Estimating Concussion Incidence Using Sports Injury Surveillance Systems

Complexities and Potential Pitfalls

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KEYWORDS

• Concussion • Surveillance • Sports injury • National Collegiate Athletic Association • High School Reporting Information Online • Traumatic brain injury

KEY POINTS

- Numerous sports injury surveillance systems exist with the capability of tracking concussion incidence data, but it is important to understand their strengths and limitations.
- Current sports injury surveillance lacks access to sports with lower visibility and settings that lack medical staff.

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- Potential variations in the definitions of injury and at-risk exposure may affect comparability across findings.
- Sports injury surveillance is able to assess both the immediate and longitudinal effects of rule/policy changes.

INTRODUCTION

Concussions remain a high-profile topic given the research that has elucidated both potential short- and long-term effects.[1–4] Because of this burgeoning research, it is imperative to obtain valid and reliable estimates of concussion incidence.[5] Although estimates related to those individuals presenting at emergency departments or other traditional health care system touchpoints are important,[6–10] they do not fully capture the breadth of concussions that occur as a result of participation in sport and recreational activities.[10–14] Partially because of this known limitation, numerous studies have utilized sports injury surveillance systems to estimate the incidence of sport-related concussion across multiple levels of competition, including youth,[10,15–17] high school,[14–16,18–24] collegiate,[15,16,25–28] and professional[29–35] (**Table 1**). These estimates can be used to monitor trends over time, help identify individuals most at risk, examine the settings and characteristics that exacerbate risk, inform the development of interventions/prevention strategies to reduce the incidence and severity of concussion, and help improve management and care. In addition to research and clinical uses, surveillance findings can be informative to the numerous stakeholders within a sports setting, including parents, players, coaches, policy makers, and industry.[36]

Like all public health surveillance systems, sports injury surveillance systems are focused on capturing and distributing timely information that monitors a clearly defined problem. Given these time pressures, the data captured by surveillance systems are not guaranteed to be high-quality research data. Thus, it is important for all consumers of the sports injury surveillance data to understand the strengths and limitations of estimating sport-related concussion incidence using data captured by sports injury surveillance systems.

Previous research examining general methodologies and data quality of sports injury surveillance systems[37,38] was broad and did not examine specific injuries such as concussion. This article describes some issues pertinent to system design and data analysis that can affect the interpretation and understanding of concussion incidence data captured by sports injury surveillance systems. Such understanding will help improve decision making based on these data and could inform the design of future sports injury surveillance systems and research studies aiming to identify risk factors and develop and evaluate prevention strategies.

WHO COLLECTS THE DATA?

To date, most sports injury surveillance systems have relied upon sports medicine clinicians to collect and report data. In some parts of the world (eg, Europe, Australia, New Zealand), sports injury surveillance systems have traditionally been established in settings where athletic teams are covered by trained sports medicine clinical teams including physiotherapists and physicians.[33,34] In those settings, the team medical staff is capable of collecting and reporting high quality data to sports injury surveillance systems. In the United States, such extensive clinical coverage is usually

Table 1
Sampling of sports injury surveillance systems capturing published concussion data

Sports Injury Surveillance System[a]	Athletes	Type of Sample	Data Collectors	Concussion Definition Provided	Concussion Rates Sports Included in Estimate	Study Period	Estimate[b]
Youth							
Youth Football Safety Study (YFSS)	Youth football players aged 5–15 y	Convenience	Athletic trainers	No definition provided, but after its publication, ATs were encouraged to follow Zurich Consensus Statement on Concussion in Sport[67]	Football	2012/13–2013/14 seasons	0.99 concussions per 1000 AEs[17]
High school							
National High School Sports-Related Injury Surveillance System, High School Reporting Information Online (HS RIO)	High school student-athletes from a large national sample of schools	Stratified random sample and concurrent convenience sample	ATs	No definition provided	Boys' football, wrestling, soccer, basketball, baseball; Girls' volleyball, soccer, basketball, softball	2011/12 academic year	0.51 concussions per 1000 AEs[20]

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Table 1
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National Athletic Treatment, Injury and Outcomes Network (NATION)	High school student-athletes	Convenience	ATs	No definition provided, but after its publication, ATs were encouraged to follow Zurich Consensus Statement on Concussion in Sport[67]	Boys' football	2012/13–2014/15 academic years	Game: 1.16 concussions per 1000 AEs; Practice: 0.47 concussions per 1000 AEs[16]
North Carolina High School Athletic Injury Study (NCHSAIS)	High school student-athletes within the North Carolina High School Athletic Association (NCHSAA)	Stratified random	AT or athletic director	Congress of Neurological Surgeons Committee on Head Injury Nomenclature definition	Boys' football, wrestling, soccer, basketball, baseball, track; Girls' soccer, basketball, softball, track; Cheerleading	1996/97–1998/99 academic years	0.17 concussions per 1000 AEs[22]
National Athletic Trainer Association (NATA) injury surveillance program	High school student-athletes from a large national sample of schools	Stratified cluster sample	ATs	No definition provided	Boys' football, wrestling, baseball, soccer, basketball; Girls' volleyball, field hockey, softball, soccer, basketball	1995/96–1997/1998 academic years	Reported separately per sport[24]

Fairfax County Public School System Injury Surveillance Database	All high school student-athletes from a large public school system	Census	ATs	Based upon examination of the athletic trainer	Boys' football, wrestling, soccer, basketball, lacrosse, baseball; Girls' field hockey, soccer, basketball, lacrosse, softball, cheerleading	1997/98–2007/08 academic years	0.24 concussions per 1000 AEs[21]
College							
NCAA Injury Surveillance Program (ISP)	NCAA student-athletes	Convenience	ATs	No definition provided, but after its publication, ATs were encouraged to follow Zurich Consensus Statement on Concussion in Sport.[67]	Men's football, wrestling, ice hockey, soccer, basketball, lacrosse, baseball; Women's volleyball, ice hockey, soccer, basketball, lacrosse, baseball	2011/12–2014/15 academic years	0.55 concussions per 1000 AEs[25]
Professional							
MLB Health and Injury Tracking System (HITS)	All major and minor league baseball players within the MLB	Census	ATs and team physicians	Zurich Consensus Statement on Concussion in Sport definition[67]	Baseball	2011–2012 seasons	0.42 concussions per 1000 AEs[32]

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Table 1
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NHL- NHL Players Association (NHLPA) Concussion Program	All professional ice hockey players within the NHL	Census	Team physicians	Internal definition, followed by 2001 Consensus Statement on Concussion in Sport definition[92]	Ice hockey	1997/98–2003/04 seasons	1.8 concussions per 1000 game player-hours[31]
NFL Injury Surveillance System (ISS)	All professional football players within the NFL (game only)	Census	Team physicians and athletic trainers	Internal definition provided by the NFL Mild Traumatic Brain Injury (MTBI) committee[93]	Football	2002/03–2007/08 seasons	0.19 concussions per team-game[29]
Australian Football League (AFL) annual injury survey	All professional Australian Football Players	Census	Team medical staff	No definition provided, only injuries requiring the player to miss a match recorded	Australian Rules Football	2003–2012 seasons	0.5 concussions per club-season[33]
England Professional Rugby Injury Surveillance Project	13 English Premiership Rugby Union clubs	Convenience	Team Medical Staff	2001 Consensus Statement on Concussion in Sport definition[92] and Maddocks questions[94]	Rugby	2002/03, 2003/04, and 2005/06 seasons	4.1 concussions per 1000 player-hours[34]
Qatar Stars League (QSL) Injury Surveillance	7–10 QSL Clubs per season	Census (study used subsample)	Team medical staff	Based upon examination of the team medical staff	Soccer	2008/09–2011/12 seasons	0.016 concussions per 1000 player-hours[35]

[a] Only sports injury surveillance systems with publications specific to concussion were included; when multiple publications regarding concussion were available, only those publications with the most recent data were included.
[b] If sports injury surveillance systems include multiple sports, only the concussion rate reported across all sports is shown in this table.

available only to athletes competing in the professional or upper level collegiate settings.[29,31,32] Youth and high school sports are usually covered by only a shared athletic trainer (AT), if they have any on-site medical coverage at all.[39] Thus, several existing surveillance systems covering youth and high school sports have utilized ATs as data reporters (see **Table 1**). When compared with physicians, ATs provided comparable injury reports, particularly for concussions.[40]

Research at the high school level found that ATs were more likely to report more injury and exposure data than coaches.[41] Using coaches to report injury data can be challenging, because they are not as educated as ATs regarding the identification of concussion. They are first and foremost focused on coaching duties, and may not regularly keep detailed injury logs. They may also feel pressures to win, which could influence their decision making regarding pulling athletes with suspected concussions from play and reporting those injuries.

As an alternative, parents have been used as data collectors or as assistants to clinical data collectors.[42,43] In 1 youth soccer study, each team designated an assistant coach or parent to record exposure data. When an injury occurred, this designee initiated the injury tracking form, which was then completed by an onsite AT.[42] In another study, both ATs and parents reported injuries via Web-based surveys with good agreement noted.[43] With the lack of AT resources in many youth and high school settings,[39,44] coupled with the influx of injury tracking devices on handheld mobile devices, it may be feasible for parents to report concussion data. However, future research is needed to establish the validity and reliability of parent reports of concussion. As demonstrated previously, while it is not always feasible, when available, trained sports medicine clinicians should be utilized to collect and report injury data to sports injury surveillance systems.

WHAT SPORTS ARE INCLUDED?

Sports such as football and soccer have typically been included in large numbers in previous sports injury surveillance systems (see **Table 1**). In fact, football comprises a large proportion of participation in organized high school and collegiate sports[45,46] and is estimated to comprise the largest proportion of all concussions within high school and collegiate sports.[23,25] Yet, it is imperative to generate estimates of concussion incidence among under-represented sports to help identify sport-specific risk factors and prevention strategies. Other sports, such as golf, beach volleyball, and sailing, are seldom examined, which may be due to lower participation numbers in those sports or these sports being perceived as low risk. A recent study examined a small sample of crew injuries in high school,[47] but numbers for concussions were limited. What may be of the utmost concern is that sports not traditionally included in prior sports injury surveillance systems may have higher concussion incidence. For example, surveillance on rugby concussions is limited in the United States; however, 1 study examining injuries in football and rugby across 3 seasons at 1 National Collegiate Athletic Association (NCAA) member institution found that concussion rates were higher in rugby than football.[48] Potentially high concussion rates may also be present in low-visibility sports, such as water polo, equestrian, and figure skating.

In addition, the sports included in prior sports injury surveillance systems have varied widely. Thus, readers should compare all-sport concussion rates from various surveillance systems with caution. Including sports with lower concussion incidence will naturally reduce the resulting all-sport concussion rate. For example, when examining data from the National High School Sports-Related Injury Surveillance System, High School Reporting Information Online (HS RIO) during the 2008/09 to 2009/10 academic years,[18] the all-sport concussion rate was 2.5 concussions per 10,000 athlete exposures (AEs) ; however, when excluding the sports with concussion rates under 1.0 concussions per 10,000 AEs (boys' baseball, track/field, swim/dive, and girls' gymnastics, volleyball, swim/dive, and track/field), the resulting all-sport concussion rate was 3.5 concussions per 10,000 AEs.

At the same time, there is debate given what activities are even eligible to be considered sport and thus, included in sports injury surveillance. **Table 2** presents the definitions of sport provided by: the NCAA, the US Department of Education's Office for Civil Rights (OCR), and the Women's Sports Foundation (WSF). All 3 organizations utilize criteria that specify: athletic physical activity, whether explicitly or implicitly stated, competition, and administration of the sport by staff and/or rules. However, such criteria hinder some organized physical activities from being considered a sport. For example, competitive cheerleading requires great gymnastic ability from its participants,[49] is considered a sport under Title IX in many states,[50] and has oversight from The National Federation of State High School Associations (NFHS).[51] But within the NCAA, cheerleading is not considered a sport, and thus does not need to abide by NCAA by-laws restricting practice durations and frequencies, requiring coach certification and concussion education, and ensuring safe practice facilities and equipment, as done with sanctioned sports.[52] Cheerleading has been included in HS RIO but historically not been included in the NCAA-ISP, a direct reflection of the difference in NFHS and NCAA categorization of cheerleading. In the context of OCR or WSF definitions, cheerleading is also not considered a sport, as cheerleading's primary purpose is to cheer for a competitive team on the sidelines, not compete against other teams, although many cheer squads compete in regional and national competitions.[53] In addition, a US judge in Connecticut ruled that cheerleading is too undeveloped and unorganized to be suitably labeled a competitive sport.[54] Yet, the need to examine such an activity is essential given recent high school sports injury surveillance data on concussion reported that practice concussion rates in cheerleading are higher than many sanctioned sports.[55] Other examples of the blurred lines of what is and is not a sport include nonschool-sanctioned sporting activities, such as pick-up basketball, or nontraditional sports such as snowboarding, skateboarding, or rock climbing. Because of the inevitable financial and personnel limitations, all sports injury

Table 2
Criteria for organizations' definition of sport

Organization	Criteria
National Collegiate Athletic Association[95]	• An institutional activity involving physical exertion with the purpose of competition within a collegiate competition structure • At least 5 regularly scheduled competitions within a season • Standardized rules with official rating/scoring systems
US Department of Education's Office for Civil Rights[96]	• Athletic ability • Athletic competition • Preparation similar to other athletic teams • Multilevel championship competitions • Administration by an athletics department
Women's Sports Foundation[96]	• Physical activity involving mass resistance • Against/with an opponent • Governing rules • Skill-based competition

surveillance studies are faced with difficult decisions regarding which sports should be covered, and little consensus exists.[56]

DEFINING AT-RISK EXPOSURE TIME

In many epidemiologic studies, calculating at-risk person time is straightforward. At-risk person time is continuous (ie, the populations of concern are always at risk for the disease outcome by simply being alive). In sports injury epidemiology, at-risk person time is staggered, comprised of times at which athletes compete, practice, and/or train. Accurately defining at-risk exposure time is of the utmost importance if valid between-sport comparisons are to be made. An objective time measure (ie, hours and minutes) would seem the most logical method of tracking at-risk person time, and this has been proposed by previous researchers as the preferred method of capturing athlete exposure.[57,58] However, sports settings vary widely across geographic locations, competitive levels, and age groups; thus, it may simply be unrealistic for data collectors in some surveillance systems to be able to capture such detailed exposure data. For example, in the US high school setting, where 1 AT covers all sports, it is impossible for that single AT to be present at every school-sanctioned competition and practice for every sport simultaneously to track every athlete's participation to the exact minute. Furthermore, one must consider the true concept of being at risk. For example, even those surveillance systems capable of capturing exposure as athlete minutes still fail to accurately capture the exact amount of time an athlete is at risk at practice (ie, actually active rather than listening to coaches or watching as other athletes take their turn in drills). Even in competition, accurately capturing minutes at risk can be difficult. For example, in football, should one include all the time in which the game clock is running, or only the time when athletes are actually directly involved in sport-specific physical activity? A *Wall Street Journal* article[59] estimated that each 60 minute football game is comprised of only approximately 11 minutes of time that the ball is in play. For other sports, such as baseball, there can be even more disparity between the length of a game and the number of minutes any individual athlete is actual at risk of injury from sport-specific physical activity.[60]

AEs are a common alternative to tracking at-risk time and have been recommended.[38] The AE is a measure of activity (eg, practices attended, games played in) rather than time (eg, athlete minutes, person years), and is thus an abstract estimate of at-risk person time. Prior surveillance systems have defined AE as "one athlete's participation in a practice or competition."[61] The quantification of AEs is more feasible for most surveillance systems than measuring minutes played/practiced by each athlete, because it only requires the knowledge of an athlete's attendance at practice or competition, not their specific activities within each. Yet, the AE presents a paradox in which it may be simultaneously a superior and inferior measure of at-risk time compared with minute-based measures. Consider the following scenario. During a high school football game, a kicker and quarterback are both injured in the last minutes of the first quarter, and leave the game. The at-risk time for both players would be 1 AE. With a minute-based exposure, the at-risk time for the kicker, who is on the field for only a few plays a game, is far less than that of the quarterback. Is it accurate then to state the quarterback has the same at-risk time? In this scenario, the AE may overestimate injury risk among athletes who play sparingly. Considering another scenario, the quarterbacks from 2 opposing teams both sustain similar injuries with similar severities from a clinical perspective, but one is injured in the first minute of the game while the other is injured in the last minute of the game. The at-risk time for both quarterbacks would be 1 AE, but using a minute-based exposure, one quarterback's at-risk time would be far less than the others, due to leaving the game earlier. However, both will likely face similar rehabilitation needs and similar time loss from play. Additionally, both attended practices and trained with the team, and were on the roster for the entire season consuming the same team resources (uniforms, travel, food, coaching, medical care). Use of a minute-based exposure, if scenarios like this occur over the course of seasons in large population samples, will introduce a healthy player bias similar to the previously reported healthy worker bias.[62] Therefore, it may make sense to treat their at-risk exposure as comparable.

Another complex decision is which athletes on a team contribute exposure. Athletes listed on the game roster for each competition may be counted as having a competition AE, regardless of whether they played in the game, if they participated in precompetition warm-ups. One method, known as the athlete-participation model, includes all athletes on the roster, regardless of playing time. This method has the potential to underestimate injury rates.[57,63] In this scenario, the magnitude of the underestimation will depend on the ratio of athletes on the roster to the number of athletes who played in that game.[63] In addition, if an injury took place during pre-game warm-ups, this is counted as a competition-related injury, when in reality it did not occur during competitive play. These scenarios, as well as those provided previously, demonstrate the difficulty in declaring 1 measure of exposure preferred over others. Researchers must be diligent in documenting how data were collected, and readers must be aware of these nuances. These considerations are especially important when comparing information across multiple studies using different estimates of time at risk. **Table 1** highlights the use of a variety of at-risk exposure time measures in prior sports injury surveillance systems.

Alongside the specific measurement of at-risk exposure time, defining the parameters of when injuries occur is essential. Many sports injury surveillance systems will track concussions that occur in competitions and practices sanctioned by the overarching organization (eg, league,[15,16] high school,[15,16,18] NCAA[64,65]). However, publications using the National Football League (NFL) Injury Surveillance System (ISS) and National Hockey League (NHL)-NHL Players Association (NHLPA) Concussion Program only included competition concussion data.[29,31] This is a limitation as it fails to provide data on the frequency of practice-related concussions. Although concussion rates are higher in competitions for most sports, many have large absolute numbers of practice-related concussions.[18,25] Also, most players on a squad participate in practice while not all play in competitions, which means more individual athletes are at risk during practices, particularly during game-speed, full-contact drills and scrimmages.[66]

There are additional settings and scenarios outside competition and practice that may be underexamined. For example, many surveillance systems do not collect data from individual training or weightlifting sessions that occur outside of formal practice sessions.[18,65] Also, surveillance systems often exclude nonsport-related concussions (eg, falls, motor vehicle crashes), even when such injuries occurred during team-related activities (eg, fall in locker room or team travel). Capturing such concussions that occur outside team-sanctioned sport-specific physical activities is arduous and likely not possible for many sports injury surveillance systems. Thus, this will likely remain another area of variation across surveillance systems that researchers must clearly define, and readers must understand.

DEFINING INJURY/CONCUSSION

Rather than providing a specific definition of concussion, most prior sports injury surveillance systems have instead relied upon the professional judgment of the sports medicine clinicians serving as data collectors and reporters (see Table 1). This is both, because sports medical professionals such as ATs and team physicians typically maintain a good, up-to-date, knowledge base regarding concussions and because currently numerous professionally accepted definitions of concussion exist.[67] In some surveillance systems, a working clinical definition is endorsed. For example, ATs participating in sports injury surveillance programs, such as NCAA Injury Surveillance Program (NCAA-ISP), the National Athletic Treatment, Injury and Outcomes Network (NATION), and Youth Football Surveillance System (YFSS),[15,16] have, in recent years, been encouraged to follow the definition provided by the Consensus Statement on Concussion in Sport.[67] The NFL ISS and NHL-NHLPA Concussion Programs instead provide internally created frameworks for concussion reporting.[27,29]

Defining concussion consistently across studies is complex given that concussion injuries have varying effects among athletes, and diagnosis and management of such injuries varies by clinician.[68] Whereas orthopedic injuries can be defined using standardized structural imaging techniques, a diagnosis of concussion may depend on the disclosure of symptoms by the athlete to a clinician. Athletes' willingness to make such disclosure may depend on gender, age, and many other factors.[16] At the same time, concussions that remain unreported because of athlete nondisclosure[69–76] are not identified by medical professionals and thus cannot be captured by surveillance systems using clinicians as data reporters. Although acquiring a consensus on the definition of concussion in sports may never be reached, researchers should specify their definition of concussion utilized, report whether data collectors were trained in the definition, and, if so, describe how they were trained.

DETERMINING WHICH MEASURES OF INCIDENCE TO USE

Most published concussion data from sports injury surveillance systems present concussion incidence as rates (see Table 1). Although injury rates may be typically preferred because they account for all cases of injury in the numerator and for variation in the amount of exposure time via the denominator, they may not be intuitive for all of the various sports stakeholders (eg, policy makers, parents, or coaches). Few studies have utilized risk, which may be a more intuitive measure, as it simply measures the probability that an injury will occur during sports participation within a specific timeframe (eg, 1 season). This metric merits strong consideration in outreach and communication settings, as it is frequently requested, and most people who understand probability have an intuitive concept of risk.

As the number of epidemiologic studies of concussions over the past decade has increased,[77] Kerr and colleagues[36] argued that it was necessary to broaden the range of metrics utilized to measure concussion incidence. Using concussion data from the NCAA-ISP, Kerr and colleagues[36] computed 4 measures of concussion incidence: rates, risk, the average number of concussions per team season, and the proportion of team seasons with at least 1 concussion. Despite some variation in the rank order of included sports, full-contact sports such as wrestling, football, and ice hockey consistently generated the highest incidence of concussion. However, squad size may serve as a confounder, particularly in football.[45] Furthermore, such measures can be biased when comparing incidence across teams (or sports) that vary greatly by the number of athletic sessions per season. Thus, it is important for readers to understand the strengths and limitations of measures of concussion incidence utilized by various researchers.

SAMPLING CHALLENGES AND GENERALIZABILITY

Many sports injury surveillance programs at the professional level, such as those for the NFL, Major League Baseball (MLB), National Basketball Association, and NHL, are census data (ie, they obtain data from all teams) (see **Table 1**). However, in many cases, sports injury surveillance relies upon a sample of participating programs. Thus, findings may not be generalizable to nonparticipating programs. This is especially true for programs in which data are collected using a convenience or volunteer sample; programs that choose to participate may differ from those that do not. However, in general, such concerns are outweighed by the merits of obtaining some surveillance information, even from a nonrandom sample.

Findings may also not be generalizable to other organizations and programs within the same level of competition. For example, data from 1 NCAA conference or division may not apply to the entire NCAA due to different rules, officiating, school resources, or personnel. Furthermore, although the NCAA-ISP obtains data from all 3 divisions, data from programs within the National Association of Intercollegiate Athletics (NAIA) and the Junior National Collegiate Athletics Association (JNCAA) are seldom examined. Only 1 study utilizing data from the NAIA and JNCAA exists to the authors' knowledge,[78] and it reported differences in injury rates among the 3 NCAA divisions, NAIA, and JNCAA. Because resources such as staffing may not be equitable across settings within the same level of competition and may confound observed injury estimates, researchers should fully describe their sample characteristics to help readers determine comparability across studies. It is also recommended that, when feasible, sports injury surveillance systems should attempt to recruit across diverse populations (eg, institutions, geographic regions, levels of competitiveness) in order to best account for the broadest spectrum of athletes within the population. Such a breadth of findings can also help to determine whether the incidence of concussion varies within population subgroups.

MONITORING TRENDS ACROSS TIME

Given the long durations in which many have existed, 1 strength of sports injury surveillance is the potential to ascertain secular trends. In a recent examination of concussion data from the NCAA-ISP, Zuckerman and colleagues[25] found that a linear trend did not exist in the national estimates across 5 years (2009/10–2013/14 academic years); however, increases were reported for specific sports, including men's football, women's ice hockey, and men's lacrosse. Similar trends were observed in high school level data.[20] Furthermore, Zuckerman and colleagues[25] found that annual national estimates were the lowest in 2009/10 and the highest in 2011/12. This may be partially attributable to the introduction of concussion policy in April 2010 by the NCAA Executive Committee that mandated each school adopt a concussion management plan; observed increase in incidence may be due to heightened awareness and reporting due to such policies. Using the same timeframe, Wasserman and colleagues[27] found that the proportion of sport-related concussions that required at least a week before return to participation increased from 42.7% in 2009/10% to 70.2% in 2013/14. The authors noted that these findings likely do not indicate increased injury severity, but rather reflect improved symptom monitoring and management protocols. However, it is also essential for future research to directly examine the implementation of, and compliance with, such concussion-related policy. In addition, given that continued surveillance efforts occur across multiple settings, it is imperative to utilize such data to generate a better understanding of the trends over time in concussion incidence and management.

Despite the ability to monitor trends, variation in annual participation may potentially influence estimates of incidence. Zuckerman and colleagues[25] found that men's wrestling has a concussion rate higher than any other NCAA sport. In response to the need to further analyze data from men's wrestling given this finding, Kerr[79] noted two important aspects related to data collection. First, during the 2009/10 to 2013/14 academic years, NCAA-ISP participation in men's wrestling was lower than that of many other sports, which consequently yielded less precise concussion rate estimates (**Fig. 1**).[25] In contrast, football had a larger number of programs participating, and thus, concussion rates were more precise (**Fig. 2**). Part of this increased precision is due to the larger squad size in football.[45] Second, when annual injury rates fluctuate, resulting aggregated rates may vary based upon the time periods examined. For example, the men's wrestling concussion rate was 10.9 concussions per 10,000 AEs in 2009/10 to 2013/14, but 8.2 concussions per 10,000 AEs in 2012/13 to 2014/15 (see **Fig. 1**). When comparing concussions rates from 2012/13 to 2014/15 in wrestling and football, both estimates were more similar than comparisons from 2009/10 to 2013/14 (see **Fig. 2**). Providing precision metrics such as confidence intervals can help readers gauge the quality of findings presented.

EVALUATION OF RISK FACTORS AND INTERVENTIONS

An additional benefit of sports injury surveillance is the ability to identify risk factors and evaluate interventions aimed to reduce concussion incidence and severity across large, population-based groups. For example, to measure neck strength, Collins and colleagues[80] developed a hand-held tension scale, which served as a cost-effective alternative to the commonly used hand-held dynamometer. This hand-held tension scale was then used with 6704 high school athletes in boys' and girls' soccer,

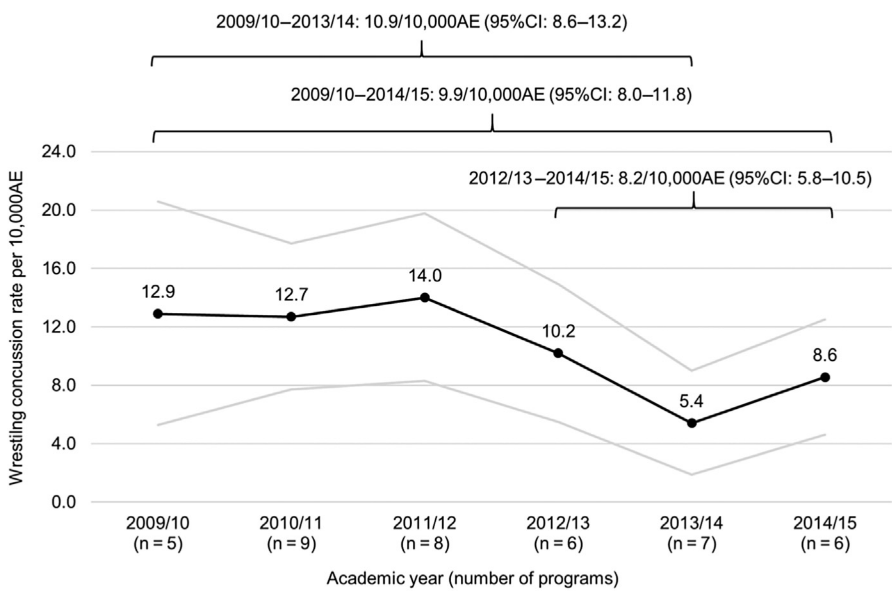

Fig. 1. Variations in reported concussion rates in wrestling from the NCAA Injury Surveillance Program, based upon academic years included. AE, athlete-exposure; CI, confidence interval. Note: gray lines represent 95% CI.

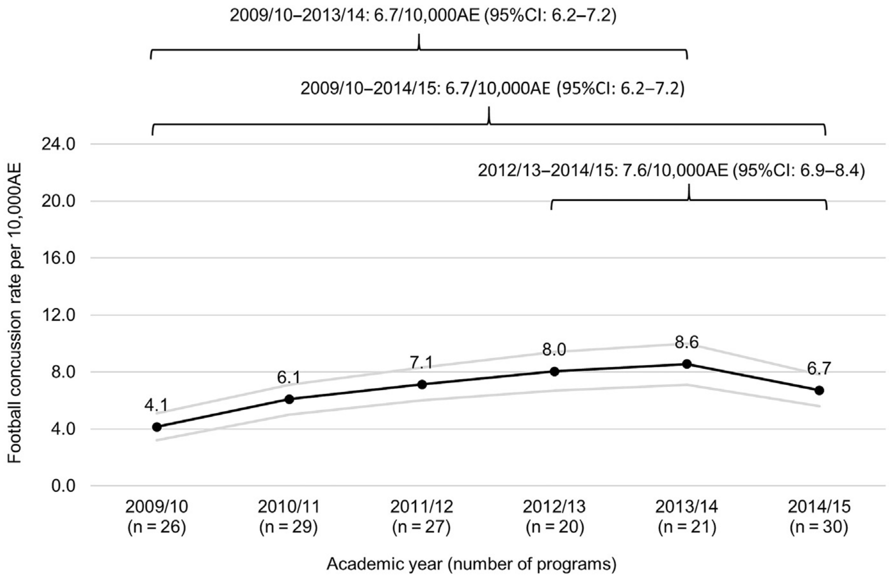

Fig. 2. Variations in reported concussion rates in football from the NCAA Injury Surveillance Program, based upon academic years included. AE, athlete-exposure; CI, confidence interval. Note: gray lines represent 95% CI.

basketball, and lacrosse from 51 high schools in 25 states. Concussion and exposure data were captured via HS RIO. The study found that, after adjusting for gender and sport, for every 1-pound increase in neck strength, the odds of concussion decreased 5%.

Another study examined youth football leagues implementing the Heads Up Football (HUF) educational program and Pop Warner practice contact restriction guidelines.[44] In the HUF educational program, each league had a player safety coach who was responsible for providing other coaches with educational resources on concussion, heat illness, and recognition and immediate management of cardiac events, and hands-on training of proper equipment fitting, proper tackling technique, and strategies for reducing player-to-player contact. The Pop Warner practice contact restriction guidelines forbade full-speed head-on blocking or tackling drills in which the players lined up more than 3 yards apart, and reduced the amount of contact at each practice to a maximum of one-third of practice time. Concussions and all other injuries were tracked using the YFSS. Overall injury rates were lowest among leagues utilizing both the HUF educational program and Pop Warner practice contact restriction guidelines. Concussion rates did not differ significantly, with the exception of leagues of 11- to 15-year-olds using both the HUF educational program and Pop Warner practice contact restriction guidelines, which had a lower concussion rate than leagues using neither. Nevertheless, in an additional study comprised of 6 Indiana high school football programs, all of which were required to have coaches undergo concussion education, those utilizing the HUF educational program with a player safety coach had a lower concussion rate in practices.[81]

Despite the promising surveillance-based findings regarding interventions and programming intending to reduce the incidence of concussion, it is important to continue examining the efficacy of such prevention strategies with additional samples, settings, and study designs. Several survey studies have highlighted organized concussion education plans, only to show a lack of meaningful change in knowledge. Kroshus and colleagues[82] evaluated the effectiveness of mandated, institutional concussion education among male collegiate hockey players, but found no improvements in knowledge and a minimal decrease in intention to continue playing through a concussion. Another study[83] cluster-randomized 256 adolescent boys from 12 ice hockey teams into 3 groups that were provided either one of two concussion education videos, or an informational handout. No changes in concussion knowledge were seen in posteducation surveys, and 1 video actually led to an increase in under-reporting of concussions at 1-month after the survey. These studies emphasize an important point regarding public health mandates; implementation alone may not lead to meaningful change. The use of mixed methods to assess implementation and effectiveness of concussion interventions could help pinpoint areas of focus for future research efforts.

COMPARABILITY ACROSS SPORTS INJURY SURVEILLANCE SYSTEMS

One challenge in comparing surveillance data is that the data elements collected vary across systems. For example, whereas the NCAA-ISP, NATION, and YFSS collect similar data on concussion symptoms (17 symptoms ranging from headache to sensitivity to light),[16,27] HS RIO collects data on 13 symptoms, excluding symptoms such as insomnia and excess excitability. Thus, caution must be taken when comparing findings across systems, particularly related to the average number of symptoms reported (ie, a smaller number reported in HS RIO compared to NATION may simply be due to a smaller number of options available). Previous research has examined concussion incidence across levels of competition from sports injury surveillance systems that utilize the same data collection methods.[16,23,27] However, even these studies note the inability to account for varying level-specific factors that may confound concussion reporting, such as team medical staff coverage and variation in individual clinicians' diagnostic practices.

Readers must also be aware of different dynamics of data collection among varying levels of competition. For a professional or division I collegiate athletic team, there is often at least 1 AT or team physician per team, with abundant resources and constant contact with athletes. In contrast, there may be at best a single AT for multiple sports at the high school level with significantly decreased resources and limited contact with some athletes. Some high school and youth sports settings may have very limited or no access to ATs and data collection infrastructures.[39,44] Thus, many high school sports injury surveillance programs only collect data from schools with AT coverage.[16,18,21,27] Moreover, changes in data collection measures, such as shifts from paper-and-pencil forms to an electronic system, may lead to changes in school participation and subsequent data quality.[65] Readers should be aware of such inherent limitations of sports injury surveillance systems, particularly when attempting to compare data from multiple systems, and critically evaluate how reported findings may be affected.

ACCESS TO DATA

Both orthopedic injury studies[84] and concussion studies have used public records of injuries among professional athletes rather than actual medical records.[85–88] However, because data based on media reports have not been validated, use of an organization's internal sports injury surveillance system data would likely be more valid. Unfortunately, access to existing sports injury surveillance data currently varies widely. Some systems such as HS RIO, NATION, and NCAA-ISP provide data to external researchers through an application process. However, many professional level datasets are not as accessible. Currently, the MLB Health and Injury Tracking System (HITS) allows researchers to apply for access, but assigns priority to particular areas of research. Papers on concussions using MLB HITS data have been published only by the researchers managing the system.[32] Accessing data from NFL ISS is even more limited. The primary purpose of many sports injury surveillance systems is to allow organizations to internally examine injury trends and patterns so they can make evidence-based policy and guideline decisions. Yet, publications reporting data captured by sports injury surveillance systems help external researchers, clinicians, and the general public understand the most up-to-date sports injury patterns. Furthermore, surveillance systems providing access to external researchers not involved with the organizations overseeing the surveillance systems reduce concern regarding lack of objectivity. Just as readers are more critical of drug studies financed by pharmaceutical companies, they should critically evaluate the institutional affiliation of researchers publishing reports using sports injury surveillance data.

FUTURE DIRECTIONS

The wealth of concussion data collected by sports injury surveillance systems is undeniable. With the ability to monitor trends over time and compare populations internally and across systems, while upholding high quality data standards, sports injury surveillance systems have helped provide a better understanding of the incidence of concussion and its risk factors as well as the effectiveness of various interventions on reducing concussion incidence and severity. Nevertheless, future investments are required both to strengthen existing surveillance systems and to inform the development of future sports injury surveillance efforts (**Table 3**).

Increase Buy-In from Stakeholders

When data from sports injury surveillance systems are collected from the entire population of interest, a census is obtained. However, in many cases, only a sample of the population is collected, thus potentially limiting generalizability to the entire population. Currently, both HS RIO and NCAA-ISP have participation from only a small proportion of all schools eligible to participate. Thus, although HS RIO utilizes a stratified random selection approach for participation,[89] and NCAA-ISP solicits participation from all 3 divisions,[65] such strata likely do not control for all variables of importance (eg, staff resources). However, to allow for more strata, more participation by eligible data collection sites is required. Additionally, in both HS RIO and NCAA-ISP, participation levels vary across sports. Increased participation would help obtain more data for sports in which concussion incidence is lower or lower overall school participation hinders obtaining sufficient data. Although both the NFHS and NCAA have long supported HS RIO and NCAA-ISP, participation by eligible schools has always been voluntary. Without increased financial incentives or required participation, the best way to increase participation and thus, the generalizability of these datasets, likely lies with increased endorsement by regional stakeholders (eg, collegiate conferences and state high school athletic associations).

To increase participation, buy-in from a wide variety of stakeholders is necessary. The data collectors, in many cases, team or school sports medicine clinicians, need to be further educated about the benefits of participation and data collection. Coaches and athletic directors should also understand how such data can benefit their programs. The rapidly growing number of private sports organizations with internal sports injury surveillance systems should be encouraged to collaborate with external researchers to help disseminate data, compare findings across populations, and revise data collection tools in response to future research needs. Finally, researchers must aim to find ways to help provide such stakeholders with the resources that aid in better translating surveillance data to concrete prevention initiatives and interventions to prevent concussions and manage concussion recovery.

Common Data Elements

Although numerous sports injury surveillance systems collect data on concussions, the data elements collected vary widely from system to system. It is important to identify common data elements that can allow for comparisons of data among existing systems and that may help inform development of future systems. Such data points should pertain to athlete demographics, mechanism of concussion, symptomatology prevalence, return to play time, and symptom resolution time. The National Institutes of Health have developed common data elements for varying types of traumatic brain injury (TBI) in an effort to streamline the clinical aspects of such data collection to allow for more adequate comparison across studies, including those around concussion.[90] However, that effort demonstrates the difficulty of creating common data elements applicable to both the traditional health care setting (eg, emergency department, physician's office, concussion clinic) and the broader clinical settings currently covered by existing sports injury surveillance systems, as well as concussion that occur from sport- and non-sport-related mechanisms. Thus, while use of common data elements should be encouraged when feasible, an understanding of the primary purpose of the sports injury surveillance system and the needs of the stakeholders investing in the system must be allowed to drive data collection rather than an expectation to conform to any individual set of common data elements.

Additionally, continued efforts should be made to develop a consensus definition of concussion feasible across sports injury surveillance systems using varied data collectors to report concussion. Until such a consensus definition exists, researchers should clearly outline the definition for concussion used in all publications. It is important to note that, although common data elements would help increase comparability, it is unavoidable that differences among systems will exist. This may be attributable to differences in data collectors (eg, parents vs ATs vs team physicians), as well as the level of competition (professional team, where team medical staff are always present vs high school, where an AT may have to choose one sport to cover among multiple occurring simultaneously, vs youth sports league, where clinicians are rarely present). Disseminated research findings need to specify the limitations of the results based upon how injury was defined and how data were collected.

Exploring Novel Approaches

It is important for future research to consider novel approaches to addressing current limitations in data collection. One important consideration is that many of the current surveillance systems require additional entry beyond the medical records kept by the AT or physician. Utilizing existing electronic medical records, when available, is important in reducing the burden on the clinician and can aid in not only increased participation in surveillance systems, but also better tracking of outcomes. Because electronic medical record keeping systems are too expensive for many high schools, providing free/reduced fee access to high school ATs could increase participation in surveillance systems. When the presence of medical professionals is limited in a particular sports setting, considering other options for data collectors (eg, parents, coaches) could expand the populations included in sports injury surveillance systems. At the same time, with the abundance of individuals using handheld mobile devices,

Table 3
Strengths, limitations, and future directions for estimating concussion incidence via sports injury surveillance systems

Issue	Strengths	Limitations	Future Directions
Who collects the data?	Use of medical staff (eg, ATs, team physicians) educated and experienced to appropriately diagnose and manage concussion in the sports setting	Difficult to conduct surveillance where medical staff coverage is limited Medical staff may not have full authority (eg, medical decisions may be overridden by head coach)	Explore parents, athletes, and/or coaches as data collectors and the use of mobile-friendly Web-based tracking devices through validation research Use pre-existing electronic medical records to help ensure complete data entry
What sports are included?	Numerous sports captured across systems	Access to sports with lower visibility Access to youth sports without/with multiple national organizing bodies	Further buy-in from stakeholders to increase participation of sports with limited data Further buy-in from national sports governing bodies overseeing youth sports (eg, children aged 5–10)
Defining at-risk exposure time	Many established options available that can help reduce burden on data collector	Varying methods of capturing at-risk exposure time may impede comparability	Specify and define the at-risk exposure time measurement used
Defining injury/concussion	Use of medical staff (eg, AT, team physicians) may reduce need to provide specific definition	Varying definitions of concussion	Specify the injury/concussion definition used
Determining which measures of incidence to use	Most studies use injury rates, which allows for comparability across studies	Nonintuitiveness of certain measures Lack of published data using more intuitive measures	Specify and define the incidence measurements used Establish common analysis procedures

Sampling challenges and generalizability	Large samples, many of which are census data	Samples not generalizable across entire continuum of athletes participating in sport	Increase buy-in from stakeholders to increase participation Create unique athlete IDs to allow linkage of athlete data from 1 surveillance system to another as athletes move across the age continuum
Monitoring trends over time	Longitudinal effects of rule/policy changes	Incidence estimates may be associated with study period	Increase buy-in from stakeholders to increase participation
Evaluation of risk factors and interventions	Assess immediate effects of rule/policy changes	May be unable to directly examine the level of compliance with rule/policy changes	Consider surveillance alongside other research study designs to identify risk factors and develop and evaluate prevention strategies
Comparability across sports injury surveillance systems	Many common elements captured	Variations in data collection methods exist Levels of competitions have varying characteristics (eg, medical staff coverage, resource allocation), which surveillance efforts may not be able to fix	Examine manners to increase ability to compare studies, to standardize methodologies, but in the context of the purposes of the sports injury surveillance systems and the needs of the stakeholders investing in the systems
Access to data	Some systems allow external researchers to access data via simple data requests for no/low fee	Some data sources seldom publish data findings and are not available to external researchers	Increase buy-in from sports organizations overseeing systems

creating Web-based surveillance that is mobile-friendly may also aid data collection efforts. However, for such novel approaches to become integrated into the current structure of sports injury surveillance systems, it will be necessary to conduct validation research.

Going Beyond the Tip of the Iceberg

Although there is more known about the epidemiology and etiology of sport-related concussion today than ever before, only the tip of the iceberg has been uncovered. Surveillance is 1 component of injury prevention; it can help identify risk factors and assist in the development and evaluation of inventions to reduce injury frequency and severity.[91] Current ongoing sports injury surveillance, coupled with the commitment of federal agencies to develop surveillance mechanisms in other areas, will only continue to expand on this knowledge. General sports injury surveillance efforts have also driven more detailed studies, such as those under the NCAA-Department of Defense (DOD) Grand Alliance Project CARE (Concussion Assessment, Research and Education Consortium), that will further advance understanding of the etiology and outcomes following concussion. However, as the field continues to move forward, it is important to continue to work to streamline and align methodologies so that accurate comparisons can be made between studies.

SUMMARY

Understanding of concussion incidence through data captured by sports injury surveillance systems allows for bettered inform policy, organizational, and individual decision making about sport. It is important that all consumers of this information understand the methodologies and metrics of each surveillance system, including their strengths and limitations. The past few decades have seen dramatic shifts in concussion knowledge, moving beyond believing that loss of consciousness must occur with concussion, to understanding that concussion is more diffuse and nuanced. There is a better understanding that sports outside of football have higher than perceived concussion risk, and attained unprecedented levels of concussion education across broad non-clinical stakeholders (eg, sports policy makers, coaches, parents, athletes) have been attained. The next decade will hopefully show a continuing refinement of methods, a better understanding of the risk for concussion, and the discovery of how to best prevent these injuries across all sports at all levels.

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