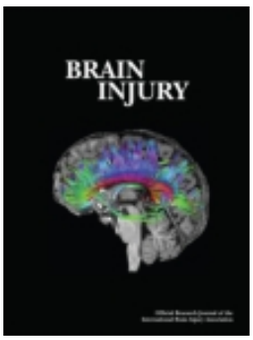

Brain Injury

ISSN: 0269-9052 (Print) 1362-301X (Online) Journal homepage: http://www.tandfonline.com/loi/ibij20

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To cite this article: Jae O. Koh, J. David Cassidy & E. Jane Watkinson (2003) Incidence of concussion in contact sports: a systematic review of the evidence, Brain Injury, 17:10, 901-917, DOI: 10.1080/0269905031000088869

To link to this article: http://dx.doi.org/10.1080/0269905031000088869

BRAIN INJURY, VOL. 17, NO. 10 (OCTOBER 2003), 901–917

Taylor & Francis
healthsciences

Incidence of concussion in contact sports: a systematic review of the evidence

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(*Received 8 May 2002; accepted 13 January 2003*)

Primary objective: To estimate incidence of concussion in contact sports.
Research design: Systematic review of the literature on concussion in contact sports.
Methods and procedures: MEDLINE was searched from 1985–2000. Older articles cited in retrieved articles were also reviewed. Articles meeting the inclusion/exclusion criteria were critically appraised for methodologic quality. The incidence of concussion was recalculated in some cases.
Results: Twenty-three out of 63 identified articles were accepted to estimate the risk of concussion. Overall, ice hockey and rugby have the highest incidence of concussion and soccer has the lowest. Male boxers and female taekwondo participants have the highest frequency of concussion at the recreational level.
Conclusions: There are few good studies on the incidence of concussion and limited information on the risk of concussion for females in contact sports. Some common methodological problems were also identified in this literature with the hope of improving future studies.

Introduction

Concussion is a common type of head injury that can occur in most contact sports. It is defined as traumatically induced physiological disruption of brain function with a short period of altered or loss of consciousness [1]. Past literature indicates that the incidence of concussion in contact or collision sports is higher than in non-contact sports. Although the consequences of a concussion are controversial, there is concern about cumulative effects and the risk of developing long-term behavioural or cognitive problems from multiple concussions. In addition, some studies suggest that athletes who have had a prior concussion have a higher risk of repeated concussions. Such considerations can have a significant impact on the continuance of an athletic career, causing temporary suspension of play and even early retirement in some cases.

In general, injury incidence studies have become useful tools to estimate risk, to identify risk factors and to guide injury prevention. Narrative reviews have also provided broad information on this topic. However, narrative reviews do not have

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Brain Injury ISSN 0269–9052 print/ISSN 1362–301X online
http://www.tandf.co.uk/journals
DOI: 10.1080/0269905031000088869

explicit methods and are, therefore, prone to bias. For example, narrative reviews have no explicit search strategy or method of quality appraisal of articles. On the other hand, a systematic review should be reproducible and have explicit criteria for appraising evidence from articles. [2, 3]. A systematic review could be thought of as an experiment where the unit of analysis is a research paper. These issues of methodology are important when the results of reviews are used to direct athletes' care or to assist the leisure planner and parent in decision-making for the choice of sports or to provide the coach, governing body, manufacturer or medical personnel with the best scientific evidence to promote injury prevention. Moreover, a good systematic review will link conclusions to evidence tables that summarize evidence from accepted articles.

The purpose of this systematic review is to estimate the incidence of concussion in contact sports.

Methods

The method for this systematic review is based on guidelines for systematic reviews published by the Evidence-Based Medicine Working Group [2–5] and methods developed from past experience [6, 7].

For the systematic review, concussion was defined as a mild brain injury resulting from a direct blow (blunt trauma) to the head resulting in physiological changes in brain function. A concussed athlete may experience at least one of the following: any period of loss of consciousness (30 minutes or less); any loss of memory for events immediately before or after the injury (post-traumatic amnesia not greater than 24 hours); any alteration in mental state at the time of the event (e.g. feeling dazed, disoriented or confused); focal neurological deficit(s) that may or may not be transient; and an initial Glasgow Coma Scale (GCS) of 13–15. There should be no evidence of skull fracture or intra-cranial pathology.

The systematic review is focused on cohort studies that documented the incidence (i.e. cumulative incidence and/or incidence density) of a concussion as a result of the following contact sports: American football, boxing, ice hockey, martial arts (judo, karate and taekwondo), rugby and soccer. Boxing and the martial arts were selected because forceful contact between opposing players in these sports is required for earning points. Football and rugby were selected because body contact between opposing players occurs routinely during each play. Ice hockey and soccer were included because of special circumstances in each game that may predispose players to injury. In ice hockey, athletes are at risk of concussion because of the speed at which body contact occurs and the surfaces (ice and boards) that opposing players are checked against. Heading the ball in soccer may place the athletes at risk of concussion.

The systematic review includes all male and female athletes of all ages who took part in one of the eight sport activities, including practice or training and game or competition, regardless of competitive levels.

Literature search and selection of articles

The goal of the search strategy was to be as comprehensive as possible. The first step was to create core concepts (i.e. brain, concussion and sports) using review articles. The second step was to sub-divide those concepts into head, injury, football, box-

ing, hockey and other sports. The third step was to search Medline (1985–2000) using OVID software. This search was based on MeSH terms (brain injuries, brain concussion and incidence) and the text words (mild traumatic brain injury, concussion, incidence, injury, head injury and the eight sports). All search terms were limited to the English language, studies of humans, and the years 1985–2000. The period 1985–2000 was chosen in order to focus on current information, but older papers cited in this literature were also reviewed.

A three-step screening strategy was used to identify the articles to be reviewed. First, the titles were screened by one of the authors. An examination of randomly selected articles that were excluded by title revealed that theses articles addressed sports or injuries that were irrelevant to the purpose. Secondly, the abstracts were subsequently screened for the inclusion and exclusion criteria to identify relevant articles. The inclusion criteria were as follows:

(1) Studies of the incidence of injury to the head or brain.
(2) Article reports results relevant to concussion, mild traumatic brain injury (TBI) or diagnostic criteria that are used for concussion. Also included were other terms such as mild brain injury, minor head injury and mild closed head injury.
(3) Eight contact sports (football, boxing, ice hockey, martial arts (judo, karate, taekwondo), rugby and soccer) were included.
(4) All systematic review articles about mild TBI or concussion were included.
(5) Articles published from 1985–2000.

The exclusion criteria were as follows:

(1) Concussion is due to whiplash injury (no evidence of direct trauma or blunt trauma to the head).
(2) Spinal cord injury, facial bone fracture and soft tissue injuries.
(3) Article reports prevalent, rather than incident, cases of concussion.
(4) Absence of a denominator (athletes at risk or time at risk).
(5) Studies of chronic TBI.
(6) Single case reports or letters to the editor.

In a third screening step, relevant and unknown articles from the abstract screening were reviewed independently for the inclusion/exclusion criteria. Once again, a sample of the excluded articles revealed that they were irrelevant to the purpose.

Assessment of methodological quality, data abstraction and synthesis of results

All articles that met the inclusion/exclusion criteria were critically appraised using general methodological criteria (table 1) for appraising the quality of cohort studies [7]. These criteria were selected to assess the presence of common biases. To be accepted, an article had to meet five of the 11 criteria, including: (1) the source population had to be described; (2) the inclusion/exclusion criteria had to be described and appropriate; (3) the results had to be verifiable from the raw data; (4) the injury occurrence had to be differentiated into practice or game time; and (5) the denominator (population at risk or person-time at risk) had to be adequately measured. Each condition was rated as yes, no or sub-standard. If any of the above five mandatory criteria were rated as no, the article was rejected as scientifically inadmissible.

Table 1. Criteria for the assessment of the methodological quality

General methodological criteria
(1) Research question is clearly stated
(2) Source population is described*
(3) Inclusion/exclusion criteria are described and appropriate*
(4) Number of subjects excluded or refusals before study is reported
(5) Sample size is pre-planned to provided adequate statistical power or precision
(6) Statistical analysis is appropriate
(7) The results are verifiable from the raw data*
(8) The injury incidence is clearly differentiated into practice or game settings*
(9) Important variables are measured (e.g. gender and age) at entry into study
(10) Numerator (concussion) is defied
(11) Denominator (population or person-time at risk) is adequately measured*

*Mandatory criteria for acceptance of article.

In some papers, the incidence rate was re-calculated using the number of concussed athletes as a numerator and the population at risk or person-time at risk as a denominator. Also, 95% confidence intervals were calculated around the incidence estimates.

Results

The results from the literature search and selection of articles are summarized in figure 1. Overall, the search found 559 publications. A title screening of these left 213 abstracts to review. These abstracts were screened for relevance, giving 62 relevant abstracts and 65 abstracts where the relevance could not be determined.

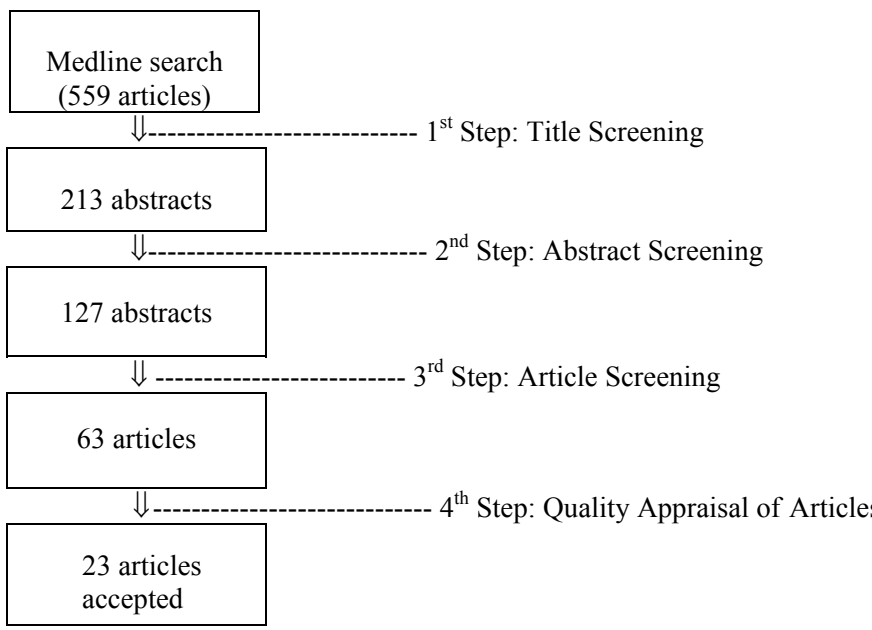

Figure 1. Paper search procedure and results.

The inclusion/exclusion criteria were applied to the full text of these 127 articles. Of those, several papers were excluded since the study subjects or results were duplicated in another paper. Overall, 57 articles were identified as relevant for mild TBI (concussion) in eight contact sports. In addition, six other papers were found by searching reference lists. Therefore, 63 articles were subjected to critical review by the investigators. No study or systematic/narrative review of concussion in judo was identified.

Of the 63 reviewed articles, 40 were excluded because they failed to meet the five methodological quality criteria [8–47]. Most of these papers did not report gender, give a denominator (i.e. athlete or time at risk of injury), report raw data or differentiate risk sessions (either games or practices). Also, three papers were excluded because they were duplicated articles [42–44]. Two studies on concussion of 395 college football teams reported inconsistent numerators (i.e. numbers of concussions in games) and denominators (i.e. numbers of subjects at risk), although the frequency of total concussion from these two papers was identical [44, 48].

In many studies of team sports, time at risk for concussion was not measured accurately, which limits one's ability to determine risk. Few studies reported both 'persons at risk of injury' and 'time at risk of injury' [49–52]. Also, a number of studies did not differentiate whether concussions occurred during training or game time [28–39, 45, 47]. This limitation hinders precise evaluation of the risk of concussion due to the different risks existing in practice and competition. Moreover, most studies used a definition of injury or reportable injury, but only 14 studies [28, 37, 40, 47–49, 51–58] used an explicit definition of concussion. Furthermore, incidence rate computations in some studies were calculated inaccurately or questionably [42, 59, 60]. Thirteen studies did not report the total number of participants [30, 34, 43, 51, 53, 55, 56, 58–63]. In addition, only four out of 63 papers reported previous history of concussion [8, 12, 28, 32]. Finally, four studies did not specify the year of investigation [30, 39, 62, 64]. Only one study included an a priori sample size calculation to ensure an adequate sample to present a stable risk estimate [33].

Taking into account the limitations discussed, information from the 23 accepted articles is presented in tables 2-8, including the incidence rates. For some studies, the rates were recalculated from the raw data. This was done to check the accuracy of published rates or to calculate rates when they were not presented. These tables are based on the studies that have clearly specified gender, sessions (either games or practices) and a re-calculable denominator. Only 23 [48–70] out of 63 relevant papers could be used to estimate the risk of concussion in the selected sports.

Overall, ice hockey shows the highest incidence of concussion amongst the team sports (American football, ice hockey, rugby and soccer) for high school male athletes. However, ice hockey and rugby have similar rates at the professional level. Soccer has the lowest frequency of concussion in high school male athletes among the team sports. Not surprisingly, boxing shows the highest frequency of concussion in terms of time at risk among the three individual sports (boxing, karate and taekwondo) at the recreational and competitive level in males.

There are few studies of concussion in contact sports involving females. Of those, taekwondo shows the highest incidence of concussion, regardless of age.

Table 2. Summary of study characteristics of risk of concussion in American football

Study period	Source population	Denominator	Injury definition and number of concussions	Author's incidence	Recalculated incidence and 95% confidence intervals (CI)*
1975–1982 [48]	395 US college teams (males)	3 012 063 AE in practices and 216 691 AE in games	Immediate impairment of neural function including all signs, symptoms, and sequelae. Overall 2124 concussions; 725 game-related concussions.	6.6/10 000AE in games and practices.	3.35 (95% CI, 3.10–3.59)/1000 AE in games and 0.46 (95% CI, 0.44-0.48)/1000 AE in practices.
1995–1997 [51]	235 US high schools (males)	21 122 player-seasons	Cessation of participation for initial observation and evaluation before returning to play. Total of 773 concussions.	0.25 (95% CI, 0.16-0.34)/1000 practice exposures and 2.82 (95% CI, 2.58-3.07)/1000 game exposures.	

* Incidence was recalculated in some cases. 95% confidence intervals were also calculated, if not presented in the original paper.
AE = Athlete Exposures; MTBI = Mild Traumatic Brain Injury.

Table 3. Summary of study characteristics of risk of concussion in boxing

Study period	Source population	Denominator	Injury definition and number of concussions	Author's incidence	Recalculated incidence and 95% confidence intervals (CI)*
1982–1983 and 1983–1984 [54]	Professional boxers in New York State	3110 rounds (1636 from 82–83 and 1474 from 83–84).	Any technical knockout or knockout from head blows. Total of 262 craniocerebral injuries (138 from 1982–1983; 124 from 1983–1984).	0.8/10 rounds (2.9 injuries/10 boxers from 1982–1983 and 2.9 injuries/10 boxers from 1983–1984).	Overall 0.8 (95% CI, 0.75-0.95)/10 rounds; 0.8 (0.71-0.99)/10 rounds for 1982–1983; 0.8 (0.70-0.99)/10 rounds for 1983–1984.
Nov. 1992–May 1993 [58]	Amateur boxing competitors in Dublin, Ireland	4170 man-minutes for competitions. Not reported for training sessions.	The early stoppage of the contest and/or time loss and/or preventing competing maximum potential. Overall 33 concussions.	51.6% in competitions; 0% in training.	7.9 (95% CI, 5.45–11.09)/1000 man-minutes in competition.
1983–1984 and 1984–1985 [70]	US Military Academy in West Point, New York (males)	23 625 hours for instructional programme; 1680 hours for competitive phase programme.	Excused from physical activity for more than 1 day. Total of 22 concussions (18 from the instructional phase and four from the competitive phase).		0.76 (95% CI, 0.45-1.2)/1000 hours for instructional phase; 2.4 (0.65-6.1)/1000 hours for competitive phase.

* Incidence was recalculated in some cases. 95% confidence intervals were also calculated if not presented in the original paper.

Table 4. Summary of study characteristics of risk of concussion in ice hockey

Study period	Source population	Denominator	Injury definition and number of concussions	Author's incidence	Recalculated incidence and 95% confidence intervals (CI)*
Two consecutive seasons [64]	14 randomly chosen Danish elite hockey teams	Training time of 5.3 hours a week over 8 months; playing time of 50 minutes per player per week in 5 months; 18 matches 60 minutes per season.	Hindered activity, and/or required special treatment. Total of 27 concussions; six from training; 21 from matches.	14.3 %.	0.16 (95% CI, 0.06–0.35)/1000 training-hours; 6 (95% CI, 3.7–9.2)/1000 game-hours.
Three days (1994) [68]	High schools in Minnesota (1994 Junior Gold ice hockey tournament, males)	1099 athlete-exposures; 213.9 player-hours.	Requiring assistance from the athletic trainer and time loss. Total of four concussions.		18.7 (95% CI, 5.1–47.1)/1000 player-game hours; 3.6 (95% CI, 0.99–9.29)/1000 athlete exposures.
1988–1992 [60]	Swedish elite ice hockey league	7536 player-game hours (~70% of all player-game hours in the league during four seasons).	Concussion with loss of consciousness. Total of 49 concussions.	6.5/1000 player-game hours	6.5 (95%CI, 4.8–8.6)/1000 player-game hours.
Sept. 1979–May 1985 [56]	Canadian Intercollegiate ice hockey (males)	9424 player-games (including league and non-league).	Professional attention or time loss. Total of 14 concussions.	7.5%.	1.5 (95%CI, 0.8–2.5)/1000 player-game hours.
1993–1994 season [67]	High school varsity, Junior Gold (males); Girl's Peewee in Minnesota (females)	511.2 player-game hours(PGH), 2320 athlete exposures (AE) for males (86.4 PGH, 401AE for Peewee A; 93.6 PGH, 410AE for Bantam A; 108PGH, 410AE for High school; 223.2PGH, 1099AE for Junior Gold); 79.2 player-game hours, 357 athlete exposures for Girl's Peewee A&B.	Injury evaluated by the medical personnel, time loss or dental injury (NAIRS and CAIRS [71]). Total of nine concussions.	17.6/1000 player-game hours during boy's games (Peewee boys, 23.1/1000 PGH; Bantam, 10.7/1000 PGH; Junior Gold, 18.7/1000 PGH; High school varsity, 18.5/1000 PGH).	17.6 (95% CI, 8.1–33.2)/1000 player-game hours during boy's games; 3.9 (1.8–7.4)/1000 athlete-exposures.

*Incidence was recalculated in some cases. 95% confidence intervals were also calculated if not presented in the original paper.
CAIRS = Canadian Athletic Injury/Illness Reporting System; NAIRS = National Athletic Injury Reporting System; AE = Athlete-Exposures; PGH = Player-Game Hours.

Table 5. Summary of study characteristics of risk of concussion in karate

Study period	Source population	Denominator	Injury definition and number of concussions	Author's incidence	Recalculated incidence and 95% confidence intervals (CI)*
1976–1979, 1982 [69]	Six national/ inter-national Karate tournaments: (males from 14 countries)	309 matches	Grade 1: injured, but able to continue competition; Grade 2: injured and forced to withdraw from competition; Grade 3: injured and required hospitalization. A total of one concussion.		618 athlete-exposures; 3.24 (95% CI, 0.08–17.89)/1000 matches or 1.62 (0.04–8.98)/1000 athlete-exposures.

* Incidence was recalculated in some cases. 95% confidence intervals were also calculated if not presented in the original paper.

Table 6. Summary of study characteristics of risk of concussion in taekwondo

Study period	Source population	Denominator	Injury definition and number of concussions	Author's incidence	Recalculated incidence and 95% confidence intervals (CI)*
1988-1991 [49]	US National Senior Championships and US Team Trials (males and females)	3408 AE, 25 383 ME for males; 1654 AE, 12 961 ME for females.	Assistance was sought from medical personnel and Nelson *et al.*'s [72] concussion classification used. 28 concussions (24 for males and four for females).	7.04/1000 athlete exposures, 0.95/1000 minute exposures for males; 2.42/1000 athlete exposures, 0.31/1000 minute exposures for females.	7.04 (95% CI, 4.5–10.46)/1000 AE and 0.95 (0.61–1.41)/1000 ME for males; 2.42 (0.66–6.18)/1000 AE and 0.31 (0.08–0.79)/1000 ME for the females.
1991 [57]	World Championships (49 countries, males and females)	Raw exposure data not reported.	Serious injuries that lead to time-loss and Nelson *et al.*'s [72] concussion classification used. Nine concussions (eight males and one female).	15.27/1000 athlete exposures for males; 3.23/1000 athlete exposures for females.	Approximately 523.90 AE for males and 306.60 AE for females. 15.3 (95% CI, 6.6–29.86)/1000 AE for males; 3.2 (0.08–18.07)/1000 AE for females.
1993 [66]	European Cup (16 countries, males and females)	258 AE for males; 114 AE for females.	Injuries that occurred in the ring or during the warm-up that were brought to the attention of the medical personnel. Five concussions (four males and one female).	15.50/1000 athlete exposures for males; 8.77/1000 athlete exposures for females	15.5 (95% CI, 4.24–39.2)/1000 AE for males; 8.77 (0.22–47.9)/1000 AE for females.
1989-1990 [50]	US National Junior and unofficial Junior World Championships (males and females)	6068 AE, 21 894 ME for boys; 1538 AE, 5855 ME for girls	Discontinuing the present bout and/or subsequent bouts and practice. 38 concussions (31 boys and seven girls).	5.11/1000 AE for boys; 4.55/1000 AE for girls.	5.1 (95% CI, 3.47–7.24)/1000 AE and 1.42 (0.96–2)/1000 ME for boys; 4.6 (1.83–9.36)/1000 AE and 1.2 (0.48–2.46)/1000 ME for girls.
1999 [52]	14th World Championships (66 countries, males and females)	596 AE, 5304 ME for males; 422 AE, 3786 ME for females.	A trauma induced alteration in mental status that may or may not involve loss of consciousness. Eight concussions (six males and two females).	10.07/1000 AE, 1.13/1000 ME for males; 4.7/1000AE, 0.53/1000 ME for females.	10.1 (95% CI, 3.7-21.8)/1000 AE and 1.1 (0.4–2.5)/1000 ME for males; 4.7 (0.6–17)/1000 AE and 0.5 (0.06-1.9)/1000 ME for females.

* Incidence was recalculated in some cases. 95% confidence intervals were also calculated if not presented in the original paper.
AE = Athlete Exposures; ME = Minute Exposures.

Table 7. Summary of study characteristics of risk of concussion in rugby

Study period	Source population	Denominator	Injury definition and number of concussions	Author's incidence	Recalculated incidence and 95% confidence intervals (CI)*
1996 [59]	The first team at one professional rugby league club (European Super League season, UK)	596.5 player-hours for winter; 397.67 player-hours for summer.	Impairment preventing participation in the next competitive game. Total of nine concussions (eight winter and one summer).	3.35/1000 player-hours in winter**; 2.51/1000 player-hours in summer	9.05 (95% CI, 4.1-17.1)/1000 player-game hours: 13.41 (95% CI, 5.8-26.23)/1000 player-game hours in winter; 2.51 (0.06–13.95)/1000 player-game hours in summer.
1979 rugby union season [55]	Club and representative matches at Ballymore in Brisbane.	221 matches, 8365 player-hours.	Any period of unconsciousness, confusion, amnesia, unsteadiness or altered vision whether or not neurological signs are present. Total of 24 concussions.		2.87 (95% CI, 1.84-4.27)/1000 player-hours.
1979, 1980, 1982 [65]	Senior Victorian Football League players, Australia.	29 568 game-hours.	Attention of the club medical officer, requiring active treatment and interfering with subsequent play or training. Total of 74 concussions.		2.5 (95% CI, 1.9-3.1)/1000 player-game hours
1989–1991 [61]	Three teams of the South Sydney Rugby League Football Club (only games).	3140 player-position game hours.	A player missing subsequent games. Total of 75 concussions.		1.6 (95% CI, 0.52-3.71)/1000 player-position game hours.
1990–1994 [53]	One professional rugby league club in UK (only games).	4305.21 player-hours. A total of 249 games.	Concussion with or without loss of consciousness and memory problems. Total of 35 concussions.	8 (95% CI, 6–11)/1000 player-hours.	
Sept. 1950–Dec. 1979 [63]	Rugby School	500 000 player-hours.	Injury led to at least 1 week's absence from the game. Total of 513 concussions.		10.26/10 000 player-hours or 1.03 (95% CI, 0.94–1.12)/1000 player-game hours.

*Incidence was recalculated in some cases. 95% confidence intervals were also calculated if not presented in the original paper.
**Calculation of the winter concussion rate is not correct based on the given denominator (596.5 player hours).

Table 8. Summary of study characteristics of risk of concussion in soccer

Study period	Source population	Denominator	Injury definition and number of concussions	Author's incidence	Recalculated incidence and 95% confidence intervals (CI)*
1995–1997 [51]	235 US high schools (males and females)	7539 player-seasons for boys; 5642 player-seasons for girls.	Cessation of participation for initial observation and evaluation before returning to play. Total of 69 concussions for males and total of 76 concussions for females.	0.18 (95% CI, 0.14–0.22)/1000 athlete exposures, 0.04 (0.01–0.06)/1000 practice exposures, 0.57 (0.43-0.72)/1000 game exposures for males. 0.23 (0.18–0.28)/1000 athlete exposures, 0.05 (0.02–0.08)/1000 practice exposures, 0.71 (0.53–0.88)/1000 game exposures for females.	
Seven weeks (year?) [62]	A local indoor soccer arena (US Soccer Federation regulations for indoor soccer, males and females)	2700 player-hours; 1548 player-hours for males; 1152 player-hours for females.	Injury requiring medical attention and stopped the game. Two concussions in males		0.13/100 player-hours for males or 1.3 (95% CI, 0.16–4.66)/1000 player-game hours for males.

* Incidence was recalculated in some cases. 95% confidence intervals were also calculated if not presented in the original paper.
? = Not reported or not clearly reported; M = male and F = female.

Discussion

A full discussion of the incidence of concussion in team sports must acknowledge that the rules, techniques and strategies of a particular game may significantly predispose athletes to concussion. Football linemen, for example, frequently use their heads and shoulders to contact the opponent with considerable force, while this is illegal in soccer. However, shoulder contact can be made against a soccer opponent if they have possession of the ball. In the case of soccer, head contact occurs when heading the ball. Furthermore, significant differences in player roles may predispose some player positions to concussion and not others. Specific local, national or international rules regarding contact may influence the incidence of concussion in different age groups (e.g. Masters level ice hockey) and in women (e.g. in ice hockey). Overall, one would expect to see an increased incidence of concussion in sports involving frequent forceful contact such as hockey, football, taekwondo and boxing, and lower rates in sports, such as soccer, where contact between players is less frequent.

Overall, ice hockey shows the highest incidence of concussion among the four sports for high school, college and amateur adult males. Although ice hockey and American football players wear full equipment compared with rugby and soccer players, the incidence of concussion in the former sports is higher. One possible reason for this phenomenon is over-reliance on protective equipment. Athletes who use full protective equipment may believe they are protected from injurious forces and may tend to be more aggressive and violent. Furthermore, protective equipment, especially helmets, may not be properly placed or secured and may not be of suitable size or quality. For safety reasons, athletes, coaches and sport governing bodies should not ignore these issues.

Boxing shows the highest frequency of concussion among the three individual sports. Interpretation of these results requires caution due to potential information bias. For example, the definition of concussion used in each study may not be the same. In boxing, a knockout or any technical knockout is often used as a definition of concussion. However, all technical knockouts do not always result in concussion [54]. Therefore, the incidence of concussion in boxing might be over-estimated. On the other hand, in other sports, including team sports, the incidence of concussion may be under-reported or under-estimated due to a lack of concern when no apparent loss of consciousness is present. In order to compare the risk of concussion across sports, a valid and uniform definition of concussion is required.

The literature search yielded no studies on judo, which involves much physical contact during matches and training. The authors need more research on concussion in this sport. There are also insufficient studies of injury in contact sports involving females. Of these, taekwondo shows the most frequent occurrence of concussion, regardless of age. This may be due to the large number of female participants in taekwondo and to the nature of competition taekwondo, which promotes attacking the face and head using kicking techniques. The governing bodies of this sport might need to reconsider the safety of this approach.

In this review, only 23 articles could be used to estimate risk of concussion in the sports under study. In other words, only 37% out of all relevant research papers (63 papers) were useful to measure risk of concussion in this review.

Several general methodological problems were identified in the studies reviewed. First, the source population was not always clearly identified, including

characteristics such as gender, age, country and the year of the data collection. Secondly, the inclusion and exclusion criteria for many studies were not reported. Thirdly, raw data were not always reported, such as exposure data and the frequency of injury. Fourthly, only one study reported a pre-planned sample size, which helps to plan better precision around incidence estimates [33].

Other limitations were found in the studies reviewed. Some studies failed to identify whether injuries occurred during game or practice or the level of competition of the sport under study. Reported concussion rates were often combined from game and practice sessions. Also, only four studies reported on previous history of concussion. This issue is very significant in terms of adequate measurement of exposures, since the risk of concussion may be higher for someone who has had a concussion in the past. [8, 12, 28, 32]. In addition, the denominator (number of persons or person-time at risk) was roughly measured in many team sports. Also, substitute players were not always included in the calculation of both persons at risk of injury and time at risk of injury. In some cases, calculations of results were incorrect or difficult to reproduce. Finally, many studies did not have an explicit definition of concussion. Future studies on the incidence of concussion should address these issues.

The findings from the present systematic review are significant in terms of identifying the incidence of concussion in eight different sports. These rates may be useful guides for future studies of prevention. However, few good studies were found on the incidence of concussion in contact sports and a lack of research on concussion for females in contact sports and judo. Furthermore, there are some significant methodological limitations in this literature and considerable scope for improvement for future studies. In this respect, future studies should address the methodological criteria listed in table 1.

Acknowledgement

The authors would like to acknowledge Lori Giles-Smith, MLIS, for her assistance with the literature search. Dr Cassidy is supported by a Health Scholar Award from the Alberta Heritage Foundation for Medical Research.

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