

The number of CEs for the top 16 sports, together with neck injury prevalence by sex, are presented in Table 2. Combining both sexes, the top eight sports accounted for 75% of all sport concussions, and the top three sports – football, soccer, and basketball – accounted for 50% of all sport concussions. Football had the highest prevalence of concussion-related neck injuries, representing 23.6% of all neck injuries among sport-concussed youth in this community-based sample. Only one concussion-related football neck injury was sustained by a female.

The most common sports associated with concussion-related neck injuries in girls were snowboard, equestrian and volleyball, respectively. For boys

Figure 1. Electronic health record selection flow diagram.

Figure 2. Concussion and sport concussion prevalence by age.

the most common sports with concussion-related neck injuries documented together were swimming, equestrian and soccer. Soccer, with 19 cervical injuries in concussed girls and 16 cervical injuries in concussed boys, is the only sport with a high (>5%) prevalence of neck injuries shared by both sexes.

Risk estimates for neck injury among concussed youth

Neck Injury Proportion Ratios (IPR) – the probability of neck injury among concussed youth based on the presence or absence of sport exposure – calculated by age group (Figure 3), demonstrate a 1.7 to 4.7 times higher probability of diagnosed neck injury among non-SRCs compared to SRCs for youth aged 14 to 19 (range: $0.000 < p < 0.036$). Furthermore, the overall likelihood of neck injury was 66% higher among non-SRCs by logistic regression (OR 1.66; 95% CI 1.39 to 1.98; $p < 0.000$).

The overall female-to-male neck IPR by sports involvement was significantly higher for females in non-SRCs than in SRCs (IPR 1.90; 95% CI 1.60 to 2.25). Female-to-male neck IPRs ranked by sport showed significantly higher risk of diagnosed neck injury in concussed females than males in six sports, and higher risk of diagnosed neck injury in concussed males than females in three sports (Table 3).

The data were examined for diagnosed neck injury trends among SRCs by age. Analysis by individual

Table 2. Sports ranked by concussion prevalence.

BOYS								
N =	1972	Concussions	Concussions	TOTAL	Neck injury		Percent total con-	Percent total neck
RANK	BOYS	without neck injury	with neck injury	CONCUSSIONS	prevalence (%)	95% CI	cussions by sport	injuries by sport
1	Football	645	51	696	7.3	5.50, 9.52	35.3	7.3
2	Soccer	188	16	204	7.8	4.55, 12.42	10.3	7.8
3	Basketball	176	6	182	3.3	1.22, 7.04	9.2	3.3
4	Softball	133	6	139	4.3	1.60, 9.16	7.0	4.3
5	Hockey	125	6	131	4.6	1.70, 9.70	6.6	4.6
6	Bicycling	123	6	129	4.7	1.73, 9.85	6.5	4.7
7	Baseball	91	2	93	2.2	.26, 7.55	4.7	2.2
8	Running	78	2	80	2.5	.30, 8.74	4.1	2.5
9	Lacrosse	68	4	72	5.6	1.53, 13.62	3.7	5.6
10	Snowboard	63	4	67	6.0	1.65, 14.59	3.4	6.0
11	Ski	51	4	55	7.3	2.02, 17.59	2.8	7.3
12	Rugby	22	1	23	4.3	0.11, 21.9	1.2	4.3
13	Equestrian	8	2	10	20.0	2.52, 55.61	0.5	20.0
14	Volleyball	8	0	8	0.0	**	0.4	0.0
15	Swimming	2	1	3	33.3	0.08, 90.57	0.2	33.3
16	Tennis	1	0	1	0.0	**	0.1	0.0

GIRLS								
N =	1068	Concussions	Concussions	TOTAL	Neck injury		Percent total con-	Percent total neck
RANK	GIRLS	without neck injury	with neck injury	CONCUSSIONS	prevalence (%)	95% CI	cussions by sport	injuries by sport
1	Soccer	289	19	308	6.2	3.75, 9.47	28.8	6.2
2	Basketball	124	4	128	3.1	.86, 7.81	12.0	3.1
3	Volleyball	80	10	90	11.1	5.46, 19.49	8.4	11.1
4	Equestrian	59	12	71	16.9	9.05, 27.66	6.6	16.9
5	Bicycling	45	3	48	6.3	1.31, 17.20	4.5	6.3
6	Softball	46	1	47	2.1	0.01, 11.29	4.4	2.1
7	Lacrosse	41	3	44	6.8	1.43, 18.66	4.1	6.8
8	Running	40	2	42	4.8	.58, 16.16	3.9	4.8
9	Ski	28	3	31	9.7	2.04, 25.75	2.9	9.7
10	Hockey	21	2	23	8.7	1.07, 28.04	2.2	8.7
11	Snowboard	13	5	18	27.8	9.69, 53.48	1.7	27.8
12	Football	15	1	16	6.3	.16, 30.23	1.5	6.3
13	Baseball	1	0	1	0.0	**	0.1	0.0
14	Rugby	1	0	1	0.0	**	0.1	0.0
15	Swimming	1	0	1	0.0	**	0.1	0.0
16	Tennis	1	0	1	0.0	**	0.1	0.0

BOTH								
N =	3040	Concussions	Concussions	TOTAL	Neck injury		Percent total con-	Percent total neck
RANK	BOTH	without neck injury	with neck injury	CONCUSSIONS	prevalence (%)	95% CI	cussions by sport	injuries by sport
1	Football	660	52	712	7.3	5.50, 9.47	23.4	7.3
2	Soccer	477	35	512	6.8	4.80, 9.38	16.8	6.8
3	Basketball	300	10	310	3.2	1.56, 5.85	10.2	3.2
4	Softball	179	7	186	3.8	1.53, 7.60	6.1	3.8
5	Bicycling	168	9	177	5.1	2.35, 9.43	5.8	5.1
6	Hockey	146	8	154	5.2	2.27, 9.98	5.1	5.2
7	Running	118	4	122	3.3	.90, 8.18	4.0	3.3
8	Lacrosse	109	7	116	6.0	2.46, 12.04	3.8	6.0
9	Volleyball	88	10	98	10.2	5.00, 17.97	3.2	10.2
10	Baseball	92	2	94	2.1	.25, 7.47	3.1	2.1
11	Ski	79	7	86	8.1	3.33, 16.05	2.8	8.1
12	Snowboard	76	9	85	10.6	14.03, 32.68	2.8	10.6
13	Equestrian	67	14	81	17.3	9.78, 27.30	2.7	17.3
14	Rugby	23	1	24	4.2	.11, 21.12	0.8	4.2
15	Swimming	3	1	4	25.0	.63, 80.59	0.1	25.0
16	Tennis	2	0	2	0.0	**	0.1	0.0

** = No concussions with neck injury, therefore no confidence interval

Figure 3. Female-to-male neck injury proportion ratios. The ★ indicates statistically significant difference.

Table 3. Neck injury proportion ratio (IPR) by sport with 95% confidence intervals.		
SPORT	IPR (F to M)	95% CI
Snowboard	4.65	4.11, 5.20
Hockey	1.90	1.73, 2.07
Running	1.90	1.81, 2.00
Bicycling	1.34	1.22, 1.47
Skiing	1.33	1.14, 1.52
Lacrosse	1.23	1.09, 1.36
Basketball	*0.95	0.89, 1.01
Football	0.85	0.73, 0.98
Equestrian	*0.85	0.51, 1.18
Soccer	0.79	0.67, 0.91
Softball	0.49	0.45, 0.53
F= female, M= male, * = not statistically significantly different)		

age level failed to show significant differences between the sexes by age.

DISCUSSION

This study is the first to evaluate the epidemiology of diagnosed neck injuries in sport-concussed youth, and the first to report sport and non-sport concussion epidemiology in pre-adolescents, adolescents and early adults together in a community-based sample. This was made possible by using an enterprise data warehouse to access over 31,000 de-identified community-based health records. Previous studies have separately evaluated the epidemiology of sport-related neck injuries and sport-related concussions in professional, college, high school, and younger athletes using nationwide databases.²⁹⁻³⁴

Concussion prevalence

Concussions in this community-based sample of 16,885 youth CEs and in 3,040 SRCs were normally distributed across age levels from five to 21 years for boys, girls, and for both sexes combined, with a mean age of 13.5 years and a median age of 14 years. This distribution may provide clues regarding the mean age range of head-stabilizing neck strength deficit from age five to skeletal maturity. Several studies have highlighted the inverse relationship between neck strength and concussion risk in high school, collegiate and adult amateur athletes.³⁵⁻³⁸ A study of 6,662 high school athletes found smaller neck circumference, smaller neck-to-head circumference ratio and lower neck strength in concussed athletes compared to non-concussed athletes.³⁵ While neck strength data were not available, one reason for the symmetrical distribution and mean age of concussions and concussion-related neck injuries may relate to adolescent development. That is, the disparity between increasing head circumference in puberty coupled with lagging neck strength may create greater difficulty in the ability to stabilize the weight of the head with the neck muscles. The disparity may slowly diminish in the latter teen years. Except for one study of adolescent rugby players in Scotland,³⁹ research examining changes in head-stabilizing neck strength has focused on adult, college-age and older adolescent athletes.^{37, 38} Studies that characterize evolving head-stabilizing neck strength over the full age-span of pubertal development are needed to identify the optimal age for incorporating neck strengthening protocols in youth sports programs.

Neck injury prevalence

Sport vs. non-sport differences:

Higher prevalence and correspondingly greater risk of diagnosed neck injury were found among youths with non-SRCs. One possible explanation may relate to factors distinguishing non-sport from sport concussions. Common causes of non-sport concussions include motor vehicle trauma, accidental falls, and other activities where protective sporting equipment is not in use and where acceleration/deceleration of the head-neck complex is not anticipated as it may be in collision sports. Evidence from this study supports the finding that unexpected impacts result

in significantly increased accelerations to the head and neck⁴⁰ with higher risk of injury. Moreover, non-SRC cases presenting with a history of high-force trauma may compel more thorough diagnostic attention by healthcare personnel resulting in a higher prevalence of neck injury diagnoses in the non-sport group.

Differences by age:

Sport-concussed youth were significantly younger than non-sport-concussed youth. The trend by parents and coaches to involve children in sports earlier and ever-more competitively⁴¹ may account for at least part of this difference. Higher but non-significant probability for diagnosed neck injury at either end of the age spectrum is explained by the small overall prevalence of concussions in these boundary age groups in the study population.

The mean age of females was consistently older than males across all subcategories of comparison for both concussions and concussion-related neck injury diagnoses. Though it is likely this is due to a combination of factors, one major contribution may be boys' participation in community football programs, exposing them to more forceful impacts in the highest risk sport at a young beginning age. By comparison, girls' opportunities for exposure to higher intensity and higher risk sporting activities may be relatively delayed.

Differences by sex:

Concussion-related diagnosed neck injury prevalence and the risk of diagnosed neck injury among concussed females were both significantly higher than males in non-SRCs compared to SRCs in this study. As noted above in relation to age distributions for both concussion and neck injury, higher observed neck injury risk and prevalence in females may be attributable to lower neck strength among females. Though recently established normative neck strength data for healthy adults demonstrate women are significantly weaker than men,⁴² normative data for youth have yet to be established.

Differences by sport:

The data include sports unique to this community's geography such as skiing, snowboarding, equestrian

sports, and bicycling (including cycling and mountain-biking) not typically reported in NCAA and high school epidemiologic studies on concussion. Sports were arbitrarily stratified by diagnosed neck injury prevalence per 100 CE as low (< 5%) and high (≥5%); the results are shown in Table 4. CEs were infrequent in the “rare” sports listed at the bottom of Table 4 and, consequently, neck injury prevalence listed for these sports in Table 2 are higher due to the use of small denominators in prevalence calculations.

While the sideline assessment of concussion is becoming standardized,²² results of this investigation highlight the need for standardization in the community setting using a reproducible strategy for concussion diagnosis.⁴⁷ Future prevalence studies will benefit from detailed clinical documentation of competitive and recreational sport history, and the use of outcome measures and clinical tests to quantify symptom severity. The 22-item graded symptom checklist,²¹ a widely used standard symptom history used routinely in sports medicine, should be standardized in the community-based EHR, together with a simple yes-no checkbox for sport vs. no-sport

Table 4. Categorized neck injury prevalence among sport-concussed youth aged five to 21.			
	BOYS	GIRLS	COMBINED
LOW PREVALENCE (< 5%)	Bicycling Hockey Rugby Softball Basketball Running Baseball Tennis Volleyball	Running Basketball Softball Baseball Rugby Swimming Tennis	Rugby Softball Running Basketball Baseball Tennis
HIGH PREVALENCE (≥ 5%)	Soccer Football Ski Snowboard Lacrosse	Equestrian Volleyball Ski Hockey Lacrosse Bicycling Football Soccer	Volleyball Ski Football Soccer Lacrosse Hockey Bicycling
RARE	Equestrian Swimming	Snowboard Volleyball	Swimming Equestrian Snowboard Volleyball

involvement and a place to record which sport was involved. The neck disability index (NDI) should also be considered. The inclusion of data fields for the sport being played at the time of trauma, and use of reliable, valid tests to differentiate between cerebrogenic and cervicovestibular symptoms should be included and prompted in the EHR. Despite high reported sensitivity and specificity,²⁰ reliability and validity studies are needed for these tests. Once implemented, the ability to distinguish cerebrogenic from cervicovestibular symptoms will lead to better outcomes through earlier initiation of appropriate care. An evidence-based concussion classification system with directions for treatment, including recommendations for the management of cervical injuries following concussion, has recently been published.⁴⁷

Study Limitations

The cross-sectional design of this observational study prevents the inference of cause-effect relationships. This study had no access to the athletic exposure (AE) data often used to report concussion and neck injury incidence rates. Instead CEs were used to calculate diagnosed neck injury prevalence, with neck injury diagnoses used as a proxy for true neck injury and calculating neck injury prevalence as a proportion of concussion exposure. It may not be possible to pool these findings with studies that used AEs. The use of cervical injury as a proportion of CEs allowed for the calculation of IPRs, facilitating useful comparisons and risk estimation in the analysis of the data.

Keywords for a sporting activity were collapsed to a specific sport where appropriate. However, two sports in this report – running and bicycling—may not represent a true sport accurately. For example, running may represent an activity that was documented when the acceleration/deceleration trauma occurred; however, running may not represent the actual sport. For example, running on a playground at recess would be included as a sport-related CE in this study. Similarly, bicycling may represent a recreational ride in the neighborhood, a cycling event, or a mountain-biking competition.

The EHR data extraction method generated a large subset of CEs with no information regarding sports

participation. As a result, the prevalence of both sport and non-sport related CEs may not be accurate in this large sample population due to missing data. However, an analysis of the epidemiology of concussion in the larger cohort was possible, with the results of useful comparisons between large groups with known relation to sport presented herein.

This cross-sectional study is a first step to understanding the epidemiology of neck injury among concussed and sport-concussed youth. Future research must address gaps in knowledge regarding head-stabilizing neck strength in youth, and the validity and reliability of tests purported to distinguish between concussion and neck injury. The potential for diagnostic biases⁴⁶ that may lead to circumvention of a complete and carefully documented cervical spine examination in sport-concussion evaluations should also be investigated.

CONCLUSION

This is the first study to examine the prevalence of neck injury among concussed youth, and the first to describe comparative prevalence and risk estimation for neck injury between the sexes and between SRCs and non-SRCs. Concussion accounts for up to 14% of high school sports injuries, with highest incidence in collision sports.^{29, 43-45} This study found a significant difference between the prevalence of neck injury diagnoses accompanying non-SRCs (12.1%) versus SRCs (7.2%). Neck injury diagnoses accompanying SRCs are not uncommon. Further investigations are warranted to explore whether neck injuries in SRCs are under-diagnosed.⁴⁶ Higher prevalence of neck injury diagnoses among non-sport-concussed youth may reflect a greater intensity of forces with unanticipated,³⁶ unprotected trauma in the non-sporting pediatric population. The mean age for both diagnosed concussion and for diagnosed concussion-related neck injury was consistently higher for females than males across all subcategories of comparison. Further, the risk of neck injury among concussed females was higher than males in the non-SRC group compared to the SRC group.

REFERENCES

1. Master CL, Mayer AR, Grady MF. Minds Matter: Concussion Care for Children. *Curr Sports Med Rep*. 2016; 15: 230-2.

2. Darling SR, Leddy JJ, Baker JG, et al. Evaluation of the Zurich Guidelines and exercise testing for return to play in adolescents following concussion. *Clin J Sport Med*. 2014; 24: 128-33.
3. Blumenfeld RS, Winsell JC, Hicks JW, et al. The epidemiology of sports-related head injury and concussion in water polo. *Front Neurol*. 2016; 7: 98.
4. Bryan MA, Rowhani-Rahbar A, Comstock RD, et al. Sports- and recreation-related concussions in US youth. *Pediatrics*. 2016; 138.
5. Chin EY, Nelson LD, Barr WB, et al. Reliability and Validity of the Sport Concussion Assessment Tool-3 (SCAT3) in High School and Collegiate Athletes. *Am J Sports Med*. 2016; 44: 2276-85.
6. Schneider DK, Grandhi RK, Bansal P, et al. Current state of concussion prevention strategies: a systematic review and meta-analysis of prospective, controlled studies. *Br J Sports Med*. 2017; 51:1473-82.
7. Zuckerman SL, Wegner AM, Roos KG, et al. Injuries sustained in National Collegiate Athletic Association men's and women's basketball, 2009/2010-2014/2015. *Br J Sports Med*. 2018; 52:261-8.
8. Evans RW. Persistent post-traumatic headache, post-concussion syndrome, and whiplash injuries: the evidence for a nontraumatic basis with an historical review. *Headache*. 2010; 50:716-24.
9. Evans RW. Chronic whiplash syndrome. *Neurology*. 1995; 45:2117-18.
10. Haldorsen T, Waterloo K, Dahl A, et al. Symptoms and cognitive dysfunction in patients with the late whiplash syndrome. *Appl Neuropsychol*. 2003; 10:170-5.
11. Freitag P, Greenlee MW, Wachter K, et al. fMRI response during visual motion stimulation in patients with late whiplash syndrome. *Neurorehabil Neural Repair*. 2001; 15:31-7.
12. Findling O, Schuster C, Sellner J, et al. Trunk sway in patients with and without mild traumatic brain injury after whiplash injury. *Gait Posture*. 2011; 34:473-8.
13. Radanov BP, Dvorak J, Valach L. Cognitive deficits in patients after soft tissue injury of the cervical spine. *Spine*. 1992; 17:127-31.
14. Gimse R, Björger IA, Tjell C, et al. Reduced cognitive functions in a group of whiplash patients with demonstrated disturbances in the posture control system. *J Clin Exp Neuropsychol*. 1997; 19:838-49.
15. Yadla S, Ratliff JK, Harrop JS. Whiplash: diagnosis, treatment, and associated injuries. *Curr Rev Musculoskelet Med*. 2007; 1:65-8.
16. Rubin AMA, Woolley SMS, Dailey VMV, et al. Postural stability following mild head or whiplash injuries. *Am J Otol*. 1995; 16:216-21.
17. Schneider KJ, Meeuwisse WH, Nettel-Aguirre A, et al. Cervicovestibular rehabilitation in sport-related concussion: a randomized controlled trial. *Br J Sports Med*. 2014; 48:1294-98.
18. Leddy JJ, Baker JG, Merchant A, et al. Brain or strain? Symptoms alone do not distinguish physiologic concussion from cervical/vestibular injury. *Clin J Sport Med*. 2015; 25: 237-42.
19. Marshall CM, Vernon H, Leddy JJ, et al. The role of the cervical spine in post-concussion syndrome. *Phys Sportsmed*. 2015; 43: 274-84.
20. Cheever K, Kawata K, Tierney R, et al. Cervical injury assessments for concussion evaluation: a review. *J Athl Train*. 2016; 51: 1037-44.
21. McCrory P, Johnston K, Meeuwisse W, et al. Summary and agreement statement of the 2nd International Conference on Concussion in Sport, Prague 2004. *Br J Sports Med*. 2005; 39: 196-204.
22. Echemendia RJ, Meeuwisse W, McCrory P, et al. The Sport Concussion Assessment Tool 5th edition (SCAT5): Background and rationale. *Br J Sports Med*. 2017; 51: 848-50.
23. Reneker JC, Moughiman M, Cook CE. The diagnostic utility of clinical tests for differentiating between cervicogenic and other causes of dizziness after a sports-related concussion: an international Delphi study. *J Sci Med Sport*. 2015; 18: 366-72.
24. Delaney JS, Al-Kashmiri A. Neck injuries presenting to emergency departments in the United States from 1990 to 1999 for ice hockey, soccer, and American football. *Br J Sports Med*. 2005; 39:189.
25. Fuller CW, Junge A, Dvorak J. A six-year prospective study of the incidence and causes of head and neck injuries in international football. *Br J Sports Med*. 2005; 39(Suppl): i3-i9.
26. Borowski LA, Yard EE, Fields SK, et al. The epidemiology of US high school basketball injuries, 2005-2007. *Am J Sports Med*. 2008; 36: 2328-35.
27. Reche JA, Yard EE, Comstock RD. An epidemiologic comparison of high school sports injuries sustained in practice and competition. *J Athl Train*. 2008; 43: 197-204.
28. Hootman J. Research designs for descriptive studies. In: Verhagen E, van Mechelen W, eds. *Sports Injury Research*. New York (NY) : Oxford University Press 2010: 55-67.
29. Grady MF. Concussion in the adolescent athlete. *Curr Probl Pediatr Adolesc Health Care*. 2010; 40: 154-69.
30. Kerr ZY, Zuckerman SL, Wasserman EB, et al. Concussion symptoms and return to play time in youth, high school, and college American Football Athletes. *JAMA Pediatr*. 2016; 170:647-53.

-
31. Tierney RT, Sitler MR, Swanik CB, et al. Gender differences in head-neck segment dynamic stabilization during head acceleration. *Med Sci Sports Exerc.* 2005;37:272-9.
 32. Agel J, Evans TA, Dick R, et al. Descriptive epidemiology of collegiate men's soccer injuries: National Collegiate Athletic Association Injury Surveillance System, 1988-1989 through 2002-2003. *J Athl Train.* 2007; 42:270-7.
 33. Pfister T, Pfister K, Hagel B, et al. The incidence of concussion in youth sports: a systematic review and meta-analysis. *Br J Sports Med.* 2016; 50:292-7.
 34. Covassin T, Moran R, Elbin RJ. Sex differences in reported concussion injury rates and time loss from participation: an update of the National Collegiate Athletic Association Injury Surveillance Program from 2004-2005 through 2008-2009. *J Athl Train.* 2016; 51:189-94.
 35. Collins CL, Fletcher EN, Fields SK, et al. Neck strength: A protective factor reducing risk for concussion in high school sports. *J Primary Prevent.* 2014; 35:309-19.
 36. Eckner JT, Oh YK, Joshi MS, et al. Effect of neck muscle strength and anticipatory cervical muscle activation on the kinematic response of the head to impulsive loads. *Am J Sports Med.* 2014; 42: 566-76.
 37. Gutierrez GM, Conte C, Lightbourne K. The relationship between impact force, neck strength, and neurocognitive performance in soccer heading in adolescent females. *Ped Exercise Sci.* 2014; 26: 33-40.
 38. Hrysomallis C. Neck muscular strength, training, performance and sport injury risk: a review. *Sports Med.* 2016; 46:1111-24.
 39. Hamilton DF, Gatherer D, Jenkins PJ, et al. Age-related differences in neck strength of adolescent rugby players: a cross-sectional cohort study of Scottish schoolchildren. *Bone Joint Res.* 2012; 1:152-7.
 40. Kumar S, Narayan, Amell T. Role of awareness in head-neck acceleration in low velocity rear-end impacts. *Accid Anal Prev.* 2000; 32:233-41.
 41. Bahr R. Demise of the fittest: are we destroying our biggest talents? *Br J Sports Med.* 2014; 48:1265-7.
 42. Catenaccio E, Weiya M, Kaplan A, et al. Characterization of neck strength in healthy young adults. *PM R.* 2017 Sep; 9(9):884-91.
 43. Register-Mihalik JK, Kay MC. The current state of sports concussion. *Neurol Clin.* 2017; 35: 387-402.
 44. Meehan WP 3rd, d'Hemecourt P, Collins CLK, et al. Assessment and management of sport-related concussions in United States high schools. *Am J Sports Med.* 2011; 39:2304-10.
 45. Khodae M, Currie DW, Asif IM, et al. Nine-year study of US high school soccer injuries: data from a national sports injury surveillance programme. *Br J Sports Med.* 2017; 51:185-93.
 46. Saposnik G, Redelmeier D, Ruff CC, et al. Cognitive biases associated with medical decisions: a systematic review. *BMC Med Informat Decision Making.* 2016; 16:138-51.
 47. Ellis MJ, Leddy JJ, Willer B. Physiological, vestibulo-ocular and cervicogenic post-concussion disorders: an evidence-based classification system with directions for treatment. *Brain Inj.* 2015; 29:138-48.