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Sex-Based Differences in the Incidence of Sports-Related Concussion: Systematic Review and Meta-analysis

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Context: The incidence of sports-related concussion in females has been increasing in recent years.

Objective: To conduct a meta-analysis on sex-based differences in concussion incidence in various sports and to determine the effects of study design (retrospective vs prospective), setting (competition vs practice), and population (university and above vs high school and below) via a meta-regression.

Data Sources: PubMed (Medline), EMBASE, and Cochrane Library databases were searched from January 2000 to January 2018.

Study Selection: Studies reporting sports-related concussion incidence data for both males and females (age ≥10 years) were included.

Study Design: Systematic review with meta-analysis and meta-regression.

Level of Evidence: Level 4.

Methods: The rate ratio was calculated as the concussion rate in females/males. Data were pooled using the DerSimonian-Laird random-effects model.

Results: Thirty-eight studies met the eligibility criteria and were included in the meta-analysis. Soccer and basketball demonstrated significantly higher incidence of concussions in females compared with males (rate ratio [95% CI], 1.76 [1.43-2.16] and 1.99 [1.56-2.54], respectively; $P < 0.01$). Sex-based differences in concussion incidence rates for baseball/softball, ice hockey, lacrosse, swimming/diving, and track and field were not statistically significant. In the meta-regression analysis, there were no significant effects on the rate ratio when evaluating study design, setting, and population.

Conclusion: Concussion incidence rates were significantly higher in females than in males for soccer and basketball.

Keywords: concussion; incidence; soccer; basketball; sex-based differences

The estimated annual incidence of sports- and recreation-related concussions in the United States ranges from 1.7 million to 3.8 million.[18,27,34] In the pediatric population, this number ranges from 1.1 million to 1.9 million,[10] although the actual number may be greater due to underreporting.[26,60] Concussions have garnered increased attention in the past few years due to the potential for long-term, postconcussion health problems in athletes.[33]

In children, the majority of sports-related concussions occur during contact sports, such as football, soccer, basketball, ice hockey, and lacrosse.[25] Concussions are also commonly reported in noncontact sports, particularly gymnastics and cheerleading.[25,41] The likelihood of sustaining a sports-related concussion depends on various factors.[1]

Recent studies have shown sex-based differences in concussion incidence; females are more likely to sustain a

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sports-related concussion than males playing the equivalent sport.[8,51,58] Female high school athletes are 1.56 times more likely to sustain a sports-related concussion than their male counterparts.[8] Similarly, at the middle school and high school levels, concussion risk is higher in girls than in boys.[58] Girls' soccer exhibited the highest incidence of concussions among all high school sports.[51]

The aim of this meta-analysis was to compare concussion incidence between males and females in both contact and noncontact sports. A meta-regression was also performed to evaluate factors (study design, setting, and population) that may affect sex-based differences in concussion incidence.

METHODS

Literature Search Methodology

A comprehensive search of the PubMed (Medline), EMBASE, and Cochrane Library databases was performed in January 2018 by a medical librarian, according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. Search terms included "sex," "gender," "sex differences," "gender identity," "brain concussion," "concussion," "traumatic brain injury," "sports," "athletes," "incidence," "epidemiology," "symptoms," and "injury rate." The actual search string is included in Appendix 1 (available in the online version of this article). All searches were carried out on the same day. Other potential studies were identified by manually searching the reference lists of relevant review articles.[1,20,40,45,46]

Studies that were published from January 2000 to January 2018 and reported sports-related concussion incidence data on both male and female athletes aged 10 years or older were included. Studies were excluded if they (1) were not published in English, (2) reported data primarily collected from emergency room settings, or (3) included data for only males or females. Emergency room setting–based data were excluded due to the (1) inclusion of nonsports-related sources of concussion (eg, motor vehicle accidents), (2) lack of detail on sport, or (3) inability to separate out our age group of interest.

Using the online software program Covidence (Veritas Health Innovation Ltd; Melbourne, Australia), 2 authors independently screened studies for inclusion. Title and abstract screening were conducted first, followed by full-text screening. Any disagreements were resolved through consensus.

Data Extraction

The following data were independently extracted from full-text articles: study design, sample size information (eg, number of athletes or number of athlete-exposures), concussion incidence data, sport, setting (eg, some competition or practice only), population (eg, university and above or high school and below), and database used (if applicable). For studies that reported concussion incidence data for different sports, settings, and populations, data were extracted separately according to each variable. In addition, only data relevant to sex-comparable sports were collected. These sports included lacrosse, ice hockey, soccer, basketball, softball/baseball, track and field, cross-country, swimming, diving, gymnastics, rugby, volleyball, quidditch, water polo, taekwondo, cheerleading, badminton, crew, golf, and tennis. Concussion incidence data for sports involving only males or females (eg, American football) were not collected. Studies published in conference abstracts were also excluded at the data extraction stage, as only limited data could be extracted.

Assessment of Study Quality

The quality of studies was assessed using the Newcastle-Ottawa scale, which was established specifically for cohort and case-control studies.[61] For cross-sectional studies, a modified version of the Newcastle-Ottawa scale was used.[42] A score was given to each of the following categories: selection, comparability, and outcome. Scores per category were then summed for the determination of quality.

Data Synthesis and Meta-analysis

Each study in the meta-analysis contributed a pair of numbers: the number of concussions in males and females. Most studies reported these data per number of athlete-exposures, defined as 1 practice or game. Incidence rates were converted to 10,000 athlete-exposures as the common denominator. Some studies reported rates per number of athletes, and they were analyzed separately. The rate ratio (RR) was calculated as the rate of concussions in females divided by the rate of concussions in males. A value greater than 1 would indicate that females suffer more concussions than males. Some studies reported data stratified by competition or practice and level of competition (eg, high school or below and university or above). These comparisons between males and females were also extracted separately. Thus, some studies contributed multiple comparisons to the meta-analysis.

Data from each study were pooled using the DerSimonian-Laird random-effects model (REM). The REM gives more conservative estimates with wider CIs, compared with fixed-effects models, because it assumes that the meta-analysis includes only a sample of all possible studies.[21,35] In addition, the REM accounts for both within-study variability (random error) and between-study variability (heterogeneity). Meta-analyses were performed by sport and only when there were more than 5 comparisons to pool. The RR from each study and the 95% CI are displayed in forest plots, included in Appendix 2 (available online).

Meta-regression

Heterogeneity is usually a concern with meta-analyses and refers to a high degree of variability in study results. When significant heterogeneity is present, summary estimates from meta-analyses are not meaningful. Heterogeneity was detected using chi-square and I-square tests.[28] Further reasons for the heterogeneity were investigated by meta-regression analysis. In this linear regression model, the studies are the units of analysis. The RR is the outcome (dependent) variable. The independent

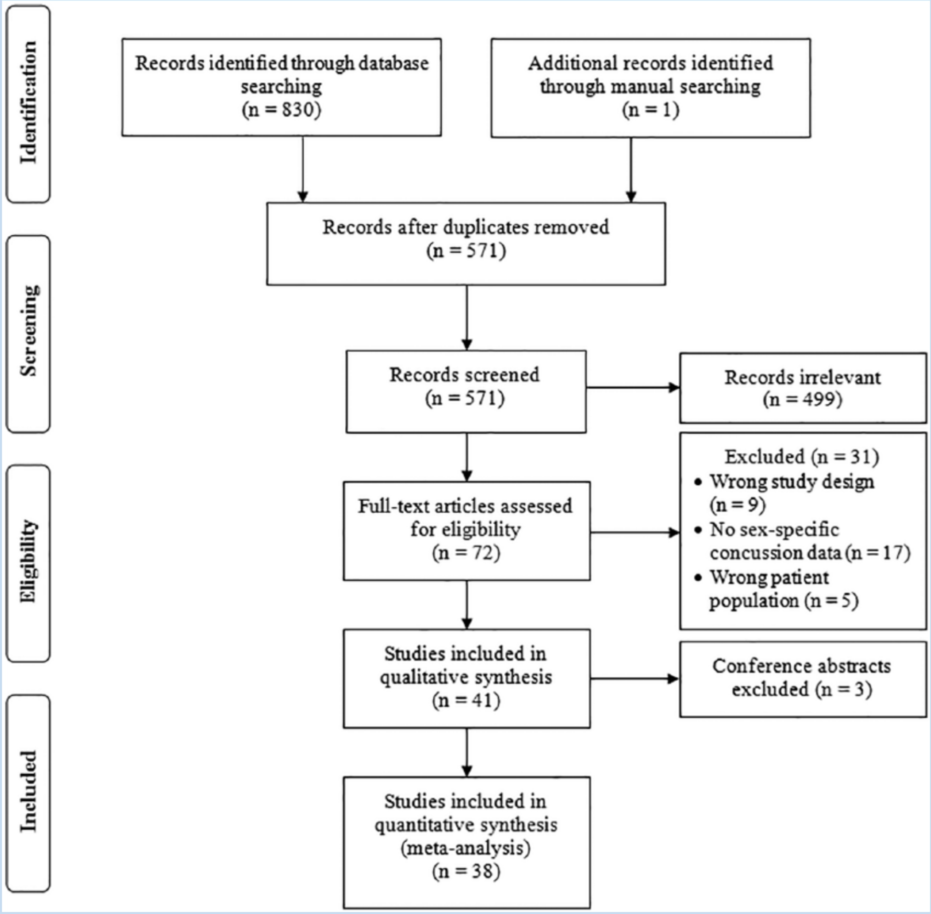

Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) study selection flow diagram. The numbers of screened, excluded, and included studies are shown.

variables are the covariates that may be associated with variability in the RR. The relevant covariates that were determined a priori for the meta-regression included study design (retrospective/database vs prospective), setting (some competition vs practice only), and population (university and above vs high school and below). All analyses were conducted in Stata SE, version 14 (StataCorp LLC).[56]

RESULTS

Study Selection

A total of 831 records were identified through database and manual searches. Of these, 260 records were duplicates. Title and abstract screening were performed on the remaining 571 records, of which 499 were determined to be irrelevant to the study aims. Seventy-two studies were then assessed for eligibility with full-text review. After excluding 31 studies for study design (eg, reviews) and the absence of sex-specific concussion data, 41 studies were included for data extraction. Three studies were conference abstracts and were subsequently excluded. Thus, 38 studies were included in the meta-analysis (Figure 1).

Study Characteristics

The 38 studies included both prospective and retrospective cohort studies. Detailed study characteristics are shown in Appendix 2, Table A1 (available online). Eighteen (47%) studies reported concussion incidence data for multiple sports. The majority of retrospective studies utilized a high school or collegiate national injury surveillance database, such as the National Collegiate Athletic Association–Injury Surveillance Program (NCAA-ISP), High School Reporting Information Online (RIO), or National Athletic Treatment, Injury, and Outcomes Network (NATION). Two studies utilized 2 databases (High School RIO and NCAA-ISP, and NATION and NCAA-ISP) to report both high school and collegiate data.[24,48] Thirty-two (84%) studies were based in the United States.

Concussion Incidence

Concussion incidence data were extracted for both contact and noncontact sports. Contact sports included lacrosse, ice hockey, soccer, baseball, softball, basketball, water polo, taekwondo, rugby, volleyball, and quidditch.[2-4,6,7,11,12,14-16,19,22-24,29,31,32,37-39,43,44,48-54,63,64]

Table 1. Pooled summary estimates of relative risk for concussion incidence comparing females versus males in various sports, measured per 10,000 athlete-exposures

Sport	No. of Comparisons	Relative Risk (95% CI)	*P*
Baseball/Softball	24	1.45 (0.94-2.26)	0.10
Basketball	**28**	**1.99 (1.56-2.54)**	**<0.01**
Ice hockey	10	0.90 (0.70-1.17)	0.44
Lacrosse	18	0.94 (0.73-1.21)	0.65
Soccer	**31**	**1.76 (1.43-2.16)**	**<0.01**
Swimming/Diving	6	1.65 (0.35-7.81)	0.53
Track and field	11	1.41 (0.43-4.56)	0.57

Boldfaced *P* values indicate statistical significance.

Noncontact sports included track and field, swimming, diving, cheerleading, badminton, cross-country, crew, gymnastics, golf, and tennis.[3,5,11,16,17,19,29,41,43,53,62,65]

Meta-analyses were conducted only for sports that were represented by at least 5 comparisons. These sports were lacrosse, soccer, baseball/softball, basketball, track and field, and swimming/diving. A total of 128 comparisons from 26 studies were included.[2,7,12,14-16,22-24,29-31,37,38,41,43,48-54,63-65] Soccer demonstrated a significantly higher incidence of concussion in females compared with males (RR [95% CI], 1.76 [1.43-2.16]; $P < 0.01$). All but 1 of the 31 comparisons reported an RR greater than 1.0 (Appendix 2, Figure A1, available online). In addition, the concussion incidence in female basketball players was significantly higher than that in male basketball players (RR [95% CI], 1.99 [1.56-2.54]; $P < 0.01$) (Appendix 2, Figure A2, available online). All but 2 of the 28 comparisons reported an RR greater than 1.0.

Sex-based differences in concussion incidence rates for the other sports were not statistically significant (Table 1). There was a trend toward an increased RR for baseball/softball, swimming/diving, and track and field, but there was a large range in RR from individual comparisons (RR [95% CI], 1.45 [0.94-2.26] and $P = 0.10$; 1.65 [0.35-7.81] and $P = 0.53$; and 1.41 [0.43-4.56] and $P = 0.57$, respectively) (Appendix 2, Figures A3-A7, available online).

Some sports were represented by only a few studies, and pooled summary estimates were not calculated (Appendix 2, Figures A8 and A9, available online). In those studies, a higher concussion incidence was reported in females versus males for quidditch (RR, 1.87; single study),[44] badminton (RR, 1.94; single study),[5] and water polo (RR, 1.27 and 1.43; 2 studies),[5,6] although statistical significance could not be established. Concussion incidences for female and male tennis players were low and varied greatly depending on the study and setting (RR range, 0.19-4.31).[11,43,65] Other sports with low concussion incidence in both females and males were crew, cross-country, and golf.[11,43,65] There did not appear to be a sex-based difference in concussion incidence for taekwondo (RR range, 0.82-1.06)[4,32] or volleyball (RR, 1.15; single study).[3]

Meta-regression Analysis

Since the meta-analysis included comparisons from different settings and populations, a meta-regression analysis was performed to evaluate the effect of different factors on the concussion incidence of females and males for each sport. No significant effects of setting, population, or study design on RR were found for any of the sports. For soccer, the regression coefficients (95% CI, *P* value) for study design (retrospective vs prospective), setting (competition vs practice), and population (university and above vs high school and under) were 1.13 (0.72-1.77; $P = 0.58$), 0.99 (0.50-2.00; $P = 0.99$), and 0.90 (0.60-1.36; $P = 0.61$), respectively. For basketball, the regression coefficients (95% CI, *P* value) for study design, setting, and population were 0.93 (0.40-2.15; $P = 0.86$), 1.21 (0.55-2.64; $P = 0.62$), and 0.89 (0.43-1.85; $P = 0.75$), respectively.

Quality Assessment

Quality assessment results are shown in Appendix 2, Table A2 (available online). The majority of studies were rated "fair" (n = 31). All studies involved athletes only. In 29 of the 36 cohort studies, the outcome of interest (eg, concussion incidence) was present at the start of the study; this was likely due to the retrospective nature of those studies.

DISCUSSION

This meta-analysis on concussion incidence in lacrosse, soccer, baseball/softball, basketball, track and field, and swimming/diving found that compared with males, females had a higher concussion incidence rate in soccer, basketball, baseball/

softball, track and field, and swimming/diving. The higher concussion incidence rate for females was statistically significant in both soccer and basketball. The higher pooled RR for females in softball/baseball, swimming, and track and field may be clinically significant, despite not reaching statistical significance. There were no effects of study design, setting, or population on sex-based differences in concussion incidence.

A recent meta-analysis of concussion studies through 2016 showed that females had an increased concussion risk in soccer and ice hockey.[46] That study used a fixed-effects model, which can lead to more optimistic findings due to narrower CIs. A nonsystematic review also highlighted increased concussion incidence in females for other sports, such as lacrosse, baseball/softball, and basketball.[36] In this meta-analysis, a statistically significant difference in concussion incidence was not found for lacrosse, baseball/softball, ice hockey, track and field, or swimming/diving. However, the pooled RR estimates for baseball/softball, track and field, and swimming/diving were greater than 1.0, with wide ranges in RRs among individual comparisons.

In this study, the RR for soccer was greater than 1 when considering both athlete-exposures and number of athletes as the unit of analysis. This was in line with the Healthy Sport Index, which showed that the highest concussion rate in females was in soccer and basketball; these rates were twice that seen in males playing the same sports.[55] Interestingly, for basketball and soccer, there are no differences in the rules between the men's and women's game, and no protective equipment is required.

The sex-based differences in concussion incidence may be attributed to several factors. Females have decreased head-neck strength, greater peak angular acceleration, and increased angular displacement compared with males.[9,27,57] Moreover, mechanism of injury may differ between male and female soccer players; females are more likely to incur a head injury due to contact with a playing surface or an apparatus.[13] Additionally, female athletes are more likely to disclose their symptoms to coaches and parents.[59]

Concussion incidence in middle school athletes appears to exceed that in high school and collegiate athletes.[30] Furthermore, more concussions are reported during competition than in practice.[18] A meta-regression analysis of setting, population, and study design showed no effects. This finding was not surprising, as the majority of the studies were retrospective and based on large injury data sets, thus earning "fair" ratings in the quality assessment. Unlike studies that reported increased overall concussion incidence in collegiate athletes compared with high school athletes,[24] our meta-regression included comparisons from multiple studies across multiple sports. When pooled together, it is likely that any potential differences between populations were diminished.

The strengths of this meta-analysis include a comprehensive search strategy with overlapping approaches. In addition, a large amount of data was available for comparison and analysis. The search strategy was developed in consultation with a medical librarian; 1 study has shown that including a librarian as a coauthor improved the quality of the strategy in systematic reviews.[47] Furthermore, we were able to extract data based on setting and population and analyze these factors separately in a meta-regression.

This meta-analysis also had several limitations. First, many of the included studies were based on the same databases (eg, High School RIO or NCAA-ISP). However, the studies covered different date ranges and sports. For sports such as ice hockey and lacrosse, the incidence between male and female athletes may not be directly comparable, given the differences in rules and equipment. Second, the quality assessments of many studies ranged from poor to fair, due to their retrospective design. Of the 38 studies, 31 were scored as "fair," 3 as "good," and 4 as "poor." Third, only English-language studies could be included.

Overall, results from this meta-analysis demonstrate higher concussion incidence in female soccer and basketball players. The exact factors underlying this sex-based difference in concussion incidence for these 2 sports remain unknown. However, it is important for health care providers to recognize this difference when treating patients who participate in soccer and/or basketball.

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