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Injury Surveillance in Young Athletes

A Clinician's Guide to Sports Injury Literature

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Abstract

As participation in junior, high-school and college sports has increased dramatically over the last three decades, sports injuries have increased commensurately. In the US alone, sports-related injuries account for 2.6 million visits to the emergency room made by children and young adults (aged 5–24 years). Injuries sustained by high-school athletes have resulted in 500 000 doctor visits, 30 000 hospitalisations and a total cost to the healthcare system of nearly 2 billion dollars per year. Sports injury surveillance studies have long formed the backbone of injury prevention research, serving to highlight the types and patterns of injury that merit further investigation. Injury surveillance studies have been integral in guiding rule changes, equipment improvement and training regimens that prevent injury. Despite findings that the methodology of injury surveillance studies may significantly influence the design and efficacy of preventative interventions, relatively few sources address epidemiological considerations involved in such studies.

The purpose of this review is 3-fold. First, to perform a review of the current injury surveillance literature in order to identify key epidemiological and methodological issues that arise when reading or conducting an injury surveillance study. Second, to identify and describe how injury surveillance studies have addressed these issues. Third, to provide recommendations about the identified issues in order to guide clinicians in the interpretation of data presented in such studies.

Searches of Ovid MEDLINE (1966–present) and PubMed were performed. Thirty-three descriptive and review articles addressing epidemiological and methodological considerations in injury surveillance were selected, as well as 54 cohort studies and studies with an experimental design. Data with respect to each study's treatment of the three epidemiological issues of interest were extracted and synthesised into a table.

This review identifies the following three key epidemiological issues to consider when reading injury surveillance literature or when designing an injury surveillance study: (i) the definition of a sports injury; (ii) the denominator with which injuries are reported; and (iii) the method of data collection. A meaningful definition of injury should incorporate time lost from participation in order to reduce the bias associated with estimates of incidence. The use of multiple denominators (e.g. both athlete-hours of exposure and total athletes) provides the most precise information about injury rate and injury risk. The method of data collection that captures the widest range of injuries, while also allowing for the collection of exposure data, will vary depending on geographical location and the organisation of youth sports in that area.

Injury surveillance studies of young athletes and the epidemiological issues involved are evolving with a changing study population. Although early studies focused primarily on catastrophic injuries experienced by football players,[1] more recent studies have focused on catastrophic injuries experienced by female athletes (including cheerleaders) and noncatastrophic injuries in all sports.[2-5] Over the last three decades, injury surveillance studies have expanded the definition of injury and the definition of athlete to accommodate the changing face of youth athletics.

Increasing participation in organised sports by both sexes has resulted in increasing numbers of sports injuries. In the US alone, as many as 45 million children and adolescents are currently involved in organised sports.[3,6] In 2001, sports-related injuries accounted for 2.6 million visits to US emergency rooms made by children and young adults (aged 5–24 years).[3,7] Participation in high-school athletics has increased from 4 million in 1971 to >7 million in 2004, resulting in nearly 2 million high-school athletic injuries each year.[7-9] Female participation, in particular, has increased nearly 1000% since 1971, leading to new patterns of injury that merit investigation.[10,11] Newly emerging evidence indicates that female high-school and college athletes in basketball, soccer, lacrosse, field hockey and skiing experience a greater number of knee and ankle injuries than their male counterparts.[5,10-26] Noncontact anterior cruciate ligament (ACL) injury rate has been found to be 2–10 times higher in female athletes.[10,21-26]

The injuries sustained by male and female high-school athletes alone have been costly. There are ≈500 000 doctor visits and ≈30 000 hospitalisations each year, which cost the US healthcare system nearly 2 billion dollars.[3] Injured athletes are forced to miss days of school, which can cost their parents hours of lost work productivity. In addition to the physical and financial costs of sports injuries, injured athletes experience negative psychological consequences, including mood disturbance and lowered self-esteem.[27]

As a result of the great physical, financial and psychological costs of sports injuries to young athletes and their parents, there is international recognition of the need for sports injury surveillance systems in order to reduce the incidence and severity of such injuries.[28-33] Injury surveillance studies have prompted rule changes, equipment improvement and strengthening regimens that prevent injury.[18,31,34-38] However, despite findings that the methodology of injury surveillance studies may significantly influence the design and efficacy of preventative interventions,[30,34,35,37] relatively few articles address the epidemiological considerations involved in such studies.[28,29,37,39-45] Variability in reporting methods has contributed to a lack of universal comparability across studies, which is a central challenge in sports injury research.[29,30,32,46]

This review encompasses injury surveillance literature focused on young athletes participating in organised sports. The injury surveillance literature reviewed concentrates primarily on elementary and secondary-school age (6–13 years), high-school (14–18 years) and college (18–22 years) athletes. As an easily-accessible and centralised population, high-school athletes have been one of the most studied cohorts in injury surveillance literature, par-

ticularly in the US. However, in other areas of the world, organised youth sports are not necessarily structured around the high-school sports team; therefore, the age-group focus of injury surveillance studies differs depending on geographical area. The method of data collection also impacts on the range of ages over which injuries can be detected. For example, injury surveillance studies utilising emergency department (ED) records will capture sports injuries over a wider age range than surveillance studies that collect data through certified athletic trainers (CATs). CAT-collected data also tends to focus on high-school and college athletes.

Our objectives are (i) to delineate key epidemiological issues to consider when reading injury surveillance literature or when conducting such studies; (ii) to describe how a wide range of studies in the literature have addressed these issues; and (iii) to provide recommendations about the identified issues in order to guide clinicians in the interpretation of data presented in such studies. Three central epidemiological issues have been identified: (i) the definition of a sports injury; (ii) the denominator with which injuries are reported; and (iii) the method of data collection, including who, how and where data are being collected.

1. Methods

Searches of Ovid MEDLINE and PubMed were performed using multiple combinations of the following titles and key words: 'adolescent', 'athlete', 'athletic injury', 'athletic injury reporting', 'data collection', 'denominator', 'emergency department', 'epidemiology', 'female', 'high school', 'injury definition', 'injury rate', 'injury risk', 'injury surveillance', 'male', 'method', 'methodology', 'sports injury', 'youth' and 'young'. In addition, searches utilising multiple combinations of the above key words and the following medical subject headings and subheadings were performed: 'adolescence', 'athletic injuries/ep' (epidemiology), 'athletic injuries/pc' (prevention and control), 'child', 'data collection methods', descriptive statistics', 'diagnosis', 'information systems', 'injury pattern', 'psychology' and 'secondary schools'. Searches were restricted to English-language sources from 1970 to the present. From the studies identified in these searches, those articles most relevant to the review, according to their title and the information contained in the abstract, were selected. Descriptive and review articles addressing epidemiological and methodological considerations in injury surveillance were included, as were cohort studies, studies with an experimental design and studies that provided demographic data about youth athletic participation and injury incidence. For studies considering specific types of injuries and particular sports, a limited number of representative articles were selected after review of multiple studies. Additional sources were identified through cross-referencing articles obtained from the primary database searches.

The studies selected were reviewed with the goal of identifying key epidemiological and methodological issues to consider when reading injury surveillance literature. Once the epidemiological issues emerged, cohort studies and studies with an experimental design were evaluated for their definition of injury, the denominators employed to describe injury rates/risk and their method of data collection.

2. Results

Initial Ovid MEDLINE and PubMed searches identified >200 articles. This number was reduced on the basis of titles and abstracts, then, after review of >100 articles, 91 were selected. We identified 33 review articles either discussing methodological and epidemiological considerations in injury surveillance, or providing descriptive analyses of sports-injury reporting in a variety of settings. The remaining articles were cohort studies (retrospective and prospective) and studies with experimental designs. Of these, 14 focused exclusively on male athletes, 12 on female athletes and 15 compared male and female sports injuries. The remaining articles did not have a specific gender focus. With respect to particular populations of athletes, high-school athletes were the most studied cohort in this review, with 26 articles addressing injuries in this group. Twelve studies examined injuries in elementary and secondary-school aged athletes, 9 focused on college athletes and 8 on sports club athletes. While basketball (16), soccer (13) and football (12) were the most studied sports in this review, volleyball (10), softball (7), wrestling (6), tennis (5), baseball (5), cheerleading (4), swimming (4), track and field (4), gymnastics (4), Australian rules football (2),

field hockey (2), fencing (1), netball (1), rugby (1), water polo (1), golf (1) and lacrosse (1) were also represented. The knee was the most studied body part, with 12 articles devoted to knee and/or ACL injuries. Three articles focused on head and cervical spine injuries sustained while participating in football and one considered ankle injuries. Table I provides a summary of the selected representative articles.

3. Discussion

3.1 Defining an Injury

There is no single consensus on the definition of a reportable injury.[29,32,63] Early injury surveillance studies primarily investigated concussions and catastrophic injuries.[1] Definitions used in more recent studies have been as inclusive as "any tissue damage," including even minor bruises,[59] any physical damage caused by a sport-related incident, whether or not it results in any incapacity to the participant,[29,39] or "any time an athlete sought medical help."[47] Others have defined injury as any damage occurring during organised practice or competition, which (a) resulted in either missed practice or game time; (b) required physician consultation; or (c) involved the head or face.[57,61] The National Electronic Injury Surveillance System All Injury Program (NEISS-AIP), a reporting system that collects data on initial visits for all types and causes of injuries treated in US EDs, defined "sports-related" injuries as those occurring during organised and unorganised activities, whether work-related or recreation-related. The NEISS-AIP defined injury broadly, as "bodily harm resulting from exposure to an external force or substance," excluding cases in which the principal diagnosis was not ultimately found to be sports-related or was not found to be an actual physical injury.[65] Hoy et al.[58] provide an example of a study that defines injury more narrowly, as any sports-related incident requiring hospital-based treatment of the athlete.

A measure of injury severity must be incorporated into the definition of injury. As van Mechelen et al.[32] note, the more severe the injuries sustained, "the higher the priority will be to prevent these injuries, regardless of injury incidence." Although some studies define the severity of an injury based on time lost from sport, there is utility in considering 'severity' and 'time loss' definitions of injury as separate, although not mutually exclusive. For example, multiple studies judged certain injuries to be reportable, regardless of time lost to sport, based on the catastrophic potential of those injuries (e.g. concussions, nerve injuries, eye injuries, dental injuries and fractures).[39,57,61,62,66] Other studies that separate definitions of 'severity' from 'time lost' employ the Abbreviated Injury Scale or some permutation of it, which outlines standardised guidelines for injury severity based on the extent of tissue damage.[58,67-69] Many authors concur that including time lost from participation in the definition of injury effectively reduces the bias associated with the incidence estimate.[40,70,71] Prager et al.[63] suggested that a definition of injury that incorporates both a time factor and a severity component, such as the definitions used by the research committee of the American Orthopaedic Society for Sports Medicine and by the US National Athletic Injury Reporting System,[72] be adopted by all sports injury surveillance studies.[63] Finally, the definition of injury must encompass not only severity and time lost to sport, but also context. Studies that simply define an athletic injury as an event[63,73] or incident,[60] satisfying certain severity or treatment criteria, neglect to differentiate a 'sports injury' from other medical or health-related events, or from a similar injury not sustained while playing sports.[39]

Most current studies utilise time lost from sport participation as part of the definition of injury, but this can range from the loss of any game or practice time,[50] to the loss of a full competition or practice session.[11,13,56,74] The National Collegiate Athletic Association (NCAA) Injury Surveillance System (ISS) defines a reportable injury as an event that occurs during participation in intercollegiate athletics (practice or competition), requires medical attention from the CAT or team physician, and "results in restriction of the student-athlete's participation for ≥1 days beyond the day of injury."[12,13] The US National Athletic Trainer's Association defines a reportable injury as one that occurs during sports participation and prevents the athlete's return to the current session (game or practice) or return to the next session following evaluation by a CAT, or any

Table I. Injury surveillance studies and their methodology

Study location (year)	Study population	Definition of injury	Method of data collection	Denominators[a]	Reference
USA (2005)	Collegiate basketball and soccer athletes	Event requiring medical attention from CAT or team physician resulting in restriction of participation for ≥1 days beyond day of injury	NCAA-ISS database; injuries are recorded weekly by coaches and athletic trainers	Total athletes, total athlete-events (total number of games and practices)	12
Hawaii, USA (1997)	Students, grades 7–12	Any athlete complaint that required the attention of an athletic trainer, regardless of time lost from activity	CAT	Total athletes	47
Latrobe Valley, Victoria, Australia (2003)	Latrobe Valley residents >4 years old	Presentation for medical treatment to ED as a result of sport, and labelled with 'external cause of injury' code	Hospital admissions database, ED database, database monitoring presentations to general practitioners	All residents in geographical area, regardless of sports participation	48
Oklahoma, USA (1985)	Male and female athletes in 130 Oklahoma secondary schools	Any injury incurred during practice or game that resulted in an altered or lost practice session or game. Major injury = any injury satisfying this above criteria that resulted in >7 days lost	Secondary Schools Injury Registry, Department of Orthopedics, University of Oklahoma	Total athletes	14
Ohio, USA and New York, USA (2003)	Patients 5–21 years old	Cause of injury recorded as 'sports-related'	Patient visit records at four paediatric EDs	All musculoskeletal injuries presenting to the ED	49
Texas, USA (1992)	Male athletes participating in football at 100 public high schools in Texas	Occurring in football and meeting one or more of the following criteria: (i) causing a student athlete to miss all or part of a single practice or game; (ii) any injury (including dental) treated by a physician; (iii) all head injuries	CAT	Total athletes, athlete-hours of exposure	50
Canada (1995)	Athletes 5–19 years old (stratified by age in years into three groups: 5–9; 10–14; 15–19)	Any injury incurred while the victim was playing basketball or practicing basketball skills	CHIRPP database, ED-based injury surveillance database	All injuries to children seen in the ED, all sports injuries seen in the ED (compared injury frequencies between basketball and other sports in the CHIRPP database)	51

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Table I. Contd

Study location (year)	Study population	Definition of injury	Method of data collection	Denominators[a]	Reference
Australia (1998)	All patients, sub-divided into children (<15 years old) and adults (>15 years old)	Incurred as a result of sport (organised competition or practice; informal; unspecified) or active recreation or hobby	Australian National Injury Surveillance Unit, ED-based injury surveillance database	All ED presentations resulting in hospital admission, all sports injury presentations[b]	52
Washington, USA (1978)	Female junior varsity and varsity high-school athletes participating in nine sports	A medical problem arising as a result of sports participation that resulted in a player being removed from practice or competitive event and/or missing a subsequent practice or competitive event	CAT	Total athletes, athlete-hours of exposure, team-seasons (total number of teams fielded in each sport by participating high schools over the years of the study)	53
Washington, USA (1978 and 1981)	Male and female junior varsity and varsity high-school athletes participating in 19 sports	A medical problem arising as a result of sports participation that resulted in a player being removed from practice or competitive event and/or missing a subsequent practice or competitive event	CAT	Total athletes, athlete-hours of exposure, team-seasons	54,55
Pennsylvania, USA (in process)	Varsity and junior varsity athletes at Philadelphia-area high schools	Minor injuries = required evaluation by athletic trainer, and resulted in ≥1 day of playing time lost. Major injuries = required evaluation by athletic trainer and resulted in ≥7 days of playing time lost. All closed head injuries, fractures, dental injuries, nerve injuries and eye injuries	CAT	Total athletes, athlete-hours of exposure	56
Texas, USA (1996)	Female varsity basketball athletes at 100 public high schools in Texas	Occurring in a practice or game and resulting in either missed practice or game time, necessitating the consultation of a physician, or involving the head or face	CAT	Total athletes, athlete-hours of exposure	57
Ohio, USA (1999)	Female soccer, volleyball and basketball athletes (43 teams at 12 Cincinnati high schools)	A knee ligament sprain or rupture that caused the player to seek care by an athletic trainer and that resulted in ≥5 consecutive days of lost time from practice and/or games	CAT and athlete questionnaires	Total athletes, athlete-exposures (number of athletes × number of practice sessions or game sessions)	18

Continued next page

Table I. Contd

Study location (year)	Study population	Definition of injury	Method of data collection	Denominators[a]	Reference
Randers, Denmark (1992)	Soccer players, all ages	An occurrence that caused players to go to the ED of one hospital (Randers City Hospital) for treatment	Questionnaire administered to patients in ED (self-reported)	Total number of sports injuries seen at hospital ED during the study period[a]	58
Switzerland (2002)	Youth soccer players participating at the club level	Any physical complaint caused by soccer that persisted for >2 weeks or resulted in absence from subsequent match or practice	Physician documentation	Total athletes, athlete-hours of exposure	59
Illinois, USA (1989)	Male and female student athletes participating in interscholastic sports at one high school	Any incident resulting from athletic participation that prevents an athlete from completing a practice or game, or causes an athlete to miss a subsequent practice or game	CAT (Injuries requiring physician visits and surgery were recorded based on physician reports and hospital records)	Total athletes	60
Texas, USA (1999)	Male and female varsity basketball athletes at 100 public high schools in Texas	Occurring in a practice or game and resulting in missed practice or game time, necessitating the consultation of a physician, or involving the head or face	CAT	Total athletes, athlete-hours of exposure	61
USA (1987)	All participants in organised tackle football programmes (youth football, middle school, high school, college, professional)	Any head or cervical-spine injury sustained during blocking or tackling (whether practice or game) that resulted in death	Questionnaires filled out after each fatality by coaches and/or training personnel for each tackle football team in the US. All questionnaires are returned to the American Football Coaches Association	All football-related fatalities	31
Selected high schools, USA (2000)	Interscholastic athletes from selected high schools in the US	Any injury that causes cessation of participation in current game or practice, and prevents player's return to that session. Any injury that causes cessation of a player's customary participation on the day after the day of onset. Any fracture, regardless of time lost. Any dental injury. Any mild brain injury/concussion	CAT	Total athletes	62

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Table I. Contd

Study location (year)	Study population	Definition of injury	Method of data collection	Denominators[a]	Reference
Illinois, USA (1989)	High-school varsity football players in Peoria (IL)	An event causing a time loss of 48 hours after injury	CAT, questionnaire completed by athlete (self-reported)	Total athletes	63
North Carolina, USA (2004)	Female varsity cheerleaders in 44 squads at North Carolina public and private high schools	Occurred as a result of participation in varsity cheerleading and either limited the student's full participation in cheerleading the day following the injury or required medical attention. All concussions, nerve injuries, eye injuries and fractures regardless of time lost	CAT	Total athletes, total athlete events	4
Ireland (1993)	'High level' (i.e. participating in athletics at the international, national, club and county level) athletes 12–42 years old (mean age 22 years)	Occurring during, or as a result of, competition or training that resulted in incapacity to train or compete normally	Athlete questionnaire (self-reported)	Athlete-hours of exposure, year. Numerators employed included: (i) number of injuries (per year, per athlete-hour exposure); (ii) days injured (per year); (iii) and duration of injury (per 1000 athlete-hours exposure)	64
North Carolina, USA (1999)	Male and female varsity athletes at 100 North Carolina high schools	Occurred as a result of participation in high-school sport and either limited full participation in the subsequent match/ practice or required medical attention. All concussions, nerve injuries, eye injuries, and fractures, regardless of time lost	CAT	Total athletes, total athlete events	39
USA (1980)	Male and female athletes at colleges participating in the National Athletic Injury/ Illness Reporting System	Caused an athlete to stop customary participation throughout the day of onset or required substantial professional attention before the athlete could return to participation	CAT-entered injury data into a computerised database	Total athlete exposures	5

a Unless otherwise indicated, numerator is total number of injuries.

b ED studies cannot offer an injury rate or risk for a particular sport because the exposure data is limited to those athletes who presented to the ED. Therefore these results do not shed light on the number of athletes exposed to injury vs those who were injured.

CAT = certified athletic trainer; **CHIRPP** = Canadian Hospitals Injury Reporting and Prevention Program; **ED** = emergency department; **NCAA-ISS** = National Collegiate Athletic Association Injury Surveillance System.

concussion or dental injury.[62,66] Such inclusive definitions of injury might overestimate the burden of injury in certain sports (e.g. sports where players tend to sustain relatively minor but frequent injuries).

Not only may strict time loss definitions, which do not incorporate a measure of severity, overestimate the burden of injury in certain sports, but they also have the potential to underestimate serious injuries. DeLee and Farney,[50] Prager et al.[63] and Thompson et al.[71] all highlight the fact that basing severity of injury solely on time lost from participation produces a significant bias. While one player may elect not to practice based on his or her own subjective determination of the severity of the injury, another player may choose to participate despite an objectively more significant injury (e.g. a player with a fracture may use protective equipment and continue to play).

The Punahou School Longitudinal Study[47] considered "every time an athlete sought medical help" to be a reportable injury and argued for the inclusion of "those injuries not resulting in a day lost from activity" in the definition of a reportable injury. Beachy et al.[47] recommended that injuries not resulting in a day lost from activity are reported and designated as "minor injuries." They assert that "reporting only those injuries resulting in lost days does not give an accurate picture of the daily workload of the athletic trainer or of the type of injuries that may occur in practice or a game."[47] While injuries not resulting in lost days can certainly be collected, including such injuries in the analysis may present a skewed picture to those hoping to design prevention programmes based on a study's results. Prevention efforts should be directed towards the most consequential or significant injuries; days lost from sport is a more powerful measure of significance for the athletes than is time spent by a trainer with injured athletes.

The North Carolina High School Athletic Injury Study (NCHSAIS)[39] defined a reportable injury as "one that occurred as a result of participation in high-school sport and either limited the student's full participation in the sport the day following the injury or required attention by a medical professional." In addition, all concussions, nerve injuries, eye injuries and fractures were considered reportable injuries, regardless of whether the athlete missed a practice or game. Thus, the NCHSAIS considered "most events requiring medical attention in the sporting environment as reportable injuries." The authors hoped this more flexible approach would allow subsequent articles from their data to be comparable with other studies of a particular sport. They chose to consider injury severity, type and treatment in the analysis phase only.

The Children's Hospital of Philadelphia (CHOP) Injury Surveillance Study[11,56] had a similar data-collection protocol to the NCHSAIS.[39] All injuries sustained during scholastic athletics evaluated by the school's CAT and/or team physician were recorded, regardless of severity, type or treatment. However, in the CHOP analysis, a reportable injury was defined as one that incurred as a result of participation in a sport requiring evaluation by the team trainer and resulting in loss of either at least 1 day (1+ injury) or at least 7 days (7+ injury) of playing time, including practices and games.[11,56] All concussions were included in both the CHOP and NCHSAIS definitions, regardless of time lost. Thus, those injuries initially recorded that resulted in <1 lost day of playing time were discarded and the remaining injuries were subdivided into two severity categories (1+ and 7+). The 7+ definition of injury spanned an amount of time lost that typically resulted in a missed competition and in loss of conditioning, with increased likelihood of loss of school time for the athlete and work time for the parents. The CHOP study found the 7+ definition to be an efficient way to collect injuries of consequence; although this definition excluded 75% of all trainer-collected incidents, it was able to capture 77% of the total days lost to sport.[11,56]

3.2 Denominators

There is great variability among studies with respect to the denominator, or the function with which injuries are expressed. An injury report without a denominator can only describe frequencies,[41] while a report with a denominator can provide an injury rate. Injuries can be reported in terms of (i) injuries per athlete per year/season (the total number of participating athletes is the denominator); (ii) injuries per practice or game exposure (total number of games or practice sessions is the denominator); or

(iii) injuries per athlete-hour of exposure (total number of player-hours of exposure is the denominator.) The ratio of injuries per athlete, which is synonymous with injury rate, roughly estimates the likelihood that an athlete will be injured during the season. Finding injuries per athlete-hour of exposure gives information about injury risk.

The most recent trend in the literature is to report injuries per athlete-hour of exposure to sport.[53-55,57,59,61,64,75-77] This method of reporting injuries standardises relative risk and allows meaningful comparison between different teams, schools, genders and sports. de Loes[41] maintained that a denominator incorporating an element of time-at-risk provides the best information for preventative approaches. Some studies have subdivided the denominator 'athlete-hour of exposure' into 'athlete-hour of competition' and 'athlete-hour of practice,' to better evaluate the risks in different contexts of participation.[59]

The data collected for the NCHSAIS,[39] and for the NCAA 5-[13] and 13-year[12] reviews of ACL injuries in college basketball and soccer, allowed for the calculation of injury rates per number of athletes and per athlete event, but did not allow for the calculation of injury risk per athlete-hour of exposure. The Punahou School high school injury surveillance study[47] reported injury rates per athlete and days lost from sport per athlete, but also failed to report athlete-hours of exposure. The NCHSAIS, NCAA-ISS-derived and Punahou injury density (injury rate) calculations did not account for differing practice or competition lengths among sports, and therefore different hours of exposure.

Despite the strength of athlete-hours of exposure as a denominator, analysing only with respect to athlete-hours of exposure (injury risk) may not present the most complete picture. Prevention efforts should be geared not only towards the riskiest sports, as defined by high rates of injury per athlete-hour of exposure, but also towards sports with a high incidence of injury. In order to gain the most complete picture of injury patterns from the data, both incidence rate (injuries per athlete) and injury risk (injuries per athlete-hour of exposure) must be evaluated. Sports with a relatively large number of practice and/or game hours may have low rates of injury per athlete-hour of exposure, but large numbers of athletes may be injured. Gregg et al.[11] highlighted the need to examine the same data using different denominators, with their finding that girls' basketball had the highest rate of concussion of any sport (using athlete-hours of exposure as the denominator), but boys' football had nearly three times as many concussions. The large number of practice and game hours in boys' football diluted the calculation of football injuries per athlete-hour of exposure, but each individual football player was nearly 20% more likely to experience a concussion than a girl playing basketball.[11]

There still is no widespread consensus on how to report injuries in sports such as football that have many hours of practice and game time. Lindenfeld et al.[43] argue that using athlete-hours of exposure would produce a more accurate incidence rate for sports such as football, in which many members of the team do not regularly participate in competitions. They believe that using the total number of athletes as the denominator in such circumstances would deflate the injury rates, given that only a third to a half of team members play regularly. The best solution may be to use multiple denominators to analyse injury surveillance data, which has become a relatively common practice in recent literature.[50,53-57,59,61,64]

3.3 Data Collection

Several investigations have used ED records to track sports injuries.[33,42,49,51,52,65,78,79] This method of data collection has the advantage of providing diagnoses made by physicians with the benefit of in-hospital diagnostic technology. The goal of ED-based studies is not to report all injuries that occur, but to effectively capture and efficiently document many season-ending injuries, acute surgical sports injuries and catastrophic injuries. As such, ED-based studies occupy an important niche in injury surveillance. However, recent studies pinpoint three potential disadvantages of using ED presentation or hospital admissions rates to investigate incidence of, or patterns in, sports injuries. First, using ED/hospital admissions for data collection in sports injury surveillance may over-represent male sports injuries, the most severe/acute injuries and the injury rate among young athletes.[48] Second, an ED study precludes critical linkage of injuries to overall expo-

sures or to other 'denominator' estimates of injury opportunity.[40,51] Third, collecting data through EDs and hospital admissions records alone misses many sports injuries, as studies have demonstrated that up to 75% of sports injuries are not treated at an ED or admitted to a hospital.[48,80] The majority of medically-treated sports injuries present to community-based sources such as general practitioners or sports medicine clinics.[45,52,81-85] In a study of Australian rules football injuries in children and adolescents, EDs treated only 28% of all reported injuries.[85] In addition, sports injuries treated in a hospital tend to be of different types and severity, and tend to occur within different patient populations from those treated in a clinic.[79,83]

As with data from EDs, data collected through primary care physician (PCP) visits or sports clinic presentations can provide more definitive diagnoses. However, given the recent findings of one study[40] that 65% of all basketball injuries (40% of serious injuries and 71% of non-serious injuries) occurred during practice sessions and many of these injured athletes did not present to a primary care or sports medicine physician, studies collecting data through clinics alone also have the potential for significant bias. Thus, to capture the widest range of injuries with respect to severity, injury type, age group and gender, a method of data collection at the point of injury is needed.

The use of CATs to collect data for injury surveillance studies has become a relatively common practice,[4,11,37,39,47,50,53-55,57,60,62,63,66,86-89] but is not without its inherent problems. On-site trainers do not have access to the diagnostic technologies available in hospitals or sports medicine clinics, and as such, their diagnoses may be less precise than those of a physician. Access to team trainers may vary by sport and age group (e.g. a tennis team may be less likely to have a trainer than a football team) and elementary and secondary-school aged athletes participating in club sports may have less access to team trainers than high-school or college athletes. In addition, qualifications of athletic trainers vary throughout the world, as does the structure of junior, adolescent and college sports; therefore, access to training staff for these athletes also differs.

Despite these limitations, there are significant advantages to using CAT-collected injury data in certain contexts. In most areas of the US and in countries with similarly-structured competitive sport settings, collecting data through athletic trainers allows for the detection of more injuries than could be identified by tracking injuries via ED, PCP or sports clinic presentations. This is supported by the finding of Gregg et al.[11] that only 32% of athletic injuries sustained in practice or games were referred to the ED or to a physician for treatment. The use of team trainers to collect injury data also allows for the collection of exposure data (i.e. total athletes and/or total athlete-hours of exposure), which is an advantage over ED-based data collection methods. Therefore, while CATs may provide an excellent method of data collection for junior and adolescent sports in the US, the optimal method of data collection varies throughout the world. The optimal method of data collection depends on the structure of youth sports in a particular location, who provides initial care to the largest number of injured athletes, how qualified those individuals are to diagnose injury and the presence or absence of national injury surveillance registries/systems.

Strengths of this review include: (i) the breadth of literature reviewed; (ii) the identification of three key epidemiologic issues to guide the clinician reading injury surveillance literature or when conducting such studies; and (iii) the provision of recommendations regarding the advantages and disadvantages of different definitions of injury, the denominators employed and the methods of data collection. The fact that this is not a systematic review of the literature in the form of a meta-analysis may be a potential limitation. However, to accomplish our particular objectives, we felt that the constraints of a meta-analysis systematic review of the literature, including formal inclusion and exclusion criteria for studies reviewed, might limit our ability to sample the broadest range of articles and therefore our ability to provide summary data and recommendations applicable to a wide variety of settings. The articles selected provided significant geographical diversity, representing a wide range of sports in various countries.

4. Conclusions

This article highlights the following three key epidemiological and methodological issues to con-

sider when reading or conducting an injury surveillance study: (i) the definition of a sports injury; (ii) the denominator with which injuries are reported; and (iii) the method of data collection (who and where). Given the increasing number of young athletes participating in organised sports throughout the world, and the negative physical, financial and psychological consequences experienced by injured athletes and their families, injury surveillance studies are more important and numerous than ever before. The methodology employed in sports injury surveillance studies may significantly impact on the design, and therefore the efficacy, of interventions. We reached three conclusions or recommendations. First, a meaningful definition of injury should incorporate both severity (i.e. the catastrophic potential of the injury and the degree of skeletal/tissue involvement) and time lost from participation, thereby effectively reducing the bias associated with the incidence estimate. Second, athlete-hours of exposure, in conjunction with another denominator that gives information on the absolute number of injuries (e.g. total athletes), will provide the most revealing picture of injury rates and injury risk from a given data set. Third, the optimal method of data collection is one that can capture the widest range of injuries with respect to severity, injury type, age group and gender. The data collection method must also allow for the collection of exposure data, providing an assessment of injury rate and risk that is relevant to the broadest cohort of athletes. This method of data collection will vary depending on geographical location, the organisation of youth sports in that area and the age group in which injury data are to be collected.

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