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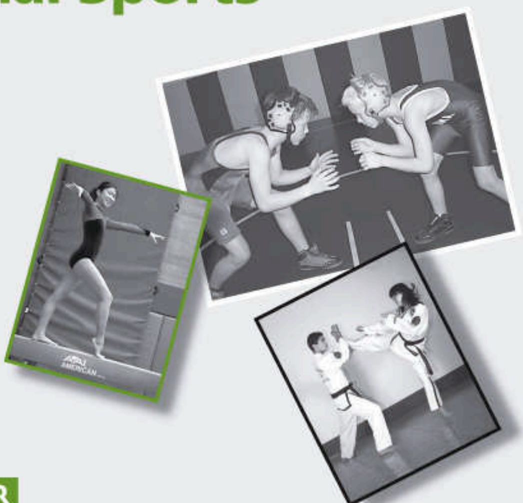
Epidemiology of Pediatric Sports Injuries

Individual Sports



Editors
D.J. Caine
N. Maffulli

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Individual Sports

Volume Editors

Dennis J. Caine *Bellingham, Wash.*
Nicola Maffulli *Stoke on Trent*

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Epidemiology of Children's Individual Sports Injuries

An Important Area of Medicine and Sport Science Research

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Introduction

Participation in children's and youth sports is increasingly popular and widespread in Western culture. Many of these youngsters initiate year-round training and specialization in their sports at a very early age. This is probably due to the 'catch them young' philosophy, and to the belief that, to achieve international standing in later sporting life, intensive training should be started before puberty [1]. It is not uncommon today, for example, for preteens to train 20 or more hours each week at regional training centers in tennis or gymnastics, to compete in triathlons, or for youngsters as young as 6–8 years of age to play organized hockey or soccer and travel with select teams to other towns and communities to compete against other teams of similar caliber.

The Uniqueness of the Young Athlete

Engaging in sports activities at a young age has numerous health benefits but also involves risk of injury. Indeed, the young athlete may be particularly vulnerable to sport injury due to the physical and physiological processes of growth. Injury risk factors that are unique to the young athlete include susceptibility to growth plate injury, nonlinearity of growth, limited thermoregulatory capacity, and maturity-associated variation. Although problems do not ordinarily arise at normal levels of activity, the more frequent and intense training and competition of young athletes today may create conditions under which this susceptibility exerts itself.

Susceptibility to Growth Plate Injury

Growth plate injuries have no counterpart in adult life. The fear is that the tolerance limits of the growth plate may be exceeded by the mechanical stress of injury in sports like wrestling or by the repetitive physical loading demanded in gymnastics [2]. The major concern with physeal injuries is that they can produce permanent injury to the growth cells, resulting in growth disturbance.

The resistance of growth plate cartilage to stress is low [3]. It is also less resistant than articular cartilage to compression and shearing, and than adjacent bone to shear and tension forces. In addition, the growth plate may be two to five times weaker than surrounding fibrous tissue [4]. Therefore, when disruptive forces are applied to an extremity, failure may occur through the growth plate. The susceptibility of the growth plate to injury appears to be especially pronounced during periods of rapid growth [5–15]. Research pertaining to the development of physeal cartilage in animals shows a decrease in physeal strength during pubescence [6]. The data on humans are consistent with these findings [7–9]. An increase in the rate of growth at the growth plate is accompanied by structural changes that result in a thicker and more fragile plate [7, 10]. In addition, bone mineralization may lag behind bone linear growth during the pubescent growth spurt, thus rendering the bone temporarily more porous and more subject to injury [11, 12]. Studies of the incidence of physeal injuries in humans indicate an increased occurrence of fractures during pubescence [11–15].

Unfortunately, good epidemiological data are lacking on the incidence of physeal injuries in individual sports. However, literature reviews on this topic reveal multiple published case reports and case series that attest to the occurrence of both acute and chronic growth plate injuries in children's individual sports [2, 16, 17]. Reports of sport-related physeal injuries resulting in growth disturbance are also reviewed in these papers [2, 16, 17].

Nonlinearity of Growth

The normal growth pattern is nonlinear; that is, differential growth of the body segments (head, trunk, and lower extremities) occurs throughout growth and influences body proportions accordingly [18]. At birth, the relative contribution of head and trunk to total stature is highest and declines through childhood into adolescence. Thus, the child is characterized by a proportionately larger head and trunk, and shorter legs compared to an adult. Consequently, it could be argued that under a given physical load a child's locomotor apparatus is exposed to greater stress: hence to a higher risk of overuse injury than that of an adult [16]. Yet, often these child athletes progress rapidly to training regimens, skills, and stunts that were originally introduced and intended for more mature individuals. Indeed, they may well have surpassed the extent of physical loading and skill complexity that characterized training and competition a generation ago.

Limited Thermoregulatory Capacity

Exercising children do not adapt as effectively as adults when exposed to high temperature. This may affect their performance and wellbeing, and increase the risk for heat-related illness. The thermoregulatory shortcomings of children relative to adults during heat and exercise have recently been reviewed [18].

- children gain heat faster from the environment by convection, conduction, and radiation than do adults as a result of their greater surface area-to-body mass ratio than adults;
- children also produce more metabolic heat per mass unit than adults during activities that include walking and running;
- sweating capacity is considerably lower in children than in adults, which reduces their ability to dissipate body heat by evaporation; and
- children acclimate to exercise in hot weather at a slower rate than do adults.

Thus, a child will generate more heat for a given activity, yet is less able to dissipate body heat particularly in a hot environment. As children frequently do not feel the urge to drink enough to replenish fluid loss either before or following exercise, they may experience dehydration and increased risk of heat illness [19].

Maturity-Associated Variation

Children of the same chronological age may vary considerably in biological maturity status, and individual differences in maturity status influence measures of growth and performance during childhood and adolescence [18]. For example, the structural, functional, and performance advantages of early-maturity boys in sports requiring size, strength, and power are well known. The fear is that an unbalanced competition between early and late-maturing boys in contact sports such as martial arts and wrestling contributes to at least some of the serious injuries in these sports. A noninvasive method for estimating maturity status as a basis for grouping young athletes has recently been proposed [20]. However, the classification for participation in youth sports continues to rely primarily on chronological age, which may add yet another dimension of individual variation. For example, within a single age group (e.g., 12 years of age), the child who is 12.9 years of age is likely taller, heavier and stronger than the child who is 12.0 years of age, even though both are classified as 12 years of age. Thus, when children are grouped by age, variation is associated with chronological age per se and also with differences in biological maturity [18].

Concern for the Health and Safety of Young Athletes

The increased sports involvement of children from an early age and continued through the years of growth, against a background of their apparent vulnerability to injury, gives rise to concern about the risk and severity and long-term effects of injury. Some recent data suggest that the risk of pediatric sports injury is high and constitutes a significant public health burden. In the United States during 2000–2001, for example, there were an estimated 4.3 million nonfatal sports- and recreation-related injuries treated in US hospital emergency departments [21]. Injury rates for both sexes peaked during the periadolescent years and were highest for boys. Children aged 5–14 years accounted for nearly 40% of all sports-related injuries [22]. Since only the more serious injuries present to hospital emergency departments, these data reflect only part of the overall injury picture in children's and youth sports. Many more, albeit less severe, injuries are treated in other settings such as healthcare providers' offices and clinics.

Parents need to know about the risks of injuries in children's and youth sports and what they can do to help prevent injury [22]. Indeed, young athletes of all ages and everyone who works with them, whether they be parents, sports medicine personnel, sports governing bodies, or coaches, need to know answers to questions such as the following: Is the risk of injury greater in some sport activities, or level of activity, than in others? What types of injuries are most common in a given sport? What is the average time lost from injury and what is the risk of permanent impairment? Are some children prone to sports injury? Are some physical, psychological, or sport-related factors associated with an increased risk of injury? Can injury be prevented and if so, how? How effective are the preventive measures that have been implemented? These are all questions which sports medicine personnel and coaches should be prepared to respond to, and the information should be made readily available to them. Providing this information, at least as far as possible, is an important objective of sports injury epidemiology research.

Epidemiology of Sports Injuries in Children

Sports injury epidemiology is the study of the distribution and determinants of varying rates of sports injuries for the purpose of identifying and implementing measures to prevent their development and spread [23]. The epidemiologist in sports medicine is concerned with quantifying injury occurrence (*how much*) with respect to *who* is affected by injury, *where* and *when* injuries occur, and *what* is their outcome, for the purpose of explaining *why* and *how* injuries occur and identifying strategies to control and prevent them. The study of the distribution of varying rates of injuries (i.e., who, where, when, what) is referred to as descriptive epidemiology. The study of the determinants of an exhibited distribution of varying rates of injuries (i.e., why and how) and the effectiveness of selected preventive measures is referred to as analytical epidemiology. For a more extensive discussion of the epidemiological approach to sports injuries the reader is referred to Caine et al. [23].

The epidemiology of sports injuries in children and youth is an important area of research that has been largely overlooked in the medicine and sport science literature; it deserves more serious study, particularly with regards to the identification and analysis of risk factors and preventive measures [24]. However, existing epidemiological research on pediatric sports injuries has already resulted in rule changes, equipment standards, improved coaching techniques, and better conditioning of athletes [24]. For example, the prohibition of 'spearing' in football and rules regarding water depth and the racing dive in swimming are examples of how data on deaths and catastrophic injuries can be used to help promote the safety of young athletes. Other preventive measures supported by research include anchoring movable soccer goals to prevent tipping, improved training for high school wrestling coaches and increased awareness of pathogenic weight control in wrestling and gymnastics [25].

Purpose and Organization of This Book

The benefits of physical activity for children and youth are substantial. However, growth in sports participation has contributed to an increase in pediatric sports-related injuries. In addition to the immediate healthcare costs, these injuries may have long-term consequences on the musculoskeletal system, resulting in limb dysfunction and a subsequent reduction in levels of physical activity [26]. However, half of all organized sports-related injuries among children can be prevented [27].

The purpose of *Epidemiology of Pediatric Sports Injuries: Individual Sports* is to review comprehensively what is known about the distribution and determinants of injury rates in a variety of individual sports, and to suggest injury prevention measures and guidelines for further research. This book provides the first comprehensive compilation and critical analysis of epidemiological data over children's individual sports: including equestrian, gymnastics, martial arts, skiing and snowboarding, tennis, track and field, and wrestling. The next volume (vol. 49) in Medicine and Sport Science will address the epidemiology of injuries in pediatric team sports. A common, uniform strategy and evidence-based approach to organizing and interpreting the literature is used in all chapters. All the sports-specific chapters are laid out with the same basic headings, so that it is easy for the reader to find common information across chapters. Section headings include, besides the Abstracts and Introductions:

- Incidence of Injury
- Injury Characteristics
- Injury Severity
- Injury Risk Factors
- Suggestions for Injury Prevention
- Suggestions for Further Research

In each sports-specific chapter, an epidemiological picture has been systematically developed from the data available in prospective cohort, retrospective cohort, case-control, and cross-sectional studies (i.e., denominator-based designs). From this picture, it became possible to suggest preventive measures which seemed at least reasonable, given the level of evidence available, and to suggest needed areas for further research. A chapter titled 'Injury Prevention and Future Research' that addresses individual and team sports is included at the end of both volumes to provide a more global, across-sport examination of the literature identifying risk factors and prevention strategies for injury in child and adolescent sports.

Sport scientists and healthcare professionals will find *Epidemiology of Pediatric Sports Injuries – both Volume 48: Individual Sports and Volume 49: Team Sports* – useful in identifying problem areas in which appropriate preventive measures can be initiated to reduce the risk and severity of injuries. They will also want to use these as a resource for research initiatives in the epidemiology of children's sports injuries. Sports administrators and coaches will find these books a thought-provoking reference that spurs discussion and encourages changes in the rules, equipment standards, coaching techniques, and athlete conditioning programs they use. Finally, the books will provide these individuals with current information on the epidemiology of pediatric sports injuries so that they, in turn, can inform parents about the risks of injury in children's sports and how they can help their children avoid or limit these risks.

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Equestrian Injuries

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Abstract

Objective: This chapter reviews the current evidence for the epidemiology of pediatric equestrian injuries. **Data sources:** The relevant literature was searched through the use of MEDLINE (1966–2004) and SPORT DISCUS (1975–2004) searches, hand searches of journals and reference lists and discussions with experts and sporting organizations worldwide. Keywords and Mesh headings used in all searches included horse racing, children, pediatric injuries, sports injuries, equestrian injuries and sports trauma. **Main results:** Limited data exist on the epidemiology of pediatric equestrian injuries. Most studies note the high preponderance of females with a peak incidence at approximately 14 years of age. This is likely to reflect the higher rate of female riders. The two most common horse riding-related injuries are long bone fractures and head injury. Although most injuries occur during recreational riding, approximately 15% of injuries occur in nonriding activities such as feeding, handling, shoeing and saddling. **Conclusions:** While there is little knowledge of injury demographics or the efficacy of prevention countermeasures in this field, it is likely that injuries will continue to occur. The major challenge in reducing pediatric equestrian injuries is the formal scientific demonstration that the various proposed injury prevention measures are effective. With the majority of equestrian injuries happening during unsupervised leisure riding, the prospect of injury prevention is limited.

Introduction

The demographics and nature of horse riding injuries suffered by children is largely unknown. Although retrospective case series studies have been published, there are no prospective studies detailing these injuries. This is also the case for equestrian injuries in adults, although more information is available in specific subgroups of riders, such as professional jockeys, rodeo riders and polo participants [1].

The limited available pediatric injury data are largely a reflection of the way horse riding is conducted. Namely the sport is amateur, variably supervised and apart from limited competitive situations, is not subject to administrative control that would enable the compilation of injury data. Injuries, especially minor injuries, are seldom reported, and there are no regulatory requirements anywhere in the world that compel formal injury notification for this sport. This lack of detailed information is somewhat surprising given that horse riding is one of the most popular participation sports with tens of millions of active riders in most Western countries.

Although falling from horses or being kicked are the most familiar mechanisms of injury, horses can also inflict injuries by biting, pulling, kicking the rider, standing or rolling on the rider and hitting the rider with sudden movement of the head [2]. Further, horses may injure their riders during nonriding activities such as grooming, feeding, handling, shoeing and saddling. Fully-grown horses can weigh up to 550 kg (1,200 lbs) and are capable of reaching speeds of over 60 kph (40 mph). It is not surprising that severe injuries do occur in this sport [1].

This chapter reviews the current evidence for the epidemiology of pediatric equestrian injuries. The relevant literature was searched through the use of MEDLINE (1966–2003) and SPORT DISCUS (1975–2003) searches, hand searches of journals and reference lists and discussions with experts and sporting organizations worldwide. Keywords and Mesh headings used in all searches included horse racing, children, pediatric injuries, sports injuries, equestrian injuries and sports trauma.

Frequency of Injury

Participation Level

There is little or no detailed information about the demographics of pediatric equestrian injuries. Although numerous case series have reported specific injury occurrences, such as catastrophic head or spinal injury, the common thread missing throughout all these studies is information on exposure. Similar criticisms can be made about electronic injury surveillance systems, such as the US national injury surveillance system (http://www.nyssf.org/statistics1998.html) or the North American CHIRPP database (http://www.hc-sc.gc.ca/pphb-dgspsp/publicat/).

In broad terms, the approximate numbers of horse riders is known. In the USA, over 30 million people ride on a regular basis with more than 2 million of these being under the age of 19 years [3–5]. In the UK, this figure is put at 3 million regular participants with one third being children [6]. In Australia, there are over 250,000 people actively engaged in recreational horse riding with

Table 1. Retrospective and case series studies including pediatric data

Study reference	Patient source	Total number of equestrian injuries	Number of injuries <15 years old (% of total)	Demographics
[8]	Horse Shows Association survey, United States	290	62 (21%)	85% female 34% falls 15% fractures
[8]	Pony Club survey, United States	31	19 (61%)	No analysis performed
[9]	Hospital admissions, United States	136	NS	76% female 75% falls 62% fractures
[10]	Pediatric hospital, Norway	23	23 (100%)	90% female 60% falls 50% fractures
[11]	National Electronic Injury Surveillance System, United States	167,578	48,822 (29%)	65% female
[12]	National Injury Database, New Zealand	827	315 (38%)	74% female 46% fractures
[3]	Postal survey, United States	589 (27% of total surveyed)	46 (8%)	IR 0.4/1,000 h
[13]	Pediatric hospital data, Sweden	516		95% female 27% fractures IR 14/1,000 h
[14]	Pediatric Emergency Dept, United Kingdom	41	41 (100%)	95% female 66% falls 26% fractures
[15]	National Pediatric Trauma Registry, United States	720	276 (38%)	62% female 64% falls 35% fractures
[7]	Australian Bureau of Statistics data, Australia	64		
[16]	Emergency Dept, United Kingdom	260 (10% of all sports injuries)	62 (23%)	80% female 80% falls 60% fractures

IR = Injury rate.

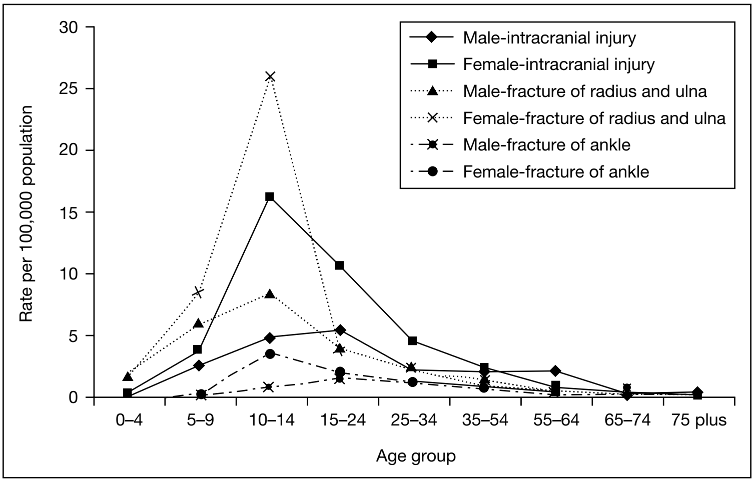

Fig. 1. Specific equestrian injuries by age and sex. Adapted from [7].

74,000 registered child participants in events run by pony clubs and the Equestrian Federation of Australia [7].

Incidence of Injury

A summary of retrospective and case series studies including pediatric data on equestrian injuries is shown in table 1 [3, 7, 8–16]. Virtually all studies note the high preponderance of females suffering horse riding-related injuries (table 1). Crude injury rates of the two most common injuries, long bone fracture and head injury, consistently note higher rates in females and these peak at approximately 14 years of age (fig. 1). This is likely to reflect the higher rate of female riders. However, no precise figures exist in this regard (with the limited exception of pony club membership) to allow accurate analysis of injury rates.

Injury Characteristics

Injury Onset

All published studies of equestrian injuries report acute injuries only. There is no published information in the pediatric age group as to whether riders suffer from chronic musculoskeletal injuries related to riding or whether these may contribute to the acute injury episode.

Both Gierup et al. [17] and Williams and Ashby [18] have reported a one third incidence of previous injuries in riders presenting to hospital with a new acute injury. No specific details nor exposure information were provided to suggest that the injured riders represent the typical horse riding population.

Injury Location

Injuries to the extremities comprise the largest group of injuries. They are predominantly soft tissue injuries and long bone fractures [19, 20]. Typically such injuries are not routinely admitted to hospital and may be under-represented in published studies. Equestrian-related head injuries in children are typically admitted to hospital, and hence recorded more accurately.

Head injuries are responsible for the majority of serious equestrian injuries and deaths [4, 6, 11, 21, 22]. Such injuries are almost invariably related to falls. Injuries to the thorax, abdomen and pelvis are also often severe and account for a smaller but substantial number of hospitalizations [4, 11].

Situational

No information exists as to the situation where injuries occur such as in training or in specific maneuvers such as jumping. The majority of injuries, however, occur during leisure riding rather than in competition [23, 24].

Furthermore, approximately 15% of equestrian injuries occur in nonriding activities such as feeding, handling, shoeing and saddling [9, 25, 26].

Action or Activity

No published information exists regarding the specific activities that were engaged in at the time of the injury with the possible exception of where an injury occurs from a collision between horse and car whilst road riding [6]. Most published studies report mechanisms of injury in terms of falls from the horse or other specific factors related to riding.

Chronometry

Equestrian injuries tend to occur when the rider is mounted [3, 5, 9, 21, 25], during lessons [26], on farms or in paddocks [18], during warm weather and in school holidays [6, 18] and on weekends [18]. These likely represent the most frequent type of riding conducted rather than suggest that they represent a particular propensity to injurious situations.

Injury Severity

Injury Type

There are no data available from prospective studies or where the exposure incidence is known that enables injury rate calculation. The published retrospective and case series studies are outlined in table 1 and are presented as a percentage of total injuries. Although the broad categories of anatomical injuries are commonly reported, the widely varied methodologies make comparison impossible.

Catastrophic Injury

Various case series and recommendations have been reported detailing catastrophic head and spinal injury from pediatric equestrian participation [7, 12, 16, 24, 27–36]. In general, fatal head injury from horse riding is relatively low both in general terms and by comparison to other sports [27, 28]. In one of the few prospective estimates, this horse riding-related mortality risk was put at 0.08 per 100,000 population [7]. This risk estimate includes all age groups.

Time Loss as a Result of Injury

Limited published information exists and is summarized in the section below. The time lost reported in those studies generally refers to either chronic injuries or those severe enough to warrant hospital presentation. There are no prospective data available for acute injuries.

Clinical Outcome

No published prospective information exists. There are a variety of case series and retrospective questionnaire-based studies reporting long-term outcome and time lost from equestrian injuries. In general terms, all of these papers suffer from selection bias given the population by which injuries are obtained in addition to the methodological limitations of the study design [5, 14, 15, 38–42].

Injury Risk Factors

There are no published data on injury prevention or risk factor analysis that have been subjected to formal analysis. In the absence of specific information, a conceptual framework based upon published studies is presented in figure 2 and discussed in the next section.

Suggestions for Injury Prevention

As discussed above, all suggestions in this section relate to retrospective, case series and other limited data. At best, this could be described as sufficient for Level 3 or 4 recommendations.

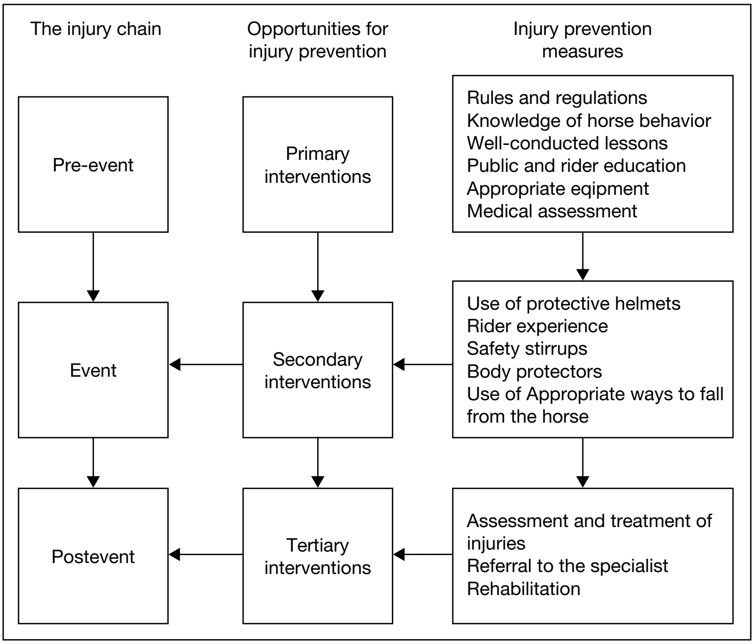

Fig. 2. Injury countermeasures in equestrian sports. Adapted from [10].

Intrinsic Factors

There are relatively few intrinsic factors that predispose a rider to injury with none that have been validated scientifically. In general, a rider requires a sense of balance, reasonable physical fitness and alertness to ride. Clearly anything that impairs these functions would be a contraindication to riding. In the same manner, avoidance of alcohol and drugs that may impair riding should be mandatory.

Some authors [43] have suggested specific neurological contraindications including unstable spinal cord lesions, permanent sequelae from head injury and repeated painful injury to the cervical and lumbar spine. None of these have been validated prospectively, and would need to be individually assessed.

Rider and public education may assist in informing riders about specific risks with riding and hence alter the behavior toward avoiding such situations as well as encouraging protective equipment use. Although laudable, such campaigns need to be validated against defined outcomes [44].

Extrinsic Factors

Most equestrian organizations have regulations governing the conduct of the sport and include specific equestrian safety issues. In professional horse racing and to a lesser extent in amateur racing, there are strict licensing requirements, supervision of racecourses, veterinary assessment of horses, medical assessment of jockeys, and enforcement of riding and safety rules. Pony clubs and similar groups in the pediatric age group have specific safety standards for supervisors and riders, and strict requirements for helmet use.

Ensuring that riding instructors are certified, experienced and have a good knowledge of horses are all reasonable measures, although no formal analysis has correlated injuries with instruction, and any certification needs to be formally evaluated. Horse selection may have a role whereby instructors can match suitable horses with the level of rider experience. As with all primary prevention measures, the efficacy depends upon both whether the regulations are enforced and whether the safety requirements are themselves effective.

Horse behavior is also a significant factor in many equestrian injuries. In US Pony Club surveys, it has been estimated that up to 80% of injuries resulted from the behavior of the horse [26]. Although horses are by their very nature unpredictable, some basic principles are important and may be taught as part of the basic horse riding instruction. Warm-up procedures for the horse, rider training, supervisor awareness of aberrant horse behavior, specific instruction in the safe approach to horses and avoidance of situations where other animals or vehicles may frighten a horse, have all been proposed [18, 19]. Specific 'tuck and roll' techniques if dismounted have been suggested as a means, albeit unproven, of reducing injuries in falls [45].

Appropriate and well-maintained equipment (e.g., tack or saddlery) is important to prevent falls. The checking of equipment as part of a premounting and dismounting routine is critical, although it has not been rigorously assessed [46]. Similarly appropriate clothing such as riding boots and gloves are important.

Protective equestrian helmets are widely recommended. Such helmets need to be certified to an appropriate materials testing standard. Although they are widely recommended, there has been no formal prospective or controlled study conclusively demonstrating their benefit or, in fact, that the current helmet standards are adequate to prevent injury [19]. There is some anecdotal evidence, however, suggesting a benefit for helmet use in preventing or lessening the severity of head injuries [33, 47]. Similarly other safety equipment such as body protectors and safety-release stirrups remain unproven.

Suggestions for Further Research

The major challenge facing pediatric equestrian injuries is the formal scientific demonstration that the various proposed injury prevention measures are effective. Ideally, this should be performed before they are implemented or promoted. In addition, the barriers to the adoption of injury prevention measures should be studied.

Given the high participation in organized instructional programs such as Pony Club, an assessment of the effectiveness of rider (and supervisor) training should be undertaken. External accreditation of instructors and riding schools should be performed to set standards that have been independently verified.

With the majority of equestrian injuries happening during unsupervised leisure riding, the prospect of injury prevention is reduced. Rider education campaigns to ensure adequate training, maintenance and inspection of equipment, wearing of appropriate clothing and helmets may all assist in reducing injuries.

While there is so little knowledge of injury demographics or the efficacy of prevention countermeasures in this field, it is likely that injuries will continue to occur.

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Gymnastics Injuries

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Abstract

Objective: The purpose of this chapter is to review the distribution and determinants of injury rates as reported in the pediatric gymnastics injury literature, and to suggest measures for the prevention of injury and directions for further research. **Data sources:** An extensive search of Pubmed was conducted using the Text and MeSH words 'gymnastics' and 'injury' and limited to the pediatric population (0–18 years). The review focused on studies using denominator-based designs and on those published in the English language. Additional references were obtained from hand searches of the reference lists. Unpublished injury data from the USA Gymnastics National Women's Artistic Gymnastics Championships during 2002–04 were also analyzed. **Main results:** Comparison of study results was compromised due to the diversity of study populations, variability of injury definition across studies, and changes in rules and equipment across years. Notwithstanding, this review of the literature reveals a reasonably consistent picture of pediatric gymnastics injuries. The incidence and severity of injuries is relatively high, particularly among advanced level female gymnasts. Body parts particularly affected by injury vary by gender and include the ankle, knee, wrist, elbow, lower back, and shoulder. Ankle sprains are a particular concern. Overuse and nonspecific pain conditions, particularly the wrist and low back, occur frequently among advanced-level female gymnasts. Factors associated with an increased injury risk among female gymnasts include greater body size and body fat, periods of rapid growth, and increased life stress. **Conclusions:** Above all, this overview of the gymnastics injury literature underscores the need to establish large-scale injury surveillance systems designed to provide current and reliable data on injury trends in both boys and girls gymnastics, and to be used as a basis for analyzing injury risk factors and identifying dependable injury preventive measures.

Introduction

Gymnastics has enjoyed resurgence in participation and a rise in spectator popularity in recent decades largely due to an increased emphasis on girls' sports, the inherent athleticism of gymnastics, and some important personalities who captured the public attention via astonishing performances in competition [1]. Associated with this increased participation is an earlier age of entry and specialization in the sport. Elite female and male gymnasts may initiate training for their sport as early as ages 6 and 9 years, respectively, with peak performance being 10 or more years away. During this period, the degree of difficulty of maneuvers practiced and performed, and the volume and intensity of training increases dramatically.

The increased participation in gymnastics is encouraging because physical activity clearly provides many health-related benefits to those who participate. However, the increased involvement and difficulty of skills practiced at an early age and continued through the years of growth, with the volume or intensity of training required to be competitive, gives rise to concern about the risk and severity and long-term effects of injury to the young gymnast. Indeed, most gymnasts do not pass through their years of training and competition without incurring injury [2].

The purpose of this chapter is to review integratively and comprehensively the distribution and determinants of injury rates as reported in the pediatric gymnastics injury literature, and to suggest measures for the prevention of injury and directions for further research. Data collection focused on the English literature; however, foreign publications that have been translated were also included. Data collection was limited primarily to published articles and reports and was conducted using Pubmed (keywords = gymnastics and injury). Relevant articles cited in the literature retrieved were also located (i.e., ancestry approach). In addition, unpublished data collected at the USA Gymnastics National Women's Artistic Gymnastics Championships during 2002–04 were also included to provide a more complete picture, given the relative paucity of published literature on injuries affecting national-level competitors.

Our search was limited to denominator-based designs including cross-sectional, retrospective, and prospective studies. The gymnastics injury literature is replete with epidemiological data, yet too few studies have focused on the pediatric population of gymnasts, especially male gymnasts. Additionally, most of the studies are descriptive in nature and few have sought to analyze risk factors or injury prevention measures [2]. Furthermore, the following methodological shortcomings among the cohort studies restricted the potential to interpret and compare their findings through a common statistical treatment:

- diversity of study populations;
- instability of study results due to relatively short periods of data collection in some studies;
- insufficient sample size to warrant risk factor analysis in some studies;
- low response rates, short- and long-term recall bias, and response motivation bias associated with the frequent use of questionnaires;

- nonrandom selection or convenience samples (i.e., the possibility that some schools or clubs most concerned with safety may be the ones to consent to involvement in an epidemiological study of injuries); and
- variability in injury definition across studies.

In addition to these methodological shortcomings, comparison of results across studies and years may be further complicated by changes in rules and equipment. Every 4 years, for example, rules are changed that affect the way judges score gymnasts, the way coaches train gymnasts, and the way gymnasts prepare their minds and bodies. Additionally, women's artistic gymnastics frequently changes its equipment to increase the difficulty of skills that a gymnast can perform and to decrease the forces on the body. The use of resi-mats, square foam pits and shredded loose foam pits, for example, have helped to decrease the physical stress on the gymnasts landing their skills. Changes in equipment and rules may lead to different injury patterns and risk of injury.

Incidence of Injury

Participation Level

A comparison of injury rates reported in prospective and retrospective injury studies is shown in table 1. Study samples include both female and male recreational [3–5], club [3–18], and high school gymnasts [6, 19]. Overall, there were seventeen studies reporting on injuries affecting female gymnasts and six studies on male gymnasts. Review of table 1 indicates that most injury rates were calculated with reference to participant-seasons and therefore do not account for individual differences in exposure to injury risk. A meaningful comparison across these studies, both within and between genders, is, therefore, difficult.

As shown in table 1, exposure-based injury rates (i.e., number of injuries/1,000 h) for club-level female gymnasts reported in studies using the same definition of injury (i.e., any damaged body part that would interfere with training) range from 1.4 to 3.7 injuries per 1,000 h [9–13, 15, 17]. Only one study reported an injury rate relative to the number of athletic-exposures. Caine et al. [13] reported a rate of 8.5 injuries per 1,000 athletic-exposures, which notably is quite similar to that reported for female collegiate gymnasts in the USA [20].

Injury Characteristics

Injury Onset

A percentage comparison of injury onset in girls gymnastics is shown in table 2 [3, 4, 7, 9–14, 16, 17, 21, 22]. A review of these data indicate that the

Table 1. A comparison of injury rates in girls' and boys' gymnastics (adapted from Caine [2] and Caine et al. [27])

Study	Design pros/retro (P/R)	Data collection interv/question (I/Q)	Duration of injury survival	Number of injuries	Sample Number of participants (1 participant = 1 gymnast participating in one season)	Sample Number of teams	Rate Number of injuries per 100 participant seasons	Rate Number of injuries per 1,000 h of exposure	Rate Number of injuries per 1,000 athletic exposures*
Females									
Recreational									
Pettrone and Ricciardelli [3]	P	Q	7 months	33	2,016	15	1.6		
Goodway et al. [4]	P	Q	1 year	7	5,929		0.1		
Lowry and Leveau [5]	R	Q	11 months	128	3,042	14	4.2		
Club									
Garrick and Requa [6]	P	Q	1 season	16	72	3	22.2		
Weiker [7]	P	Q	9 months	95	766[a]	6	12.4		
Vergouwen [8]	P	I	3 seasons	353	42		840.5		
Pettrone and Ricciardelli [3]	P	Q	7 months	29	542	15	5.3		
Caine et al. [9]	P	I	1 year	147	50	2	294	3.7	
Goodway et al. [4]	P	Q	1 year	93	725		12.8		
Lindner and Caine [10]	P	QI	3 seasons	90	362	5	24.9	0.5	
Bak et al. [11]	P	Q	1 year	41	46		89	1.4	

Table 1 (continued)

Study	Design pros/retro (P/R)	Data collection interv/question (I/Q)	Duration of injury survival	Number of injuries	Sample Number of participants (1 participant = 1 gymnast participating in one season)	Sample Number of teams	Rate Number of injuries per 100 participant seasons	Rate Number of injuries per 1,000 h of exposure	Rate Number of injuries per 1,000 athletic exposures*
Kolt and Kirby [12]	PR	Q	18 months	349	64	17	364	3.3	
Caine et al. [13]	P	I	3 years	192	79[b]	1		2.5	8.5
Lowry and Leveau [5]	R	Q	11 months	260	370	14	70.3		
Steele and White [14]	R	Q	2 seasons	146	268	9	54.5		
Backx et al. [15]	R	Q	7 months		220			3.6[c]	
Dixon and Fricker [16]	R	I	10 years	325	162	1	200		
Kolt and Kirby [17]	R	Q	1 year	321	162	18	198	2	
High School									
Garrick and Requa [6]									
1973–75	P	IQ	2 seasons	39	98		39.8		
1973–74	P	I	1st			3	56.0[d]		
1974–75	P	Q	2nd			2	28		
Garrick and Requa [6]	P	Q	1 season	73	221	12	33		

McLain and Reynolds [19]	P	I	1 season	11	24	1	45.8
Males							
Recreational							
Lowry and LeVeau [5]	R	Q	11 months	1	377	14	0.3
Club							
Weiker [7]	P	Q	9 months	10	107[e]	6	9.3
Kerr [18]	P	Q	8 months	61	24	2	254[f]
Lowry and LeVeau [5]	R	Q	11 months	16	21		76.2
Dixon and Fricker [16]	R	I	10 years	247	121	1	204
High School							
Garrick and Requa [6]	P	I	2 seasons	5	18	1	13.9
McLain and Reynolds [19]	P	I	1 season	8	20	1	40

*An athletic exposure (A-E) is one athlete participating in one practice or game in which the athlete is exposed to the possibility of athletic injury.
[a]Including 477 recreational gymnasts.
[b]Total number of participants during 3 years (mean duration = 17.5 months).
[c]Rates include data from 25 male gymnasts.
[d]This rate was inflated due to high incidence of trampoline injuries; trampoline was eliminated as a scholastic event after this year.
[e]Includes 70 recreational gymnasts.
[f]Includes data from 8 female gymnasts.

Table 2. A percent comparison of injury onset in girls' gymnastics (adapted from Caine [2] and Caine et al. [27])

Study	Study design P/R	Number of injuries	Number of participant seasons*	Injury onset	
				Sudden	Gradual
Club					
Weiker [7]	P	95	766	42.9	57.1
Pettrone and Ricciardelli [3]**	P	29	2,558	17.7	82.3
Goodway et al. [4]	P	93	725	48	52
Caine et al. [9]	P	147	50	55.8	44.2
Lindner and Caine [10]	P	90	362	21.9	78.1
Bak et al. [11]	P	98	115	39	61
Kolt and Kirkby [12]	P	349		35.8	64.2
Caine et al. [13]	P	192	159	40.6	59.4
Steele and White [14]	R	146	268	33	67
Dixon and Fricker [16]	R	325	162	36.9	63.1
Jones [21]	R			38	62
Mackie and Taunton [22]	R	279		44	56
Kolt and Kirkby [17]	R	321	162	41.7	58.3

*A participant season is one gymnast participating in one season.
**Includes data on recreational gymnasts.

majority of injuries were of sudden onset in nature (range = 52.0–83.4%). The pattern of injury onset injuries may vary according to the competitive level. For example, studies of Australian gymnasts [12, 17] report that elite gymnasts are characterized by a significantly greater proportion of chronic injuries than subelite gymnasts. In the Eugene study [13], where 82/147 (55.8%) injuries were gradual onset, gymnasts were highly competitive and trained 20–27 h weekly.

The pattern of injury onset may also vary by injury location. For example, in one study [13] the majority of wrist and low back injuries were gradual onset while most ankle injuries were sudden onset injuries.

Injury Location

Identification of commonly injured anatomical sites is important because it alerts sports medicine personnel associated with gymnastics teams to areas in need of special attention. A percentage comparison of injury location reported girls club and high school gymnastics studies is shown in table 3 [6, 9–14, 23, 24]. A review of the prospective data in this table indicates that the lower extremity was the most frequently injured body region for club-level gymnasts

Table 3. A percent comparison of injury location in girls' club and high school gymnastics (adapted from Caine [2] and Caine et al. [27])

	Club: Prospective studies							Club: Retrospective studies					High School studies	
Number of injuries	Garrick [6] 16	Weiker [7] 95	Caine [9] 147	Lindner [10] 90	Bak [11] 46	Kolt [12] 64	Caine [13] 192	Steele [14] 146	Kerr [23] –	Dixon [16] 325	Kolt [17] 321	Homer [24] 49	Garrick [6] (mixed)	Garrick [6] (interscholastic)
Head	6	3.2	0.7	4.1	2.4	1.1	1.6	1.4		1.5	0.6	2	3	7.7
Skull		2.1		1								2		
Face		1.1		2.1										
Teeth		0		1										
Spine/Trunk	0	7.5	15	16.7	9.8	17.2	19.2	13.7		22.3	17.8	24.4	13	43.6
Neck	0	1.1	0.7	6.3			4.2	2.7		3.9		4.1		
Upper back	0	0	0.7	3.1			1	0		2.4				
Lower back	0	6.4	12.2	5.2			13.5	11	13	13.3		20.3		
Ribs	0	0	0.7	2.1			0.5	0		2.1				
Stomach	0	0	0.7	0					0				0.6	
Upper extremity	25	18.1	20.5	22.9	17.1	20.9	21.4	14.4		21.7	22.7	18.3	36	12.8
Shoulder		1.1	0.7	4.2			4.2	0		1.2				
Arm		0	0.7	1			0.5	0.7		0				
Elbow		5.3	4.8	7.3			3.7	4.8		8.5		4.1		
Forearm		1.1	0.7	0			1	0		0.6		2		
Wrist		6.4	9.5	5.2			9.4	7.5		6		10.2		
Hand/Fingers		4.2	4.1	5.2			2.6	1.4		5.4		2		
Lower extremity	69	70.2	63.7	54.1	61	59	57.8	69.1		55.3	57.3	54.9	48	35.9
Pelvis, hips		2.1	2.7	1			2.1	1.3		4.5		6.1		
Thigh		1.1	8.7	1			4.2	1.3		3		2		
Knee	19	24.5	14.3	19.8			10.9	18.5	15	10.9		12.2	7	5.1
Leg		8.5	6.8	0			5.2	7.5		1.5				
Ankle	25	19.1	21.1	20.8			12	22	29	16		16.3	10	10.3
Heel/Achilles		4.2	5.4	4.2			10.9	0		6.9		18.3		
Foot/Toes		10.6	4.7	7.3			12.5	18.5	12	11.5				

(range = 54.1–70.2%) followed by the upper extremity (range = 17.1–25%), and spine/trunk (range = 0–43.6%). The retrospective data suggest a similar injury distribution except that injuries appear somewhat evenly distributed among the spine/trunk (range = 13.7–24.4%) and upper extremity (range = 14.4–22.7%) regions. The most frequently injured body part in the spine/trunk was the lower back in both prospective and retrospective studies. Common injury locations in the upper extremity were the wrist, elbow and hand/fingers. The ankle was typically the most often injured body part in the lower extremity followed by the knee.

Three prospective [7, 18, 25] and one retrospective [16] study report injury location data on young male gymnasts. In these studies the upper and lower extremities were injured most often, followed by the spine/trunk and head. However, only two of these studies provide complete data [16, 25]. The proportion of injuries affecting the upper (range = 36.4–53.4%) and lower (range = 32.8–43.1%) extremities was quite similar. In the most extensive and well-documented study of male gymnasts [16], the proportion of upper extremity injuries (53.4%) was greater than the proportion of lower extremity (32.8%) injuries.

In all of the studies of young male gymnasts, the shoulder was injured most often (range = 16.8–19%) followed by the wrist (range = 8.4–13.8%) and ankle (range = 9.7–13.9%). These findings differ from those of girls' gymnastics and may reflect the different types of apparatus used in men's gymnastics that place greater physical demands on the upper body.

Situational

Injury Rates in Practice versus Competition

It is not surprising that more injuries occur during practice than competition since more time is spent training than competing. In girls' gymnastics studies [3, 6, 9–11, 13, 23] the percentage of all injuries that occur in practice varies from 79 to 96.6%. In contrast, the proportion of injuries occurring in competition varies from 3.4 to 21% [3, 6, 9–11, 13, 23]. However, when the number of injuries is computed with reference to exposure data, injury rates are greater during competition than training for (7.4 vs. 2.4 injuries/1,000 h) [9]. This finding may be explained by the fact that gymnasts are better protected in training than in competition because of landing in foam pits, spotting, and softer mats [26]. Nerves and time pressures may also be contributing factors.

Unpublished data on injuries sustained by competitors at the 2002, 2003, and 2004 USA Gymnastics National Women's Artistic Gymnastics Championships are summarized in table 4. Definition of injury was any gymnastics-related condition that required treatment by the USAG Medical Staff. These included both acute and overuse conditions. Perusal of table 4 reveals that 27.6–80% of the junior and from 62.5 to 70% of senior gymnasts, respectively, were treated for

Table 4. Injuries treated at the 2002–04 USA Gymnastics National Women's Artistic Gymnastics Championships

Diagnosis	2002 Junior	2002 Senior	2003 Junior	2003 Senior	2004 Junior	2004 Senior	Total	Per cent
Apophysitis							[5]	3.4%
Osgood-Schlatter disease			1		2		3	
Sever's disease		1	1				2	
Contusion							[5]	3.4%
Calcaneous						1	1	
Foot			1				1	
Iliotibial band				1			1	
Metatarsal			1				1	
Toes			1				1	
Dislocation							[1]	0.7%
Elbow		1					1	
Fracture							[13]	8.9%
Fibula (stress fracture)		1					1	
Ischial tuberosity (avulsion)		1					1	
Metacarpal				1	1		2	
Metatarsal (stress reaction)		1					1	
Phalanx		1					1	
Phalanx (Salter-Harris III)						1	1	
Spondylolysis		1		1			2	
Talus		1	1			1	3	
Tibia tubercle (avulsion)			1				1	

Table 4 (continued)

Diagnosis	2002 Junior	2002 Senior	2003 Junior	2003 Senior	2004 Junior	2004 Senior	Total	Per cent
Impingement							[2]	1.4%
Ankle				1			1	
Shoulder						1	1	
Laceration/Rip							[5]	3.4%
Hand			1				1	
Toes			1	3			4	
Muscle Spasm/Tightness							[8]	5.5%
Calf		2					2	
Gluteus						1	1	
Quadriceps		2		1			3	
Paraspinal		1		1			2	
Nonspecific pain							[21]	14.4%
Low back		1	6	3	3	5	18	
Lumbar facet syndrome				1		1	2	
Thoracic myalgia				1			1	
Osteochondritis dessicans							[2]	
Knee					1	1	2	
Overuse (Muscle/Tendon)							[26]	17.8%
Achilles tendonitis			1		1	2	4	
Bursitis				1			1	
Costochondritis						1	1	
Epicondylitis (elbow)				1			1	

Medial tibial stress syndrome				3		8	11	
Patellar tendonitis				1		1	2	
Planter fascitis	1					1	2	
Rotator cuff tendonitis						3	3	
Sesamoiditis				1			1	
Respiratory problem							[2]	1.4%
Infection			1				1	
Pharyngitis				1			1	
Sprain (ligament)							[40]	27.4%
Ankle	3	5	5	3	5	3	24	
Cervical			1				1	
Elbow	2						2	
Foot	2		2			1	5	
Knee				1		3	4	
Sacroiliac joint			1	2			3	
Wrist			1				1	
Strain (Muscle/Tendon)							[12]	8.2%
Achilles	1						1	
Adductor					1		1	
Forearm						1	1	
Groin			1				1	
Hamstring		1		2		1	4	
Hip flexor			3				3	
Quadriceps					1		1	
Torn cartilage							[3]	2.1%
Medial knee meniscus				2		1	3	

Table 4 (continued)

Diagnosis	2002 Junior	2002 Senior	2003 Junior	2003 Senior	2004 Junior	2004 Senior	Total	Per cent
Torn tendon							[1]	0.7%
Achilles						1	1	
Total number of injuries	9	20	31	32	15	39	146	
Total number of participants	29	20	25	28	20	35		
Number of injuries/100 participants	31	100	124	114.3	75	111.4		
Total number of injured gymnasts	8	14	18	20	12	27		
Percent of injured gymnasts	27.6%	70%	72.0%	62.5%	80%	69.2%		

injuries at the various championships. The most common injury types were sprains (27.4%), overuse conditions (17.8%), and nonspecific pain (14.4%). The most common injury locations were the ankle (16.4%), low back (12.3%), and lower leg (7.5%). Overall, 16 injuries (11%) required surgery. The most common surgeries were for fracture repair (n = 4), anterior cruciate ligament reconstruction (n = 3), and meniscus repair (n = 3). Injury rates ranged from 31 to 124 injuries per 100 participants.

Action or Activity

Most reported data on events associated with injury in girls' gymnastics are flawed because they include both sudden and gradual onset injuries [27]. That is, it is difficult to determine whether gradual onset injuries are specifically related to maneuvers in a given event. Additionally, most injury data on events are expressed as percentage values, which do not account for differential gymnast exposures among the various gymnastics events [27]. One study which reports exposure-based acute injury rates for events in girls' gymnastics indicates that floor exercise is the event with the highest injury rate among club-level female gymnasts [9]. Notably, floor exercise also had the highest frequency of injury during the international competitions between 1983 and 1998 [28].

Only one study reported events associated with injury in boys' gymnastics. Lueken et al. [25] reported 345 injuries affecting club level gymnasts attending the U.S. Olympic Training Center over a 15-year period. Floor exercise was most often associated with injury (24.9%), followed by still rings (19.2%), horizontal bar (16.9%), parallel bars (16.4%), pommel horse (14.7%), and vault (7.9%).

Chronometry

Time of practice

Three studies [9, 10, 13] report a relatively high frequency of injuries occurring early in practice, suggesting the possibility of a qualitatively or quantitatively insufficient warmup for the gymnasts studied. Other possible explanations include the possibility that appropriate progressions were not provided and that gymnasts may practice difficult skills earlier in practice when they are most fresh. Of note, one study [9] reported that 7 of 12 acute competition injuries occurred during the first half-hour of competition, which was during the timed warmup.

Time of Season

Several injury studies report the time of season when injury occurs in girls' gymnastics [9, 13, 16, 23]. These studies report a relative increase in injury rates:

- Following periods of reduced training such as a short vacation or recuperation [9, 13] – perhaps due to an increased workload demands [26];

- During competitive routine preparation [13] – perhaps due to increased fatigue during performance of longer combinations and routines and/or hurried attempts to prepare routines with skills, which are not thoroughly learned [29]; and
- During the weeks just prior to competition [9, 23] – perhaps due to a heightened competitive anxiety or stress [23], or performing skills which are not thoroughly learned.

Injury Severity

Injury severity can span a broad spectrum from abrasions to fractures, to those injuries that result in severe permanent functional disability or even death. In the gymnastics literature, injury severity is usually indicated by one or more of the following: injury type, time loss, surgery, and clinical outcome.

Injury Type

A percentage comparison of injury types sustained by female participants in recreational [5], club [3, 5, 6, 9, 10, 12, 13, 17], and high school [6] gymnastics is shown in table 5. Sprains (range = 15.9–43.6%) and/or strains (range = 6.4–31.8%) are consistently among the three most common injury types for these gymnasts. Other common injury types include contusions, fractures, and overuse injuries. There were no corresponding data for young male gymnasts.

Lower Back

As shown in table 3, the low back is typically the most frequently injured body part in the spine/trunk region of female gymnasts. The young gymnast engaging in strenuous training and competition places demands on the lower back unparalleled in most other sports. Demands on the gymnast's back include repetitive flexion and hyperextension postures during vaulting, dismounts, and somersaults. In addition to the hyperlordotic postures, vertical impact loading occurs as the gymnast lands on both feet during dismount activities [30]. It is the chronic repetitive flexion, hyperextension, rotation, and compressive loading of the spine during these activities that may cause injuries to the spinal elements [31, 32]. The spine, as with the rest of the skeleton, is at greater risk of injury during the adolescent growth spurt [33].

Table 6 summarizes radiographical data on specific injuries and conditions involving the lower back of female and male gymnasts [34–45]. Common injury sites reported include the vertebral bodies, intervertebral discs, and pars interarticularis. Common problems reported include back pain, radiographical

Table 5. A percent comparison of injury types in girls' gymnastics (adapted from Caine [2] and Caine et al. [27])

Level/Study	Number of injuries/ particular season	Abrasion	Concussion	Contusion	Dislocation	Fracture	Inflammation	Laceration	Nonspecific	Sprain	Strain	Other
Recreational												
Retrospective study												
Lowry and Leveau [5]	128/3042	0	0	27.3	1.6	3	11.7	2.3	0	32	21.9	0
Club												
Prospective studies												
Garrick and Requa [6]	16/72			0		31.2				15.9	16.2	18.7
Pettrone and Ricciardelli [3]**	29/542	0	0	9.7	6.4	27.4	8.1	0	0	41.9	6.4	0
Caine et al. [13]	147/50	0	0.7	4.1	0.7	3.4	10.2	0	40.1	19	17.7	4.1
Lindner and Caine [10]	90/362	2.2	0	6.5	4.3	4.8	6.5	1.1	11.8	19.4	11.8	9.7
Kolt and Kirkby [12]	349/–	0	0	6	0.6	8.3	17.9			29.7	23.2	14.3
Caine et al. [9]	192/159	0.5	0.5	8.9	0.5	1.6	3.1	1.6		19.3	31.8	29.2
Retrospective studies												
Lowry and Leveau [5]	260/370	0	0	34.2	1.5	8.1	13.8	0	0	41.9	6.4	0
Kolt and Kirkby [17]	321/162			3.1	1.6	8.4	15.3			29.6	20.6	21.4
High school												
Propective study												
Garrick and Requa [6]												
1 year (mixed study)				4.1		8.2				39.7	31.5	16.4
2 year (interscholastic study)				20.5		0				43.6	17.9	17.9

*A participant season is one gymnast participating in one season.

**Includes data for recreational as well as club gymasts.

Table 6. Cross-sectional studies of lower back conditions affecting young female and male gymnasts (adapted from Caine [2] and Caine et al. [27])

Study	n	Age	Level	Condition/Diagnosis
Jackson et al. [34]	100	14	regional	Bilateral L5 pars interarticularis defects (11%), 6 of the 11 cases had coexisting spondylolisthesis at L5
Rossi [35]	132		olympic	32.8% spondylolysis; 8.9% spondylolisthesis
Ohlen et al. [36]	64	11.9	club	Low back pain in 20% of the subjects
Sward et al. [37]	26	16–25	national	19.2% spondylolysis, 4/5 with existing spondylolisthesis
Rossi and Dragoni [38]	417	15–27	competition	16.31% spondylolysis
Tertti et al. [39]	17 F	8–19	district, national and international	Sacrilization of L5 (5.9%), Scheuermann's disease (5.9%), spondylolysis at L5 (5.9%)
	18 M	8–14 yrs	district, national and international	Sacrilization of L5 (11.1%), Scheuermann's disease (11.1%), disc degeneratioin (5.6%)
Hellstrom et al. [40]	26 F	14–25	nationally ranked	Scoliosis (11.5%), spondylolysis (19.2%) with coexisting spondylolisthesis in 4 of the 5 cases, abnormal configuration of the vertebrae (15.4%), disk height reduction (3.8%), Schmorl's nodes (11.5%), apophyseal abnormalities (15.4%)
	26 M	16–25	national	Scoliosis (19.2%), spondylolysis and spondylolisthesis (11.5%), abnormal configuration of the vertebrae (38.5%), disc height reduction (11.5%), Schmorl's nodes (26.9%), apophyseal abnormalities (11.5%)
	30 M/F	16–25	nonathletes	Scoliosis (3.3%), spondylolysis (3.3%), coexisting spondylolisthesis (3.3%), spina bifida occulta (13.3%), abnormal configuration of the vertebrae (10%), disk height reduction (6.7%), Schmorl's nodes (40%)
Sward et al. [41]	26 F	14–25	national	65.4% had moderate or severe pain; 42.3% radiological abnormalities of the thoraco-lumbar spine
	26 M	16–25	national	84.6% had moderate or severe pain; 42.3% radiological abnormalities of the thoraco-lumbar spine
Goldstein et al. [42]	8 F	25.7	national	Spondylolysis (12.5%); abnormal disk (62.5%)
	14 F	16.6	elite	Spondylolysis (21.4%); abnormal disk (21.4%)
	11 F	11.8	pre-elite	Spondylolysis (9.1%); abnormal disk (0)
	11 F	18.6	swimmers	Abnormal disk (9.1%)

Table 6 (continued)

Study	n	Age	Level	Condition/Diagnosis
Sward et al. [43]	26 F	14–25	national	Abnormalities of the anterior aspects of the vertebral ring apophyses (30.8%)
	26 M	16–25	national	Abnormalies of the anterior aspects of the vertebral ring apophyses (19.2%)
Soler and Calderson [44]	112	14.3	top-level	Spondylolysis (17%)
Szot et al. [45]	52 M	15–31	national	Radiological changes of the spinal column (65.8%) (i.e., fracture and deformation of vertebral bodies, degeneration of the intervertebral discs, degenerative changes of the intervertebral articulations)

abnormalities of the vertebral bodies including abnormal configuration (flattening, wedging, and increased sagittal diameter), Schmorl's nodes and apophyseal changes, increased degenerative disc changes, and damage to the pars interarticularis with resultant spondylolysis (prevalence = 5.9–32.8%) and spondylolisthesis.

In the past, women's gymnastics focused on extreme reclination of the lumbar spine (e.g., frequent walkovers with extremely extended lumbar spine), which is believed to relate to the relatively high prevalence of spondylolysis in this sport [31]. In contrast, women's gymnastics has recently concentrated on a fixed and well-controlled spinal movement with forward flexed spine during landing, which may result in a decreased risk of spondylolysis [2, 31]. The repeated trunk flexion when landing from various heights, however, may create biomechanical compression forces sufficient to damage the anterior aspects of the spine. Anterior vertebral fractures and other anterior spine problems are now more common than the posterior problems seen during the era of contortionistic spine positions in poses, walkovers and limbers [31, 33, 46–51].

Upper Extremity

Unlike most other sports, in gymnastics, the upper extremities are used as weight-bearing limbs causing high impact loads to be distributed through the elbow and wrist. Considering the upper extremity's ill-adapted design for weight-bearing, it is not surprising that it is the second most frequently injured body region. As shown in table 3, the wrist is the most frequently injured site in the upper extremity of female gymnasts followed by the elbow. In male gymnasts, the shoulder has been the most frequently injured upper extremity body part followed by the wrist. However, wrist injuries and conditions have been the focus of many cross-sectional reports for both male and female gymnasts.

Table 7 briefly summarizes data from cross-sectional studies of injuries and conditions involving the wrist of female and male gymnasts. Wrist pain is a common complaint among gymnasts, with prevalence estimates ranging from 46 to 87.5% [52–55]. Eight cross-sectional studies [45, 52–60] report prevalence estimates of radiographical abnormalities consistent with distal radius physeal-stress reaction in 10–85% of gymnasts.

A concern voiced in the literature is that gymnastics training may inhibit radial growth in female gymnasts [61]. Although case studies have established the presence of premature closure of the distal radius among female gymnasts [62–65], there are currently few data which provide prevalence or incidence estimates for this condition. However, in one cross-sectional study of Chinese opera students (training included gymnastics) there were 2 cases (2/77 or 2.6%) of early partial closure of the distal radial growth plate [59]. In another study involving 18 top-level Chinese gymnasts, the nature and frequency of growth-plate conditions were monitored radiographically over 9 years [66]. During that period, 6/18 (33.3%) of the girls developed progressive pathology leading to 'hindered radial growth' and a 'relatively lengthened ulna'.

Lower Extremity

The lower extremity is also a site of tremendous physical loading in gymnastics. This involves the repetitive jarring impact of vault takeoffs and dismounts from a variety of heights and during tumbling activities. A review of the data in table 3 shows that the lower extremity is actually the region most affected by injury in girls' gymnastics. Yet surprisingly, there are no published prevalence data on lower extremity injuries affecting female or male gymnasts. However, two cohort studies report inversion ankle injuries are the most frequent lower extremity injury followed by Sever's disease [16, 22]. Ankle sprains were also the most common injury sustained by gymnasts participating in the USA Gymnastics National Women's Artistic Gymnastics Championships during 2002–04 (see table 4).

Catastrophic Injury

The worst case scenario in gymnastics is catastrophic injury. The recently publicized spinal cord injuries of national-level gymnasts Sang Lan of China and Julissa Gomez of USA [67, 68] focused public attention on the potential for catastrophic injury in gymnastics. The limited incidence data shown in table 8 suggest that catastrophic injury is a relatively infrequent occurrence among high school male and female gymnasts [69, 70]. However, there is a conspicuous absence of research reporting rate data for catastrophic injuries affecting

Table 7. Cross-sectional studies of wrist injuries and conditions affecting young female and male gymnasts (adapted from Caine [2] and Caine et al. [27])

Study	n	Age	Level	Diagnosis/Condition
Auberge et al. [56]	57 F	14–17	junior national	Chronic osteoarticular lesions involving the distal radial growth plate (85%)
	41 M	17–33	junior national	Chronic osteoarticular lesions involving the distal radial growth plate (80%)
Szot et al. [45]	41 M	15–31	national	Distal radial epiphyseal irregularities (58.5%)
Roy et al. [57]	26 F	9–14	class II	Minimal widening and irregularity of the distal radial growth plate (30.8%)
Caine et al. [52]	39 F	12.6	III, II, I	Minimal widening and irregularities of the distal radial physis (10%)
	21 M	12.6	IV, III, II, I	Definite changes of subchondral sclerosis, physeal widening, marginal new bone formation, and distortion of the distal end of the radius (4.8%)
DeSmet et al. [58]	156 F (not fused)	15.9	national	Enlargement of the distal radial growth plate with irregular borders in 10% of the cases; at baseline, 23 of 50 gymnasts had wrist pain
Chang et al. [59]	176 M/F (77 F, 99 M)	11–16	Chinese Opera students	Unfused group: 10 girls (14.3%) and 32 boys (32.3%) showed stress-related changes of the distal radial growth plate; 23 cases show early partial closure of the distal radial growth plate
De Fiori and Mandelbaum [53]	52 M/F (32 F, 20 M)	11.8	club level	38 (73%) reported wrist pain within the past 6 months; gymnasts with wrist pain were older, trained at a higher skill level, trained more hours per week, and began training at an older age
De Fiori et al. [54]	44 M/F (27 F, 17 M)	11.6	nonelite	11 gymnasts (25%; MF) showed radiographical evidence of stress injury to the distal radial physis

Table 7 (continued)

Study	n	Age	Level	Diagnosis/Condition
De Fiori et al. [60]	47 M/F (21 F, 26 M)	5–16 yrs	club level	Wrist pain was reported by 57% (27 of 47) of the gymnasts; 81% (24 of 27) reported wrist pain both at study onset and one year later; 42% of subjects with wrist pain reported that symptoms interfered with training
Di Fiori et al. [55]	59 MF (28 F, 31 M)	9.3	club level	Wrist pain was reported by 56% (33 of 59) of the gymnasts, with 45% (15 of 33) describing pain of at least 6 months; 51% of the gymnasts (30 of 59) had a finding of stress injury to the distal radial physis of at least a grade 2

Table 8. A summary of catastrophic injury rates in high school gymnastics (adapted from Caine [2] and Caine et al. [27])

Study	Duration	Injuries	Condition	Rate*, Number of cases/injures per 100,000 male participants	Rate*, Number of cases/injuries per 100,000 female participants
Clarke [69]	3 years (1973–75)	1 F	permanent[a]		
		1 M	permanent[a]		
National Center for Catastrophic Sports Injury Research [70]	21 years (1982–2003)	1 M/F	fatal	1.15	0
		8 M/F	nonfatal[b]	2.3	1.1
		4 M/F	serious[c]	1.15	0.55

[a]Refers to permanent disability, including death, secondary to spinal cord injury.
[b]Permanent, severe functional disability such as quadriplegia.
[c]No permanent severe functional disability, but severe injury.

club-level gymnasts. This finding is a concern given the escalation of difficulty and combination ratings in gymnastics; also, because the vast majority of competitive gymnasts participate at the club level.

Notably, several recent longitudinal studies of injuries affecting club-level female gymnasts report no catastrophic injuries [9, 10, 12, 13, 16]. In contrast, a national spinal cord injury registry in Japan revealed 23 spinal cord injuries to competitive gymnasts during 1990–92 [71], and between 1985 and 1997 there were 6 competitive gymnasts with spinal cord injuries treated at the Orthopedic Department at the University of Heidleberg [72].

Time Loss

A commonly used measure of injury severity is the duration of restriction from training and competition. Time loss due to injury is difficult to measure in gymnastics because injured gymnasts, depending on the severity of injury, tend to continue to train on selected apparatus with some skill or movement modifications. In addition, there are many possible subjective and objective factors that may influence performance time lost due to injury (e.g., personal motivation, peer influence, coaching staff reluctance or encouragement, approaching competition). This bias is minimized when numerical definitions are used [73].

Data from two studies of club-level female gymnasts using the same injury definition [9, 13] indicate that advanced-level participants experience a greater proportion of severe (>21 days time loss) injuries than beginning-level girl gymnasts. Similarly, several studies report that mean time loss per injury is greater for advanced- than beginning-level female gymnasts [9, 12, 17].

Clinical Outcome

Re-Injury

A high frequency of re-injury suggests an underestimation of the severity of the primary injury, inadequate rehabilitation, and/or premature return to training or competition [12]. There are few data on percentage or rate of re-injury among female gymnasts. In three cohort studies involving female gymnasts, percentage of injuries that were re-injuries ranged from 24.5 to 32.3% [9, 10, 12]. Cross-tabulation of re-injury with injury onset in two studies [9, 12] suggests that the majority of re-injuries affecting club-level gymnasts are chronic injuries.

Residual Symptoms

Two studies investigated former top-level female gymnasts for back pain and radiological changes [74, 75]. Both studies reported no significant differences in back pain between gymnast and control groups; however, the prevalence of radiological abnormalities was greater in gymnasts than controls in one study [74]. Maffuli et al. [76] reported the long-term follow-up (mean = 3.6 years) of lesions of the articular surface of the elbow joint in a group of 12 gymnasts (6 females, 6 males). In this group there was a high frequency of osteochondritic lesions, intra-articular loose bodies, and precocious signs of joint aging. Residual mild pain in the elbow at full extension occurring after activity was present in 10 patients, and all patients showed marked loss of elbow extension compared with their first visit.

Nonparticipation

Several case series studies have reported 'career-ending' injuries affecting the elbow [76–78] and low back [50] of young gymnasts. In a 10-year cohort study of Australian elite gymnasts, 7 females and one male (8/116) retired as a result of injury [16]. In this study, injuries that resulted in retirement included chronic rotator cuff injury, navicular stress fracture, loose bodies in the ankle joint, medial and lateral meniscus lesions, anterior cruciate ligament rupture, and osteochondritis of the elbow joint. In three cohort studies [9, 12, 79] from 16.3 to 52.4% of dropouts were injured when they withdrew from participation, thus implicating injury as a likely contributing factor in the decision to retire from gymnastics.

Injury Risk Factors

An important part of gymnastics injury epidemiology is the identification and analysis of factors that contribute to the occurrence of gymnastics injury.

These factors (i.e., the *why*) are commonly referred to as risk factors and may be classified as either intrinsic or extrinsic. Intrinsic factors are individual biological and psychosocial characteristics predisposing a gymnast to the outcome of injury. Extrinsic risk factors are factors that have an impact on the gymnast while she is participating in her sport, for example training methods or equipment.

Results of gymnastics risk factor studies are summarized in table 9 and discussed below with reference to intrinsic or extrinsic factors [3, 4, 9, 12, 13, 17, 23, 80–83]. The information provided should be interpreted cautiously due to the methodological problems and study differences described earlier. Further, risk factors may interact differently with the categories of injury onset, a possibility which was not accounted for in most of the studies reviewed. The risk factors identified should be viewed as initial steps in the important search for predictor variables and may provide interesting characteristics for manipulation in other experimental designs.

Intrinsic Factors

Physical Characteristics

Analytical cohort studies indicate that in comparison with uninjured or low-injury-risk gymnasts, the injured or high-injury-risk gymnasts are characterized by greater body size (height and weight), age, and body fat [80–82]. In one of these studies [80], however, measurements were taken after injury occurred, thus invoking the possibility that an injury itself caused the observed difference. Additionally, exposure patterns in injured and uninjured gymnasts were not identified as a basis for determining reasons for injury occurrence.

It is possible that factors such as greater height, weight and age tend to characterize older gymnasts with more years training and involvement in higher levels of training and competition. Older gymnasts may be more likely to sustain injury because of more complex and difficult skills and greater accumulated exposure to training.

There are some data which suggest that somatotype may relate to risk of injury. One study [80] reported mesomorphy to be negatively related to injury. However, as mentioned previously, these analyses were based on the injury data obtained retrospectively (before injury occurred). Additionally, comparing only one somatotype component may give a misleading interpretation of the role of overall somtatotype, as the relative dominance of components may vary from one gymnast to another. Nonetheless, it seems reasonable to expect that gymnasts characterized by a somatotype most congruent to the physical demands of their sport would also be most protected from injury. Notably, Caine et al. [13] reported that gymnasts who lost the most time from training due to injury were also characterized by body types which were least typical of female gymnasts.

Table 9. A comparision of results arising from analytical cohort studies (adapted from Caine [2] and Caine et al. [27])

Study	Duration	Design	Method	n	Purpose	Results
Steele and White [80]	2 years	retrospective	questionnaire	40 F	To determine whether high and low injury groups could be identified	High and low injury risk gymnasts could be classified with 70% and 79% accuracy, respectively; significant differences ($p < 0.05$ or better) were found in the following variables: weight high > low height high > low age high > low mesomorphy high < low quetelet index high > low shoulder flexion high < low lumbar extension high > low
					To identify injury predictors	Variables associated with injury risk ($p < 0.05$ or better): weight (+), mesomorphy (−), lumbar curvature (+), age (+), and height (−)
Kerr and Minden [23]	2 years	retrospective	questionnaire	41 F	To determine whether selected psychological variables (trait anxiety locus of control, self-concept, and stressful life events) were related to the number and severity of injuries	Moderately strong relationship between stressful life events and injury number ($r = 0.53$; $p < 0.01$) and between stressful life events and injury severity ($r = 0.53$; $p < 0.01$)

Pettrone and Ricciardelli [3]	7 months	prospective	questionnaire	542 F	To identify physical parameters which predispose the athlete to injury	Duration and frequency of workouts in clubs with high injury rates were significantly greater ($p < 0.05$) than in clubs with low injury rates (20–30 hours/week vs. 4–6 hours/week)
Caine et al. [13]	1 year	prospective	interview	50 F	To identify the nature of the relationship between injury status and selected host and environmental factors	No significant canonical relationship between the limited selection of predictor variables and the injury measures ($p = 0.11$); separate muliple regression tests ($p < 0.05$) showed maturation rate associated with injury rate (+) and competitive level associated with time loss (+)
					To determine the extent to which group classification into high and low injury risk groups could be predicted	The results of discriminant analysis involving the criterion variable injury rate were not significant ($p = 0.10$); for the criterion variable individual proportion time loss, the groups were significantly different ($p < 0.05$) and could best be distinguished as a result of the contribution of competitive level (high > low) and

Table 9 (continued)

Study	Duration	Design	Method	n	Purpose	Results
						maturation rate (high > low). In whole sample 84.6% of high risk and 69.3% of low injury risk gymnasts were correctly classified
Goodway et al. [4]	1 year	prospective	questionnaire	6,654 F	To gain statistical verification for trends identified by descriptive means	Trends associated with increased injury risk: higher competitive level, smaller less well-equipped facilities, and lower gymnast/coach ratio
Lindner and Caine [81]	3 years	prospective	interview	68 F	To distinguish injured from uninjured gymnasts	In whole sample 85.2% of uninjured and 75.6% of the injured gymnasts were correctly classified; the best discriminating component variables were age/body size (injured > uninjured), gymnastic-specific flexibility (varied by competitive and age levels) and body fat (injured > uninjured)
					To identify injury predictors	Significant predictors ($p < 0.05$) of the injury measures (injury rate, time lost, previous injuries) were identified among the anthropometric and performance

						components, but were specific to the components and various age and competitive levels. Overall, training hours/week was a positive predictor of time lost ($p < 0.01$)
Lindner and Caine [82]	3 years	prospective	interview	68 F	To distinquish high from low level competitive gymnasts	In whole sample, 80% of low level and 100% of high level gymnasts were correctly classified; time loss due to injury ($p < 0.001$) and number of previous injuries were greater ($p < 0.05$) for high level gymnasts
Kolt and Kirkby [17]	12 months	retrospective	questionnaire	162 F	To determine the number, site, and type of injury	Injury rate for elite gymnasts (per 1,000 h) was lower than sub-eltie gymnasts ($p = 0.03$)
					Incurred by elite and sub-elite female competitive gymnasts	Distribution of injuries was significantly different ($p = 0.001$) with a higher proportion of elite gymnasts reporting tendonitis and growth plate injuries
Kolt and Kirkby [83]	12 months	retrospective	questionnaire	162 F	To assess the role of life stress, competitive anxiety, self esteem, and locus of control in injury	Life stress was a significant predictor of injury for the overall sample and for the nonelite gymnasts

Table 9 (continued)

Study	Duration	Design	Method	n	Purpose	Results
Kolt and Kirkby [12]	18 months	prospective	questionnaire	64 F	To compare injury rates in elite and sub-elite gymnasts	Rates per 1,000 h training were lower for elite than sub-elite gymnasts ($p = 0.01$)
Caine et al. [9]	3 years	prospective	interview	79 F	To estimate the relative risk of injury in competition versus training among beginning and advanced gymnasts	The RR of injury during competition relative to practice was 2.69 (95% CI: 1.53, 4.75; $p < 0.001$). The relative RR during competition was 0.47 for beginners (95% CI: 0.07, 3.42) and 4.34 for advanced gymnasts (95% CI:2.39, 7.88; $p = 0.035$)
DiFiori et al. [60]	1 year	prospective	interview	21 F 26 M	To determine the prevalence and characteristics of wrist pain among young, nonelite gymnasts	Multivariate analysis revealed that adolescent gymnasts between 10 and 14 years of age were significantly more likely to report wrist pain than those who were either above or below this age range ($p = 0.03$) either above or below this age range ($p = 0.03$)

It is believed that the growth spurt is associated with an increased risk of injury [84–86]. Caine et al. [13] reported that injury rate was almost twice as great for female gymnasts experiencing rapid compared to stable growth (as indicated by Tanner stages), regardless of competitive level. Similarly, DiFiori et al. [60] reported that male and female gymnasts between 10 and 14 years of age were significantly more likely to report wrist pain than those who were either above or below this age range. However, these findings await confirmation from an analysis of individual longitudinal growth records and injury rates.

Motor Characteristics

One study [81] reported speed (–), balance (–), endurance (+) and flexibility (+) as significant injury predictors among club-level female gymnasts; however, these were not significant at all age and competitive levels studied. Additionally, the number of gymnasts in each age and competitive level were small thus limiting the precision of analysis within subgroups.

One study [80] reported that the high injury risk was associated with a relatively low shoulder flexion and high lumbar extension. Once again, these measures were taken after the injury occurred, thus the possibility that the injury itself caused the observed difference. In addition, as mentioned above, exposure patterns in injured and uninjured gymnasts were not identified as a basis for determining reasons for injury occurrence. No doubt success in gymnastics depends on a certain minimum of joint looseness, yet flexibility is specifically difficult to define and its relationship to injury remains conjectural.

Psychosocial Characteristics

An intriguing, but relatively unexplored area of injury research in gymnastics, is the role of psychosocial factors in injury occurrence. In one study [23], a moderately strong positive relationship between the number of stressful life events and injury number and severity was reported. In a more recent study [83], life stress was a significant predictor of injury in elite and nonelite competitive female gymnasts who completed a questionnaire covering personal, training, and injury data. In both of these studies, however, the psychosocial measures were taken after the injury occurred, thus invoking the possibility that the stress profiles of the gymnasts were different at the time of injury.

Extrinsic Factors

Exposure

The results of analytical studies are inconclusive as to whether injury rates are greatest at advancing levels of training and competition [9, 12, 13, 17]. Two studies report significantly lower injury rates in elite compared to sub-elite gymnasts [12, 17]. In contrast, when proportion time loss and injury rate were used as criterion variables [13], the analysis resulted in a significant effect and competitive level surfaced as best discriminator between high and low injury risk gymnasts. In a recent study [9], the relative risk for injury among advanced gymnasts was 1.47 times greater than a beginning group. When the advanced group was divided into training versus competition time, the RR of injury compared to the beginning group was not inflated in training (RR = 0.97) while it is much higher during competition (RR = 4.22).

Suggestions for Injury Prevention

The aim of this overview of the gymnastics injury literature was to provide epidemiological information that would be useful to minimize injury morbidity and prevent injury to young athletes through an understanding of how, where, and why injuries occur in the sport. Arising from this integrative review of the gymnastics injury literature are the following injury patterns:

- higher rates of injuries among advanced-level gymnasts in some studies [7, 9, 13, 22];
- the most frequently injured body parts: shoulder, wrist, elbow, lower back, ankle and knee [6, 7, 9, 11, 13, 16, 18, 25];
- higher rates of injures in competition, especially among advanced-level gymnasts [9];
- floor exercise is characterized by the highest rate of injury [9];
- most injuries are acute [3, 4, 7, 9–12, 14, 17, 21, 22, 27]; however, there is some evidence that advanced-level or heavily trained gymnasts incur more overuse conditions than their less-advanced peers [12, 13, 17];
- national level gymnasts incur relatively high rates of injury associated with competitions; the most frequently treated injury conditions at these competitions were sprains, overuse injuries and nonspecific pain and common injury locations were the ankle, low back, and lower leg [unpubl. data];
- a relatively high frequency of injury during the early part of practice or during timed warmup for competition [9, 10, 13];
- increased rates of injury following periods of reduced training, during competitive routine preparation, and during the weeks just prior to competition [9, 13, 23];
- sprains and strains are the most common injury types [3, 5, 6, 9, 10, 12, 13, 17];
- a high prevalence of overuse injuries affecting the spine and wrist of both male and female gymnasts [33–63];

- catastrophic injuries appear to be infrequent outcomes of high school gymnastics participation [69, 70]; however, there are no rate data on this injury type among club-level gymnasts;
- time loss associated with injury is greater for competition than for practice injuries, and greater for advanced- than beginning-level gymnasts [9, 12, 13, 17];
- about one in four injuries is a re-injury [9, 10, 13]; there is some evidence that most re-injuries are chronic injuries [9, 13];
- little is known about the long-term effect of gymnastics injuries; however, there is evidence that history of back and elbow injury is related to persistence of symptoms following retirement [74–76];
- injury is a reason for dropping out for some gymnasts, perhaps as many as one in ten [9, 13, 16, 18]; and
- factors shown to be associated with increased risk of injury include: greater body size, age, and body fat [80–82]; periods of rapid growth [13, 60]; life stress [23, 83]; and, in some studies, advanced levels of training and competition [9, 13].

Suggested preventive measures arising from the studies reviewed in this chapter are listed in table 10 according to study design. Recommendations are referenced to indicate source and any available supporting evidence. As indicated in the table, most of the suggestions were derived from descriptive data and await confirmation from more controlled epidemiological study, including evaluation for their effectiveness in preventing injuries.

In closing, it is important to emphasize that the prevention of gymnastics injury is a complex phenomenon which requires interaction among gymnast, coach, gymnastics governing body and medical support staff. A multidisciplinary team including coach, athletic trainer, psychologist and physician is essential to optimizing the preventive strategies.

Suggestions for Future Research

An important purpose of this chapter has been to identify methodological weaknesses in the literature and provide suggestions for further research. This is an integral component of the 'epidemiology of gymnastics injuries' because informed decisions related to the establishment of injury prevention programs depend on accurate and reliable data. Above all, this overview of the gymnastics injury literature underscores the need to establish national injury surveillance systems designed to provide current and reliable data on injury trends in boys and girls club-level gymnastics.

Table 10. Suggestions for injury prevention (adapted from Caine [2])

Preventive measures	Type of evidence	
	Cross-sectional	Cohort
Coaching – Education		
Require coaches to meet a minimum level of qualification		Weiker [7]
On the importane of protecting gymnasts from premature attempts to execute advanced maneuvers		Clarke [69]
Coaching – Physical Preparation		
Provide specific stretching and strengthening exercises – particularly for the Achilles tendon, hamstring and quadriceps muscles		Mackie and Taunton [22]
Maximal conditioning of those muscles used for spinal and abdominal strengthening to avoid chronic back conditions	Soler and Calderon [44]	Garrick and Requa [6]
Conditioning programs to prevent muscle strains associated with the short bursts of running in floor exercise and vaulting		Garrick and Requa [6]
Coach should not emphasize gymnastics-specific flexibility (splits, leg raises) before extent flexibility at various joints is adequately developed		Lindner and Caine [10]
Encourage wrist strengthening and flexibility exercises to help protect the wrist against chronic injury	Caine et al. [52]	
Teach and practice correct landing techniques to prevent fractures and dislocations of the upper extremity		Mackie and Taunton [22]
Ensure adequate warmup		Caine et al. [13]; Pettone and Riccardelli [3]
Recognize the existence or potential for growth plate injury and the importance of referring the gymnast for medical evaluation as soon as symptoms occur	Caine et al. [52]	Kolt and Kirkby [12,17]
Pain is a signal in an important process and should be regarded as a warning, not something to get used to; 'no pain – no gain' is inappropriate	Jackson et al. [34]; Caine et al. [34]	Caine et al. [13]

Conditioning specifically designed to 'smooth the transition' from skill training to routine training (e.g., ergometer interval training, anaerobic conditioning, and weight training)	Caine et al. [52]	
Ensure the technically correct performance of movements to avoid unnecessary overloading of the spine	Soler and Calderson [44]	
Coaching – Training		
Alternate loading types during workouts; for example alternate swinging and support movements so as to reduce stress on the wrist	Caine et al. [52]	
Train gymnasts in a cyclically progressive manner so that the gymnastis not increasing the dose of load bearing in a progressive stepwise fashion but rather in a cyclical manner; every escalation is followed by a decrease in overall load for a week's time, followed by another increase, thereby allowing reparative time for connective tissue structures	Caine et al. [52]	Pettrone and Riccardelli [3]
Reduce duration of rotations and increase their number per workout to avoid lack of concentration and inattentiveness; avoid training when concentration is poor		Lindner and Caine [10]; Mackie and Taunton [22]
Reduce training loads during periods of rapid growth	Caine et al. [52]; DeFiori et al. [55]*	Caine et al. [13];* Lindner and Caine [81]*
Avoid conditions in which the gymnast is allowed merely to go through the motions of a skill without a specific assignment requiring the gymnast's attention		DiFiori et al. [60]
Spotting should be used more extensively during practice and obligatory during high-risk events		Lindner and Caine [10]
Availability of well-trained spotters		Bak et al. [11]; Weiker [7]

Table 10 (continued)

Preventive measures	Type of evidence	
	Cross-sectional	Cohort
Equipment		
Encourage use of personal protective equipment (e.g., dowel grips, handguards)	Caine et al. [52]	
Increase thickness of landing mats during practice and competition		Goldstein et al. [42]
Re-evaluation of the criteria of the scoring system for competition		Bak et al. [11]
Health Support System – Screening		
Administer a preparticipation physical examination (PPE) to each gymnast prior to entry into competitive gymnastics, before any change in the competitive level, and before returning to practice following injury	Soler and Calderson [44]	Kolt and Kirkby [12,17]; Caine et al. [13]
Biannual musculoskeletal screening and, when indicated, AP radiographs of the wrist to rule out stress changes of the growth plate		Steele and White [80]*
Periodic physical examination focusing on epiphyseal areas of growing gymnasts such that injuries to these areas can be diagnosed at an early stage and modifications made to the training program to assist in the recovery process		Kolt and Kirkby [12,17]
Health Support System – Treatment and Rehabilitation		
The physician should heighten awareness and encourage extra vigilance on the part of coaches during the period of routine preparation and competition given the increased rate of injury during these periods	Caine et al. [9]	
Gymnastic clubs include within their cost structure sufficient funds to hire an athletic trainer or physical therapist, at least on a part-time basis.	Caine et al. [52]	Jackson et al. [34]; Kolt and Kirkby [12]; Garrick and Requa [6];

The functions of this individual should include the following:	Caine et al. [9]
• early detection of developing stress injuries	Caine et al. [9]
• identify potential injury-provoking practices	
• liaison between gymnasts, coaches, and physician	
• oversee the development of special rehabilition programs for injured gymnasts identified in the PPE	
Teatment of chronic injuries before they become disabling	Steele and White [80]*
The Sport	
Re-evaluation of competition rules and the performance environment given the high incidence of injury linked with competition	Caine et al. [9]

*Derived from an analytical study.

In particular, injury surveillance systems could provide the needed and on-going descriptive data related to important epidemiological ‘targets’ or areas that merit closer scrutiny. Targets for further study identified in this literature review include the following:

- injuries that cause restriction or loss of participation for extended periods of time (e.g., $>$7 days);
- injuries that require surgery or are otherwise severe in nature (e.g., concussions);
- injuries that are catastrophic;
- re-injuries;
- injuries that may affect skeletal growth;
- injuries that occur during or following warm-up;
- injuries that occur in the weeks just prior to competition;
- injuries that occur during competition; and
- long-term follow-up of gymnastics injuries.

In addition to injury surveillance systems, in-depth epidemiological studies are needed. A critical aspect of the proposed research is the precise determination of exposure patterns in injured and uninjured gymnasts as a basis for determining reasons for injury occurrence. As this review of the gymnastics injury literature has shown, few injury risk factors have been subjected to statistical tests for correlation or evaluated for predictive value. And there have been no studies published that were designed to determine the effectiveness of specific injury prevention measures. Although the institution of a preventive strategy on the basis of clinical practice or descriptive epidemiological data may still prevent injury, the most reliable suggestions for injury prevention are believed to emerge from experimental or quasi-experimental research [9].

Examples of questions or issues that have arisen from this review of the gymnastics injury literature and which may help direct further analytical research initiatives include the following: Why is the risk of injury in competition so much higher than training, especially among advanced-level gymnasts? Do some psychosocial factors increase the risk of competition injury and can these factors be controlled or eliminated? Can an increased risk of injury during periods of rapid growth be confirmed with reference to growth velocity data? If so, what can be done to reduce this increased risk of injury? What is the relationship between poor technique and risk of injury? What factors are associated with increased risk of the nagging chronic injuries experienced by gymnasts? Can these factors be controlled or eliminated? What are the long-term effects of gymnastics injuries? And, would a well-designed pre-season conditioning and proprioceptive balance training program help to reduce the risk of lower extremity injuries?

In closing, it is important to stress that it is only through concerted collaborative efforts that optimal results could be achieved. The research team should include the coach, athletic trainer, physician, and epidemiologist who interact in a very dynamic and fluid manner. In addition, it is important to emphasize that every effort should be made by the research team to establish an open and trusting dialogue with gymnasts and their parents. Only when this could be achieved, could an adequate database be established.

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Martial Arts Injuries

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Abstract

Objective: To review the current evidence for the epidemiology of pediatric injuries in martial arts. **Data sources:** The relevant literature was searched using SPORT DISCUS (keywords: martial arts injuries, judo injuries, karate injuries, and taekwondo injuries and ProQuest (keywords: martial arts, taekwondo, karate, and judo), as well as hand searches of the reference lists. **Main results:** In general, the absolute number of injuries in girls is lower than in boys. However, when expressed relative to exposure, the injury rates of girls are higher. Injuries by body region reflect the specific techniques and rules of the martial art. The upper extremities tend to get injured more often in judo, the head and face in karate and the lower extremities in taekwondo. Activities engaged in at the time of injury included performing a kick or being thrown in judo, while punching in karate, and performing a roundhouse kick in taekwondo. Injury type tends to be martial art specific with sprains reported in judo and taekwondo and epistaxis in karate. Injury risk factors in martial arts include age, body weight and exposure. **Conclusions:** Preventive measures should focus on education of coaches, referees, athletes, and tournament directors. Although descriptive research should continue, analytical studies are urgently needed.

Introduction

East Asian martial arts have a large following worldwide among children and youth. For instance, in small countries like The Netherlands and Belgium, the number of boys and girls practicing karate and taekwondo varies from 9,000 to more than 23,500 for judo according to the major national governing bodies represented in world championships and Olympic Games [1–3]. The estimated participation in martial arts by children and youth in the USA is around 1 million [4].

With an increase in the number of children and adolescents involved in martial arts, injuries to this population are expected to increase. For instance, between 1983 and 1998, the A and E units of the Cardiff Royal Infirmary, Wales, saw a 45% increase in pediatric martial arts injuries, mostly due to an increase in participation by girls [5].

Studies involving pediatric martial arts injuries have commonly combined two or more martial arts or age groups and did not distinguish between practice and competition injuries [6–9]. The aforementioned studies were retrospective and concerned with time-loss injuries. Prospective studies combining age groups include those by Buckley [10], Poirier [11] and Critchley et al. [12].

The purpose of the present review was to present the distribution of injuries and their determinants in martial arts. In addition, suggestions for injury prevention and further research will be highlighted. The literature search was limited to retrospective and prospective studies due to the inherent methodological weaknesses of numerator-based designs [13]. Data collection covered the period 1980 to present and was accomplished using the following procedures: (1) ancestry approach: retrieval of research cited in published research; and (2) computer searches: the Sport Discus database (key words: martial arts injuries, judo injuries, karate injuries, taekwondo injuries), and ProQuest (key words: martial arts, taekwondo, karate, judo).

Incidence of Injury

What we know about injury rates among pediatric martial arts participants arises primarily from studies of tournament or competition injuries. Some reports from tournaments and competitions were at recreational level; however, most were at national level.

A comparison of injury rates based on prospective studies is summarized in table 1. Included in the table are studies on recreational [14], national [15–20] and international athletes [18, 21]. Perusal of table 1 shows significantly higher injury rates for girls in most studies of the three martial arts [14–17, 19, 21]. However, Pieter and Zemper [18] did not find any significant gender differences in injury rates in taekwondo. Tuominen [20] reported a higher frequency of injuries in boys, but this was not statistically verified.

In a retrospective study, Kujala et al. [22] reported that for boys younger than 15 years, the combined injury rate for practice and competition was 22 injuries/person years of exposure (PYO) in judo and 30/PYO in karate. The values for the girls were 75 and 42/PYO, respectively. In the 15–19-year age group, the boys recorded 90 injuries/PYO in judo and 95/PYO in karate. The girls

Table 1. A comparison of injury rates in young martial arts athletes

Study	Design	Data collection interv/question	Duration injury survival	Injuries		Sample Number of participants	Rate Number of injuries per 100 athletes	Rate, Number of injuries per 1,000 athlete-exposures
				Sex	Number			
Judo								
Pieter and De Crée [21]	P	Q	1 tournament	M	25	111	22.52	77.16
				F	17	62	24.42	104.94
James and Pieter [16]	P	Q	1 tournament	M	54	417	13.0	39.8
				F	45	270	16.7	52.1
Karate								
Tuominen [20]	P	Q		M	33	–	–	133.07
				F	1	–	–	50.00
Pieter [17]	P	Q	1 tournament	M	76	218	34.86	99.74
				F	32	84	38.10	115.11
Taekwondo								
Pieter et al. [14]	P	Q	1 tournament	M	20	139	14.39	78.74
				F	7	43	16.28	97.22
Pieter and Zemper [18]	P	Q	3 tournaments	M	354	3,341	10.60	58.34
				F	87	917	9.49	56.57
Beis et al. [15]	P	Q	1 season	M	76	1,223	6.21	34.23
				F	52	767	6.78	41.27
Pieter and Kazemi [19]	P	Q	1 tournament	M	31	170	18.2	108.4
				F	18	89	20.2	132.4

sustained 145 injuries/PYO in judo and 121/PYO in karate. De Loës [23], also in a retrospective study, reported an incidence rate in judo of 2.3 injuries/10,000 h of exposure for both boys as well as girls aged 14–20 years.

Two prospective studies reported composite rates collapsed over gender and/or age. Oler et al. [24] reported a combined injury rate of 3.4/100 participants based on an estimated 3,000 young male and female taekwondo athletes competing at the national level. Barrault et al. [25] recorded an injury rate of 113.31/ 1,000 athlete-exposures (A-E) in a combined sample of male and female children and adolescent judo athletes. The rate was also collapsed over local, regional and national tournaments.

Zetaruk et al. [26] retrospectively investigated training injuries in karate from one school in the USA. They reported a total of 22 injuries in male and female children of 6–16 years (mean: 10 years), for an injury rate of 32.35/100 participants or 3.7 injuries per 1,000 h of training. The students belonged to a karate club where sparring was not emphasized.

Injury Characteristics

Injury Onset

The vast majority of injuries in martial arts are acute or sudden onset. Only two studies reported gradual onset injuries [17, 18]. In karate, Pieter [17] found 1.9% of all injuries in boys to be of gradual onset. In taekwondo, 1.4 and 3.5% of all injuries in boys and girls, respectively, were of gradual onset [18]. However, no information is available on such factors as the frequency, duration and intensity of training of the competitors investigated, all of which are believed to have a bearing on injury onset [27].

Injury Location

Tables 2 (boys) and 3 (girls) display a percent comparison of injury location in young martial arts athletes [14–21]. In the boys, differences in techniques used and competition rules are clearly reflected in the body regions and body parts injured. In judo, the upper extremities tend to get injured more often (28.0–37.0% of total injuries), whereas the head/face in karate incur most of the injuries (51.3–90.9%). In taekwondo, the lower extremities sustain most of the injuries (36.7–65.0%).

The injury pattern in girls is less clear, probably because of the small sample size in some of the studies [14, 20]. For instance, no head injuries were reported in judo [21] and taekwondo [14]. On the other hand, the spine/trunk was found to be injured most often in one judo study [17] and not at all in karate [20] and taekwondo [14].

Table 2. A percent comparison of injury location in young male martial arts athletes based on prospective studies

Injuries	Judo		Karate		Taekwondo			
	Pieter and De Crée [21]	James and Pieter [16]	Tuominen [20]	Pieter [17]	Pieter et al. [14]	Pieter and Zemper [18]	Beis et al. [15]	Pieter and Kazemi [19]
n	25	54	33	76	20	354	76	31
Head	*8.0*	*37.0*	*90.9*	*51.3*	*20.0*	*34.2*	*34.2*	*19.4*
Head	4.0	9.3	3.0	–	5.0	10.5	6.6	12.9
Face/teeth	–	27.8	87.9	46.1	10.0	22.9	27.6	6.5
Throat	4.0	–	–	5.3	5.0	0.9	–	–
Spine/trunk	*20.0*	*11.1*	*6.1*	*23.7*	*5.0*	*12.2*	*22.4*	*6.5*
Neck	4.0	3.7	–	1.3	–	2.5	–	3.2
Torso	8.0	3.7	6.1	17.1	–	5.7	1.3	–
Back	8.0	1.9	–	1.3	–	–	1.3	3.2
Hip/pelvis	–	–	–	2.6	5.0	1.4	–	–
Groin	–	1.9	–	1.3	–	2.5	19.7	–
Upper extremity	*28.0*	*37.0*	*3.0*	*10.5*	*10.0*	*14.1*	*2.6*	*16.1*
Shoulder	12.0	14.8	–	2.6	5.0	1.1	–	–
Arm/elbow	12.0	9.3	–	1.3	–	1.4	–	–
Hand/wrist/fingers	4.0	13.0	3.0	6.6	5.0	11.6	2.6	16.1
Lower extremity	*44.0*	*14.8*	–	*7.9*	65.0	*36.7*	*39.5*	54.8
Leg	4.0	–	–	–	5.0	9.0	1.3	12.9
Knee	28.0	11.1	–	2.6	5.0	6.2	2.6	6.5
Ankle	8.0	–	–	–	5.0	5.4	4.0	3.2
Foot/toes	4.0	3.7	–	5.3	50.0	16.1	31.6	32.3
Other	–	–	–	*6.6*	–	*2.8*	*1.3*	*3.2*

Table 3. A percent comparison of injury location in young female martial arts athletes based on prospective studies

Injuries	Judo		Karate		Taekwondo			
	Pieter and De Crée [21]	James and Pieter [16]	Tuominen [20]	Pieter [17]	Pieter et al. [14]	Pieter and Zemper [18]	Beis et al. [15]	Pieter and Kazemi [19]
n	17	45	1	32	7	87	52	18
Head	–	*26.7*	*100.0*	*40.6*	–	*27.6*	*42.3*	*5.6*
Head	–	13.3	100.0	–	–	8.1	7.7	–
Face/teeth	–	13.3	–	37.5	–	17.2	34.6	5.6
Throat	–	–	–	3.1	–	2.3	–	–
Spine/trunk	*47.1*	*8.9*	–	*21.9*	–	*11.5*	*5.8*	*27.8*
Neck	–	–	–	3.1	–	2.3	–	–
Torso	29.4	6.7	–	18.8	–	5.8	3.9	5.6
Back	17.7	2.2	–	–	–	–	1.9	5.6
Hip/pelvis	–	–	–	–	–	1.2	–	16.7
Groin	–	–	–	–	–	2.3	–	–
Upper extremity	*29.4*	*37.8*	–	*12.5*	*14.3*	*19.5*	–	*22.2*
Shoulder	5.9	4.4	–	3.1	–	1.2	–	–
Arm/elbow	17.7	15.6	–	3.1	–	1.2	–	–
Hand/wrist/fingers	5.9	17.8	–	6.3	14.3	17.2	–	22.2
Lower extremity	*17.7*	*26.7*	–	*15.6*	*85.7*	*41.4*	*42.3*	*44.4*
Leg	–	4.4	–	–	–	10.3	3.9	–
Knee	17.7	6.7	–	3.1	28.6	6.9	5.8	–
Ankle	–	11.1	–	–	14.3	12.6	7.7	16.7
Foot/toes	–	4.4	–	12.5	42.9	11.5	25.0	27.8
Other	*5.9*	–	–	*9.4*	–	–	–	–

For both boys and girls combined, however, the upper extremities in judo, the head in karate and the lower extremities in taekwondo were the most frequently injured body regions. Body parts of particular concern include the shoulder and hand/wrist/fingers in judo, the face in karate and the foot in taekwondo. Head and neck injuries in all three martial arts should be of the greatest concern, especially in taekwondo [28] where it ranks as the second most often injured body region. In one study, the head and neck was the most frequently injured body region at one taekwondo tournament [24].

Zetaruk et al. [26] found that the lower extremities (45% of total injuries) were most often injured in young karate athletes during practice. No information was provided on which body part was the most frequently injured.

Action or Activity

Our knowledge of situational factors associated with pediatric martial arts injuries is mostly based on acute injuries sustained in competition. Receiving a throw (boys) and groundwork (girls) in judo were activities engaged in when the injury occurred [16, 21], whereas simultaneously executed punches were most often associated with injury in karate [17]. Attacking with a roundhouse kick or receiving it led to most injuries in taekwondo [18, 19].

Chronometry

Only one study recorded the time during competition when injury occurred. Beis et al. [29] reported that 42.1% of all injuries occurred in the first match in boys, whereas 48.1% of all injuries were sustained in the first match by the girls. Even when exposure time was taken into account, significantly more injuries occurred in the first match. Explanations for this phenomenon may include a larger variety of skill levels in the early rounds of a tournament [30] and athletes less inclined to report an injury as competition nears its end [29].

Injury Severity

Injury Type

A review of table 4 reveals that contusion is the most common injury type in judo, karate and taekwondo (tables 4 and 5) [14–21]. Sprains were reported in judo [16, 21] and taekwondo [14, 15, 18, 19], but not in karate [17, 20]. The hyperextension seems to be predominantly limited to judo [16, 21].

In girls, the contusion was also reported to be the most frequently occurring injury in all three martial arts [15–21], except in one study on taekwondo, where the sprain was the most often occurring injury [14]. Judo had a larger percentage 'other' [16, 21] than karate [17, 20] or taekwondo [14, 15, 18, 19].

Table 4. A percent comparison of injury types in young male martial arts athletes based on prospective studies

Study	# inj	Abrasion	Blister	Concussion	Contusion	Dislocation	Epistaxis	Fracture	Hyperextension	Laceration	Tear*	Sprain	Strain	Other
Judo														
Pieter and De Crée [21]	25	8.0	–	4.0	56.0	4.0	–	–	4.0	–	–	12.0	–	12.0
James and Pieter [16]	54	9.3	–	5.6	13.0	1.9	–	1.9	5.6	13.0	5.6	5.6	24.1	13.0
Karate														
Tuominen [20]	33	–	–	–	51.5	–	24.2	3.0	–	15.2	–	–	–	6.1
Pieter [17]	76	2.6	–	–	67.1	–	6.6	2.6	–	4.0	–	–	1.3	15.8
Taekwondo														
Pieter et al. [14]	20	5.0	–	5.0	60.0	–	5.0	–	–	15.0	–	5.0	–	–
Pieter and Zemper [18]	354	1.4	0.3	8.8	39.3	0.9	3.7	5.7	–	5.9	0.6	20.6	4.5	8.5
Beis et al. [15]	76	–	18.4	7.6	38.2	–	11.8	2.6	–	14.5	–	2.6	–	–
Pieter and Kazemi [19]	31	–	–	6.5	38.7	–	3.2	6.5	–	6.5	–	19.4	16.1	3.2

*Ligament tear.
inj = Number of injuries.

Table 5. A percent comparison of injury types in young female martial arts athletes based on prospective studies

Study	# inj	Abrasion	Blister	Concussion	Contusion	Dislocation	Epistaxis	Fracture	Hyperextension	Laceration	Tear*	Sprain	Strain	Other
Judo														
Pieter and De Crée [21]	17	11.8	–	–	41.2	–	–	–	5.9	5.9	–	–	–	35.3
James and Pieter [16]	45	4.4	–	6.7	35.6	2.2	–	–	8.9	2.2	6.7	11.1	13.3	8.9
Karate														
Tuominen [20]	1	–	–	–	100	–	–	–	–	–	–	–	–	–
Pieter [17]	32	3.1	6.3	–	71.9	–	–	–	–	3.1	–	–	3.2	12.5
Taekwondo														
Pieter et al. [14]	7	–	–	–	14.3	–	–	–	–	–	–	85.7	–	–
Pieter and Zemper [18]	87	1.2	–	8.1	34.5	1.2	1.2	10.4	1.2	2.3	–	27.6	6.9	5.8
Beis et al. [15]	52	–	11.5	9.6	44.2	1.9	13.5	–	–	15.4	–	–	–	1.9
Pieter and Kazemi [19]	18	5.6	–	–	44.4	–	–	11.1	–	5.6	–	27.8	–	5.6

*Ligament tear.
inj = Number of injuries.

Epistaxis was found in karate and taekwondo [14, 15, 17–20], but mostly in males. Cerebral concussions were reported in male judo and taekwondo athletes [14–16, 18, 19, 21], but less frequently in their female counterparts [15, 16, 18]. No cerebral concussions were found in the prospective studies on pediatric karate injuries [17, 20]. If exposure time is taken into account, the combined rate collapsed over studies for cerebral concussions in judo would be 2.38/1,000 A-E (boys) and 2.92/1,000 A-E (girls). In taekwondo, the corresponding rates would be 4.53/1,000 A-E (boys) and 3.99/1,000 A-E (girls).

Catastrophic Injury

Although Oler et al. [24] using a prospective design and Birrer [8], in a retrospective study, recorded one and six deaths, respectively, it is not clear whether they involved junior, senior, male or female martial arts athletes. Kujala [22] reported permanent disability in judo (0.17% of all judo injuries) and karate (0.17% of all karate injuries), but did not specify the age and gender of the athletes.

Time Loss

Time-loss injury is defined as any injury that will keep the athletes from finishing the present bout and/or continuing with subsequent bouts and that will prevent them from returning to practice or competition for one day or more [31]. Time-loss injuries were reported for karate in boys competing at the national level with rates of 4.03/1,000 A-E [20] and 2.63/1,000 A-E [17]. No time-loss injuries in karate girls were reported in the literature. In taekwondo, the time-loss injury rate for boys ranges from 25.54/1,000 A-E [31] to 6.99/1,000 A–E [19] and 7.66/1,000 A-E [32] in national and international athletes to 3.94/1,000 [33] in recreational participants.

In girls, the rates for national and international taekwondo athletes were 29.91/1,000 A-E [31] and 14.29/1,000 A-E [32], while their recreational counterparts recorded a rate of 13.89/1,000 A-E [33]. Although the girls in Pieter and Kazemi's study [19] sustained time-loss injuries, they decided to continue competing on the day of the injury. There was no follow-up, but their rate would have been 14.71/1,000 A-E. Martin et al. [34] reported time-loss injuries of 8.2 and 8.3/100 participants for boys and girls, respectively, competing at the 1985 Junior Olympics.

Using the same injury definition, one study suggests that recreational female taekwondo athletes <13 years incurred a higher injury rate of more severe injuries (≥21 days) than their male counterparts of the same age [33], while time loss per injury in national level boy and girl taekwondo athletes mostly required ≤7 days away from participation [31]. Most of the time loss per head and neck injury in young national taekwondo athletes also resulted in $\leq$7 days away from participation [28].

Clinical Outcome

Limited data exist on re-injury in pediatric martial arts athletes. Pieter and Kazemi [19] found re-injury rates of 6.99/1,000 A-E in taekwondo boys and 36.76/1,000 A-E in girls. All injuries were sustained in the same season the data were collected for the study. There were no studies that reported the residual effects of injury following retirement from the sport.

Injury Risk Factors

Age and Body Weight

It is hypothesized that injuries would increase with age in taekwondo as the athletes are expected to increase in body weight and strength [18]. However, this assumption was not analyzed for statistical significance. Later prospective studies showed either no statistically different ($p > 0.05$) [14] or a lower injury rate with age ($p < 0.001$) [19] but also a higher one ($p < 0.001$) [15]. Middle school taekwondo athletes were more likely to incur a cerebral concussion in competition compared to high school counterparts (OR = 1.89) [35].

In judo, an increase was reported [25] as well as a decrease [21] in injury rate with age. The latter study confirmed the decrease statistically ($p < 0.01$). Kujala et al. [22] found practice and competition injury rates to increase with age in both male and female judo and karate athletes. However, this was not statistically tested. Zetaruk et al. [26] found no statistical relationship between age and injury in karate practice. One prospective study suggested an increase in injury with increasing weight in young taekwondo athletes [18]. However, this was not confirmed statistically in a later investigation ($p > 0.05$) [15].

Exposure

Experience ($p < 0.001$), training hours/week ($p = 0.016$) and belt rank ($p = 0.006$) were found to be positively related to number of injuries in young karate practitioners [26]. Tuominen [20] confirmed the positive relationship between experience and sustaining an injury in adult males only (OR = 4.9), but not in younger karate athletes.

Suggestions for Injury Prevention

The purpose of this overview was to present epidemiological data pertaining to injuries in pediatric martial arts athletes with a view to facilitate understanding of how, where and why injuries occur in judo, karate and taekwondo, so that they may be prevented in the future. The review of the literature revealed the following injury patterns: (1) a higher injury rate per 1,000 A-E was reported for girls in some studies [14–17, 19, 21]; (2) the most often injured body regions/ parts: upper extremities (hand/wrist/fingers), lower extremities (knee), spine/ trunk in judo; head (face), spine/trunk, upper extremities, lower extremities in karate; lower extremities (foot/toes), head, upper extremities in taekwondo [14–21]; (3) in boys, contusion is the most frequently occurring injury type in all three martial arts, followed by strain in judo, epistaxis in karate, and sprain in taekwondo; in girls, contusion is also the most often occurring injury type, followed by abrasion in judo, blister in karate, and sprain in taekwondo; a small number of catastrophic injuries ($<$1% of all injuries) occur in all three martial arts; time-loss injuries were reported for karate (only boys) and taekwondo [14–21]; (4) performing a throw (boys) and being thrown (girls) were actions most often associated with injury in judo [16, 21]; in karate, punching was most frequently associated with injury [17, 20], while in taekwondo, it was executing the roundhouse kick [14, 15, 19]; (5) age and body weight were identified as risk factors in all three martial arts in some studies [15, 19, 21, 25], but not in others [14, 26], while exposure to injury was found to be related to karate injuries [26].

Suggestions for preventive measures are summarized in table 6. The recommendations are based on descriptive data and await further research evaluating some or all of the suggestions included in the table. McLatchie et al. [40] have conducted the only study to date investigating the effect of preventive measures on competition injuries in karate. In adult karate athletes, the total injury rate decreased from 0.25 to 0.05 injuries per bout after implementation of preventive measures involving coaches, athletes, referees and protective equipment. No such studies have been done with pediatric martial arts athletes.

Challenges for Further Research

Future research should adopt a definition of injury that is not restricted to time-loss injuries only so as to arrive at a more complete pediatric injury profile in martial arts [36]. More studies are needed to assess training injuries and compare them to those sustained in competition. These investigations should be done based on a multifactorial model and also include potential risk factors. Very little is known about injury risk factors in judo, karate and taekwondo and identifying them should be emphasized in future research. Analytical studies are also needed to evaluate suggested preventive measures based on risk factors that have been statistically verified for their predictive value.

Table 6. Suggestions for injury prevention (adapted from Pieter [36])

Preventive measures	Type of evidence	
	Retrospective	Prospective
Education		
Coaches, referees, athletes, and tournament directors should be educated relative to injuries, their mechanisms and prevention		Oler et al. [24]; Pieter and Zemper [18]; Koh and Watkinson [37]
Coaches and referees should be required to meet minimum standards of qualification	Birrer [8]	Oler et al. [24]; Critchley et al. [12]
Coaching – training		
Children and youth in martial arts should be taught not to enter competition prematurely		Oler et al. [24]; Pieter and Zemper [28]
More appropriate advice regarding the use of the roundhouse kick in taekwondo as well as more adequate game planning and blocking skills		Pieter and Bercades [33]; Pieter et al. [14]; Pieter and Zemper [28]; Koh and Cassidy [35]
The sport	Birrer [8]	
Re-evaluation of current competition rules that allow blows to the head/face to help reduce injuries		Oler et al. [24]; Tuominen [20]; Pieter and Zemper [28]
It is suggested to compete with closed fists instead of open hands in karate and taekwondo to help reduce fractures to the hands and fingers		Pieter and Zemper [31]
Equipment		
It is recommended to allow padding for the foot in taekwondo athletes to help reduce injuries to this body part		Beis et al. [15]; Pieter and Zemper [38]
Mouthguards should be mandatory at all competitions to help prevent dental and orofacial injuries as well as reduce the incidence and severity of brain injuries		Nowjack-Raymer and Gift [4]; Tuominen [20]; Biasca et al. [39]
Referee		
The referee should have competition experience, preferably at the national level as a minimum requirement, to better assess the activities in the ring in terms of the nature of the blows and other aspects of the match		McLatchie et al. [40]

The psychological profile of the pediatric martial arts athlete should also be considered as a potential risk factor for injury [28]. For instance, Filaire et al. [41] showed cognitive and somatic state anxiety to be positively related to the level of judo competition: the higher the level of competition, the higher the state of anxiety. Psychological stress was found to be related to injuries in high school basketball, wrestling and gymnastics [42] but has not yet been studied in martial arts.

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Skiing and Snowboarding Injuries

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Abstract

Objective: To critically examine the literature on skiing and snowboarding injuries in children and adolescents. **Data sources:** Searched English language articles from: Medline, SPORTDiscus, Cumulative Index to Nursing and Allied Health Literature, Current Contents, and HealthSTAR. The table of contents for Ski Trauma and Skiing Safety Series published by the American Society for Testing and Materials were also examined. MeSH headings included: Sports, Athletic Injuries, and Accidents. Keywords used within these headings were Skiing and/or Snowboarding with focus on children, adolescents, youth, students, or age group-related comparisons. **Main results:** The patterns and rates of injury differed markedly by activity and study design. Most studies were case-series investigations providing little useful information on risk factors. Intrinsic risk factors included: lower ability, younger age, past injury, and female sex. Extrinsic risk factors were improper binding adjustment, no helmet, certain slope characteristics, and no wrist guards. The literature on the effect of activity, equipment ownership and lessons on injury risk was equivocal. **Conclusions:** Suggestions for injury prevention include the use of helmets and wrist guards, participation on appropriate runs for ability level, proper fit and adjustment of bindings and other equipment, and taking lessons with the goal of increasing ability and learning hill etiquette. Many areas requiring further research are identified and discussed. New methodological approaches hold promise in advancing the field of ski and snowboard injury research.

Introduction

Skiing is an activity practiced by millions of people in snow-blessed countries. Unfortunately, studies have identified it as one of the leading causes of pediatric sport-related injuries [1–3]. Investigators have also found that skiing produces among the most severe sports-related injuries in children [4–6]. Indeed, it was argued long ago that skiing might simply be too difficult a sport for children given the speeds and forces involved [7].

Snowboarding has been gaining popularity at the expense of skiing, in particular, among the younger set. The rise in popularity, however, has meant that snowboarding is now labeled as an emerging injury-producing sport-related activity in children and adolescents [2]. There is evidence that snowboarding injury rates are among the highest of sports-related injury rates in the 9–19-year-old age group [8]. Only by examining the patterns of, and risk factors for, injury in skiing and snowboarding can we identify and target preventive strategies.

The literature on the patterns, incidence, and risk factors for skiing and snowboarding injuries in children and adolescents was reviewed. The search was restricted to English language articles. Medline, SPORTDiscus, Cumulative Index to Nursing and Allied Health Literature, Current Contents, and HealthSTAR were searched using the medical subject headings of Sports, Athletic Injuries, and Accidents. Keywords used within these headings were Skiing and/or Snowboarding. The Ski Trauma and Skiing Safety Series published by the American Society for Testing and Materials was also reviewed. Each title was searched manually for any with a focus on children, adolescents, youth, students, or age group-related comparisons. The reference lists of selected articles were searched using the same criteria.

Most reports are case-series investigations where the characteristics of a series of individuals who were injured in a given activity (e.g., skiing) are detailed. These investigations allow for a comprehensive account of the types of injuries seen, but don't allow calculation of incidence rates or the identification of risk factors unless denominator data (e.g., ski or snowboard lift-tickets) are available. Most studies that do allow for the calculation of risk factors are case-control studies. These studies use a case-series as well as a denominator series (i.e., controls). Many of these studies, however, fail to adjust fully for factors that likely influence crude associations (i.e., the proportion of a given characteristic in the 'case' group is compared with the proportion in the 'control' group). The only information typically available on incidence of injury is based on a denominator of lift-ticket sales (i.e., injuries per 1,000 tickets or visits), which does not account for the differential participation that can occur with the purchase of a single lift-ticket. These issues aside, there are some well-conducted studies we can use to draw from in terms of describing the patterns, rates, and risk factors in these activities for the pediatric age group.

Incidence of Injuries

The incidence of injury in skiing and snowboarding is largely a function of the injury definition and the nature of the study design. For example, if the numerator of a rate is based on a more severe injury definition (e.g., admission to hospital), it will be lower than if it is based on a more inclusive injury definition (e.g., ski patrol reports). In addition, studies of closed or cohort populations (e.g., an enumerated list of skiers followed over a ski season), with less chance of missed injuries compared with studies that rely on injury reporting to a particular care provider (e.g., ski patrol or emergency department), will also contribute to a larger numerator and result in a higher rate.

A comparison of injury rates reported in retrospective cohort, case-control, and case-series studies is shown in table 1 [9–20]. Most rates are calculated as injuries per skier days of participation, although some use runs [9], hours [20] or participants per year [15] for a denominator. Garrick and Requa [13, 18] report the highest injury rate of 9.1 injuries per 1,000 skier days in their cohort study of ski injuries in children and youth. Estimates from case-control and case-series studies are typically much lower ranging from 2.86 to 6.6 injuries per 1,000 skier days [10, 12, 14, 19]. Although the higher rates reported in the cohort studies may be due to the earlier time period or the more inclusive injury definition (i.e., self-reported injuries interfering with work or recreation for at least one day), it is likely as much a function of more complete case capture.

Using lift-ticket-based denominators and ski patrol-reported injuries in their case-series investigation, Cadman and Macnab and colleagues [11, 17] determined the incidence of injury in those under the age of 18. In skiers and snowboarders combined, the incidence of injury was 3.8/1,000 visits in those under 7, 4.8/1,000 visits in those between 7–12, and 4.4/1,000 visits in those between 13–17. Again, the more inclusive injury definition and the fact that the rates were for skiers and snowboarders combined may be the reason for the slightly higher rates compared with Deibert et al. [12].

Finally, the data from the study by Hagel et al. [15] indicate a rate of 0.6 injuries per 1,000 participants per year for skiers based on emergency department records for 12–17-year-olds.

There are only two investigations that provide incidence estimates specifically for child and adolescent snowboarders. Based on emergency department data, the study by Hagel et al. [15] indicates a rate of 1.8 per 1,000 snowboarders per year for 12–17-year-olds. In their retrospective cohort study based on medically reported injuries, Machold et al. [16] found the incidence of injury to be 15 per 1,000 snowboard days for all injuries and 10.6/1,000 days for medically treated injuries. It is likely that it is the study of a closed population (i.e., cohort), with more complete case capture, that is driving the higher rate in the Machold et al. [16] study compared with the study by Hagel et al. [15].

Table 1. Incidence of injury in skiers and snowboarders

Author	Year	Study design	Injury definition	Duration	Sample	Age range	Study locale	Incidence
Skiers								
Bergstrøm et al. [9]	2001	Retrospective cohort	Medical and rescue services	Alpine World Junior Championship of 1995	452 girls; 546 boys; 4 injuries, all in girls	15–19	Norway	4 injuries/1,000 runs overall 8.9 injuries/1,000 runs in girls
Garrick and Requa [13] see also Requa and Garrick [18]	1979	Retrospective cohort	Self-report of a ski injury that interfered with work and/or recreation for one or more days	2 years; 1971–72 to 1972–73	3,534 respondents; 432 injuries	under 18	USA	9.1/1,000 ski days
Blitzer et al. [10]	1984	Case-control with exposure estimation	Base lodge ski injury clinic	9 years; 1972–73 to 1980–81	138,133 skier visits; 696 injuries	under 17	USA	14–16: 4.9/1,000 ski days 11–13: 6.6/1,000 ski days <11: 4/1,000 ski days
Deibert et al. [12]	1998	Case-control with exposure estimation	Base lodge ski injury clinic	22 years; 1972–73 to 1993–94	626,259 skier visits from 1981–82; 2,001 injuries from 1981–82	under 17	USA	11–16:* 2.86/1,000 ski days <11:* 2.95/1,000 ski days *Restricted to 1993–94 season
Giddings et al. [14]	1993	Case-series with exposure estimation	Resort medical centre	3 years; 1988–90	61,083 visitor days; 204 injuries	under 13	Australia	3.34/1,000 ski days
Sherry et al. [19]	1987	Case-series with exposure estimation	Ski injury clinic on ski hill	July 1984–September 1984	149 children with 159 injuries	under 14	Australia	3.9/1,000 ski days

Table 1 (continued)

Author	Year	Study design	Injury definition	Duration	Sample	Age range	Study locale	Incidence
Hagel et al. [15]	2003	Case-control/ Case-series with exposure estimation	Emergency department	1991–99	1,114,000 estimated participants; 669 injuries	12–17	Canada	0.6/1,000 skiers per year* *Rate based on 1997–98 data
Wyatt and Beattie [20]	1995	Case-series with exposure estimation	Emergency department	July 1992– June 1993	116 injuries in 112 patients on an artificial ski slope	under 13	Scotland	1/394 h
Skiers-Snowboarders combined								
Cadman and Macnab [11], see also Macnab et al. [17]	1996	Case-series with exposure estimation	Ski patrol reports	1991–92 ski season	142,098 ski visits; 632 skier and snowboarder injuries	under 17	Canada	13–17: 4.35/1,000 ski-snowboard days 7–12: 4.75/1,000 ski-snowboard days 0–6: 3.81/1,000 ski-snowboard days
Snowboarders								
Machold et al. [16]	2000	Retrospective cohort	Self-reported snowboard days; medically reported injuries	1996–97	2,579 students reported 20,238 snowboard half-days and 152 injuries	Students from Austrian schools (mean age = 14.7)	Austria	All injuries: 15.0/1,000 snowboard days Medically treated: 10.6/1,000 snowboard days
Hagel et al. [15]	2003	Case-control/ Case-series with exposure estimation	Emergency department	1991–99	801,000 estimated participants; 1,436 injuries	12–17	Canada	1.8/1,000 snow-boarders per year* *Rate based on 1997–98 data

Injury Characteristics

Depending on the injury definition, and other characteristics of the study and the participants, large differences in the profile of injuries can result. Table 2 details the burden of injury to particular body regions for child and adolescent skiers and snowboarders [10–12, 14–32]. This is important information for those hoping to implement targeted injury prevention initiatives.

Skiers

Most injuries that occur in child and adolescent skiers involve the lower extremity. Specifically, study results consistently show that knee and lower leg injuries, in the youngest age groups in particular, are the most common injuries that occur in skiers [12, 14, 17–19, 24–27, 32]. These injuries are largely due to the lower extremity torsion mechanism in skiing. However, there may be large differences in the proportion of body region-specific injuries depending on both participant and study characteristics.

Head and Spinal Injuries

Depending on the injury definition, age, and sex of the group, head injuries account for between 5% [22] and 51.5% [29] of injuries in skiers. Neck and spinal injuries make up between 2.9 and 7.7% [12, 15, 29, 31].

Based on ski patrol-reported injuries, Heir et al. [25] found that head injuries represented 17.1% of all injuries in those under 13 and 19.6% in those 13–19. The study by Cadman and Macnab [11] found higher proportions of head and face injuries in male skiers (19.3–46.2%) compared with females (13.4–16.7%) under 17 [11]. Other ski patrol report-based investigations used injury definitions that do not facilitate comparisons between studies [23, 24].

Perhaps surprisingly, the proportion of head injuries is generally lower in those studies using a resort-based medical clinic injury definition. Ekeland et al. [22] found that skier head injuries represented 18% in those 10–14 but only 5% in those under 10. Other investigations using similar definitions have found that the proportion of head injuries falls between the extremes in the Ekeland study ranging from 6 to 14.1% [10, 12, 14, 19, 27, 32]. A possible reason for the lower proportion of head injuries in these studies compared with the studies based on ski patrol reports is likely to be due to their exclusion of very minor injuries such as contusions and abrasions. This was explicitly stated in the study by Blitzer et al. [10].

Table 2. A percent comparison of injury location in skiers and snowboarders

Study	Study design	Data source	Number of participants	Age of participants	Head/Face/Spine	Upper extremity	Lower extremity
Skiers							
Cadman and Macnab [11], see also Macnab et al. [17]	Case-series	Ski patrol reports	632 skier and snowboarder injuries; 142,098 visits (number of injuries in each activity not available from report)	Under 17	Head and face* Males: 13–17: 27.3% 7–12: 19.3% 0–6: 46.2% Head and face:* Females: 13–17: 15.5% 7–12: 13.4% 0–6: 16.7% *Differences between males and females statistically significant ($p < 0.05$)	Shoulder* Males: 13–17: 10.5% 7–12: 4.6% 0–6: 7.7% Shoulder:* Females: 13–17: 3.1% 7–12: 4.1% 0–6: 0% *Differences between males and females statistically significant ($p < 0.05$)	Knee* Males: 13–17:16.3% 7–12: 16.5% 0–6: 23.1% Knee* Females: 13–17: 33.3% 7–12: 29.9% 0–6: 16.7% *Differences between males and females statistically significant ($p < 0.05$)
Goulet et al. [23]	Case-control	Ski patrol reports	41 injured; 346 controls	Under 13	Head and neck: 9.76% Trunk: 12.19%	Upper limb: 14.63	Lower body: 63.42%
Hagel et al. [24]	Case-series	Ski patrol reports	832 injured	Under 18	Females Head/neck/back: 23.7% Males Head/neck/back: 35.5%	Females Upper extremity: 19.5% Males Upper extremity: 21.3%	Females Lower extremity: 53.6% Males Lower extremity: 39.1%

Heir et al. [25]	Case-series	Ski patrol reports	1,042 injured children (<13); 1,108 injured adolescents (13–19)	Under 20	Children under 13 Head: 17.1% Adolescents (13–19) Head: 19.6%	Adolescents (13–19) Hand: 12.3%	Children under 13 Lower leg: 21.7% Knee: 20.5% Adolescents (13–19) Knee: 24.4%
Blitzer et al. [10]	Case-control with exposure estimation	Resort medical center	138,133 skier visits 696 injuries	Under 17	Head and spine 14–16: 6.2% 11–13: 6.2% <11: 6.1%	Thumb 14–16: 20.8% 11–13: 16.0% <11: 7.2% Upper body* 14–16: 23.3% 11–13: 21.6% <11: 15.6% *Excluding thumb	Foot and ankle 14–16: 5% 11–13: 7.7% <11: 10.6% All knee sprains 14–16: 18.3% 11–13: 13.4% <11: 22.8% Tibia fractures: 14–16: 5.6% 11–13: 10.3% <11: 13.3%
Deibert et al. [12]	Case-control with exposure estimation	Resort medical center	626,259 skier visits from 1981–82 2,001 injuries from 1981–82	Under 17	Head injuries* 11–16: 8.9% <11: 9.9% Spinal injuries 11–16: 4.1% <11: 7.7% *Restricted to 1987–94-time period	Upper extremity fractures* 11–16: 13.3% <11: 11.7% *Restricted to 1987–94-time period	Lower extremity fractures:* 11–16: 4.2% <11: 5.9% Tibial fractures* 11–16: 3.0% <11: 4.4% *Restricted to 1987–94-time period
Ekeland et al. [22]	Case-control	Resort medical center	59 injuries 63 controls	Under 15	Head injuries 10–14: 18% <10: 5%	Skiers thumb 10–14: 8% <10: 0%	Lower extremity: 59% Lower leg fractures 10–14: 10% <10: 21%

Table 2 (continued)

Study	Study design	Data source	Number of participants	Age of participants	Head/Face/Spine	Upper extremity	Lower extremity
Giddings et al. [14]	Case-series	Resort medical center	61,083 visitor days and 204 injuries	Under 13	Head and face:* 14.1% Neck and back: 3.6% Trunk: 2.3% *Significantly ($p < 0.05$) more than 13 and older	Upper limb: 15.4%	Lower body:* 64.1% *Significantly ($p < 0.01$) more than 13 and older
Molinari et al. [27, 28]	Case-series	'Traumato-logical first aid post'	587 injuries in children	Under 15	Head and face: 13.28% Chest and abdomen: 1.02%	Upper limb including shoulder: 42.25%	Lower limb including leg: 43.45%
Sherry et al. [19]	Case-series	Resort medical center	149 children with 159 injuries	Under 14	Head and face: 13% Neck and back: 7% Trunk: 1%	Upper extremity: 11%	Lower extremity: 66%
Ungerholm et al. [32]	Case-series	Resort medical center	890 injuries	Under 16	Head: 11.2% Trunk: 3.0%	Upper extremity: 22.5%	Lower extremity: 63.3%
Hagel et al. [15]	Case-control/ Case-series with exposure estimation	Emergency department	6,441	Under 18	Head (including brain and face): 13.1% Neck: 2.9%	Not available	Not available
Hill [26]	Case-series	Emergency department	8 injuries on snow slopes; 8 injuries on dry slopes	Under 16	Head/neck/face: 0%	Upper limb: 37.5%	Lower limb: 62.5% Tibia fracture: 37.5%

Waytt and Beattie. [20]	Case-series	Emergency department	116 injuries in 112 patients on an artificial ski slope	Under 13	Head injuries: 2.6%	Not available	Not available
Shorter et al. [29]	Case-series	Admission to a pediatric trauma centre	68 injuries in 38 patients	Under 19	Head and face: 51.5% of injuries 71.0% of patients Trunk: 16.2% of injuries 29.0% of patients Spinal: 2.9% of injuries 5.3% of patients	Not available	Not available
Skokan et al. [31]	Case-series	Admission to a pediatric trauma centre	101 patients	Under 18	Head-face: 33% Spine: 5% Trunk: 17%	Upper extremity: 8%	Lower extremity: 22%
Requa and Garrick [18]	Retro-spective cohort	Self-report of injuries interfering with work or recreational activities for one or more days	431 injuries in 3,534 skiers	Under 20	3–13 age group Head/neck: 7.1% 14–19 age group Head/neck: 6.5%	3–13 age group Upper extremity: 14.8% 14–19 age group Upper extremity: 14.6%	3–13 age group Lower extremity: 69.8% 14–19 age group Lower extremity: 72.1%

Table 2 (continued)

Study	Study design	Data source	Number of participants	Age of participants	Head/Face/ Spine	Upper extremity	Lower extremity
Snowboarders							
Cadman and Macnab [11], see also Macnab et al. [17]	Case-series	Ski patrol reports	632 skier and snowboarder injuries; 142,098 visits (number of injuries in each activity not available from report)	Under 17	Head and face Males: 13–17: 9.3% 7–12: 0 0–6: 0 Head and face Females: 13–17: 20.8% 7–12: 50.0% 0–6: 0	Shoulder Males: 13–17: 2.4% 7–12: 25.0% 0–6: 0 Shoulder Females: 13–17: 0 7–12: 0 0–6: 0 Wrist Males: 13–17: 47.62% 7–12: 25.0% 0–6: 0 Wrist Females: 25.0% 13–17: 7–12: 0 0–6: 0	Knee Males: 13–17: 11.9% 7–12: 37.5% 0–6: 0 Knee Females: 13–17: 29.2% 7–12: 50.0% 0–6: 0
Hagel et al. [24]	Case-series	Ski patrol reports	557 injured	Under 18	Females Head/neck/back: 18.3% Males Head/neck/ back: 28.6%	Females Upper extremity: 53.7% Males Upper extremity: 46.8%	Females Lower extremity: 23.2% Males Lower extremity: 19.1%

Drkulec and Letts [21]	Case-series	Emergency department	118 injuries in 113 children	Under 19	Head injuries: 8% Cervical spine injuries: 1.7% Abdominal injuries: 5%	Upper extremity: 80%* *Distal radius fractures occurred in 53 of 113 children	Lower extremity: 7%
Hagel et al. [15]	Case-control/ Case-series with exposure estimation	Emergency department	3,626 injuries	Under 18	Head (including brain and face): 10.5% Neck: 1.9%	Not available	Not available
Machold et al. [16]	Retro-spective cohort	Self-reported snowboard days; medically reported injuries	2,579 students reported 20,238 snowboard half-days and 152 injuries	Students from Austrian schools (mean age of 14.7)	Head: 11.2% Trunk: 2.0%	Upper extremity: 61.1% Lower arm/wrist/hand: 51.9%	Lower extremity: 21.1%
Shorter et al. [30]	Case-series	Admission to a pediatric trauma centre	34 injuries in 27 patients	Under 19	Head and face: 38.2% of injuries 48.1% of patients Trunk: 23.5% of injuries 29.6% of patients Cervical spine: 2.9% of injuries 3.7% of patients	Not available	Not available
Skokan et al. [31]	Case-series	Admission to a level one pediatric trauma centre	101 patients	Under 18	Head-face: 31% Spine: 5% Trunk: 18%	Upper extremity: 5%	Lower extremity: 16%

Only three studies used a definition of emergency department-reported injuries. Hagel et al. [15] noted that head injuries (including brain and face) made up 13.1% of emergency department-reported injuries in skiers. Head injuries represented only 2.6% of all emergency department-reported injuries occurring on artificial ski slopes in those under 13 in the study by Wyatt and Beattie [20], while Hill [26] found no head injuries in their small study of only 16 individuals injured on dry and snow slopes. The study by Hagel et al. [15], the most recent of the three and the only one that focused on snow skiing exclusively, compares to those using a resort-based medical clinic injury definition.

For those most severe injuries requiring admission to a pediatric trauma center, head and face injuries were found to make up between 33% [31] and 51.5% [29] of all injuries in young skiers. These data are consistent with the link between injury severity and head injury.

Neck and spinal injuries, which can have life-altering consequences, also afflict skiers. These injuries make up between 2.9 and 7.7% of the total, depending on the injury definition and age group [12, 15, 29, 31].

Cadman and Macnab [11] put the issue of head and neck injuries in perspective:

> Clearly, not all head injuries are severe and only occasionally does spinal injury occur. With head injury rates as high as they are, however, the potential risks of significant injury are considerable and any measures which decrease either the incidence or the severity of head injury, or which prevent even an occasional cervical spine injury, would have major cost and humanitarian benefits.

Upper Extremity Injuries

As was the case for head and spinal injuries, the injury definition and group characteristics result in a large range of reported upper extremity injuries: <5% [11] to 42.3% [27].

Ski patrol reported upper limb injuries represented 14.6% of injuries in skiers in the study by Goulet et al. [23], while Hagel et al. [24] found they accounted for 19.5% in females and 21.3% in males based on a similar injury definition. In those under 17, Cadman and Macnab [11] noted a greater proportion of shoulder injuries in males (4.6–10.5%) compared with females (under 5%) based on ski patrol reports.

Based on resort medical clinic records, upper extremity injuries account for between 11 and 42.3% of all injuries [10, 12, 14, 19, 27, 32]. However, excluding the Italian study [27], the range falls to between 11% [19] and approximately 23% [10, 32]. Similarly, upper extremity injuries represented 15% of the self-reported injuries interfering with work or recreation for at least one day in the study by Requa and Garrick [18].

From a study of artificial and natural ski slopes, Hill found that 37.5% of all emergency department injuries were to the upper limb [26]. Apart from the data presented by Molinari et al. [27], this suggests a higher proportion of upper extremity injuries on artificial slopes.

Upper extremity injuries are not usually part of the spectrum of severe injuries in skiers. Skokan et al. [31] reported that upper limb injuries represented only 8% of all injuries in those under 18 admitted to a level I pediatric trauma centre.

Lower Extremity Injuries

The lower extremity has received the most attention in the ski injury literature due to the large portion of injuries that occur to this region. Although there is a large variation from study to study, almost all identify the lower extremity as the most frequently injured body region for skiers with the proportion ranging from 22% [31] to 72% [18].

Ski patrol-reported injury data suggest that lower extremity injuries make up between 39.1 and 63.4% of injuries in young skiers [11, 23–25]. These data suggest that lower extremity injuries are more prevalent in females and younger age groups.

Data from resort medical centers suggest that lower extremity injuries represent between 43.5 and 66% of injuries in young skiers [14, 19, 22, 27, 32]. The investigation of dry and snow slope injuries reported to an emergency department produced similar findings [26], while self-reported injuries interfering with work or recreation for one day or more represented over two thirds of the injuries in the study by Requa and Garrick [18]. As with ski patrol-based studies, these investigations have found an association between younger age and lower limb injury, particularly fractures [10, 12, 22].

As with upper extremity injuries, data based on admissions to a pediatric trauma center indicate that lower extremity injuries are generally less severe. Skokan et al. [31] reported that lower extremity injuries made up only 22% of all injuries in their pediatric trauma center series.

Snowboarders

In child and adolescent snowboarders, there is evidence that upper extremity injuries are the main problem. Most studies on child and adolescent snowboarders indicate that the wrist and forearm are most frequently injured in snowboarders due to an upper extremity impact mechanism [16, 21, 24, 30]. However, as noted for skiers, the body region distribution of injuries may change based on study and participant characteristics.

Head and Spinal Injuries

Head injuries represent between 8% of injuries to those under 19 based on emergency department records [21] to 50% in females aged 7–12 years based on ski patrol reports [11]. Based on admission to a pediatric trauma center, cervical spine injuries represent 2.9% of all injuries in those under 19 [30] while all spinal injuries make up 5% of the total injuries in those admitted under age 18 [31].

Ski patrol-reported head and face injuries combined represented 9.3% of injuries in males 13–17, 20.8% in females 13–17, and 50% in females 7–12 in the study by Cadman and Macnab [11]. No males under age 13 sustained a ski patrol-reported head injury in the Cadman and Macnab study. Snowboarder head, neck, and back injuries combined represented 18% in females, but almost 29% in males under 18 in the study by Hagel et al. [24].

From emergency department reports, head injuries accounted for between 8 and 10.5% of all injuries in young snowboarders [15, 21]. This is similar to the 11.2% head injuries found by Machold et al. [16] based on medically treated injuries in student snowboarders.

As was the case for skiers, the greater the injury severity, the more likely the head was involved. For injuries requiring admission to a pediatric trauma center, head and face injuries combined represented 38.2% of injuries in the study by Shorter et al. [30]. This is similar to the 31% found by Skokan et al. [31] using a similar injury definition.

Although the proportion of neck and spinal injuries in child and adolescent snowboarders is relatively small, ranging from 1.9% based on emergency department reports to 5% based on admission to a pediatric trauma center, these injuries can be severe and there are indications of a trend with injury severity [15, 30, 31].

Upper Extremity Injuries

Whereas the lower extremity represented the largest problem for child and adolescent skiers, the upper extremity is the body region of injury for most snowboarders. Upper extremity injuries represent between 46.8% of ski patrol-reported injuries in males under age 17 [24] to 80% of all injuries based on emergency department records [21]. Forearm and wrist injuries are by far the most common problem [11, 16, 21]. However, only 5% of admissions to a pediatric trauma center involved injuries to the upper extremity reflecting their importance in terms of frequency, but not necessarily severity [31].

Lower Extremity Injuries

Lower extremity injuries in snowboarders do not represent the same problem in snowboarders as they do in skiers. Lower extremity injuries account for 16% of all injuries in snowboarders admitted to a pediatric trauma center [31], 21.1% of medically treated snowboard injuries [16], and between 19.1 and

23.2% of ski patrol-reported injuries [24]. However, these injuries represent only 7% of all injuries based on emergency department records [21].

Time Trends

Deibert et al. [12] examined time trends in skiing injury rates from the 1971–72 through 1993–94 time period. They found that the rate of all lower extremity fractures, and tibial and ankle fractures in particular, decreased significantly in those under age 17. Similarly the rate of skull fractures in children under 11, first and second degree knee sprains and ankle sprains in those under 17, and thumb sprains in those 11–16 also decreased. However, the rate of spinal injuries in the 11–16-year age group increased significantly. Although not statistically significant, the authors also noted an increase in all head injuries combined for those under 11, and third degree knee anterior cruciate ligament sprains in those between 11–16 years of age.

A Canadian investigation of emergency department-reported injuries in skiers and snowboarders suggest that the rate of brain injuries in adolescent [12–17] skiers increased 2-fold from 1995 through 1999 (Rate ratio: 1.9; 95% CI: 1.1–3.3). In snowboarders, the rate of head (Rate ratio: 1.58; 95% CI: 1.07–2.34) and neck (Rate ratio: 3.37; 95% CI: 1.6–7.3) injuries increased over the 4-year period [15].

Characteristics of the Injury Event

The circumstances surrounding the injury event are important to consider. Although an assessment of risk is not available from only an injured series, identification of prevalent event-related characteristics provides the basis for analytic studies aimed at evaluating potential causative factors.

Competition versus Practice

The majority of injuries occur during recreational participation in skiing (66.7%) and snowboarding (74.7%) [24]. Only a small proportion of skiers [24, 29] and snowboarders [24] are injured during training or competition. However, this may simply reflect the greater number of recreational participants, rather than a relation with injury risk.

Time of Day

In terms of the time of day of injury, investigations are inconsistent. Some suggest the majority of injuries occur in the afternoon and evening [24, 29], others mid-morning and afternoon [16, 30].

The results, at least for lower extremity injuries in skiers, do not support fatigue as the main cause of injury. Specifically, Ungerholm et al. [32] found that over 70% of lower extremity-injured skiers were participating for 2 h or less at the time of the event.

Time of Season

Most injuries in skiers and snowboarders occur during the heart of the winter season (i.e., January and February in the northern hemisphere) [21, 24, 29], no doubt a reflection of greater participation during this time.

Depending on the activity and the type of injury, a large proportion (67–83%) of skier and snowboarder injuries occur within the first week [16, 33], with estimates of between 3.5% [16] and almost 25% [24, 29] the first day. For lower extremity-injured skiers, Ungerholm and Gustavsson [33] found that 83% had been skiing for one week or less. These same authors noted that in those with a lower leg fracture, 19% were in their first season [34].

Mechanism of Injury

The primary mechanisms of injury in both skiers and snowboarders are falls and collisions. However, falls are more prevalent among injured snowboarders. The difficulty in summarizing the literature is that it is generally inconsistent in categorization. For example, some investigators include jumping in the falls category [30].

Skiers

The dominant mechanism of injury in skiers is a fall accounting for 43–76% of injuries [20, 22, 31]. Ungerholm et al. [34] noted that 93% of children under 16 with lower leg fractures reported the injury event only involved them.

Collisions account for between 11 and 58% [19, 20, 22, 24, 27–29, 31]. Generally, as the severity of the injury definition increases, so too does the proportion of collision-related injuries with between 29% [31] and 58% [29] of hospital-admitted patients reporting this mechanism, primarily with trees. Restricting the injured body region to the lower extremity decreases the proportion of collision-related injuries [33, 34]. Intermediate skiers report a lower proportion of collision-related injuries than do experts or beginners [29].

Lift-related injuries in skiers account for 5–18% [20, 22, 24, 31], while jumping accounts for less than 7% [24, 31].

Skiers and Snowboarders

For skiers and snowboarders combined, the primary mechanism was personal error (0–6 years = 43%; 7–12 = 57%; 13–17 = 59%). The second most common mechanism changed depending on the age group. In those 0–6 years it was collision with an object (17%), jumping in 13–17-year-olds (12%), while those 7–12 ‘cited change in snow conditions, collisions with objects, jumping, and human collisions equally frequently (8%)’ [17].

Snowboarders

Falls are by far the main mechanism of injury in snowboarders accounting for between 69 and 93% of injuries [16, 21, 30, 31]. In their study, Machold et al. [16] suggest that ‘The primary mechanism of injury was through low-velocity falls on hard or icy snow…’ Collisions make up only 4–26% of snowboarding injuries [21, 24, 30, 31]. As for skiers, with increasing injury severity, the proportion of injuries involving collisions also increases [30, 31].

Hagel et al. [24] noted 10.1% of jumping-related and 6% of lift-related injuries in snowboarders reporting injuries to the ski patrol. However, Skokan et al. [31] found no jumping- or lift-related injuries in their series of hospital-admitted snowboarders.

Injury Severity

Few studies have been conducted on the issue of injury severity in young skiers and snowboarders. Those that have been conducted indicate that these injuries can be severe, as measured by injury severity scales, length of hospital stay, and sequelae, and can have significant associated financial and personal costs.

Injury Type

As noted earlier, it is evident that head and neck spine injuries represent the most severe injuries in both skiers and snowboarders. This is based on the contrast between those studies with an injury definition of admission to a pediatric trauma center with those requiring less rigorous medical and paramedical intervention. This can also be seen with those studies that focus on a severely injured group of skiers and snowboarders such as those admitted to hospital.

Those investigations focusing on a hospitalized series find high proportions of head injuries and long bone fractures [29–31, 35]. For skiers, head injuries make up between 22% [31] and 71% [29] of all injuries requiring hospital admission, whereas long bone fractures represent between 19% [29] and 32% [35]. Leg injuries in total account for approximately 39% of skier injuries requiring hospital admission [31].

For hospital-admitted snowboarders, however, the proportion changes where head injuries result in between 35% [30] and 42% [31] and long bone fractures account for approximately 35% [30] of all injuries.

The study by Machold et al. [16] however, based on self-reported medically treated snowboarding injuries suggests a much higher proportion of upper extremity injuries at 65%. This substantial difference indicates how important injury definition can be.

Injury Score/Scale

Another way to categorize trauma is the Abbreviated Injury Scale (AIS) [36], associated Injury Severity Score (ISS) [37], and Pediatric Trauma Score [38]. However, few studies have used this approach. Those studies that have used this approach report inconsistent results with some suggesting that snowboarders sustain more severe injuries [35], others that skiers do [29, 30], while still others note no activity-related differences [31].

Hackam et al. [35] in their case-series of hospital-admitted children under 17 years for tobogganing, skiing and snowboarding injuries noted the mean ISS [37] was significantly ($p < 0.05$) higher for snowboarders (18.3 ± 2, one death) compared with skiers (8.4 ± 2), and that 44% of snowboarders, but only 17% of skiers had an ISS greater than 15 [35].

Machold et al. [16] in studying snowboarding injuries in Austrian students, noted that of 107 injuries requiring medical care, 51.4% were classified as moderate or severe, not life threatening according to an AIS greater than one [36].

Shorter et al. [29, 30] found better Pediatric Trauma Scores in their series of hospital admitted snowboarders compared with hospital-admitted skiers to age 18.

Skokan et al. [31] examined winter sports injuries in children admitted to hospital up to age 17. Although there were 4 children injured while snowmobiling or lugeing, 98 (96%) were injured skiing (n = 72) or snowboarding (n = 26). The median ISS was 7 (range 1–75) with no difference among activities. The authors note that almost one third of those requiring hospitalization sustained head injuries and that this group had the highest abbreviated injury scale [39] and ISS along with the longest hospital stays.

Cost

Few studies have examined the financial costs associated with skiing and snowboarding injuries. Those that have, however, reveal the financial impact of hospital admitted injuries can be staggering with direct medical costs ranging from USD 10,000 for snowboarders [30] to USD 28,000 for skiers [35].

Hackam et al. [35] conducted a comprehensive cost-estimate study of children under 17 hospitalized for tobogganing, skiing and snowboarding injuries. Estimated hospital costs were almost USD 28,000 per patient, outpatient services were estimated at USD 15,243 per patient and the financial impact to the family of the victim was assessed at USD 1,500 per patient [35]. These cost estimates are similar to the estimates derived from the case-series study by Shorter et al. [29] noting that the average cost of a skiing injury admitted to a pediatric trauma centre was USD 22,000. In their subsequent study, however, Shorter et al. [30] found an average cost of only USD 10,000 for injured snowboarders admitted to hospital.

Length of Hospital Stay

In those skiers and snowboarders admitted to hospital, stays range from 1 to 40 days [29–31, 34]. There is some evidence that snowboarders require shorter hospital stays [30].

In their case-series investigation, Shorter et al. [29] found that the average hospital stay for an admitted skier under 17 years of age was 7.3 days (range 1–40). However, in their follow-up study of hospital-admitted snowboarders, the authors noted the average hospital stay was only 3.8 days (range 1–15) [30]. In the study by Skokan et al. [31] the length of hospital stay for skiing, snowboarding, snowmobiling and lugeing combined ranged from 1 to 18 days. Ungerholm et al. [34] followed children under age 16 with lower leg fractures sustained while skiing to determine the duration of convalescence and the nature and extent of sequelae. The median hospital stay was 3.5 days (range 2–16).

Outcome

Skiing and snowboarding injuries can result in significant long-term sequelae, indeed, even permanent damage and death. With the focus on injury outcome, the investigations considered demonstrate that a significant proportion of hospitalized skiers and snowboarders require intensive care [31], operations and postdischarge support services [35], and can have sequelae ranging from weeks to years [16, 29, 34]. A brief overview of each study is provided below.

Hackam et al. [35] in their case-series of hospital admitted children under 17 years for tobogganing, skiing and snowboarding injuries noted that all admitted patients had life-threatening or serious injuries [35]. Most patients required some type of operation (75%). Almost half of admitted skiers (46%) and snowboarders (44%) required either inpatient or outpatient support services after discharge.

Machold et al. [16] found that those Austrian students with moderate and severe injuries reported they were 'incapacitated' for more than 21 days.

In their case-series investigation of injured skiers admitted to hospital, Shorter et al. [29] found that, although there were no deaths in the series, 26% had long-term sequelae including hearing loss, hemiplegia, paraplegia, and below knee amputation. In their follow-up study, the authors found no deaths among hospital-admitted snowboarders under 17 [30]. These investigators also suggest that the overall severity of injury is lower in snowboarders compared with skiers based on Pediatric Trauma Score [38], length of hospital stay, and cost [30].

Skokan et al. [31] examined winter sports injuries in children admitted to hospital up to age 17. Three percent of skiers but 12% of snowboarders required admission to the pediatric intensive care unit, findings at odds with the length of stay and cost estimates of Shorter et al. [29, 30].

Ungerholm et al. [34] followed children under the age of 16 with lower leg fractures sustained while skiing to determine the duration of convalescence and the nature and extent of sequelae. From 1979 through 1982, 113 children reported to the emergency medical offices at two Swedish ski areas. The median duration of ambulatory treatment was 7.5 weeks (range 4–40). Of the 104 patients who answered a questionnaire at 1–3 years follow-up, 97 reported no sequelae, while the remainder reported 'pain on exercise (3), shortening of the leg (2), outward rotation of the foot (1), and angulation of the lower leg (1)' [34]. The median duration of morbidity was 3.5 months (range 1–18 months).

Clearly skiing and snowboarding injuries can be frequent and severe. A proper examination of risk factors with a view to prevention is the only way to mitigate their impact.

Injury Risk Factors

A number of factors have been shown to influence the risk of injury in skiing and snowboarding. The risk factors are detailed in table 3 [9–14, 16–18, 22, 23, 31, 33, 35, 40–42]. Except where indicated, a relative measure of association (e.g., odds ratio) is presented. For example, an odds ratio of 1.5 would indicate a 50% greater risk of injury in the index category of the determinant (e.g., in the study by Deibert et al. [12], those under 11 years of age) compared with the reference category of the determinant (e.g., in Deibert et al. [12], those 11–16 years old). Alternatively, an odds ratio of 0.5 would indicate a 50% reduction in injury risk comparing the index with the referent category of the determinant. The reference category of the determinant always has a value of 1.0.

Table 3. Injury determinants in skiers and snowboarders

Author	Design	Determinant	Results	
Skiers				
Bergstrøm et al., 2001 [9]	Prospective cohort	Sex	No injuries in males; 4 in females	
Blitzer et al., 1984 [10] see also Deibert et al. [12]	Case-control with exposure estimation	Age	*All injuries**	
			14–16:	4.9/1,000 skier days (significantly different from 11–13)
			11–13:	6.6/1,000 skier days
			<11:	4/1,000 skier days (significantly different from 11–13)
			*Tibial fractures**	
			14–16:	0.27/1,000 skier days (significantly different from 11–13)
			11–13:	0.68/1,000 skier days
			<11:	0.53/1,000 skier days
			*Thumb**	
			14–16:	1/1,000 skier days
			11–13:	1.1/1,000 skier days
			<11:	0.29/1,000 skier days (significantly different from 11–13)
			*No absolute numbers provided so could not calculate 95% confidence limits	
Blitzer et al., 1984 [10] see also Deibert et al. [12]	Case-control with exposure estimation	Ability	Controls had greater skill than most lower extremity-injured groups (no p value reported)	
Blitzer et al., 1984 [10] see also Deibert et al. [12]	Case-control with exposure estimation	Equipment ownership	11–16-year-olds less frequently owned their equipment compared with controls ($p < 0.05$)	

Table 3 (continued)

Author	Design	Determinant	Results
Deibert et al., 1998 [12] see also Blitzer et al., 1984 [10]	Case-control with exposure estimation	Age	*All injuries** 11–16: 1.0 (reference category) <11: 1.45 (95% CI: 1.32–1.61) *1981–82 to 1993–94
Deibert et al., 1998 [12] see also Blitzer et al., 1984 [10]	Case-control with exposure estimation	Binding testing	'… the percentage of the recommended release value for skiers who sustained a spiral fracture of the tibia averaged 158, whereas that for uninjured skiers averaged 111 ($p < 0.001$)'
Ekeland et al., 1993 [22]	Case-control	Age	*Lower extremity equipment-related (LEER) injuries* 10–14: 1.0 (reference category) <10: 2.63 (95% CI: 1.01–6.83)* *Authors report 'injury ratios' – the exposure proportion in the injured divided by the uninjured group. This measure depends on the prevalence of the risk factor category. However, a more epidemiologically appropriate and interpretable parameter is the odds ratio, which is presented here; regarding LEER injuries, this is a category defined a priori by the authors but this association should be established epidemiologically to truly know that a relation exists between equipment and these injuries; calculations from the authors' data
Ekeland et al., 1993 [22]	Case-control	Ability	*All injuries* Beginner: 16.4 (95% CI: 4.6–59.3)* >Beginner: 1.0 (reference category) *Authors report 'injury ratios' – the exposure proportion in the injured divided by the uninjured group. This measure depends on the prevalence of the risk factor category. However, a more epidemiologically appropriate and interpretable parameter is the odds ratio, which is presented here; calculations from the authors' data

Ekeland et al, 1993 [22]	Case-control	Experience	*All injuries*	
			<3 seasons:	3.15 (95% CI: 1.45–6.83)*
			≥3 seasons:	1.0 (reference category)
			*Authors report ‘injury ratios’ – the exposure proportion in the injured divided by the uninjured group. This measure depends on the prevalence of the risk factor category. However, a more epidemiologically appropriate and interpretable parameter is the odds ratio, which is reported here; calculations from the authors’ data	
Ekeland et al., 1993 [22]	Case-control	Slope grooming	*All injuries*	
			Groomed:	2.38 (95% CI: 1.08–5.22)*
			Powder:	1.0 (reference category)
			*Authors report ‘injury ratios’ – the exposure proportion in the injured divided by the uninjured group. This measure depends on the prevalence of the risk factor category. However, a more epidemiologically appropriate and interpretable parameter is the odds ratio; calculations from the authors’ data	
Garrick and Requa, 1979 [13] see also Requa and Garrick, 1978 [18]	Retrospective cohort	Age	*All injuries**	
			<10:	3.3/1,000 skier days
			10:	5.9/1,000 skier days
			11:	9.1/1,000 skier days
			12:	9.4/1,000 skier days
			13:	10.8/1,000 skier days
			14:	10.5/1,000 skier days
			15:	9.7/1,000 skier days
			16–17:	8.5/1,000 skier days
			*No absolute numbers provided so could not calculate 95% confidence limits	
Garrick and Requa, 1979 [13], see also Requa and Garrick, 1978 [18]	Retrospective cohort	Ability	*All injuries**	
			Males:	
			1 (lowest):	8.74/1,000 skier days
			2 (intermediate):	9.08/1,000 skier days
			3 (advanced):	8.06/1,000 skier days

Table 3 (continued)

Author	Design	Determinant	Results	
			All injuries	
			Females:	
			1 (lowest):	11.58/1,000 skier days
			2 (intermediate):	11.17/1,000 skier days
			3 (advanced):	9.07/1,000 skier days
			*No absolute numbers provided so could not calculate 95% confidence limits	
Garrick and Requa, 1979 [13], see also Requa and Garrick, 1978 [18]	Retrospective cohort	Sex	*All injuries**	
			1 (lowest ability)	
			Males:	8.74/1,000 skier days
			Females:	11.58/1,000 skier days
			2 (intermediate ability)	
			Males:	9.08/1,000 skier days
			Females:	11.17/1,000 skier days
			3 (advanced ability)	
			Males:	8.06/1,000 skier days
			Females:	9.07/1,000 skier days
			*No absolute numbers provided so could not calculate 95% confidence limits	
Giddings et al., 1993 [14]	Retrospective cohort	Age	*Head and face**	
			Under 13:	0.47/1,000 skier days
			13+:	0.30/1,000 skier days
			*Lower body**	
			Under 13:	2.14/1,000 skier days
			13+:	1.80/1,000 skier days
			*Lower leg fractures**	
			Under 13:	0.31/1,000 skier days
			13+:	0.05/1,000 skier days
			*Significantly ($p < 0.05$) greater than 13 and older; no absolute numbers provided so could not calculate 95% confidence limits	

Goulet et al., 1999 [23]	Case-control	Age	*All injuries*	
			No statistically significant differences between injured and control group	
Goulet et al., 1999 [23]	Case-control	Ability	*All injuries*	
			Low skill level:	7.54* (95% CI: 2.57–22.15)
			High skill level:	1.0 (reference category)
			*Adjusted for equipment ownership and whether binding adjustment was correct	
Goulet et al., 1999 [23]	Case-control	Binding adjustment	*All injuries*	
			Incorrect:	2.11* (95% CI: 1.02–4.33)
			Correct:	1.0 (reference category)
			*Adjusted for equipment ownership and skill level	
Goulet et al., 1999 [23]	Case-control	Equipment ownership	*All injuries*	
			Rented:	7.14* (95% CI: 2.59–19.87)
			Owned:	1.0 (reference category)
			*Adjusted for skill level and whether binding adjustment was correct	
Goulet et al., 1999 [23]	Case-control	Lessons	*All injuries*	
			There was no evidence that formal training reduced the risk of injury after adjusting for skill level, equipment ownership, and whether bindings were adjusted correctly	
Requa and Garrick, 1978 [18] see also Garrick and Requa, 1979 [13]	Retrospective cohort	Ability	*Males**	
			Snowplow:	6.3/1,000 skier days
			Stem turn:	10.3/1,000 skier days
			Stem Christie:	9.4/1,000 skier days
			Beginning parallel:	8.9/1,000 skier days
			Parallel:	8.6/1,000 skier days
			Short swing:	6.9/1,000 skier days

Table 3 (continued)

Author	Design	Determinant	Results	
			*Females**	
			Snowplow:	13.3/1,000 skier days
			Stem turn:	10.5/1,000 skier days
			Stem Christie:	8.6/1,000 skier days
			Beginning parallel:	12.6/1,000 skier days
			Parallel:	9.1/1,000 skier days
			Short swing:	9.0/1,000 skier days
			*No absolute numbers provided so could not calculate 95% confidence limits	
Requa and Garrick, 1978 [18], see also Garrick and Requa, 1979 [13]	Retrospective cohort	Age	*Males**	
			<10:	2.4/1,000 skiers days
			10–11:	4.8/1,000 skier days
			12–13:	10.21/1,000 skier days
			14–15:	9.2/1,000 skier days
			16–19:	8.0/1,000 skier days
			*Females**	
			<10:	3.9/1000 skiers days
			10–11:	8.1/1,000 skier days
			12–13:	10.2/1,000 skier days
			14–15:	11.3/1,000 skier days
			16–19:	10.6/1,000 skier days
			*Leg fractures**	
			3–13:	0.58/1,000 skier days
			14–19:	0.11/1,000 skier days
			*No absolute numbers provided so could not calculate 95% confidence limits	

Requa and Garrick, 1978 [18] see also Garrick and Requa, 1979 [13]	Retrospective cohort	Run difficulty	Easiest:*	10.9/1,000 skier days
			More difficult:*	9.2/1,000 skier days
			Most difficult:*	8.8/1,000 skier days
			*No absolute numbers provided so could not calculate 95% confidence limits	
Requa and Garrick, 1978 [18] see also Garrick and Requa, 1979 [13]	Retrospective cohort	Sex	_<10:*_	
			Males:	2.4/1,000 skier days
			Females:	3.9/1,000 skier days
			_10–11:*_	
			Males:	4.8/1,000 skier days
			Females:	8.1/1,000 skier days
			_12–13:*_	
			Males:	10.2/1,000 skier days
			Females:	10.2/1,000 skier days
			_14–15:*_	
			Males:	9.2/1,000 skier days
			Females:	11.3/1,000 skier days
			_16–19:*_	
			Males:	8.0/1,000 skier days
			Females:	10.6/1,000 skier days
			Snowplow ability:*	
			Males:	6.3/1,000 skier days
			Females:	13.3/1,000 skier days
			Stem turn:*	
			Males:	10.3/1,000 skier days
			Females:	10.5/1,000 skier days
			Stem Christie:*	
			Males:	9.4/1,000 skier days
			Females:	8.6/1,000 skier days
			Beginning parallel:*	
			Males:	8.9/1,000 skier days
			Females:	12.6/1,000 skier days

Table 3 (continued)

Author	Design	Determinant	Results	
			*Parallel:**	
			Males:	8.6/1,000 skier days
			Females:	9.1/1,000 skier days
			*Short swing:**	
			Males:	6.9/1,000 skier days
			Females:	9.0/1,000 skier days
			*No absolute numbers provided so could not calculate 95% confidence limits	
Ungerholm and Gustavsson, 1985 [33]	Case-control	Ability	*Lower extremity injury*	
			Beginner:	3.7* (95% CI: 1.66–8.21)
			Intermediate-expert:	1.0 (reference category)
			*Calculations from the authors data; odds ratio will be unbiased except for rounding errors but confidence limits will be too narrow depending on the extent of missing values (i.e., number of subjects used for precision estimate is based on total study numbers)	
Ungerholm and Gustavsson, 1985 [33]	Case-control	Age	*Lower extremity injury*	
			In a case-control study of children <17 years, the authors noted that the average age was slightly younger in controls (9.4) compared with cases (10.7; $p < 0.05$)	
Ungerholm and Gustavsson, 1985 [33]	Case-control	Binding adjustment	*Lower extremity injury*	
			Frequency of testing:	
			Never tested:	0.70* (95% CI: 0.32–1.54)
			Tested:	1.0 (reference category)
			The authors noted significantly more deviation from recommended values in the toe release setting of the binding in the injured compared with the uninjured group ($p < 0.01$)	
			The authors noted significantly more deviation between the recommended toe release setting and the actual force required to release the binding in the injured compared with the uninjured group ($p < 0.01$)	

			*Calculations from the authors' data; odds ratio will be unbiased except for rounding errors but confidence limits will be too narrow depending on the extent of missing values (i.e., number of subjects used for precision estimate is based on total study numbers)
Ungerholm and Gustavsson, 1985 [33]	Case-control	Equipment ownership	*Lower extremity injury* Rent-Borrow: 0.61* (95% CI: 0.26–1.39) Own: 1.0 (reference category) *Calculations from the authors' data; odds ratio will be unbiased except for rounding errors but confidence limits will be too narrow depending on the extent of missing values (i.e., number of subjects used for precision estimate is based on total study numbers)
Ungerholm and Gustavsson, 1985 [33]	Case-control	Experience	*Lower extremity injury* 1 week or less: 4.82* (95% CI: 1.77–13.09) >1 week: 1.0 (reference category) *Calculations from the authors' data; odds ratio will be unbiased except for rounding errors but confidence limits will be too narrow depending on the extent of missing values (i.e., number of subjects used for precision estimate is based on total study numbers)
Ungerholm and Gustavsson, 1985 [33]	Case-control	Sex	*Lower extremity injury* Males: 0.81* (95% CI: 0.37–1.78) Females: 1.0 (reference category) *Calculations from the authors' data; odds ratio will be unbiased except for rounding errors but confidence limits will be too narrow depending on the extent of missing values (i.e., number of subjects used for precision estimate is based on total study numbers)

Table 3 (continued)

Author	Design	Determinant	Results
Skiers-snowboarders			
Cadman and Macnab,1996 [11] see also Macnab and Cadman [17]	Case-series with exposure estimation	Age	*All injuries* 13–17: 1.14* (95% CI: 0.81–1.61) 7–12: 1.25* (95% CI: 0.87–1.78) 0–6: 1.0 (reference category) *Non-minor injuries (requiring physician treatment)* 13–17: 1.92* (95% CI: 1.16–3.17) 7–12: 1.83* (95% CI: 1.09–3.06) 0–6: 1.0 (reference category) *Head and face (not clear if nonminor or all injuries)* 13–17: 0.69* (95% CI: 0.38–1.23) 7–12: 0.56* (95% CI: 0.30–1.06) 0–6: 1.0 (reference category) *Calculations from authors' data. Caution should be used in interpretation of rate ratio and confidence limits as denominator variability not included in estimates. Rates for the 18+ age group were lower in all cases
Hackam et al., 1999 [35]	Comparative case-series	Activity	*All injuries* Mean Injury Severity Score was significantly ($p < 0.05$) higher for snowboard injuries (18.3 ± 2, one death) compared with skiers (8.4 ± 2). Forty-four percent of snowboarders but only 17% of skiers had an ISS greater than 15
Macnab and Cadman, 1996 [17]	Case-series with exposure estimation	Participation	*All injuries** School organized participation: 4.2/1,000 skier-snowboarder days Independent participation: 2.3/1,000 skier-snowboarder days *Authors indicate $p < 0.003$; no absolute numbers provided so could not calculate 95% confidence limits. It is not clear how the authors determined the distribution of lift tickets by participation type
Macnab et al., 1998 [40] see also Macnab et al., 1999 [41]	Case-control	Age	*All injuries to age 17* Authors indicate injured group was older than uninjured ($p < 0.001$)

Macnab et al., 1998 [40] see also Macnab et al., 1999 [41]	Case-control	Helmet use	*All injuries to age 17* Never use a helmet: 1.81* (95% CI: 1.16–2.83) Sometimes or always use: 1.0 (reference category) *Calculations from the authors' data; odds ratio will be unbiased except for rounding errors but confidence limits will be too narrow depending on the extent of missing values (i.e., number of subjects used for precision estimate is based on total study numbers)
Macnab et al., 1998 [40] see also Macnab et al., 1999 [41]	Case-control	Lessons	*All injuries to age 17* No lessons: 1.61* (95% CI: 1.10–2.38) Lessons: 1.0 (reference category) *Calculations from the authors' data; odds ratio will be unbiased except for rounding errors but confidence limits will be too narrow depending on the extent of missing values (i.e., number of subjects used for precision estimate is based on total study numbers)
Macnab et al., 1998 [40] see also Macnab et al., 1999 [41]	Case-control	Safety knowledge	*All injuries to age 17* According to the authors, a greater proportion of the injured group incorrectly identified the blue square as indicating run difficulty ($p < 0.0001$). However, calculation from the authors data gives a p-value of > 0.05?
Macnab et al., 2002 [42]	Case-control	Helmet use	*Head-neck-face injuries under age 13* No helmet: 2.24 (95% CI: 1.23–4.12) Helmet: 1.0 (reference category) *Activity adjusted head-neck-face under age 13* No helmet: 1.77 (95% CI: 0.99–3.19) Helmet: 1.0 (reference category) *Cervical spine injuries under age 13* No helmet: 2.0 (95% CI: 0.80–5.65) Helmet: 1.0 (reference category)

Table 3 (continued)

Author	Design	Determinant	Results	
Skokan et al., 2003 [31]	Comparative case-series	Activity	*Injury Severity Score >15*	
			Snowboard:	2.2 (95% CI: 0.46–10.66)
			Ski:	1.0 (reference category)
			Pediatric ICU admission	
			Snowboard:	4.6 (95% CI: 0.72–29.04)
			Ski:	1.0 (reference category)
			*Calculations from the authors' data; odds ratio will be unbiased except for rounding errors but confidence limits will be too narrow depending on the extent of missing values (i.e., number of subjects used for precision estimate is based on total study numbers)	
Snowboarders				
Machold et al., 2000 [16]	Retrospective cohort	Experience	*All injuries**	
			Each additional half-day:	0.91 (95% CI: 0.82–1.0)
			Half-days experience:	1.0 (reference category)
			*Moderate-severe wrist injuries**	
			Each additional half-day:	0.78 (95% CI: 0.61–0.99)
			Half-days experience:	1.0 (reference category)
			*Adjusted for age, sex, use of wrist protection, number of prior sports injuries, type of shoes, and snow condition	
Machold et al., 2000 [16]	Retrospective cohort	Helmet use	*Head injuries**	
			Helmet:	0 injuries in 196 snowboarders
			No helmet:	17 injuries in 2,366 snowboarders
			*Calculations from authors' data	
Machold et al., 2000 [16]	Retrospective cohort	Lessons	*Severe wrist injuries*	
			Falls training:	1.50* (95% CI: 0.76–2.97)
			No falls training:	1.0 (reference category)
			*Calculations from authors' data	

Machold et al., 2000 [16]	Retrospective cohort	Previous injury (in any sport)	*All injuries*	
			Previous injury:	1.35 (95% CI: 1.12–1.63)
			No previous injury:	1.0 (reference category)
			*Adjusted for age, sex, half-days of snowboard experience, use of wrist protection, type of shoes, and snow condition	
Machold et al., 2000 [16]	Retrospective cohort	Slope type	*All injuries*	
			Half pipe:	1.32* (95% CI: 0.42–4.14)
			Unmarked slopes:	0.41* (95% CI: 0.17–1.01)
			Marked slopes:	1.0 (reference category)
			*Calculations from authors' data	
Machold et al., 2000 [16]	Retrospective cohort	Snow surface condition	*All injuries*	
			Hard:	4.91* (95% CI: 3.16–7.64)
			Icy:	3.04* (95% CI: 1.78–5.19)
			Slush:	2.78* (95% CI: 1.70–4.55)
			New or powder:	1.37* (95% CI: 0.74–2.53)
			Prepared slope:	1.0 (reference category)
			*Calculations from authors' data	
Machold et al., 2000 [16]	Retrospective cohort	Wrist guards	*Moderate-severe wrist injuries**	
			No wrist guards:	2.78 (95% CI: 1.05–7.35)
			Wrist guards:	1.0 (reference category)
			Shoulder/shoulder girdle/arm	
			No wrist guards:	1.45**
			Wrist guards:	1.0
			*Adjusted for age, sex, half-days of snowboard experience, number of prior sports injuries, type of shoes, and snow condition	
			**Calculations from authors' data; no absolute numbers provided so could not calculate 95% confidence limits	

If absolute numbers of injuries were available from the study, confidence limits (the range defining the confidence interval; CI) could be calculated indicating the precision of the relative measure of association. The interpretation of a 95% CI is that if the study were repeated 100 times, 95 of the CIs calculated would capture the true relative measure of association (e.g., odds ratio), assuming the absence of bias. The more narrow the interval, the greater the precision of the estimate. If the confidence limits exclude the null value of 1.0, the risk is significantly different at $p < 0.05$.

The following sections detail the intrinsic and extrinsic determinants of injury in skiers and snowboarders.

Intrinsic Risk Factors

The inherent characteristics of an individual that influence injury risk in skiers and snowboarders include ability and experience, age, past injury and sex. The literature on the effect of lessons is equivocal.

Ability and Experience

Perhaps the most ubiquitous finding in the ski injury literature is that those with lower ability or less experience are at greater risk of injury. This is certainly the case for studies conducted on child and adolescent skiers [10, 22, 23, 33] and snowboarders [16], although the association is less clear in some investigations [13, 18].

Age

Generally, younger age groups have been shown to have a greater injury risk in skiing [12, 43–53], and snowboarding [46, 52, 54]. Adolescent skiers are commonly found to have higher injury rates than the youngest age groups [10, 11, 18, 40, 41], although the opposite is true for lower extremity injuries, particularly fractures [10, 14, 22, 33].

For all injuries combined in skiers, Blitzer et al. [10] noted a higher injury rate in 11–13-year-olds compared with those under 11 and those 14–16. The rate of tibial fractures in 14–16-year-olds was less than half the rate in those 11–13 ($p < 0.05$). Similarly, the rate of thumb injuries in those 11–13 was almost 4 times the rate in children 10 and under.

The 1981–82 to 1993–94 data from Deibert et al. [12] indicate that, for all injuries combined, those under 11 have a 45% (95% CI: 32–61%) increased risk compared with those 11–16.

Based on the case-control study by Ekeland et al. [22] the risk of a lower extremity equipment-related injury in those under age 10 was 2.63 (95%

CI: 1.01 – 6.83) times the risk in those aged 10–14. It should be noted that the lower extremity equipment-related category of injuries is defined a priori by the authors when this relation should have been established epidemiologically to truly know that the injury is 'equipment related'.

No absolute numbers were available from the retrospective cohort study conducted by Garrick and Requa [13], so no CIs could be calculated. However, their data indicate that those under age 10 had the lowest injury rates. The injury rate climbed monotonically to a peak of 10.8 injuries per 1,000 skier days at age 13, and then steadily decreased through age 17. This pattern was similar for males and females although the peak injury rate for females was 11.3/1,000 skier days in the 14–15 age group [18].

Giddings et al. [14] conducted a case-series investigation of skiers comparing injured children under age 13 to those 13 and older. Unfortunately, the authors included adolescents with adults, groups that likely have markedly different injury rates. Children under 13 had significantly higher rates of head and face and lower body injuries compared with the 13+ age group. In addition, the lower leg fracture rate in those under 13 was over six times the rate in those 13 and older.

In their case-control study of children under 13, Goulet et al. [23] noted no difference between injured and uninjured skiers in terms of the age distribution.

With the outcome of lower extremity injuries, Ungerholm et al. [33] in their case-control study of injured skiers under 17, found that the average age was slightly younger in controls (9.4) compared with cases (10.7; $p < 0.05$).

For skiers and snowboarders combined, data from Cadman and Macnab [11] show that the rate of nonminor injuries is significantly higher in children aged 7–17 compared with those 6 and under. The authors noted this association again in subsequent studies [40, 41]. However, the rate of head and face injuries in those 6 years of age and under may be higher than those 7–17 years of age.

A methodological issue to keep in mind when interpreting the age-related risk of injury is that younger age groups may report their injuries more than older age groups [55–57]. The effect of this 'over-reporting', however, would likely diminish as injury severity increased.

Despite the potential for any over-reporting, it is likely that the age differences in injury risk at least in part relate to experience and equipment. As was already stated, some authors even suggest that skiing may be too difficult a sport for children owing to the complexity of the task and the capability of reaching high speeds quickly [7]. It has also been suggested that 'In general, children use inferior equipment, which is often old and poorly serviced, and frequently their bindings are not set appropriately for their weight' [19]. These issues will be revisited in subsequent, relevant sections.

Lessons Including Safety Knowledge

Although it seems logical that lessons would decrease the risk of injury in skiing and snowboarding, the empirical evidence is equivocal. After adjusting for skill level, proper binding adjustment and equipment ownership, Goulet et al. [23] noted no relation between formal training and injury risk. The authors suggest that this finding may be due to methodological limitations. However, they also suggest that by far the more important factor may be skill level and that 'formal ski lessons … be viewed as one among several tools… to raise the level of skill of the young skier' [23]. Another possibility is that young skiers taking lessons may be more likely to report their injuries as they are being supervised by an instructor, as has been found in other investigations [56], which would bias the association toward finding no effect, assuming lessons are protective.

Similarly in snowboarders, Machold et al. [16] noted that falls training may actually increase the risk of a severe wrist injury. It was not clear from that investigation whether those who took the falls training were of lower ability to begin with (i.e., the results may be confounded by ability). It may also be that again, like in the study by Goulet et al. [23] those taking lessons were more likely to report injuries due to their supervision.

Conversely, the data of Macnab et al. [40] indicate that not having taken lessons is a risk factor for injury. These investigators also suggest that the injured group was less likely to identify the blue square as indicating run difficulty compared with an uninjured series. However, low response rates and other methodological limitations make the results of this investigation less compelling than the work of Machold et al. [16] or Goulet et al. [23].

These conflicting results indicate the need for further research into the nature and extent of ski and snowboard lessons.

Past Injury

Only one study of snowboarding injuries in students has examined the effect of past injury on subsequent injury risk. In their retrospective cohort study of Austrian school aged snowboarders, Machold et al. [16] found that those with a past sport injury were 1.35 times more likely to sustain a subsequent snowboarding injury compared with those reporting no prior sport injury (95% CI: 1.12–1.63). The authors suggest this result is due to greater risk-taking by some individuals, but this would indicate that the participation characteristics of those with and without a prior sports injury were different. This seems unlikely as the authors accounted for age, sex, experience, and other factors in the analysis, factors that would 'equalize' the groups for risk-taking propensity. An arguably more tenable explanation may be that those with a prior sports injury have not received adequate care for the injury or have not allowed sufficient time for healing and rehabilitation.

Sex

Although males generally garner the label of risk-takers, the child and adolescent ski injury literature does not bear this out. In their retrospective cohort study of alpine junior ski racers at a world junior competition, Bergstrøm et al. [9] noted 4 injuries in girls for a rate of 8.9 injuries per 1,000 runs. There were no injuries for boys in 546 runs. Garrick and Requa [13, 18] in their retrospective cohort study of child and adolescent skiers noted higher rates in girls in almost every age group and ability level. These differences were most pronounced in the under 12 and lowest ability level categories. Finally, focusing on lower extremity injuries in skiers, Ungerholm and Gustavsson [33] in their case-control study found a lower rate in males (OR: 0.81; 95% CI: 0.37–1.78). The effect, however, was not statistically significant.

It is not known whether these results reflect an actual increase in injury rates for females or merely a greater likelihood of reporting [16, 55–57]. Similarly, when particular injuries or body regions are the focus, substantial differences between males and females may emerge with females at greater risk of a lower extremity injury [58].

Extrinsic Risk Factors

A number of factors external to the individual (i.e., extrinsic factors) have been shown to influence the risk of injury in skiers and snowboarders. These include binding adjustment, helmet use, slope characteristics, and wrist-guard use in snowboarders. Those investigations examining the effect of activity and equipment ownership on injury risk are less consistent.

Activity

There is some evidence to suggest that the severity of injury may be greater in young snowboarders compared with young skiers [31, 35]. However, others suggest greater injury severity in young skiers [29, 30].

Hackam et al. [35] conducted a case-series investigation of children under age 17 admitted to hospital for skiing and snowboarding injuries. Although no denominator data were available to examine the rate of injuries in the two activities, the authors noted that the mean ISS was significantly ($p < 0.05$) higher for snowboard injuries (18.3 ± 2, one death) compared with skiers (8.4 ± 2). Forty-four percent of snowboarders but only 17% of skiers had an ISS greater than 15.

The data from the case-series investigation by Skokan et al. [31] also allow comparisons of the risk of severe injury in snowboarding compared with skiing in children under 18 requiring hospitalization for winter sports injuries. Although not statistically significant at $p < 0.05$, the data suggest that snowboarders are

2.2 times more likely to have an ISS>15 (95% CI: 0.46–10.66). Similarly, snowboarders were estimated to have an almost 5-fold (95% CI: 0.72–29.04) increase in the likelihood of being admitted to the pediatric ICU.

Interestingly, comparing the findings of two consecutive studies on skiers and snowboarders admitted to hospital for their injuries, Shorter et al. [29, 30] suggest a lower injury severity in snowboarders. The authors base this conclusion on the Pediatric Trauma Score, shorter hospital stay and lower average cost of injury. However, these studies were conducted over different time periods, which may account for the differences in the findings.

The strongest evidence suggests greater injury severity in snowboarders compared with skiers. Possible explanations for the difference may relate to the focus on aerial maneuvers characteristic of snowboarding. In addition, the very young, beginner snowboarders of the mid 1990s may now be the more experienced, perhaps more daring adolescents of today.

Binding Adjustment and Equipment Ownership

One study published in 1984 found that less than 25% of uninjured children's (<15) bindings had correct (under 20% deviation from recommended) toe release settings [59]. In addition, 40% of the series had never adjusted their bindings. Sadly, the situation has changed little. Goulet et al. [23] noted that 56% of injured and 46% of uninjured subjects in their 1999 case-control study of child injury risk factors had incorrect binding adjustment settings using a criterion of 20% deviation from recommended values.

There is evidence to suggest that those children and adolescents who own their own equipment have a lower risk of injury [10, 23]. In their case-control study, Goulet et al. [23] noted that those children under 13 years who rented their equipment had a 7-fold (95% CI: 2.59–19.87) increased risk of injury compared with children who owned their equipment, after controlling for skill level and proper binding adjustment. Ungerholm and Gustavsson [33] did not find any relation between equipment ownership and lower extremity injury risk, although the design and analysis of this study was weaker than that of Goulet et al. [23].

Similarly, those children with properly adjusted bindings are significantly less likely to sustain injuries, particularly of the lower leg [12, 33]. For all injuries combined, Goulet et al. [23] found a 2-fold (95% CI: 1.02–4.33) greater risk of injury in children under 13 when the binding settings deviated more than 20% from recommended values, after adjustment for skill level and equipment ownership.

Helmet Use

Surprisingly little research has been conducted on the effectiveness of helmets in preventing head injuries in skiers and snowboarders. Oh and Schmid [60] suggested mandatory helmet use for children and adolescents up to 17 years old as long ago as 1983. However, few studies since that time provide data on the issue in children and adolescents [16, 40, 42].

In their first investigation of the helmet issue, Macnab et al. [42] noted that injured subjects were 81% (95% CI: 16–283%) more likely to have never used a helmet. In their subsequent case-control study, the authors found that failure to use a helmet increased the risk of a head injury by 1.8-fold (95% CI: 0.99–3.19). They also reported no associated increase in the risk of a cervical spine injury with helmet use. Similarly, Machold et al. [16] found no head injuries in the cohort of 196 snowboarders using a helmet, but 17 in the 2,366 not using one. The small number of injured individuals and subsequent lack of control for possible confounding factors make the results of these studies encouraging, but far from conclusive.

There are also arguments that helmets may increase the risk-taking behavior of the user [61] or that helmets may alter the ability to hear, see, or balance, leading to skier error and subsequently more frequent or severe injury [29, 41]. Instances of death [62, 63] and head and face injury [41, 64] among snowboarders and skiers wearing helmets indicate the need for additional research.

Slope Characteristics

The data on slope characteristics suggest a greater risk of skiing injury on groomed runs compared with powder [22] and easy compared with more difficult runs [18]. For snowboarders, the injury risk may be greater on the half-pipe compared with marked runs, and on hard, icy or slushy terrain compared with prepared slopes [16].

Wrist-Guards

The retrospective cohort study by Machold et al. [16] is the only investigation to examine wrist-guard effectiveness in children and adolescents. These investigators found that those not using wrist-guards were 2.78 (95% CI: 1.05–7.35) times more likely to sustain a moderate-severe wrist injury compared with those using wrist-guards. Further, and importantly, there was no evidence to suggest that using wrist-guards increased the risk of a shoulder, shoulder girdle, or arm injury. These results mirror the findings of other investigations in all age groups [65–68].

Suggestions for Injury Prevention

Much of the research reviewed was descriptive in nature. Only a few studies represent rigorous investigations of specific risk factors and outcomes.

Therefore, the suggestions for prevention must be viewed in light of these caveats.

(1) From compelling evidence in bicycling [69, 70], and the encouraging results from the ski and snowboard injury literature, children and adolescents should be encouraged to wear helmets.
(2) Use of wrist guards will likely reduce the frequency and severity of one of the most common injuries seen in snowboarders.
(3) Children and adolescents should not participate on runs that exceed their ability. They should stay in control and not speed down the hill. Parental supervision or a greater presence of ski patrol members at ski areas would likely reduce the number of children and adolescents traveling at dangerous speeds or who are out of control. If at all possible, skiers and snowboarders should avoid participation on hard, icy or slushy terrain. Ski areas need to ensure runs are adequately groomed.
(4) Equipment for children should fit properly and be regularly maintained, including frequent binding adjustment. This is particularly true for the youngest age groups and females, individuals who may be most susceptible to lower extremity injuries.
(5) Lessons should be taken with the goal of increasing ability and experience as well as increasing knowledge of hill etiquette. However, children and adolescents should be reminded that taking lessons does not guarantee protection from injury and that they must still assume responsibility for their actions.

Suggestions for Future Research

As I have alluded to, the skiing and snowboarding injury literature lacks high quality investigations focusing on specific questions (e.g., the effect of helmet use on head injury risk) and adhering to rigorous epidemiological principles. Case-series studies abound, but reveal little about risk and protective factors. A control group identifying the prevalence of the risk or protective factor in the source population that produced the injured cases is required to identify these relationships [71]. Case-control studies are an optimal approach, given their efficiency relative to nonexperimental cohort studies and randomized controlled trials, and, if properly conducted [71–73], they can provide valid results. A variant of the case-control study, the case-crossover approach [74] focuses on transient determinants (i.e., those which can change over time) such as protective equipment use or slope type in relation to a specific injury. This design has enormous potential to elucidate many important relationships.

Based on the state of the literature, a number of recommendations for further research are outlined.

(1) The effectiveness of helmets in skiers and snowboarders needs to be clarified. Specifically, the effect of helmet use on head and neck injury risk needs to be evaluated, along with whether helmet use changes behavior due to a false sense of security. Finally, the design of helmets should be studied to ensure they provide optimal protection without influencing the user's ability to see, hear or balance.
(2) Further work needs to be done on the influence of lessons on injury risk. Certainly, engaging in an activity without having any background knowledge is inherently dangerous. However, the content of instructional programs should be investigated further for skiers and snowboarders.
(3) Based on the trends identified from the excellent work of Deibert et al. [12], severe knee sprains continue to be a problem. Although some investigators suggest that current release binding systems are optimal and cannot prevent serious knee injuries [12, 75], the AFNOR, the French standardization organization, suggests that binding adjustment settings for women and lighter men be lowered in response to a rise in the rate of knee anterior cruciate ligament injury [76]. The benefits of this would likely be realized by younger age groups as well.
(4) An absence of a reduction in head injuries overall, and an increase in spinal injuries over a time period when most other types of injuries have decreased, evident in the skier injury trends identified by Deibert et al. [12] warrants serious concern. This is particularly true given similar trends for skiers, along with the substantial increase in neck injuries in snowboarders, found in the study by Hagel et al. [15]. Some authors speculate that the popularization of snow-parks (i.e., play areas), or dedicated areas with, for example, half-pipes, rails, and other slope modifications that accommodate jumping may be partly responsible for the trends [58]. The greater use of snow-parks by snowboarders in the past few years may also be partly responsible for the evidence suggesting greater injury severity in this group compared with skiers. Further study into the cause of these concerning trends and ways to reduce head and spine injuries in child and adolescent skiers and snowboarders is needed. This is particularly true for snowboarders given that this activity continues to enjoy a greater number of participants every year.
(5) The introduction of new equipment such as skiboards with nonrelease bindings [77] should be carefully monitored. There is evidence that these devices may increase the risk of lower leg injuries including tibial fractures [46, 78] due to the nonrelease binding, although knee injuries may be less likely [46].
(6) Revisiting methodological issues, when studies are conducted, they should be focused on defined injuries. There is evidence that the relationships

between age, sex, and activity can change depending on which body region of injury is studied [58]. Some of the most successful case-control studies in terms of furthering our knowledge about injury etiology in sport and recreational activities restricted their analysis to injured individuals; cases being those with a particular body region of injury, while controls were those who sustained injuries to other body regions. This approach has been used in the study of risk factors for bicycling [69, 70, 79], in-line skating [80], and skiing injuries [81]. The key to the use of an injured control group is to ensure there is no relation between the control injuries (e.g., arm and leg injuries) and the determinant of interest (e.g., helmet use).

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Tennis Injuries

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Abstract

Objective: The purpose of this chapter is to critically review the existing studies on the epidemiology of tennis injuries in pediatric athletes, present suggestions for the prevention of injury based on these studies, and present suggestions for future research. **Data sources:** Data sources included published articles on pediatric tennis injuries, a previously published review by the authors, and unpublished data from one of the authors (MS). **Main results:** Most studies of tennis injuries show that they are of microtrauma origin, develop over time, and result in short times of absence from play. They involve all joints of the body, but have a higher incidence in the shoulder, back, and knee. Intrinsic and extrinsic risk factors may be related to the incidence of injury. These factors may be evaluated by a comprehensive preparticipation exam, and preventive strategies may be implemented. **Conclusions:** Most injury studies in pediatric tennis players vary in the population studied, methods of injury evaluation, and risk factors studied. Consequently, few specific conclusions can be derived about the causative factors. Further longitudinal prospective studies need to be done to completely discover all the factors involved in producing tennis injuries.

Introduction

The recreational pediatric tennis player experiences relatively few major or minor injuries. The frequency and duration of play and the biomechanical and physiological loads inherent in tennis at this level are low enough to allow safe play. However, if the pediatric athlete is engaged in intense participation in tennis alone or in tennis combined with other sports, injuries occur with increasing frequency [1, 2]. This is a consequence of increased frequency and intensity of play, increased duration of play, the large inherent biomechanical and physiological demands at this level of play, and the deleterious effects of maladaptations in flexibility and strength that occur in areas subject to repetitive tensile overload [3] and in association with normal growth. These injuries become a limitation to successful play. This chapter will review the available studies and discuss the epidemiology of injuries in elite pediatric tennis players.

The database for this review was mainly from published sources in the sports medicine literature and a previously published review by the authors. Some of the data is in unpublished form, resulting from one of the authors' (MS) use of a validated questionnaire at age group national tournaments. The database included publications from the last 18 years. Most of the studies involved athlete responses to directed questions or to questionnaires, so there was a level of reporting bias. The definition of injury varied between the studies. There were several studies of injury incidence that were prospective in nature, but no long-term prospective studies relating specific anatomical, physiological, biomechanical, or playing factors to injury incidence. The result is that the literature provides glimpses into types of injuries and suggests associations of certain physiological parameters and injury, but does not provide conclusive evidence of cause/effect relationships, or of conclusive benefit of any specific intervention strategies.

Incidence of Injury

The incidence of injury in tennis is a bit elusive. Only a few studies have been performed attempting to identify this information. Table 1 summarizes the incidence and prevalence of injuries in pediatric tennis players [2, 4–9]. One study [4] of college age tennis players is included to show the injuries in a group with similar playing exposure but slightly older age. A review of this table reveals that most of the studies used the prospective cohort design. Study duration ranged from one to 8 years and the sample size varied widely, from 23 to 1,440. Also, data collection methods and injury definitions varied among the studies. Injury rate definitions also varied, ranging from any injury resulting in not playing to injuries that required a medical evaluation. In general, injury rates were relatively low, from two to twenty injuries per 1,000 athletic exposures or hours played.

During the 1998 USTA Girls' 16's and Boys' 16's and 18's National Championships, Safran et al. [5] administered a validated tennis questionnaire to assess the prevalence of injury in these elite junior players. Only 23% of girls and 45% of boys reported no injury that kept them from playing for one week or more, while 53% of females and 29% of males noted more than one tennis injury in the past. The findings in this study have been reproduced in two other unpublished studies of different tennis tournaments by the same authors [Safran 1999, unpubl. study; Hutchinson 1999, unpubl. study].

Table 1. Injury incidence

Study	Study design	Data collection methods	Duration of study	Number of subjects	Number of injuries – acute	Injury rate – acute
Hutchinson et al., 1995 [2]	Prospective cohort design	Injuries seen/ evaluated by trainer or MD during annual National Championships	6 years	1,440	143	9.9/100 athletes 21.5/1,000 athletic exposures
Hutchinson 1999 [unpubl. data]	Prospective cohort design	Injuries seen/ evaluated by trainer or MD during annual National Championships	4 years	960	122	12.7/100 athletes 2.8/1,000 athletic exposures
Safran 1999 [unpubl. data]	Prospective cohort design	Injuries seen/ evaluated by trainer or MD during annual National Championships	4 years	741	77	10.4/100 athletes 1.9/1,000 athletic exposures
Winge et al., 1989 [7]	Prospective cohort design	Injuries sustained during 1 season	1 year	89	46	0.52 injuries/ player/ season; 2.3 injuries/ player/ 1,000 h
Silva et al., 2003 [8]	Prospective cohort design	Injuries seen/ evaluated by PT, trainer or MD during 13 tournament junior tennis season	1 year	258	151 players injured 272 injuries	1.8 treatments per injured player 6.9 evaluations per 1,000 games played
Lanese et al., 1990 [4]	Prospective cohort design	Weekly chart review of all injuries seen by trainer (attending each practice/competition) – university with loss of any time	1 year	23	10	43 injuries per 100 players 0.14 injuries/100 person-hours

Table 1 (continued)

Study	Study design	Data collection methods	Duration of study	Number of subjects	Number of injuries – acute	Injury rate – acute
Beachy et al., 1997 [9]	Retrospective cohort	Injuries that resulted in missed practice or play recorded by school trainer	8 years	588	146	0.35 injuries per female; 0.14 injuries per male player
Reese et al., 1986 [6]	Retrospective cohort design	Australian Institute of Sport review of medical records	4 years	45	176	0.06 injuries/ player/year
Safran et al., 1999 [5]	Case-control design	Injuries seen/ evaluated by trainer or MD during annual National Championships and prospective validated questionnaire	2 years	851		13.3/100 athletes 2.9/1,000 athletic exposures

Injury Characteristics

Injury Onset

The most common types of injury in young tennis players are microtrauma-related overuse injuries [2, 3, 5–9], particularly to the upper extremity. Examples of overuse injuries include rotator cuff tendinitis, epicondylitis, chronic muscle strain, growth plate injuries, and stress fractures. Other injuries are the effects of single incidents of trauma, such as ankle sprains, abrasions, contusions, and fractures. The greater percentage of these is to the lower extremity, particularly the ankle.

Injury Location

Table 2 summarizes the location of the injuries in pediatric tennis players [2, 6, 7, Safran 1999, unpubl. study; Hutchinson 1999, unpubl. study]. The data are usually presented as a percentage of total tennis injuries. The data may be divided into general body areas, or by anatomic areas such as joints or areas. In general, the lower extremity as a whole experienced the highest percentage

Table 2. Injury location

	Hutchinson 1995 [2]	Hutchinson 1999 [unpubl. data]	Safran 1999 [unpubl. data]	Winge 1989 [7]	Reece 1986 [6]
Central	24.6%	30.5%	21.3%	11%	21%
Head/Neck	15.4	15.1	20	–	2.7
Back	65.4	52.8	56.7	100	70.3
Abdomen	11.5	18.9	16.7	–	18.9
Groin	7.7	11.3	6.7	–	8.1
Upper extremity	26.5%	30.5%	27.7%	45.7%	20%
Shoulder	25	47.2	38.5	38.1	45.7
Elbow	44.6	28.3	17.9	33.3	34.3
Wrist	14.3	17.0	30.8	4.7	20
Hand	16.1	9.4	12.8	23.8	–
Lower extremity	48.8%	39.1%	51.1%	39%	59%
Hip	12.6	14.7	12.5	–	6.7
Thigh	25.2	29.4	16.7	11.1	16.3
Knee	12.6	14.7	9.7	16.7	22.1
Leg/Calf	6.8	8.8	18.1	22.2	16.3
Ankle	23.3	22.1	16.7	27.8	25
Feet	20.4	10.3	26.4	22.2	13.5
Other	–	–	–	4.3%	–

of injuries, ranging from 39 to 59% of the total, followed by the upper extremity, 20–45%, and the central core, 11–30%. Of the specifical anatomical locations, the ankle and thigh showed the highest frequency in the lower extremity, the shoulder and elbow showed the highest frequency in the upper extremity, and the low back was highest in the central core.

In tennis, the repetitive nature of high-velocity arm movements causes overuse injuries in the upper extremity while the sprinting, stopping and pivoting, and pounding motions place repeated rotational shear and loading forces on each joint of the lower extremities which, in turn, places the athlete at increased risk for acute and overuse injury. In children, the growth plates, particularly the apophyses, are susceptible to stress injuries as they undergo ossification, resulting in local inflammation, disordered or irregular ossification patterns, overgrowth, and pain. This is important because a forceful acute injury in the milieu of weakness and disordered ossification from recurrent microtrauma may result in small avulsion fractures at the apophysis [10].

Situational

No data currently exist as to when during practice or play or in what phase of the tennis year most injuries occur. Since the majority of injuries are musculotendinous, however, it is commonly found that acute muscular strains occur early in practice or play, usually associated with improper warm-up, or late in practice/play due to muscular fatigue.

Action or Activity

There are no published data that identify rates of injury based on the activity engaged at the time of injury. However, different strokes have been suggested to place greater risk to areas of the body that may result in injury. It has been shown that the median and peak muscular activity levels in the shoulder and forearm muscles of adult tennis players are higher during the service action than during other strokes, indicating that serve is the most strenuous stroke in tennis [11], and it is presumed that the same type of loading occurs in the similar strokes executed by pediatric players. There is also a suggestion that the abbreviated service motion may place additional loads on the shoulder and elbow in the tennis swing [11].

Additionally, style of play – serve and volley or baseline play – may also be associated with injury rate, although Safran et al. [5] found no statistical evidence to confirm this. However, it was shown that there was a higher rate of abdominal, groin, hip, thigh, and shoulder injuries in males, where approximately 12% of boys stated being serve-and-volley players and 68% noted being all-court players. Females, however, reported 58% were all-court players with 1% of females playing serve and volley-style tennis [5]. This less aggressive style of play for females may account for the difference in types of acute muscular injuries; however, again, the numbers were not large enough to show a statistical significance.

Chronometry

Junior tennis players play a disproportional amount of tennis during summers and holidays, when school is out. Most national tournaments occur during summers and holidays as well. Though not studied, it would be intuitive that the injury rates for young tennis players might be increased during these times.

Injury Severity

Injury Type

Table 3 shows data relating to injury type [2, 6, 7, 8, Safran 1999, unpubl. study, Hutchinson 1999 unpubl. study]. Perusal of this table reveals that the

Table 3. Injury type

	Hutchinson 1995 [2]	Hutchinson [unpubl. data]	Safran 1999 [unpubl. data]	Silva 2003 [8]	Winge 1989 [7]	Reece 1986 [6]
Sprains	17.1	8.6	8.5	–	17	–
Strains	55	64.9	54.6	39.6	14	–
Contusions	3.8	2.9	5.0	4	–	–
Abrasions	7.6	2.3	0	–	5	–
Lacerations	1	0.6	0	–	–	–
Fractures	1	0.6	0.7	–	2	–
Dislocations	0.5	0	0.7	–	–	–
Inflammation	10	14.9	18.4	17.7	–	–
Miscellaneous	3.8	5.1	12.1	–	–	–
Overuse	–	–	–	–	67	28.4%

most frequently occurring injury type in these studies was strain (range = 14 to 64.9%), followed by inflammation (range = 10 to 18.4%), then sprain (range = 8.5 to 17.1%). Many strains could be classified as either traumatic or overuse, depending on how long the symptoms persist, or how suddenly the symptoms appeared. Strains are the most common individual type of injury, ranging from 14–64.9%. Common injuries in tennis are listed by the region of injury.

Shoulder

The shoulder girdle is especially prone to injury because it has to maximally accelerate and decelerate the arm while maintaining precise control over the racquet at ball strike. The shoulder is the most frequently affected part of the upper extremity with incidence between 25 and 45.7% (Table 2). Rotator cuff inflammation is one of the most common injuries in tennis players. Lehman [12] found that 24% of junior tennis players complained of shoulder pain currently or in the past. In a survey of participants in the 1998 USTA Girls' 16's National Championships, 35% noted shoulder pain currently or in the past (56% of these were anterior shoulder pain, 15% posterior shoulder pain, and 31% both anterior and posterior) [5]. Of the 16- and 18-year-old participants at the 1998 USTA Boys' National Championships, 25% noted previous or current shoulder pain (38% anterior shoulder pain, 30% posterior shoulder pain, and 32% noted both anterior and shoulder pain) [5].

In the young player, rotator cuff symptoms are often secondary to instability of the glenohumeral joint [13]. Instability may result in labral degeneration or tears. Other shoulder injuries include humeral periostitis and bicipital tendinitis. Less common shoulder injuries may occur to the growth plates. This includes traction apophysitis, an overuse injury caused by repetitive microtrauma at the insertion of the supraspinatus muscle into the greater tuberosity, or the subscapularis muscle into the lesser tuberosity of the humerus. Proximal humeral physeal injury and slipped capital humeral epiphysis may also occur [10, 13].

Acute shoulder injuries are uncommon in tennis, though shoulder dislocations and acromioclavicular joint separations may occur from a fall.

Elbow

Lateral epicondylitis (tennis elbow), medial epicondylitis, and injury to the medial epicondylar apophyseal growth plate in skeletally immature players are common injuries about the elbow seen in tennis players. These injuries are associated with chronic repetitive overload. On the lateral aspect of the elbow, epicondylitis involves the extensor carpi radialis brevis but may involve the entire lateral mass. Lateral epicondylitis occurs more frequently in recreational tennis players, particularly those with poor mechanics of the backhand. Medially, the medial epicondylar growth plate, the flexor mass, or the medial collateral ligament might be involved [10]. Medial epicondylitis occurs much less frequently than lateral epicondylitis, though it tends to occur in higher level tennis players. It has been noted that the frequency of tennis elbow in world-class athletes ranges from 35-45% [14]. This frequency is much lower in elite junior athletes [2, 7]. In addition, small avulsion fractures may occur because of the anatomy of the adolescent elbow. Nonunion of the medial or lateral epicondyle has rarely been seen. Ulnar collateral ligament injuries in the tennis player are uncommon.

In the author's survey of participants in the 1998 USTA Girls' 16's National Championships, 25% noted elbow pain currently or in the past while 22% of participants at the 1998 USTA Boys' National Championships reported previous or current elbow pain [5].

Hand and Wrist

Hand and wrist complaints are common in tennis players, especially females. Further, nondominant wrist pain is common in players using two-handed backhands. In the study of participants in the 1998 USTA Girls' 16's National Championships, 29% noted dominant wrist pain and 25% noted nondominant wrist pain currently or in the past [5]. For the male participants at the 1998 USTA Boys' National Championships, 19% noted previous or current dominant wrist pain and 6% noted nondominant wrist pain [5].

Tendinitis of the wrist may develop in elite players who place a lot of spin on their shots or in novices with mechanically improper technique. Wrist extensors are most frequently involved, but flexor tendons may be involved as well. Extensor carpi ulnaris tendinitis is primarily due to overuse or technique flaws and often is associated with triangular fibrocartilage tears or ulnocarpal impingement. It is often seen in the nondominant wrist of players with two-handed backhands, possibly due to the overuse during the backswing. Extensor digitorum communis tendinitis, particularly to the index and little fingers due to their oblique course across the wrist, is often seen in tennis players. Tendinitis of the extensor pollicis longus uncommonly occurs in tennis players as the tendon passes Lister's tubercle. An occult dorsal ganglion is a common cause of radial wrist pain in the tennis player.

Recurrent dislocation of the extensor carpi ulnaris tendon has been reported in tennis players associated with hypersupination and ulnar deviation, such as with a backspin slice or low forehand or slice or topspin service motion [5]. Other, less common causes of wrist pain include a fracture of the hook of the hamate (from abutment with the bottom of the grip), injury to the triangular fibrocartilage complex, ulno-carpal impingement, chondromalacia of the pisiform, ulnar nerve compression in Guyon's canal, ulnar artery thrombosis, median nerve entrapment in the carpal canal, and triquetrolunate ligament injury. Wrist fractures and dislocations have also been reported from falls in tennis.

Forearm

Stress fractures of the ulna of the nondominant forearm in adolescents, as well as distal radius and ulna fractures of the dominant wrist, have been reported in the tennis player with forearm and wrist pain [10]. These injuries to the nondominant forearm occur in players who use a two-handed backhand.

Central Region Injuries (Back and Trunk)

In the elite junior tennis survey, 47% of females and 31% of males noted low back pain currently or in the past [5]. Various studies have found that up to 50% of randomly selected elite adult players had a history of low back pain of at least one week's duration [15, 16].

There are a variety of sources of low back pain in the tennis player. High demands placed on the lower back and trunk combined with low flexibility patterns result in frequent overuse-type injuries [17]. Other potential causes of low back pain include intervertebral disc degeneration and herniation, facet impingement, and spondylosis due to the repetitive hyperextension and rotation of the spine.

Injuries to the abdominal muscles are usually acute strains that occur during serves, particularly to the nondominant rectus abdominus muscle and obliques. Open-stance forehand strokes are purported to be the cause of the increasing incidence of abdominal muscle injury as well.

Hip/Thigh

The most common areas for strains in the thigh are the adductor muscles (groin pulls) and the hamstrings. Adductor muscle strains usually result from sudden changes in direction, particularly when attempting to stop lateral movement by sliding or posting the lead foot. Slipping on clay courts, resulting in 'the splits', may also strain the adductor muscles. Hamstring tears may occur at either end of the muscle and are usually associated with explosive acceleration, for example, when sprinting or charging towards the net. Hip flexor strains are not as common in the young tennis player. Quadriceps strains may occur when a player slides on clay courts with the knee flexed and then the player tries to forcefully extend the knee.

Knee

Statistics from the USTA national teams show that 19% of all injuries are knee injuries with 70% of the injuries being traumatic and 30% overuse. The patellofemoral joint is susceptible to overload and overuse injuries. This may be commonly manifested as Osgood-Schlatter's syndrome (tibial tubercle apophysitis) in young racquet sports players, patellar (jumper's knee) and quadriceps tendinitis in skeletally mature individuals, and patellofemoral syndrome or chondromalacia patellae [18].

Acute knee injuries, such as knee sprains and meniscal tears, are not particularly common but can occur secondary to the twisting demands of the sport on the knee [19]. Medial collateral ligament injuries are the most common injuries, though ruptures of the anterior cruciate ligament have been reported. Patellar dislocations have also been documented in tennis, racquetball, and squash.

Less common causes of knee pain in tennis players include prepatellar bursitis, pes anserine tendinitis, semimembranosus tendinitis, and iliotibial band syndrome.

Leg

Muscle cramps of the calf are very common in tennis. Gastrocnemius muscle strains are common and occur during repeated, explosive accelerations of the leg, such as while sprinting or jumping. These strains and injuries to the Achilles tendon occur when a foot that has been plantarflexed is suddenly forced into dorsiflexion while the knee is in full extension. 'Tennis leg' is described as a strain or partial tear of the gastrocnemius at its medial origin and is uncommon in the pediatric tennis player. Less commonly, soleus injuries may occur and are seen with sliding on clay courts with extreme ankle dorsiflexion with concurrent knee flexion. Achilles tendinitis and calcaneus apophysitis (Sever's apophysitis) may be seen in pediatric athletes, including tennis players [20]. Shin splints, periostitis, is an overuse injury seen frequently in tennis, particularly when played on hard courts. Stress fractures of the tibia and of the distal fibula also infrequently occur in tennis players.

Ankle

Ankle sprains are the most common macrotrauma injury in tennis due to the frequent running and pivoting, stopping and starting movements as well as lunging and jumping. As a result, high twisting forces result about the ankle. Most injuries occur during twisting while the ankle is in plantarflexion, resulting in lateral ankle sprains.

Foot

Foot injuries in tennis players may include stress fractures, plantar fascitis, and 'tennis toe'. Stress fractures are most common at the base of the fifth metatarsal and the metatarsal diaphysis. Tennis toe is an injury to the great toe or second toe due to impaction of the toe onto the toe box of the shoe. The impaction of the toe onto the anterior aspect of the shoe can lead to subungual hematomas, nail bed injuries, or to 'jammed' joints at the distal interphalangeal, proximal interphalangeal, or metatarsophalangeal joints.

Time Loss

Most of the data reporting injuries in tennis are for players seeking evaluation of medical problems [6, 8, 17]. Other studies have defined injury as missing part of practice or play [2, 4, 5, 7, 9]. Unfortunately, with so few epidemiological studies, including no studies looking specifically at the relative distribution of injuries based on time lost from tennis, no meaningful conclusions can be based on existing literature regarding time loss from play.

Long-Term Effects

The residual effects of injuries related to tennis are unknown. However, some logical outcomes may be hypothesized. With regard to chronic rotator cuff inflammation, there is the potential of accelerated rotator cuff degeneration and tearing. Tennis shoulder refers to the combination of a protracted scapula, excessive glenohumeral internal rotation, and weak muscles which produce a drooping, internally rotated shoulder, which may contribute to generalized laxity of the shoulder capsule and musculature. This is more common in professional players or those who have played for many years. This may potentiate rotator cuff pathology due to the protracted scapula not allowing the acromion to rotate sufficiently out of the way from the greater tuberosity.

Lateral epicondylitis (tennis elbow) is associated with chronic repetitive overload. Though its name suggests inflammation, microscopic examination suggests that inflammation is not really involved. Repetitive microtraumatic injury is felt to result in microtears of the muscular origin. Focal degeneration and healing with vascular and fibroblastic proliferation suggests that this is a degenerative process. It does appear that the elbow is prone to further injury with long-term use. It has been noted that an incidence of tennis elbow in world-class athletes ranges from 35 to 45% [14]. This incidence is much lower in elite junior athletes supporting the opinion that tennis elbow is related to age.

There are no studies evaluating the long-term effects of playing tennis. Many professional players have retired due to chronic low back pain. Sward [16] found 50% of randomly selected elite players had a history of low back pain of at least one week's duration, and 46.7% had abnormal radiographs of the lumbar spine.

Chronic Achilles strain may or may not be related to the 5.5% incidence of Achilles tendon ruptures reported in adult players over 40. Older racquet sports participants with poorly cushioned footwear with absent medial arch support may be prone to plantar fasciitis or rupture of the plantar fascia. Whether there is an increased risk if one played a lot when younger has never been shown. However, tennis players are particularly susceptible to this injury due to the great amount of time spent on the balls of their feet while making quick changes in direction. Hallux rigidus is a degeneration of the first metatarsophalangeal joint with dorsal exostosis, which occurs frequently in tennis players due to the excessive dorsiflexion of the first toe during play. Thus, the amount of play may be correlated to this degenerative change and thus may be increased in those who played more when younger.

Injury Risk Factors

A model has been developed to help evaluate injury and performance in sports (fig. 1) [21]. In this model, the demands inherent in participation in the sport (extrinsic factors) interact with the athlete's musculoskeletal base (the intrinsic factors) at the 'critical point' (when the ball hits the racquet) to create injury risk and performance. This model highlights the importance of the interaction between intrinsic and extrinsic factors in injury evaluation.

Extrinsic Factors

Exposure

Tennis may be considered a violent sport due to the high body segment velocities, motions, and loads inherent in the game at this skill level. Data from adult players shows that the elite player must generate 4,000 W of energy, or about 5 hp, in each serve. The entire body is involved in generating this energy. Trunk rotation velocity is around 350 deg/s, shoulder rotation velocity approaches 1,700 deg/s, and elbow extension velocity approaches 1,100 deg/s [22]. These velocities are developed rapidly over 0.4–0.6 s, creating large accelerations in the shoulder (0–43 miles/h). The total arc of shoulder internal/external

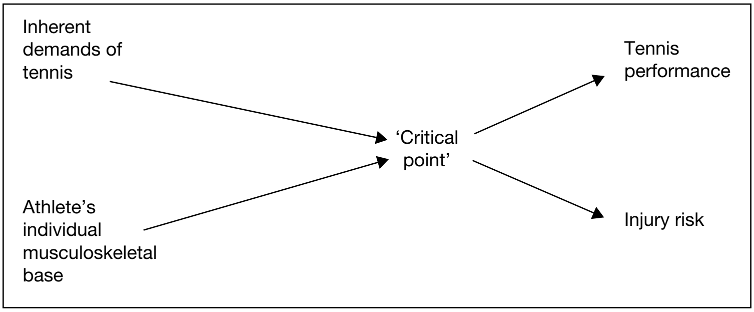

Fig. 1. The 'critical point' model showing the individual athlete's musculoskeletal base interacting with the inherent demands of the sport to produce both performance and injury risk.

rotation averages 146 degrees. These velocities and accelerations produce ball velocities of 95–105 miles per hour in females and 120–135 miles per hour in males. There is no comparable data for loads in pediatric athletes, but the forces still are quite high as shown by serve velocities approaching 85 miles per hour in females and 105 miles per hour in males.

These hitting activities are combined with repetitive running and start/stop activities that involve the legs. The average point in age group tennis matches requires 8.7 changes of direction, each change creating a load of 1.5–2.7 times body weight on the planted knee [23]. These demands require patterned muscle activations to do concentric and eccentric work.

These loads are applied frequently and with high-energy demands. The elite pediatric tennis player averages 2.3 h of practice or play per day 6.1 days per week [3]. Energy expenditure evaluation reveals that the metabolic demands in tennis are 70% alactic anaerobic, 20% lactic anaerobic, and 10% aerobic [22].

Environment

Court surface may play a role in injury rates and patterns. Different court surfaces can alter the demands that are placed on the tennis player. In general, clay courts and some synthetic courts slow the ball down, allowing for longer points and longer matches, while synthetic and hard courts speed the ball up, creating more force on the arm, and keep the bounce lower. There are no specific data correlating injury to court surface.

Equipment

Several equipment factors have been associated with tennis elbow: heavier, stiffer, more tightly strung racquets, incorrect grip size, metal racquets, and racquets with increased racquet vibration [14].

Intrinsic Factors

Growth

The pediatric tennis player's growth and development create some deficits in the musculoskeletal base that may increase injury risk. Many pediatric tennis players do not have sufficient leg strength to withstand the running, starting/stopping, or power generation demands. Differential bone growth in relation to muscle length decreases muscle flexibility and strength. These alterations create varying patterns of strength and capability to improve strength during periods of rapid bone growth, and may be the most influential intrinsic risk factor. This mismatch may also lead to a decreased ability to learn efficient athletic skills, also leading to increased injury risk.

However, other intrinsic factors are due to repetitive play. They create adaptations that may be considered maladaptations in that they alter the biomechanics of the tennis strokes, creating increased injury risk.

Physical Maladaptations

Pediatric tennis players develop decreased lumbar flexibility, evaluated by sit and reach measurements, compared with age- and activity-matched controls [24]. They also show hip rotation inflexibility. These deficits have been associated with the presence of low back injury [17].

Shoulder muscle strength may also be altered. Decreased external rotation strength and muscle work lead to altered internal/external rotation ratios [25]. This combination results in force couple imbalance in the humeral head stabilizers, decreasing the concavity/compression of the humeral ball into the glenoid socket.

The most common maladaptation is alteration in shoulder internal rotation and is named glenohumeral internal rotation deficit. This appears at an early age, and progresses with age and years of play [26, 27]. Current thought recognizes Glenohumeral internal rotation deficit as a key initiator of a series of biomechanical alterations that lead to altered humeral position in arm rotation and predispose the shoulder and elbow to injury [17, 28].

These maladaptations are very common in elite pediatric tennis players with their incidence ranging from 60 to 86% of players surveyed. Their exact origin is not clear. Strength alterations may result from a plyometric-like effect that increases strength on the trunk flexors or shoulder internal rotators, actual muscle damage due to tensile stress overload, or alteration of muscle activation patterning.

The alterations in flexibility may be an internal adaptation to a repetitive tensile load. Most authors feel it is an alteration in static (the absolute magnitude of stretching) and/or dynamic (the rate at which stretching occurs, or the stiffness) flexibility in muscles. These may be present with or without alterations in strength.

Suggestions for Injury Prevention

Prevention of injuries in pediatric tennis players would center on evaluating and modifying the extrinsic and intrinsic factors that have been identified in association with injury. It appears that a reasonable model has been developed to understand the interaction of the various intrinsic and extrinsic factors, but due to the multi-dimensional, full body involvement in tennis, it is difficult to define the exact parameters to be studied. To date, no complete study has been undertaken which correlates change in risk factors with conclusive proof of injury reduction. Studies have shown that individual risk factors may be modified.

Extrinsic Factors

Many of the extrinsic factors in tennis injuries are not modifiable. All coaches and players agree that elite tennis players require a lot of practice and play to become skillful. There have been some efforts to modify the amount of tournament play. The U.S. Tennis Association decreased the number of tennis tournaments in the younger (under 12 and under 14) age groups, substituting round-robin matches. The Women's Tennis Association established tournament play restrictions for professional players under the age of 16. These restrictions did not address the amount of practice time. There are no data on the effect of these restrictions on injury incidence. Much more research on the optimum amount of time for play and practice is needed.

The inherent biomechanical and physiological demands of hitting and running can be slightly modified. There is evidence that certain aspects of the mechanics of tennis stroke production are more efficient, producing less strain on the body. Utilization of kinetic chain sequencing from the ground reaction forces creates optimum proximal force generation, interactive moments in distal segments, and produces efficient long axis rotation of the arm before ball impact. The result is a 'push-through' mechanism by which the legs drive the arm and racquet through the hitting zone, as opposed to a 'pull-through' mechanism, in which the smaller trunk and arm muscles drag the arm and racquet through the hitting zone. It has also been shown that specific alterations in mechanics, such as incomplete flexion of the knees in cocking, or incomplete cocking of the shoulder, create increased loads in the shoulder and elbow [11]. These mechanical problems should be addressed by detailed coaching analysis and training.

Intrinsic Factors

Alterations in the musculoskeletal base can be evaluated by a sport-specific preparticipation exam with special emphasis on the areas of maximum concern. Several protocols exist [29, 30]. In order to provide meaningful data, these tests should be performed with specific guidelines. In the flexibility measurements, the proximal segments should be stabilized (pelvis for hip range of motion, scapula for glenohumeral rotation), goniometers should be used for measurement, and side-to-side comparisons are helpful for asymmetries. For strength measurement, the proximal segments (pelvis and scapula) should also be stabilized and composite motions (hip or shoulder rotation, hip abduction) should be measured because this is the way muscles are activated in tennis activities. Once again, side-to-side comparison is helpful for asymmetries.

Scapular control plays a major role in force transfer between the trunk and hand, establishing stable ball and socket kinematics and allowing maximal shoulder muscle activation. The scapula can be dynamically evaluated by observing its position at rest and motion with arm motion [31].

These prospective evaluations can then be used as the basis for a sport-specific conditioning program, using the concepts of periodization. Studies have demonstrated that changes in strength [32, 33] and flexibility [31] can be achieved. These data show a correlation between improved musculoskeletal base parameters and performance in tennis. No data exist to relate improved flexibility and strength parameters to injury in tennis players. However, there are data from other sports – running and basketball – to show this correlation.

Suggestions for Further Research

Several areas need to be addressed in order to gain more knowledge. First, a standard definition of injury must be devised and agreed upon. Second, a validated injury evaluation instrument must be implemented across all studies. Study design will need to be improved. Due to the relatively low number of injuries, the relatively wide distribution of injuries across all areas of the body, and the transient and often short term nature of high level participation in the pediatric age group. The most efficacious study of pediatric tennis injuries would be longitudinal in nature with adequate sample size to provide appropriate statistical power to evaluate intrinsic and extrinsic injury risk factors of interest. A critical aspect of this research would be the precise determination of exposure patterns in injured and uninjured athletes as a basis for determining reasons for injury occurrence. A second study would then attempt to modify all the potentially injurious factors that were identified through regression analysis from the first study through a prospective conditioning and periodized training/playing schedule, and correlate with injury incidence.

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Track and Field Injuries

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Abstract

Objective: A review of the existing literature on injuries to youth (≤18 years old) in track and field or athletics. **Data sources:** Searches of the Medline and SPORT Discus databases for English language articles through the end of 2003, using the search terms (adolescent or youth) and (track or field or running) and injuries. **Main results:** Only nine prospective or retrospective studies were found dealing with track and field injuries in children and that stated injury rates or provided enough information to allow the estimation of injury rates. Differences in study design and inconsistencies in the definition of a reportable injury provided major hindrances to making comparisons or combining data across studies. Among the few conclusions that can be drawn are that the lower extremities account for the majority of injuries, and muscle strains and ligament sprains are the predominant types of injury. While a majority of injuries may occur during training, since there is much more exposure during training than during competitions, the risk of injury is about four times higher during competitions. **Conclusions:** Informed decisions with regard to preventing injuries in youth track and field are dependent upon the quality of the basic epidemiological data available, and at this time such data are, for the most part, nonexistent. Because of the large numbers of participants and the large number and variety of activities involved in track and field, adequately designed epidemiological research is difficult, but opportunities for research in this sport are available for anyone willing to take on the challenge.

Introduction

Running, jumping and throwing are basic sport skills that provide the foundation for most other sports, but they are the focus of the sport of athletics or track and field. The running events vary in distance from short sprints (50, 60, and 100 m) to distance races (1,500, 5,000, and 10,000 m), as well as races involving hurdles (110 m hurdles, 400 m hurdles, and steeplechase).

The field events consist of throwing events (shot put, discus throw, javelin throw, and hammer throw), horizontal jumps (long jump and triple jump), and vertical jumps (high jump and pole vault). Training and competing in running events involves long periods of repetitive stress on the musculoskeletal system, with the feet striking the ground 1,000 to 1,500 times per mile with forces two to three times body weight [1, 2]. As a result, the majority of running injuries are attributable to overuse of that system. Field events, on the other hand, involve generation of maximum force in a short period of time, and many of the injuries sustained in these events are the result of the high stresses generated by maximal muscle contractions, although there are many gradual onset, repetitive stress injuries as well.

Based on participation data from the National Federation of State High School Associations [3], track and field is the third most popular high school sport in terms of the number of participants, exceeded only by football and basketball. A total of 913,629 high school students participated in the sport during the 2002–03 school year (498,027 boys and 415,602 girls). In addition, 32,850 children aged 14 and younger participated in USA Track & Field's (USATF) Youth and Junior Olympic Programs in 2003 (16,500 boys and 16,350 girls) [4]. These total 946,479 youth participants in track and field (514,527 boys and 431,952 girls). Assuming there are additional individuals not accounted for in these sources who participate through middle school or AAU programs, over one million children participated in track and field in the USA in 2003.

This chapter reviews existing literature on injuries to children (≤18 years old) participating in track and field. The literature review began with searches of the Medline and SPORT Discus databases for English language articles using the search terms (adolescent or youth) and (track or field or running) and injuries. The search covered the literature through the end of 2003. In addition, personal resources of the author were utilized. Most of the literature for this sport deals with older individuals. Much of what is available dealing with children's track and field injuries tends to be case reports, case series and opinion pieces, which do not allow analyses of injury rates or etiological factors. This issue has been noted previously in reviews of running injuries [5] and field event injuries [6] of older athletes. The number of prospective and retrospective studies is small, and studies providing data on the number of exposures to injury for the calculation of rates are rarer still. Differences in study design and inconsistencies in definition of a reportable injury provide major hindrances to making comparisons or combining data across studies. In addition, most studies do not differentiate between running athletes and field athletes. All these limitations should be kept in mind when reading this review.

Incidence of Injury

Only nine prospective or retrospective studies were found dealing with track and field injuries in children and that either stated an injury rate or provided enough information to allow some estimation of an injury rate (table 1) [7–15]. The injury rate presented in table 1 (injuries per 100 participants per year) is a minimally useful rate that allows some gross comparisons between studies. Data on exposure to risk of injury were essentially nonexistent in all but one of these studies [7], so calculation of injury rates per 1,000 exposures or 100 h of participation was not possible except in that one study. Rates per 100 per year were given in three of the studies [7–9], but sufficient information regarding numbers of participants and injuries was provided in the others to allow calculation of these rates. In five of the studies there was sufficient information to also allow a breakdown by sex. Three of the papers covered multiple sports [9–11], one included older athletes [12], one covered wheelchair athletes [11], and one covered only medial tibial stress syndrome (MTSS) in young runners [13]. Keep in mind when reviewing these data that no two studies used the same definition of a reportable injury. This fact alone makes any conclusions drawn from comparisons of these papers highly speculative.

Only two papers [8, 11] gave a breakdown of injury occurrences by the type of event, allowing a distinction between track injuries and field injuries. While presenting no specific data, Garrick and Requa [14] mention that in their sample ‘about 4 out of every 5 injuries occurred during a track event as opposed to a field event’, indicating that approximately 80% of injuries occur in running events and 20% in field events. Watson and DiMartino [8] found 82% of the injuries that occurred during participation in a track or field activity were in running events and 18% in field events. They also reported that 20% of the total number of injuries reported occurred in other activities before, during or after practice, not directly related to either running or field event activity. Taking this into account, about 65% of reported injuries in their study occurred during running activity, 15% during field event activity, and 20% during other activities.

D’Souza’s study [12] provided enough information to calculate that about 70% of the injuries reported in his study were to running event participants and about 30% to field event participants. While these figures indicate that the preponderance of reported injuries in these studies was to runners, only one of the studies provided data on the numbers of track athletes and field athletes to allow estimation of real rates of injury to these two major categories of participants. In other words, we do not have any idea whether the larger percentage of injuries reported for the track athletes is because there are many more of them than there are field event athletes in the samples, or because runners are

Table 1. A comparison of injury rates in track and field in adolescents

Study	Design	Method	Duration	Number of participants	Injury definition	Number of injuries	Rate IR/100/yr	Rate IR/1,000 athlete-exposures
Orava and Saarela [15]	P	I/MR	3 years	48 (26 M, 22 F)	Any treatment	71*	49.3* (53.8 M, 43.9 F)*	
Zaricznyj et al. [9]	P	MR	1 year	289	Any treatment	50	7.9	
Requa and Garrick [14]	P	Q	2 years	516 (308 M, 208 F)	≥1 day	174	16.9* (16.4 M, 17.5 F)*	
Watson and DiMartino [8]	P	I/Q	1 season (77 days)	234 (156 M, 78 F)	≥2 days	41	17.5 (19.2 M, 14.1 F)*	
Mueller et al. [7]	P	Q (weekly reports)	3 years	53,700 (29,700 M, 24,000 F)	≥1 day, plus any medical treatment	1,659	3.1* (2.4 M, 3.9 F)	1.2* (1.0 M, 1.5 F)
Bennett et al. [13]	P/CC	I/ME	1 season (8 weeks)	125 (57 M, 68 F)	Symptoms of MTSS	15	12.0* (3.5 M, 19.1 F)*	
Backx et al. [10]	R	I/Q	7 months	54 (25 M, 29 F)	'any physical damage'	16*	29.5*	
D'Souza [12]	R	Q	1 year	147 (all ages) (96 M, 51 F) (number of participants <18 not stated)	≥7 days	?	51.3 (=% injured in <18 group)	
Wilson and Washington [11]	R (wheelchair athletes)	Q (34% response rate)	Not stated	83 (57 M, 26 F)	Not stated	?	97 (=% injured)	

*Calculated from data in the article.
P = Prospective; R = retrospective; CC = case-control; I = interview; Q = questionnaire; MR = medical reports; ME = medical exam.

at much higher risk of injury than field event athletes, or a combination of these factors. Recording and reporting this information would be complicated by the fact that many participate in both running and field events. D'Souza [12] did report a breakdown of his study sample by the type of event, which allowed a calculation of an estimate of 63 injuries per 100 track event athletes per year and 56 injuries per 100 field event athletes per year. Unfortunately these data included participants older than 18. Hence, we still have no solid information on the separate risks for younger track athletes and field athletes.

Injury Characteristics

Injury Onset

Only one study [15] differentiated between acute or sudden onset injuries and gradual onset injuries. Of the 71 recorded injuries among 48 athletes over a 3-year period, 19 (26.8%; 13.2/100 participants/year) were acute injuries and 51 (73.2%; 36.1/100 participants/year) were 'exertional injuries' or gradual onset injuries.

Injury Location

Five of the studies (all of the purely prospective studies) provided information on the body part injured, and reported the distribution in percent of total injuries, or provided enough information to allow percentages to be calculated. These data are summarized in table 2 [7–9, 14, 15]. Given the nature of this sport, with heavy use of the legs in running, jumping and throwing activities, it is not surprising that the great majority of injuries are reported in the lower extremities. In all the studies, the lower extremities accounted for 64–87% of the reported injuries. Although there is no way to confirm it from the data presented in these studies, it is a reasonable presumption that the preponderance of the upper extremity injuries occur in field event athletes, primarily throwers. It is fairly consistent across all the studies that the highest percentages of injuries occur in the upper leg, knee, lower leg and ankle.

Situational

Three of the studies [8, 12, 14] mention that between 75 and 98% of the injuries reported occurred in training sessions. The only study to provide specific data on injuries in training and in competition was the study by Mueller et al. [7]. They report an injury rate of 1.7/100 athletes in competition and 1.4/100 athletes for training sessions. Based on athlete-exposures in competition and training (an athlete-exposure is defined as one athlete participating in one training session or one competition where he or she is exposed to the

Table 2. A percent comparison of injury location in youth track and field

Body part N =	Orava and Saarela [15]* 48	Zaricznyj et al. [9] 289	Requa and Garrick [14]* 516	Watson and DiMartino [8] 234	Mueller et al. [7]* 53,700
Head	–	*6.0*	*1.9*	–	*0.2*
Spine/Trunk	*18.3*	*6.0*	*5.5*	*12.1*	*3.1*
Neck	–	2.0	–	–	–
Back/Spine	18.3	4.0	5.5	12.1	2.9
Internal	–	–	–	–	0.2
Upper extremity	*1.4*	*24.0*	*4.9*	*2.4*	*7.0*
Shoulder	–	4.0 }	3.7 (Shoulder and Elbow)	–	1.8
Elbow	1.4	6.0 }		2.4	1.7
Wrist	–	8.0 }		–	1.7
Hand	–	4.0 }	1.2 (Wrist, Hand and Fingers)	–	1.0
Fingers	–	2.0 }		–	0.8
Lower extremity	*78.9*	*64.0*	*87.4*	*80.3*	*77.0*
Pelvis/Hip/Groin	4.2	10.0	–	12.1	10.4
Upper leg	12.7	–	28.8	7.3	20.8
Knee	11.3	24.0	12.6	2.4	15.0
Patella	2.8	–	–	14.7	1.2
Lower leg	19.7	8.0	35.8	21.9	12.6
Achilles tendon	5.6	–	–	2.4	0.6
Ankle	11.3	14.0	10.2	17.1	11.8
Foot	11.3	8.0	–	2.4	2.3
Toes	–	–	–	–	2.3
Other	*1.4*	–	–	*4.9*	*13.9*

*Calculated from data in the article.

possibility of being injured), they report an injury rate of 2.93/1,000 athlete-exposures in competition and 0.72/1,000 athlete-exposures in training. This illustrates why reporting injury ‘rates’ in percentages or per 100 participants per year can very often be misleading: a true picture of risk can be gained only when exposure data are part of the equation [16]. The reported percentages indicate that many more injuries occur during training, which is true in most any sport simply because there are many more training sessions than competitions. The rate per 100 athletes indicates a slightly higher injury rate in competitions, but the real risk cannot be appreciated unless the rate is reported in relation to the number of exposures in competition and in training sessions. In this case the much more accurate injury rates per 1,000 athlete-exposures indicate that an athlete is 4.1 times more at risk, or more likely to incur an injury, in competition than during a training session. This is a common finding across all sports, where data based on exposure show a higher injury rate in competitions, ranging from two to nine times greater than in training [16].

Injury Severity

Injury Type

Four of the prospective studies [7, 8, 14, 15] provided data that allowed calculation of a percentage breakdown of the types of injuries incurred by young track and field athletes. A summary of these data is presented in table 3. Muscle strains appear to be a predominant type of injury across all the studies. Inflammation also is a major type of injury in three of the studies, but apparently was not a category used by Mueller et al. [7] in their data collection forms. Ligament sprains also are a common type of injury across all the studies.

Catastrophic Injury

None of the studies mentioned so far reported any catastrophic injuries; i.e., injuries resulting in death or permanent disability. However, data on these severe injuries are available from the National Center for Catastrophic Sport Injury Research [17]. They report injuries of three types: fatal; nonfatal (permanent severe functional disability); and serious (no permanent disability, but a severe injury; an example would be a fractured cervical vertebra with no paralysis or transient paralysis with eventual complete recovery). The injuries are categorized as direct (resulting directly from participation in the sport), and indirect (resulting from a systemic failure as a result of exertion while participating in a sport or by a complication secondary to a nonfatal injury). These data are collected from across the USA via news and wire service reports and from a network of individuals who monitor and report any such injuries in their area.

Twenty years of high school data for track and field (1983–2002) indicate a total of 54 direct injuries: 20 fatal injuries (1/year), 14 nonfatal injuries (0.7/year) and 20 serious injuries (1/year). During this period there were also 27 indirect fatalities (1.35/year). These injuries are predominantly to male participants, with males recording 0.19 direct fatalities per 100,000 participants versus 0.01 for females, 0.13 nonfatal injuries per 100,000 for males versus 0.01 for females, and 0.15 serious injuries per 100,000 for males versus 0.05 for females. Indirect injuries show the same pattern, with 0.24 indirect fatalities per 100,000 for males versus 0.05 for females.

Pole vaulting was the activity responsible for the majority of these injuries, with 17 fatalities, 8 nonfatal and 6 serious injuries over the last 20 years. All of

Table 3. A percent comparison of injury types in youth track and field

Study (all prospective)	Number of injuries/ number of participant-seasons	Contusion	Dislocation	Fracture	Inflammation	Laceration	Sprain	Strain	Stress Fx	Tear	Tendonitis	Other
Orava and Saarela [15]*	71/144	2.8	–	–	39.4	–	12.7	16.9	1.4	1.4	12.7	12.7
Requa and Garrick [14]*	174/1,032	1.9	–	3.0	17.6	1.9	15.5	45.1	–	–	–	14.6
Watson and DiMartino [8]*	41/234	–	–	–	36.4	2.4	17.1	24.3	–	–	14.6	4.9
Mueller et al. [7]*	1,659/ 53,700	4.0	1.6	3.9	–	1.4	20.2	48.8	1.6	–	–	18.3

*Calculated from data in the article.

these 31 injuries involved the athlete bouncing out of or landing off the landing pit. The much higher rate of direct injuries to males noted above can be largely explained by the fact that females did not participate in pole vaulting until very recently. There also have been 20 direct injuries involving athletes being struck by a thrown discus, shot or javelin.

Time Loss

Only two studies [7, 14] provided any useful information on time loss for track and field injuries. Requa and Garrick [14] reported that boys and girls had a similar pattern, with 14 and 19% of injuries with greater than 10 days lost, respectively, and 30% and 40% of injuries with greater than 5 days lost, respectively. The more recent and much larger study by Mueller et al. [7] showed a different pattern, with 50% of injuries to boys lasting one week or longer and only 33% of injuries to girls lasting one week or longer. It is difficult to make comparisons with these studies because they used different breakdowns of the number of days lost.

Injury Risk Factors

Only two studies presented data that could be utilized in this section. Mueller et al. [7] tabulated data on year in school and years of experience that indicated a trend toward fewer injuries with age and experience. But without any data presented on the numbers of participants at each level, it is not possible to come to any conclusions about this issue. The study by Bennett et al. [13] investigated a number of potential factors for predicting the occurrence of MTSS in high school runners. They concluded that sex (female) and a 'pronatory foot' (larger values for the navicular drop test) are predictive of MTSS. They did not feel their sample was large enough to establish a specific threshold for the navicular drop test.

Five of the studies (table 1) provided enough data to calculate injury rates per 100 participants by sex. The results show no definable trend. Three of the studies show girls with a higher injury rate, and two show boys with the higher rate. Combining the data from the five studies gives an injury rate of 3.0/100 participants for the boys and 4.4/100 participants for the girls, but this result should not be considered definitive because the size of the database for the Mueller et al. [7] study overwhelms all the other studies, and without exposure data the results can be very misleading, as illustrated earlier. The most dependable piece of data is in the right column of table 1, where the Mueller et al. [7] study provides the only data available involving exposures. It shows an injury rate of 1.0/1,000 athlete-exposures for boys and 1.5/1,000 athlete-exposures for girls.

Suggestions for Injury Prevention

Because there are so few data currently available on the epidemiology of youth track and field injuries, there is little solid information upon which to base any suggestions for injury prevention. When discussing youth sports injuries, common subjects of concern for growing athletes are the risks of epiphyseal and apophyseal injuries and how to prevent them. These have been studied more thoroughly in a few other youth sports (for instance, see the chapter on Gymnastics in this book), and have been mentioned in reviews of adult track and field injuries [5, 6]. While the data regarding the risks for these types of injuries from other youth sports may be generalizable to youth track and field, there still are no well-designed, true epidemiological studies of these issues available for this sport. A good number of well-designed, large-scale basic epidemiological studies involving the collection of exposure data are needed for this sport (or any sport) to develop sound judgments as to the etiological factors involved in specific injuries. Knowledge of the etiological factors is needed to develop reasonable preventive measures. Then further epidemiological studies are needed to monitor the impact of the preventive measures. With the exception of the recent Mueller et al. [7] study, nothing of this nature has been accomplished for this sport at the very beginning of this cycle, let alone at any of the other stages.

While there currently is no sound scientific basis for making suggestions to reduce injuries in youth track and field, one ‘common sense’ suggestion can be made with regard to preventing the types of Catastrophic Injuries mentioned above. Over the past 20 years, nearly all these types of injuries have occurred in the pole vault and the throwing events (see Catastrophic Injury above). Recently, advances have been made with regard to rules and requirements at all levels of competition for the size and characteristics of the pole vault landing pit, which should help reduce the risk involved with that event. Beyond that, and also with regard to the throwing events, coaches and competition administrators should ensure that they have an adequate number of well-trained officials to monitor these events during competitions. Unfortunately, this sport requires a large number of officials for a competition. A high school dual meet needs at least 25–30 officials to provide adequate coverage. A large multiday championship meet can use up to 150 officials. Compare this with the very small numbers of officials needed for a football, basketball or baseball game.

Out of necessity, track and field officials for the most part are unpaid, and most often at the high school and junior high school level they are parents and spectators helping out. The national governing body for track and field, USATF, operates a national training and certification program for officials, the only program of its kind in the country for this sport. Safety, particularly in the field events, is a major point of emphasis in the USATF training program. Coaches and school administrators need only contact the officials certification chair for the local USATF association (through www.usatf.org) to request help from a few trained officials, who can help reduce the risks for these events. Most USATF association officials groups also can provide brief training programs for local parent and volunteer groups in how to properly and safely officiate a meet. When coaches and athletes regularly experience a safely run competition venue during competitions, they will more likely transfer those safe practices to the training setting as well. In addition to using adequately trained officials for competitions, schools and clubs should use coaches who have successfully completed a training program specific to track and field. For example, in the USA the USATF Coaching Education Level I program, or the American Sport Education Program available through the National Federation of State High School Associations are available.

Suggestions for Further Research

Future epidemiological research in youth track and field injuries is wide open, with much to be accomplished. As noted previously, there are very few studies currently available in the literature for the youth level in this sport, and most available studies tend to be on older athletes. There is not enough information regarding even the first stage of the epidemiology-etiology-prevention measures-epidemiology cycle that is necessary for beginning the attempt to reduce injuries in youth track and field. There is a need for a number of large-scale epidemiological studies of high school, middle school and club teams, but at this stage even smaller studies at the local level can be of value, if properly designed and carried out. While studies designed to address a specific research question may be appropriate, particularly for smaller studies, at this stage there is a great need for the larger, basic study of the overall epidemiology of injuries in this sport.

Such studies must utilize a common definition of a reportable injury [16]. As seen in table 1, none of the nine studies selected for this review used exactly the same definition of an injury, making it difficult to compare data across the studies. Currently the most commonly used (and recommended) definition of a reportable injury in sport injury epidemiology is: an injury incurred during participation in the sport, requiring medical attention at some level (e.g., coach, school nurse, trainer, and physician), and keeping the athlete from normal full participation for the remainder of that competition/training session or for one or more days following the injury. Many studies also will include any head injury that results in evaluation for a possible concussion, whether or not time loss is involved. The notion of time loss keeps the data recording system from being inundated with minor injuries that do not interfere with normal participation. Using definitions involving longer time loss periods (e.g., 2 days, 1 week) are not recommended because they may miss many of the more subtle injuries and will make the study more difficult to compare with other studies, both in this sport and across other sports, which do use the recommended definition of a reportable injury.

The population of athletes used in a study should be clearly defined, and as representative as possible. The numbers of males and females must be known and reported, as well as other characteristics of the participants, such as age, grade in school, and event(s) they are participating in, at a minimum. If they are of interest, other characteristics such as race/ethnicity, years of experience in the sport, or previous injury history should be collected at the beginning of the study and reported as well.

The data should be collected by a person with medical knowledge (e.g., certified athletic trainer, school nurse, and team physician). This individual should be present at all training sessions and competitions. Of great importance is the collection of exposure data, the major weakness of nearly all previous studies in this sport. Data must be collected and reported on the number of athletes participating in each training session and competition (not all athletes are necessarily at every training session, and not all athletes who train with a team or club are necessarily involved in a particular competition). This should be done on a standard form designed to fit the needs of a particular study. Injury data also should be reported on a standard form. This should include information such as characteristics of the injured individual, date and time of injury, competition or training session, body part injured, type of injury, circumstances of the injury, event, and severity (amount of time loss). Data forms should be submitted on a regular basis (e.g., weekly) to a central collection point, logged in and reviewed for completeness and consistency. The person completing the data forms should be contacted if there are missing forms, incomplete forms or inconsistencies in the reported data (e.g., a fractured lower leg that kept an athlete out for only 2 days should be followed up for clarification).

Utilizing the injury data and the exposure data, results should be reported as injury rates per 1,000 athlete-exposures. As noted previously, reporting percentages of injuries or injuries per 100 participants is not sufficient for the purpose of providing the information needed to explore etiological factors or for making comparisons with other studies or other sports. Reporting rates as injuries per 1,000 athlete-exposures is the recommended standard minimum reporting procedure. Ideally, collecting exposure data also in terms of hours of participation to allow reporting of injury rates per 100 or 1,000 h of exposure would be preferable, and may be possible in smaller studies. However, it is difficult to do this in large-scale studies, so rate per 1,000 athlete-exposures is recommended.

In addition to the medically trained persons responsible for on-site data collection, the research team for epidemiological studies of this nature should include a sports medicine physician, and a computer-knowledgeable data manager familiar with medical terminology and the sport involved, who prior to data entry can log in and screen the data forms for completeness and consistency as they are received. It also is preferable to have an epidemiologist and/or biostatistician available for consultation, particularly one with experience in injury epidemiology. It is possible that one individual can cover more than one of these responsibilities, particularly for smaller-scale projects. Usually, the larger the project, the more people will have to be involved.

Informed decisions about preventing injuries in youth track and field are dependent upon the quality of the basic epidemiological data available, and at this time such data are for the most part nonexistent for this sport. Because of the large numbers of participants and the large number and variety of activities involved in track and field, adequately designed epidemiological research is difficult. But the future is wide open for anyone willing to take on the challenge of doing epidemiological research in youth track and field.

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Wrestling Injuries

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Abstract

Objective: The purpose of this chapter is to review critically the existing studies on the epidemiology of pediatric wrestling injuries and to discuss suggestions for injury prevention and further research. **Data sources:** Data were obtained from the sports medicine and science literature since 1951. Literature searches were performed using the National Library of Medicine, Pubmed, Medline, Grateful Med, Sports Sciences, SportsDiscus. Keywords used included 'Wrestling, Wrestle, Wrestling Injuries, Fractures, and Dermatologic'. **Main results:** Only eight prospective or retrospective studies were found dealing with pediatric wrestling injuries and that provided sufficient information to allow the estimation of injury rates. Exposure-based injury rates were between 6.0 and 7.6 injuries per 1,000 athletic-exposures. Injury rates increased with age, experience, and level of participation. The head/spine/trunk was the body region that incurred the greatest frequency of injuries, followed by the upper and lower extremities. **Conclusions:** There are several potential areas for decreasing injury risk in wrestlers, including equipment, coaching, officiating and training. However, informed decisions with regard to preventing injuries are dependent upon the quality of the basic epidemiological data available, and at this time, analyses of risk factors and potential preventive measures are lacking.

Introduction

This chapter is a review of the epidemiological literature on wrestling injuries in the pediatric population. Due to the relative lack of information on pediatric wrestling injuries, a broad search was performed that included all studies on the epidemiology of wrestling injuries, focusing especially on the high school level. Case studies were included in some sections in order to fill the gaps left by a lack of pediatric wrestling studies. As with many other areas of sports injury research, it is difficult to compare the findings of different studies because the study designs, injury definition, and population studied are so varied.

A search of the National Library of Medicine Pubmed, Medline, Grateful Med, Sports Sciences, Sports Discus, was conducted from 1951 to present under 'wrestling' and 'injuries'. This search yielded most of the articles used in this review. We also searched under 'fractures in wrestling', and 'dermatologic conditions in wrestling'. The most useful articles were all found using the keywords 'wrestling injuries'. We also used references from some of the articles found from the literature search.

Incidence of Injury

A summary of studies reporting on the incidence of pediatric wrestling injuries is shown in table 1 [1–8]. A review of this table reveals that it is difficult to compare incidence of injury across studies because of the variety of ways in which 'injury' has been defined and the differing ways in which rates have been calculated. Kersey and Rowan [9] defined an injury as any incident in which an official halted a match. With such a liberal definition, the likelihood of over-reporting is high, where a bloody nose or stalling tactics by a wrestler may be included as data. Strauss and Lanese [8] recorded only those injuries that reached the athletic training room. This leaves the potential for many minor injuries to be under-reported. There was a little more consistency in defining injury between studies done by Lorish et al. [5] and Pasque and Hewett [7]. In these cases, the definition of injury usually involved: (1) limitation of function to an extent that the athlete sought treatment by an athletic trainer or physician; (2) restricted participation of at least one day beyond the initial injury.

Pasque and Hewett [7] prospectively examined injury patterns of high school athletes over one 3-month season. The overall injury rate at the end of the season was 6.0/1,000 athlete-exposures. Similarly, Hoffman [3] reported a rate of 7.6 injuries per 1,000 athletic-exposures in high school wrestlers followed over two seasons.

Only two studies examined injury rates in school-age wrestlers exclusively. Lorish et al. [5] reported on injury patterns occurring during the course of two wrestling tournaments involving athletes between the ages of 6 and 16. When comparing risk of injury and severity of injury between preadolescent and adolescent boys, older boys were at significantly greater risk for injury. Strauss and Lanese [8] also reported on injuries at a wrestling tournament.

Table 1. Epidemiological study summary

Author	Study design	Collection methods	Study duration	Number of participants	Number of injuries	Injury rates
Bailes et al. [1]	R; HS and C; cervical spine and cord	D	12 years	63 athletes	13/63 injured wrestlers	
Boden et al. [2]	R; HS and C; catastrophic injuries	D, I, Q	18 years	HS = 4,041,486 C = 129,858	54 catastrophic injuries	2.11 catastrophic injury/year, HS = 0.00084% C = 0.0007%
Hoffman and Powell [3]	P; HS	D, I	2 seasons	159,470 A-E	not given	7.6/1000 A-E
Kvitten et al. [4]	P; HS; orofacial injuries	I, Q	1 season	101	73	69.9% of wrestlers sustained at least one injury
Lorish et al. [5]	likely P; grade school, HS	I, Q	1 season (2 tournaments)	1,742	221	12.70%
Mueller and Cantu [6]	likely R; HS, C; catastrophic injuries	I, Q	6 years	HS = 250,000 C = 8,000	HS = 23 C = 0	no rates given
Pasque and Hewett [7]	P; HS	I, Q	1 season	418 36,473 A-E	219	52/100 wrestlers/season 6.0/1,000 A-E
Strauss and Lanese [8]	P; grade school, HS, C	I	1 season (4 tournaments)	1,049 total 291 boys 758 HS and C	11 boys 91 HS and C	3.78 injuries/100 wrestlers (HS, C) 12.0/100 athletes (HS, C)

R = Retrospective; C = college; HS = high school; D = data review; I = interview; Q = questionnaire; P = prospective; A-E = athlete-exposure

Amongst boys, the rate of injury was 3.78 injuries per 100 participants, compared to high school and college injury rates of 12.0 per 100 participants.

Injury Characteristics

Injury Onset

Although overuse injuries can and do occur in wrestling, they are few in number relative to the acute injuries, which tend to be the ones reported in the studies reviewed. Pasque and Hewett [7] specifically stated that any injury that was an aggravation of a previous injury or was a reinjury was not recorded as a new injury in their study. However, the study later reported that 6% of the athletes injured in the preseason suffered a reaggravation of that injury during the regular season. Strauss and Lanese [8] included reinjury and new injury in incidence rates, and reported that aggravation of old injuries accounted for 39% of all injuries reported. Mysnyk et al. [10] looked specifically at the incidence of prepatellar bursitis and reported that 8 of 13 athletes suffering from this condition had at least one recurrence.

Injury Location

A breakdown of the epidemiological data by location of injury is seen in table 2 [5, 7, 8, 11–17]. Review of this table reveals that the body region incurring the greatest percentage of injuries is the head/spine/trunk (range of 24.5–48%) followed by the upper extremity (range of 9.3–42%). The next highest is the lower extremity (range of 7.5–45.1%) and lastly the skin (range of 5–21.6%).

Head Injury

Concussions and other head injuries have occurred from 1–8% of all wrestling injuries [5, 7, 11]. Bruce et al. [18] documented the low incidence of major head and spine trauma in children, but showed an increase in the 15- to 18-year-old age group. Powell and Barber-Foss [14], in a 3-year high school study, found that concussions occur more frequently in matches and that takedowns were the most high-risk situation for concussion.

Ocular trauma rates are very low in the epidemiological studies shown in table 2. Forrest et al. [19] reported 2 cases of orbital blowout fractures in wrestlers. One case was from an elbow to the eye, the other from a knee to the eye.

Lee-Knight et al. [20] reviewed dental injuries at the Canada games. In this 7-day freestyle competition, 101 wrestlers aged 14–21 sustained only one dental injury. Persson and Kiliaridis [21] compared the incidence of dental and temporomandibular injuries in a group of 26 wrestlers to a matched group of controls. They found that wrestlers had more frequent severe injuries located to the

Table 2. Injury Location: percent of total injuries

Study	Konrad [12]	Patacsil [11], HS	Lorish et al. [5]	Strauss and Lanesse [8]	Requa and Garrick [13]	Powell and Barber-Foss [14]	Pasque and Hewett [7]	Lok and Yuceturk [15]	Estwanik et al. [16]	Acksel [17]	Range
Study design	P	P	P	P	P	P	P	R	R	R	
Skin	21.6		6.8				5				5–21.6
Head/Spine/Trunk	39.5	47.2	43.9	48	37.5	28.4	27	25.7	24.5	45.35	24.5–48
Head		1.2	6.3		3.6		8			3.8	1.2–8
Face/Mouth		2.5	2.3							1	1.0–2.5
Ear	23.4	16.2	0.9						7.6	17.3	0.9–23.4
Nose	1.2	2.5	1.8					3.2	5.7	0.7	0.7–5.7
Eye		3.7	4.1								3.7–4.1
Teeth		2.5								2.1	2.1–2.5
Neck	3.6	8.7	14.9					6.4		3.5	3.5–14.9
Upper back		2.5	1.4								1.4–2.5
Lower back	4.7	1.2	7.7	18.6					6.2	8.3	1.2–18.6
Rib/Chest	6.6	6.2	4.1					16.1	5	8.3	4.1–16.1
Abdomen			0.4							0.35	0.35–0.4
Upper extremity	9.3	22.4	33	20.6	29.1	32.6	42	29	26.2	32.8	9.3–42
Shoulder	3.5	7.5	16.7				24	22.6	16.2	10.7	3.5–24
Arm	0.8		1.4							1.4	0.8–1.4
Elbow	1	3.7	3.6				7	3.2	5	7.9	1.0–7.9
Wrist	2.8		2.7					3.2		4.8	2.7–4.8
Forearm											
Hand/Finger	1.2	11.2	8.6		5.9				5	8.6	1.2–11.2
Lower extremity	7.5	29.9	15.4	31.4	33.3	27.2	31	45.1	42.3	24.45	7.5–45.1
Pelvis/Hip		2.5	1.8					3.2		2.1	1.8–3.2
Thigh		2.5			1.2			3.2		0	0–3.2
Knee	1.2	13.7	7.7		19.6	14.8	17	29	38.4	9.3	1.2–38.4

Leg			0.9								0.9
Ankle	6.3	8.7	3.2		5.4			9.7	3.9	9.7	3.2–9.7
Heel/Foot/Toe		2.5	1.8							0.35	0.35–2.5
Other	21.4		0.9				3		7.1	0.35	
Total number of injuries	735	80	221	102	168	2,910	219	31	666	289	
Total number of participants	4,835	907	1,742	1,059	234	522,608	418	128		2,032	

P = Prospective; R = retrospective.

frontal region of the maxilla than controls, but found no increased incidence of temporomandibular joint disorders or dental caries.

Kvittem et al. [4] reviewed orofacial injuries at seven high schools during one school year. They found that 69.9% of wrestlers sustained some type of orofacial injury. Most of these were lacerations and contusions. Dental injuries in this study accounted for 10% of the overall total.

One of the classic injuries of wrestling is acute or recurrent auricular hematomas resulting in 'cauliflower ear' or 'wrestler's ear'. Although it is possible to incur these injuries while wearing headgear, most occur when the wrestler is not wearing headgear. In an early study of high school wrestlers, only two of forty-nine coaches (4.1%) required their wrestlers to wear headgear [18]. In the few studies which have documented ear injuries, these have comprised from 1.7 to 24.6% of the total number of wrestling injuries.

Data on injuries occurring to the nasal region have been collected in several studies [5, 11–17]. As table 2 reveals, these injuries range from 0.7% as reported by Acksel [17] to 5.7% of total injuries recorded by Estwanik et al. [16].

Neck Injury

In a variety of prospective and retrospective epidemiological studies of wrestling injuries, neck injuries were 0.8–14.9% of the total number of injuries [5, 11, 12, 15, 17, 22].

A cervical strain is a tear of one of the musculotendinous units in the neck. The spectrum of injury ranges from mild to moderate, with rupture being extremely rare. These account for approximately 50% of neck injuries in wrestling.

Both Torg [23] and Boockvar et al. [24] have studied cervical cord neurapraxia in athletes. Torg [23] found that 87% of the cases occurred in football and only 2% in wrestling. Boockvar et al. [24] found 13 children, ages 7–15 years, with cervical cord neurapraxia. Two of them were wrestlers.

Upper Extremity

Upper extremity injuries are also commonplace in the sport of wrestling due to the heavy forces placed on this region and the extreme positions that can occur during wrestling [5, 13]. Table 2 outlines that these injuries have been reported anywhere from 9.3 to 42% of all injuries. The shoulder had the highest proportion of injury, as high as 24% of total reported injuries. The upper arm had the lowest reported frequency of upper extremity injury ranging from 0.8 to 1.4%.

Percentage of shoulder injuries has been reported in the range of 3.5–24% of wrestling injuries in the pediatric population, and occur second only to injuries occurring at the knee [7, 12]. A recent prospective study showed shoulder injuries to be the most common overall injury in a high school wrestling population, at 24% of the total injuries reported [7].

Several case series of ruptures of the pectoralis major have been reported. Bak et al. [25] reported on 87 athletes with pectoralis major ruptures, 10 of whom were wrestlers. Pavlik et al. [26] reported on 7 athletes, 4 of whom were wrestlers. All patients had successful surgical treatment. The final case reported by Berson [27] was also treated with early surgical repair. Other shoulder injuries occurring in wrestlers have been documented in a variety of case reports. Those include documented injuries to the suprascapular nerve, subscapularis tendon, sternoclavicular joint and avulsion fractures of the scapula and lesser tuberosity [28–32].

Elbow injuries are sustained less frequently than shoulder injuries but appear to be more severe. In the prospective and retrospective studies shown in table 2, elbow injuries accounted for 1.0–7.9% of all wrestling injuries. The most common elbow injury is the hyperextension abduction sprain affecting the ulnar collateral ligament and the anterior capsule. Younger wrestlers appear to be susceptible to various types of avulsion fractures about the elbow, including the olecranon and the medial humeral epicondyle [33–35].

Injuries to the hand are almost always minor. Fractures or dislocations occur uncommonly. As shown in table 2, hand and wrist injuries accounted for 1.2–11.2% of all injuries. The most common hand injuries are metacarpophalangeal sprains, proximal interphalangeal sprain, and thumb metacarpophalangeal ulnar collateral ligament sprain (gamekeeper's thumb).

Trunk and Spine

As shown in table 2, low back injuries have comprised from 1.2 to 18.6% of total wrestling injuries in prospective and retrospective studies. Estwanik et al. [16] also noted that 25% of the wrestlers in his study presenting with back pain had spondylolysis or spondylolisthesis; 58% of his patients were diagnosed with lumbar strain. Rossi and Dragoni [36] reviewed the radiographs of 3,132 athletes aged 15–27 who were evaluated for low back pain over a 26-year period. Wrestlers with back pain had a 29.8% prevalence of spondylolysis (17 of 67 wrestlers).

Injuries to the rib and chest comprise 4.1–16.1% of total injuries in prospective studies. Most of these injuries are contusions or costochondral sprains, but rib fractures are also common. Injuries to the rib cage can result from direct or indirect trauma.

Among the prospective and retrospective studies documented in table 2, abdominal injuries account for only 0.35–0.4% of the total number of injuries found in wrestling. Diamond [37] described abdominal wall contusions as the most common injury, characterized by tenderness only in the area affected with no referred pain.

Table 3. Knee injuries

Study	Study design	Injuries/ total (%)	Significant injuries/ total (%)	Sprains (% of total)	Lateral meniscus/ medial meniscus (ratio)
Lorish et al. [5]	P	17/221 (7.6)			
Requa and Garrick [13]	P	33/176 (18.7)			
Powell and Barber-Foss [14]	P	430/2,910 (14.8)			
Pasque and Hewett [7]	P	38/219 (17) Range 7.6–18.7%			
Estwanik et al. [16]		256/666 (38.4)		77 (30)	41/48 (.46)
Lok and Yuceturk [15]		9/31(29) Range 29–38.4%			

P = Prospective.

Lower Extremity

A summary of studies reporting on the frequency of knee injures is shown in table 3 [5, 7, 13–16]. In prospective studies, knee injuries range from 7.6 to 18.7% of all wrestling injuries. In the only study with the percentage of knee injuries below 10%, Lorish et al. [5] described injuries in tournaments to wrestlers aged 6–16 years. A liberal injury definition was used that required only that medical attention be sought. A study of high school wrestlers showed that knee injuries were the most common season-ending injuries, and represented 44% of the total [7].

Common knee injuries include prepatellar bursitis, medial and lateral collateral ligament sprains, and medial and lateral meniscus tears. The most common knee injuries are sprains, which constitute 30–65% of the total number of knee injuries. Meniscal injuries are also common, with a relatively high proportion of lateral to medial meniscus tears. In the two studies that broke this down, lateral meniscus injuries represented 46% of the total number of meniscal injuries [16], and there were 45% lateral versus medial meniscectomy in a study of 56 meniscectomies in wrestlers [38].

Mysnyk et al. [10] documented 28 cases of prepatellar bursitis, representing 21% of all knee injuries. Of the bursitis cases 50% were recurrent injuries. Eight cases of septic bursitis were reported. Anterior cruciate ligament injuries were noted in 14 of 256 knee injuries in one study [16]. Stanish et al. [39] presented 2 cases of isolated posterior cruciate ligament rupture in Canadian National Team members. He described the mechanism being forced flexion and internal rotation, which occurs in several wrestling maneuvers.

In prospective studies, ankle injuries range from 3.2 to 9.7% of all wrestling injuries. Garrick [40] described the results of the first year of the Seattle High School injury study. Ankle injuries were 6/105 (6% of wrestling injuries in that portion of the study). The most common ankle injury is the lateral ligament sprain, which most often occurs during takedowns.

Action or Activity

Due to the many different situations encountered in any individual match, the exact mechanism of injury is not always easily identified. In most cases, the injuries are the result of a situation during a wrestling match and not due to a specific move. In addition, there is also wide variability in the reporting of offending maneuvers, thus making accurate determinations of injurious moves difficult at best [7].

Knowledge of when injuries are most likely to occur can be of great assistance in prevention methods and in organizing medical coverage for wrestling events. During their study on catastrophic high school wrestling injuries, Boden et al. [2] noted that the takedown was the most common activity occurring during catastrophic injury, and that the athlete was at a disadvantage 74% of the time. Pasque and Hewett [7] reported that most of the injuries in their studies occurred during takedown, but more specifically, when the athlete was at a disadvantage or in the defensive position. Hoffman and Powell [3] also cites the takedown as the most injurious action.

Strauss and Lanese [8] reported no difference between injury rates occurring during takedown and mat wrestling. Only Kersey and Rowan [9] reported that mat wrestling had a higher rate for injury (49%) than takedown (24.5%). This high rate of injuries during mat wrestling may be a reflection of the way in which injuries were reported in the study. Any instance in which an official halted a match was recorded as an injury.

The most common wrestling situation resulting in injury is the takedown position in which both wrestlers are in the standing position attempting to take the other down to the mat [7, 13]. Most of these injuries occur in the defensive wrestler, since they are at the mercy of their opponents while trying to protect themselves as they are being taken down to the mat. The higher occurrence of injury in the takedown position is likely attributable to the high intensity, speed and forces involved when trying to take the opponent to the mat, especially in older athletes. There is also a higher likelihood of more time spent in this position due to the increasing emphasis on takedown moves for scoring points in all forms of wrestling [7].

Chronometry

Lorish et al. [5] was unable to calculate injury by match, but could determine an injury rate of 3% for all wrestlers in the first period. Strauss and Lanese [8] reported the greatest number of injuries to be in the second period, not the third as they hypothesized. Pasque and Hewett [7] also reported a trend toward more injuries in the latter half of practice and during the second and third periods. This finding, however, was not statistically significant and therefore suggests that fatigue may not be a factor that increases risk of injury.

The overall pattern of training during the season may also affect injury rates. Patacsil [11] found that the majority of injuries, 123/200 (61.5%), occurred in the first half of the season. Early in this season, more wrestlers are vying for starting roles and more are preparing for their first tournaments of the year. Wrestle-offs for spots on the team also occur during the first month of the season. Intensity may subsequently diminish because many wrestlers resolve themselves to non-starting status and do not push themselves as hard. Early season tournaments may present an increased risk. Wrestlers' conditioning has not reached optimum levels and with multiple matches in a day, it is easy for a minor injury to evolve into a significant injury.

Injury Severity

Injury Type

Common general injury categories in pediatric wrestling include muscle strains, joint sprains, concussions, contusions and abrasions or lacerations. Muscle strains usually involve the shoulder or lower back. Joint sprains usually involve the ankle, knee or hand/wrist regions. Contusions typically involve the knee, chest and head. Abrasions or lacerations almost always involve the face area [7], but can also occur on the extremities.

Head/Spine/Trunk

Injuries to the head from wrestling, mainly concussions, occur by head-to-head or head-to-knee collisions during takedowns. Concussions are also produced by contact with the wrestling mat or the floor surrounding the wrestling mat area. The head-injured athlete should always be assumed to have sustained neck trauma as well, and further evaluation, management, and possible transportation should take place.

Acute facial trauma can be a common problem in any age group [17]. Most injuries involve nose bleeds or minor abrasions that require only local wound care. Facial lacerations can occur, and usually involve the periorbital region, mouth or chin region. Nosebleeds occur commonly due to a combination of trauma and drying of the nasal mucosa secondary to relative dehydration and generally low ambient-relative humidity in gyms and wrestling rooms. Most occur in the anterior chamber of the nose and arise from the lower portion of the septum [4, 41]. Periorbital contusions causing severe edema swelling or subcutaneous hematomas can occur from a blunt blow, such as a head-to-head collision, and can result in blockage of vision.

Auricular hematoma or 'wrestler's ear' is usually a chronic problem due to repetitive friction injuries to the external ear from improper headgear or from not wearing any at all [16, 42]. Dental injuries are another area where occasional injuries occur with severe blows to the face, especially in young wrestlers with braces [4]. Most involve only oral lacerations, but some can include tooth fractures or avulsions.

Spine injuries have been reported in some studies, with most involving the cervical [9] or lumbar areas [5, 13]. Noncatastrophic injuries to the neck are common despite generally superior neck muscle strength among wrestlers. A common mechanism for a neck injury occurs during a takedown when the wrestler drives into his opponent with his neck, hyperextending it while 'shooting'. This can cause sprains, strains, and neurological trauma such as stingers. In rare instances, severe fractures, subluxations or dislocations of the spine occur and can result in devastating catastrophic injuries [2, 6].

Most commonly due to traumatic stretching or pinching of the brachial plexus or nerve roots, stingers occur almost exclusively during takedowns. The most common mechanism is forced hyperextension with ipsilateral flexion or extension when a wrestler 'shoots' a takedown with his neck bulled, striking his opponent's chest or thigh with his forehead. Vaccaro et al. [43] documented three different mechanisms for stingers: the compression mechanism, a stretch mechanism which occurs when the head and neck are displaced to the contralateral side of the shoulder and the plexus is stretched, and a direct mechanism when a direct blow is received to the posterior triangle of the neck under which lies the brachial plexus.

Lower back injuries in wrestling commonly take place during takedowns. While sparring for position, wrestlers push against each other with the lumbar spine in mild hyperextension. This extension, coupled with twisting, results in injuries. Extension against resistance, as in lifting an opponent off the mat, and hyperflexion, as in rolling, are also mechanisms that account for low back sprain or strain.

Upper Extremity

Upper extremity injuries are also common in wrestling due to the heavy forces placed on this region and the extreme joint positions that can occur during live wrestling [5, 13]. Most of these injuries are self-limiting such as rotator cuff strains and contusions, but many result in significant lost time, such as acromioclavicular separations and glenohumeral subluxations or dislocations. A common mechanism for injuring the shoulder occurs when being thrown to the mat from a standing position. The wrestler may attempt to brace his fall with his extended arm, imparting force to the shoulder girdle. However, if he is unable to extend his arm, the fall may be taken directly on the shoulder.

Lower Extremity

The lower extremity has classically been held as the most commonly injured area in wrestling. The knee is usually the main area of injury [16], with the ankle a close second [8]. The medial and lateral collateral ligaments are at risk due to the potential for varus, valgus and rotational stresses. Effusion, if present, is usually indicative of a meniscal or articular cartilage injury [38]. Meniscus injuries occur most commonly via a twisting injury to a weight-bearing extremity. If a severe injury occurs with rapid effusion and pain, this usually indicates a more severe injury such as an anterior cruciate ligament tear or a patella dislocation. These injuries are usually season ending and often require surgical intervention. Prepatellar bursitis is another common type of knee injury, and is fairly unique to wrestling [10, 16].

The most common ankle injury is usually the lateral ligament complex sprain from an inversion injury, with the occasional distal fibula fracture occurring with more severe injuries. High ankle sprains can also occur and are usually due to forced external rotation injuries to the ankle-foot region. These are more severe, and can result in significant time lost.

Foot injuries are fairly rare in wrestling, especially in the younger athletes. Occasional mid-foot sprains occur due to severe twisting injuries to this region. First metatarsal-phalangeal joint injuries equivalent to a football 'turf-toe' injury can occur due to repetitive hyperextension injuries to the first ray region.

Skin

Skin infections continue to be a problem in the sport of wrestling. Most skin infections are caused by a fungus ('ringworm') or the herpes virus and occasionally involve staphylococcus or streptococcus bacterial infections. The location of infection is usually in areas of high contact with other wrestlers such as the head and neck region or the upper extremity [44, 45]. Immediate proper identification and isolation of infected wrestlers prevents outbreaks among teams or tournament participants [46, 47].

Catastrophic Injury

Catastrophic injuries can occur in wrestling [2, 6]. Most catastrophic injuries involve severe rotational or axial blows to the cervical and head region that can result in fractures or dislocations with or without head trauma.

The reports of these types of injuries are summarized in table 4 [36, 48–66]. Various case reports have appeared in the literature describing catastrophic injuries to other anatomical locations, and are also summarized in the table.

Mueller and Cantu [48] published an annual report from the National Center for Catastrophic Sports Injury Research (NCCSIR). Data for this ongoing study were obtained from clipping services, individuals, and from the National Federation of State High School Associations. Mueller et al. [48] described 46 catastrophic high school injuries, 2 of which were fatal, and one catastrophic college injury. The rate of direct catastrophic injury in high school was 0.97 per 100,000 wrestlers and 0.72 per 100,000 wrestlers for college competition. Mueller et al. also documented indirect fatalities over that 20-year period, 14 in high school and 3 in college.

The studies by Laudermilk [49] and Boden et al. [2] analyzed NCCSIR data specific to wrestling. Laudermilk [49] reviewed 1982–87 data from the NCCSIR. Fifty percent of the 24 injuries involved the cervical spine, spinal cord or head. Other problems were cardiac arrhythmia, cardiomyopathy, respiratory arrest, pulmonary embolism, and unspecified cardiac disease. Forty-two percent of the injuries occurred during takedown and 71% occurred during matches. Boden et al. [2] reviewed the NCCSIR data from 1981 to 1999. He documented 35 cases of catastrophic injuries, 34 among high school wrestlers and one among college wrestlers. Of the 35 injuries, 17 were classified as nonfatal, 17 serious, and one fatal. The rate of catastrophic injuries was about one per 100,000 participants. Of the 27 cervical spine injuries, 15 resulted in permanent disability, and 12 achieved full recovery. There were 4 cases of transient quadriplegia, 3 severe head injuries, one herniated disk, and one death. They defined the at risk settings: the wrestler defending on a takedown and match competition as opposed to practice.

Clarke [50] sent surveys to state high school associations and to individual colleges, defining a catastrophic injury as one causing permanent paralysis or death. From 1973 to 1975, 8 injuries were found, all at the high school level. All resulted in permanent spinal cord injury, none in death. In 1989, Bailes and Maroon [67] reported on cervical spine injuries in athletes. Four percent of the total admissions to their spinal cord unit were related to sports injury.

In 1991, Bailes et al. [1] described a series of 3,200 spinal cord injuries at two centers over a 12-year period from 1975 to 1987. Two percent of these admissions were sports-related. 45 of the injuries were permanent. There were 13 injuries due to wrestling. Of these, 10 were spinal cord injuries, and 3 were fractures/subluxations without neurological injury. Five of the cervical cord injuries were permanent and 5 achieved a full recovery. Several other spinal cord injuries have been reported and are also summarized in Table 4. A very low incidence of major head and spine trauma has been documented in children, but the incidence increased in the 15–18-year-old group [18].

Table 4. Catastrophic injuries

Study	Level	Study design	Data collection methods	Duration	Number of injuries	Rate	Condition
Mueller/ NCCSIR [48]	HS, C	R	Q	20 years (1982–2002)	46 HS (2 fatal, 28 nonfatal, 16 serious), 1 C (1 nonfatal)	HS 0.97/100,000 wrestlers, C 0.72/100,000 wrestlers	
Mueller/ NCCSIR [48]	HS, C	R	Q	20 years (1982–2002)	indirect – 14 HS (14 fatal), 3 college (3 fatal)	HS 0.30/100,000 wrestlers, C 2.16/100,000 wrestlers	C dehydration/weight-loss related: hyperthermia, rhabdomyolysis
Boden et al. [2][b]	HS, C	R	Q	19 years (1981–1999)	35 (1 fatal, 17 nonfatal, 17 serious)		27 SCI (15 permanent, 12 full recovery), 4 CCN, 3 head, 1 HNP
Laudermilk [49][b]	JHS, HS	R	Q	5 years (1982–87)	24 (8 serious, 6 nonfatal, 10 fatal)	1.07/100,000 wrestlers	12 cervical/head, 12 cardiac/systemic
Bailes et al. [1]		CS			13 (10 SCI, 3 fracture/ subluxation)		5 SCI permanent, 5 SCI full recovery
Clarke [50]	HS, C	R	Q	3 years	8 HS, 0 C		8 permanent SCI[a]
Kewalramani and Krauss [51]		R	I		5		5 SCI (5 permanent)

Acikgoz et al. [52]	HS, S	CS	I	4	4 SCI (1 full recovery, 2 permanent, 1 fatal)
Wu and Lewis [53]	HS	CS	I	3	3 SCI (3 permanent)
Rontoyannis et al. [54]	HS	C		1	1 SCI (1 fatal)
Rogers and Sweeney [55]	HS	C		1	stroke
Cohn et al. [56]	HS	C		1	11th cranial nerve injury
Croyle et al. [57]	HS	C		1	pulmonary embolism
Baratta et al. [58]	Y	C		1	auxillary artery disruption with/shoulder dislocation
McCormack and Bliss [59]	HS	C		1	ruptured diaphragm
Tudor et al. [60]	HS	C		1	Pott's puffy tumor, sinusitis, osteomyelitis, and epidural abscess
Romner et al. [61]	S	CS		1	carotid art dissection
Annenberg et al. [62]	HS	C		1	femoral artery pseudoaneurysm
Rossi and Dragoni [36]	HS	C		1	subclavian artery pseudoaneurysm
Thomas and Noellert [63]	HS	C		1	brachial artery disruption/ elbow dislocation

Table 4. (continued)

Study	Level	Study design	Data collection methods	Duration	Number of injuries	Rate	Condition
Schaefer and Voight [64]	HS	C			1		brachial artery disruption/ elbow dislocation
Pearsall and Russell [65]	HS	C			1		long thoracic nerve injury with/clavicle fracture and spinal cord subluxation
Medler and McQueen [66]	HS	C			1		subclavian vein thrombosis

[a] Spinal cord injury. Permanent indicates residual paralysis.
[b] Detailed analysis of NCCSIR data.
HS = High school; S = school; JHS = junior high school; C = college; CS = case series; Q = questionnaire; I = interview; SCI = spinal cord injury; CNN = cervical cord neurapraxia; HNP = herniated nucleus pulposus.

Injury Risk Factors

Exposure

The risk of injury increases as exposure to injurious situations increases. Only one pediatric wrestling study actually examined injury rate with reference to exposure. Pasque and Hewett [7] considered one wrestler participating in one practice or match, in which he was exposed to the possibility of injury as the definition of athlete-exposure.

Many studies report on the incidence of injury occurring in practice and competition. Incidence rates are higher during competition, but more injuries occurred during practice because significantly more time is spent in practice. Pasque and Hewett [7] reported that 63% of their injuries occurred in practice, while only 37% of the injuries occurred during competition. Matches lasted 6 minutes for a total exposure rate of 8,885. When injuries were expressed in terms of exposure, a rate of 5 injuries per 1,000 practice-exposures as compared to 9 per 1,000 match-exposures occurred.

Boden et al. [2] reported a significantly greater number of catastrophic injuries occurring during match competition (80%). This study further reported that approximately 86% of the catastrophic injuries that occurred during practice happened during live wrestling.

Increasing the level of competition and the amount of time-spent wrestling will increase the exposure of a wrestler to injury. Strauss and Lanese [8] studied injury patterns occurring at a boys' tournament, one high school, and two college tournaments. The boys had the lowest injury rates, but also spent the shortest amount of time exposed to injury, with matches lasting only 3 min. The high school matches lasted 6 min, and the college matches lasted up to 8 min.

Pasque and Hewett [7] studied injuries among high school wrestlers over the course of one season and reported that the injured wrestlers had significantly more years of wrestling experience. There was a trend toward more injuries occurring at the varsity level. Varsity wrestlers comprised 44% of the study, but accounted for 60% of the injuries. This may be the result of more aggressive wrestling at that level. Pasque and Hewett [7] also found a slightly higher rate of injury for those who wrestled year round, though not statistically significant.

Training Methods/Conditioning

Few data are published on training conditions as risk factors in wrestling, but anecdotal observations can be made. Inadequate supervision of a wrestling team, especially in younger athletes, may increase injury risk by lack of monitoring potentially dangerous situations and techniques, and the inability to discourage horseplay. Inadequate wrestling technique may also increase injury risk. Boden's [2] study on catastrophic injuries suggests that the inexperienced wrestlers may get themselves into precarious situations that predispose them to a serious injury. One of the injured wrestlers in that study had attempted to extricate himself out of a situation, but the full weight of his opponent landing on him caused serious neck injury. Another instance occurred when a wrestler was unable to protect himself from landing on his head while being slammed to the mat by his opponent. Boden et al. [2] also report that poor officiating, rules infractions, and dangerous moves were probably to blame for 11 of the 54 catastrophic injuries in that study.

Puggelli [68] made specific recommendations for wrestling coaches in regard to training factors. He emphasized careful drilling of steps in a technique, organization of practice so that all bodies move in generally the same direction and teaching moves commensurate with the physical capabilities of the athletes.

Protective Equipment/Facilities

In wrestling there is not much extraneous equipment, but what little there is may be a factor in sustaining injury. Headgear is mandated most for competitions, but there is otherwise very little gear worn in wrestling. Although the headgear does not always prevent injury, it does offer protection from serious auricular injury [69]. In Boden's [2] study, headgear played at least a small role in 2 athletes suffering a catastrophic injury when the strap got caught on the mat. Absence of headgear is a risk factor in sustaining auricular hematoma. If the headgear is not properly fitted, the sweat on a wrestler's head can cause the headgear to slide and result in a hematoma by abrading the external ear. The role of knee pads, shoes, and mouth guards have not been evaluated, but in other sports they have been effective in preventing injuries.

The wrestling mat is, by far, the largest piece of equipment used in wrestling. A mat in good condition is essential for aiding in the prevention of serious injuries. Placement of objects close to the mat must be carefully monitored and padded. Mysnyk's [10] study of prepatellar bursitis in college wrestlers showed a much higher incidence (69%) in the off-season when compared to the regular season. The use of older, de-conditioned wrestling mats during the off-season is cited as the potential reason. If mats are in poor condition, their ability to absorb shock may deteriorate, and thus increase injury risk when wrestlers land on them. A second major item is cleanliness of the mats. Without daily disinfection, counts of microorganisms on the mat will theoretically increase, and hence increase the chance of transmission of dermatological infections from mat to wrestler. Unpadded walls, obstacles such as columns or bleachers, inadequate space, and extreme heat or humidity are obviously detrimental. Antonacci [70] recommended appropriate padding of walls and any objects near mats as well as appropriate ventilation and lighting and mat washing technique in his preventive program.

Mouthguards are not a required piece of equipment for wrestling, as they are for other sports like American football and hockey, therefore their use is low. Kvittem et al. [4] studied orofacial injuries in high school and reported that about 70% of the wrestlers in that study sustained at least one injury. Utilization of mouthguards amongst wrestlers was only 5.6%. In Lee-Knight's [20] study, no wrestler used a mouthguard. In another study by Diab et al. [71], 359 parents of children aged 7–18 years were surveyed about the mouthguard usage in a variety of sports. Only 29% of children wore mouthguards. Parents reported 206 instances of oral trauma. Eighty-eight percent of these injuries occurred without mouthguards and only 12% with mouthguards. Most injuries were contusions and lip lacerations, but 'chipped teeth' were also documented. Wrestlers cited several reasons for not wearing mouthguards. These included poor retention secondary to fit, discomfort, and interference with breathing or speech.

Persson and Kiliaridis [21] also examined dental injuries among wrestlers and found them to suffer more injuries than the controls. Considering that US football, ice hockey, and rugby players have seen a drastic decrease in dental injuries with mouthguard use, wrestlers would also likely see a decrease with its use.

Dehydration and Weight Loss Methods

Wrestlers often lose large amounts of weight in a short period of time. Fluctuations in weight may occur frequently throughout the season [72]. Studies of weight loss practices among high school and college wrestlers indicate that some 3–20% of the preseason body weight is lost prior to certification or competition. Most of this weight loss occurs on the final day or days before the official weigh-in, with the youngest and/or lightest team members, losing the highest percentage of their body weight.

The effects of acute and prolonged dehydration are significant reductions in blood plasma volume, performance, and muscular strength [73–77]. Aerobic performance is affected to a much larger degree than the anaerobic performance [78]. When fluid loss exceeds 2% of normal stable body weight, significant changes occur during submaximal work, which include elevated heart rate, reduced stroke volume, and lowered cardiac output. These changes in cardiovascular function are potentially dangerous especially in combination with an elevated core temperature, altered electrolyte balance, and possible renal changes [79]. Current rules call for weigh-in to take place within a maximum of one hour and a minimum of one-half hour before the scheduled start time of a dual meet. But, even when 5 hours is allowed between weigh-in and the match, time is not sufficient for restoration of electrolyte balance and replenishing muscle glycogen concentration [75, 79]. The practice of fluid deprivation has been discouraged by the American College of Sports Medicine [73].

Suggestions for Injury Prevention

Equipment

Wrestling is an aggressive contact sport, and will never be free from potential injury situations. However, by examining how injuries occur, we can gain insight into their prevention. Having adequate practice space for the wrestlers can lead to the avoidance of many injuries. Snook [22] recommends providing at least 100 square feet per wrestling pair whenever possible. Larger practice areas prevent pairs of wrestlers rolling into each other or other objects like walls.

Injuries due to direct blows, forces or falls will likely never be completely eliminated given the physical nature of the sport, but certain measures are helpful in decreasing injuries. High quality mats of proper material and thickness (1½–2″) are crucial to the overall safety of the wrestler. It is important to replace or recondition wrestling mats when they become worn. In addition, proper padding should be placed over any hard objects around the mat such as hard wood or concrete floors, walls or scoring tables.

Wearing properly fitted headgear for practice and competition is also recommended. Although wearing headgear is mandatory for most competitions, it is not a required piece of equipment for practice. Even though most coaches believe headgear to be effective in preventing serious auricular injury, many do not mandate its use for practices. It is recommended that headgear have a sufficient number of straps to fix the headgear firmly on the head and with deep enough earpieces so that there is no contact between the ear itself and the headgear. We often add a ¼–½″ thick high-density foam 'donut' around the earpiece to further increase its depth. Headgear is currently required during all matches. It is also recommended they be worn by all wrestlers at all practices.

Mouthguards have never been a standard piece of equipment used by wrestlers. Most wrestlers do not wear them due to poor fit or difficulty breathing. Use of well-fitted mouthguards during practice and competition may prevent irreversible dental injury.

Coaching and Refereeing

Many wrestlers are inexperienced, especially at the middle- and high-school levels, and thus close attention to proper technique is essential for a safe competition. Boden et al. [2] recommends that coaches teach wrestlers to keep their heads up when performing shooting or takedowns, to avoid axial compression or flexion of the spine leading to serious injury. This is already common practice among football coaches when teaching the tackling the technique. Better attention by wrestling officials to rules infractions and dangerous moves can also be crucial in preventing serious injury.

Pasque and Hewett [7] suggest that limiting the amount of time spent practicing live wrestling may decrease the incidence of injuries occurring during practice. Wroble [80] recommends beginning practices earlier in the season, and delaying the onset of competition to allow for wrestlers to be better prepared for competition.

Referees must remain in control of the match at all times. A solid, aggressive wrestling match is a safe athletic event as long as the referee is able to control the tempo of the match and prevent volatile tempers from getting out of hand. The referee must know illegal or potentially dangerous moves, and how to anticipate them. This is especially important in preventing improper slams to the mat or other potentially injurious moves. Such moves must be anticipated and prevented when possible, and penalized heavily when they occur.

Healthcare Team

Having an appropriate healthcare system in place prior to the start of the season is important. The healthcare team should consist of a minimum of a team physician and an athletic trainer. Ideally, an athletic trainer should be present at all practices and competitions, and the team physician at all competitions. Prior to the start of the season, all athletes would undergo a preparticipation evaluation, including an orthopedic screening, to detect any potential preexisting conditions. Wroble [80] suggests outlining treatment protocols and having strict guidelines for return to competition following injury.

Preseason protocols should be established for handling emergency situations during both practices and matches. A medical professional team and good communication with other healthcare professionals in the community is essential. It is necessary to discuss in advance with the local emergency response team how emergency situations will be handled. The medical team should enlist the services of a good dentist to assist with properly fitted mouthguards. Consulting with a local dermatologist may also be beneficial in handling some of the skin infections that will invariably occur.

Training: Neck Injury Prevention

Prevention of cervical spine injuries is facilitated by rules in amateur wrestling banning all holds that result in a wrestler being thrown to the mat out of control, particularly with spearing of the head and shoulders to the mat. Preseason history and physical examination are very important in screening for previous neck injuries in wrestlers. At the time of entry into high school or on starting in a new program, radiographs of the cervical spine should be obtained on those individuals who have either a positive history or physical examination for previous neck injury. Supervision by physicians and athletic trainers plays a great role in the reduction of neck injuries by establishing and enforcing strict return to action criteria.

Proper management of neck injuries should be a thoroughly familiar procedure to all medical personnel involved in the care of participants in high-risk sports and should include cardiopulmonary resuscitation as well as the acute care of head and neck injuries. The athletic trainer or the physician, or both, should make the coaching staff aware of the occurrence of minor head and neck injuries, and identify those athletes at high risk. Coaches should also be taught the importance of preseason neck strength conditioning and the signs and symptoms that are important to recognize in the injured wrestler. Strength, endurance, and flexibility are important elements in decreasing the frequency of neck injuries. A neck exercise program should therefore be incorporated into each team's conditioning program.

Nutrition

Fluid Replacement

Dehydration compromises an optimal performance and, if allowed to become severe, may be life-threatening. Thirst is an unreliable mechanism for determining hypohydration and fluid replacement, and athletes need to drink beyond satisfying thirst to rehydrate. Fluids should be taken before, during, and after exercise. While cold water appears to be a good fluid replacement, carbohydrate-electrolyte drinks can also be used effectively. When choosing a replacement fluid other than water, the most important factor to consider is promotion of rapid gastric emptying. Gastric emptying is affected by volume, temperature, and caloric content. Increasing fluid volume (up to 500 ml) and decreasing fluid temperature will increase gastric emptying. Increasing caloric content, the most important factor, decreases the gastric emptying rate. During exercise, however, dilute glucose solutions are emptied as quickly as water [81].

Athletes may find it uncomfortable to exercise after a large volume of fluid is consumed, and may therefore, prefer smaller amounts taken every 10–15 min. Ideally, the drink should contain a glucose concentration of less than 2.5 g/100 ml H_2O, as higher level of glucose will significantly slow gastric emptying. Low levels of potassium and chloride ions should be present, but only become vital with extreme, prolonged exercise. All fluids should be taken cold.

Energy Expenditure

Weight control is an important aspect of wrestling, and wrestlers should understand the basic principles of nutrition. Information provided by a qualified professional can minimize misinformation. Calorie expenditure for wrestling is 14.2 kcal/min [82]. In general, daily calorie consumption should not fall below 2,000 kcal to ensure that the nutrient needs of training and growth are met [83].

Wrestlers who are in negative calorie balance compromise their ability to synthesize glycogen. An adequate carbohydrate intake is essential for maintenance and repletion of glycogen stores, as carbohydrate for the wrestler contribute 55–60% of total caloric intake. While protein is essential for synthesis and repair of muscle, protein intake above 15% of total calories did not provide any added benefit [84]. Once protein needs are met, excess is either utilized for energy or converted to and stored as fat. Fat, though a valuable source of energy for athletic activity, should not exceed 20–30% of total calories.

Suggestions for Further Research

Future epidemiological research in youth wresting injuries is required. There are few studies currently available in the literature for the youth level in wrestling. There is not enough information regarding even the first stage of the epidemiology-etiology-prevention measures-epidemiology cycle that is necessary for beginning the attempt to reduce injuries in youth wrestling. There is a need for large-scale epidemiological studies of high school, middle school and club teams. Studies designed to address this specific research question must be attempted. However, there is a need for the larger, basic epidemiological studies of injuries in youth wrestling. The prevention of injuries in youth wrestling requires quality epidemiological research. The future is bright for epidemiological researchers interested in the study of youth wrestling.

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Injury Prevention and Future Research

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Abstract

Objectives: To critically examine and summarize the literature identifying risk factors and prevention strategies for injury in child and adolescent sport. **Data Sources:** Seven electronic databases were searched including: Medline, Cumulative Index to Nursing and Allied Health Literature (CINAHL), Psychinfo, Cochrane Database for Systematic and Complete Reviews, Cochrane Controlled Trials Registry, HealthSTAR and SPORTDiscus. Medical subject headings and text words included: athletic injury, sport injury, risk factors, adolescent and child. Additional articles were reviewed based on sport-specific contributions in the previous chapters of this book. **Main Results:** Despite the diversity of injuries occurring in various pediatric sporting populations, the uniformity with respect to many of the risk factors identified in the literature is noteworthy (i.e. previous injury, age, sport specificity, psychosocial factors, decreased strength and endurance). The literature is significantly limited with respect to the prospective evaluation of risk factors and prevention strategies for injury in pediatric sport. The consistencies, however, between the adult and pediatric literature are encouraging with respect to prevention strategies involving neuromuscular training programs (i.e. balance training programs) to reduce lower extremity injuries in some sports and the use of sport-specific protective equipment (i.e. helmets). **Conclusions:** Notwithstanding the limitations in the literature, the successful evaluation of some sport-specific prevention strategies to reduce injury in pediatric sport is encouraging. There is significant opportunity to methodologically improve upon the current pediatric sport injury literature in descriptive surveillance research, risk factor evaluation research, and prevention research. There is a need for prospective studies, ideally randomized controlled trials, in the evaluation of prevention strategies in pediatric sport. The integration of basic science, laboratory and epidemiological research is critical in evaluating the mechanisms associated with injury and injury prevention in pediatric sport. Finally, long-term studies are needed to identify the public health impact of pediatric sport injury.

Introduction

Sport injuries in children and adolescents may be predictable and potentially preventable [1, 2]. However, it is impossible to eliminate all injury in youth sport. In some sports, the number and severity of injuries can be reduced through various injury prevention strategies. Though there is less research evidence specifically for the prevention of injuries in youth sport than in adult and elite sport, the impact of sport injury in this population warrants attention.

Participation in physical activity by children and adolescents has important implications for individual and public health benefits. Based on the Canadian Population Health Survey, 65% of adolescents reported participation in regular physical activity at least 12 times per month [3, 4]. For adults, this has decreased significantly to less than 40% of the population over 18 participating in regular physical activity [4]. Similar findings are reported in other countries [5–9]. On average, children 5–12 years spend 18 h per week doing physical activity and youth 13–17 years 15 h per week [3, 4]. This provides ample opportunity for sport injury in this population. Also, 8% of adolescents drop out of recreational sporting activities annually because of injury [8].

Reduction of sport injury would have a major impact on quality of life through the maintenance and promotion of physical activity. There is epidemiological evidence that level of physical fitness is a significant predictor of all-cause mortality, morbidity and disease-specific morbidity (i.e. cancer, cardiovascular disease, diabetes) [10–13]. Injuries are also a leading cause for the development of osteoarthritis (OA) in later life. There is evidence that knee and ankle injury, specifically, result in an increased risk of development of OA [14–16]. As such, there is a significant public health impact associated with these injuries and future development of OA and other diseases associated with decreased levels of physical activity. The benefits of sport participation in youth go beyond future health concerns, but also include the benefits of greater self-esteem, relaxation, competition, socialization, teamwork, fitness and greater motor skill development.

A four-stage approach has been proposed to study injury prevention [17]. First, surveillance must be used to measure the extent or magnitude of injury in a given population. Second, causes of injury or risk factors must be identified. Third, prevention strategies need to be developed and validated. Lastly, randomized controlled trials (RCTs) or other intervention studies should be conducted to measure the impact of the prevention strategy, again through surveillance.

Incidence of Injury in Pediatric Sport

Prior to examining potential prevention strategies in child and adolescent sport, we must have a good understanding of the extent of the problem (incidence rates for injury), who is at risk (sport participation), and risk factors for injury in this population. Sport and recreation injuries are a major health problem in Canada and the USA. They represent a leading cause of injury morbidity in many age groups. There is evidence that sports are *the* leading cause of injury requiring medical attention, as well as emergency department admissions, in adolescents [4, 18–20]. Sport injuries account for 50% of all injuries to secondary school children [21]. In Alberta, the reported cumulative incidence rate of adolescent (ages 15–19) sport injuries requiring medical attention is 26 injuries/100 adolescents/year [22]. Sport-specific injury incidence rates exceed this average number in sports such as football, hockey, basketball, wrestling, and gymnastics [5, 20, 22–29]. Studies which have examined only sport injuries reporting to hospital Emergency Departments report rates from 7.03 to 8.55 injuries/100 adolescents/year [18, 30, 31]. Cumulative incidence rates suggest the significance of the public health impact of sport injury. However, they do not take exposure to risk (i.e. hours of participation or number of athlete exposures) into consideration. Increasingly more sport-specific epidemiological studies have included exposure to risk into the study design, and estimate incidence density (i.e. number of injuries/1,000 participation hours or 1,000 athlete exposures) in the results. This facilitates the ability to examine injury risk factors as well as making comparisons across studies.

Acute trauma is one type of injury sustained in child and adolescent sport. In addition, there is growing concern about overuse injury in this population of athletes [32]. This likely reflects increased intensity of training and competition in sport at younger ages, increased skill level at younger ages and longer, often year-round, training seasons [32].

Risk Factors for Injury in Pediatric Sport

Risk factors in sport are any factors which may increase the potential for injury [2]. Risk factors may be extrinsic (i.e. weather, field conditions) or intrinsic (i.e. age, conditioning) to the individual participating in the sport. Modifiable risk factors refer to those which can be altered by injury prevention strategies to reduce injury rates [2, 19]. Nonmodifiable risk factors, which cannot be altered, may affect the relationship between modifiable risk factors and

Table 1. Potential risk factors for injury in child and adolescent sport

Extrinsic risk factors	Intrinsic risk factors
Non-modifiable	*Non-modifiable*
Sport played (contact/no contact)	Previous injury
Level of play (recreational/elite)	Age
Position played	Sex
Weather	
Time of season/Time of day	*Potentially modifiable*
	Fitness level
Potentially modifiable	Preparticipation sport specific
Rules	Training
Playing time	Flexibility
Playing surface (type/condition)	Strength
Equipment (protective/footwear)	Joint stability
	Biomechanics
	Balance/Proprioception
	Psychological/Social factors

injury. Identification of these factors will assist in defining high-risk populations. Potential risk factors are listed in table 1 [1, 19, 33].

Much of the literature addressing child and adolescent sport injury is sport specific and based on descriptive data, which portray primarily the extent of the injury problem. There is a substantial body of literature accumulated over the past decade which demonstrates that risk factors are identifiable for sport- and recreation-related injuries in the adult and elite populations. The evidence for injury prevention strategies reducing the risk of injury in youth sport is weaker and based primarily on cohort studies for specific injuries in specific sports. There is some epidemiological evidence that modifiable risk factors (i.e. decreased levels of sport-specific training in the off-season, endurance, strength and balance) do increase the risk of injury in sports [1, 34–40]. Most of these studies, however, address adult populations and are sport and/or injury specific.

Nonmodifiable Risk Factors for Injury in Pediatric Sport

In identifying nonmodifiable risk factors for injury in child and adolescent sport, there is evidence that males are generally at greater risk for injury (OR = 1.16–2.4) [6, 29, 31, 41–43]. The exception to this is in studies examining specific sports including soccer, baseball, and basketball where females appear to be at greater risk [29, 31, 41–44]. Male children and adolescents participating in sport may generally be at a greater risk of injury as they may be more aggressive, have larger body mass and experience greater contact compared to girls in the same sports. All of these factors may lead to increased forces in running, jumping, pivoting, and contact which may increase susceptibility to injury. In soccer, baseball, and basketball, studies show an increased risk of injury in girls. The reasons for this may be due to lower skill level, or may be of a physiological nature.

Left-handedness also appears to be a risk factor for injury [45]. Left-handed adolescents may be at increased risk of injury because of environmental biases in a right-handed world (i.e. equipment used in sport) or functional differences related to neurological development [45].

Re-injury rates range from 13.1 to 38% [1, 23, 24, 28, 46, 47]. The risk of re-injury in some sports is greater than the risk of first-time injury (RR = 1.35–1.7) [48–50]. Previous injury clearly increases the risk of injury in sport. This finding may be related to persistent symptoms, underlying physiological deficiencies resulting from the initial injury (i.e. ligamentous laxity, muscle strength, endurance, proprioception) and/or inadequate rehabilitation.

Sport-specific rates of injury vary considerably with the highest rates of injury reported for boys participating in hockey [26, 27], basketball [5, 23, 29] and football [28, 29] and for girls participating in gymnastics [18, 29], basketball [5, 23], and soccer [5, 23, 51]. The lowest rates of injury are consistently reported in swimming, tennis, and badminton [5, 23, 29]. It is not surprising that hockey, basketball, and football are consistently among the top-rated sports for injury in male athletes. There is certainly body contact involved in two of the three sports (hockey and football) and some contact in basketball also. All three sports involve a high rate of jumping, sprinting, and pivoting activity, which are often involved in the mechanism of injury in sport. The findings of Backx et al [5] of outdoor sports, high jump rate sports, and contact sports increasing the risk of injury are consistent with the high rates of injury in these three sports. It is also not surprising that gymnastics, basketball, and soccer are consistently among the top-rated sports for injury in female athletes. These three sports also involve a high rate of jumping, sprinting, and pivoting activities.

The risk of injury consistently increases with age across studies [6, 23, 27–29, 44, 48, 52–59]. In all sports, adolescents (>13 years) are at a greater risk of injury than younger children [6, 23, 27–29, 44, 48, 52–59]. The peak injury rate is consistently in the oldest adolescent age group in youth studies examining all sports, soccer, hockey, football, baseball, and gymnastics [6, 23, 27–29, 44, 55, 59]. Consistency in these findings is not surprising, as level of competition, contact, and size typically increase with age. The time participating in sports likely increases with age and experience. However, exposure-adjusted injury rate (i.e. incidence density) is not always examined.

Injury rates decrease with increasing skill level in hockey [27] and increase with increasing skill level in wrestling and gymnastics [27, 46, 52]. Risk of injury increases with organized sport versus unorganized sport [29], amount of time spent doing sporting activity [42], competition versus practice [37, 52], tournament play versus regular season play [26, 51], increased level of competition [23], indoor versus outdoor soccer [53, 60], and large field size and reduced number of players in Australian Rules football [55]. Injury reporting may be more accurate in studies examining organized sport (i.e. levels of competition) and tournament play accounting for higher injury rates than in unorganized sport. In addition, competitors are more likely to be playing at greater intensity and speeds in competition and tournaments than in practice and regular season play, increasing the risk of sustaining an injury. In Australian Rules football, it is not surprising that larger field size and fewer players (i.e. likely reducing the risk of contact) appear to be associated with a lower risk of injury [55].

There is conflicting evidence regarding anthropometric measurement and risk of injury which appears to be injury and sport specific. Brust et al. [27] demonstrate an increased risk of injury in lighter hockey players with the same age and experience. In football, however, where age categories are also restricted by weight categorization, heavier players are at higher risk of injury than lighter boys [28, 55, 61, 62]. In gymnastics, athletes who are taller or heavier are at an increased risk of injury compared with those shorter or lighter [56, 58, 63]. In soccer, Backous et al. [44] demonstrate that taller players are at an increased risk of injury compared with shorter players. Lyman et al. [54] demonstrate increased risk of elbow symptoms in pitchers who are heavier and taller. Taller and heavier athletes (i.e. in football, gymnastics, soccer, and baseball) may be more susceptible to injury due to greater forces being absorbed through soft tissue and joints. In hockey, a contact sport where there is no weight classification, it is not surprising that the smaller players are more susceptible to injury. Although skeletal maturity may not in itself be a modifiable risk factor, in the context of sport it may be considered modifiable in some sports such as hockey by grouping children by skeletal rather than chronological age.

With rapid skeletal growth occurring in children and adolescents, there are potentially physiological reasons why children and adolescents may be at an increased risk of injury [64]. For example, sudden intense muscular traction exerted on an immature skeleton (i.e. during a period of rapidly increasing muscular strength) may result in an acute avulsion fracture of a growth plate, an injury not possible in adulthood [64]. Chronic repetitive muscular traction exerted on an immature skeleton, usually at the time of a growth spurt, may result in traction apophysitis (i.e. Osgood-Schlatter or Sever's disease) [64]. These are both injuries exclusive to children and adolescents. There is also evidence that there is a noteworthy association between peak height velocity and peak fracture rate of the distal radius, suggesting that a growth spurt may increase the risk of some athletes to some injuries [65].

Potentially Modifiable Risk Factors for Injury in Pediatric Sport

Most studies examining biomechanical alignment, flexibility or strength demonstrate no association of these factors with injury in child and adolescent sport [1, 66–70]. The exceptions to this are found in sport-specific studies. In gymnastics and figure skating there is some evidence of an association between poor flexibility and injury [58, 71]. Both anterior tibiofemoral laxity and pronation are predictive of anterior cruciate ligament knee injury in adolescents [72]. Pasque and Hewett [52] demonstrate an increased risk of shoulder injury in wrestling with increased shoulder ligament laxity. Decreased flexibility is not a risk factor generally for injury in adolescent [1, 69, 70] or adult sport [73]. However, it may be a risk factor for injury in gymnastics, figure skating, and wrestling, all sports that demand a high degree of flexibility for execution of many maneuvers [58, 71].

There is conflicting evidence that elbow injury in baseball pitchers is related to pitching style [68, 74]. Albright et al. [74] found an increased risk of elbow injury with a horizontal arm during delivery (particularly with a whipping or snapping motion) in Little League pitchers ($\leq$14 years). Grana and Rashkin [68] found no relationship between injury and sidearm delivery or speed of delivery in older pitchers (14–19 years). Fatigue based on number of pitches in a game and number of pitches in a season seems to be associated with an increased risk of elbow injury [54]. Fatigue also appears to play a role in hockey where there is an increased risk of injury in the last 5 min of a period and the last period of a game [37]. Lysens et al. [1] report an increased risk of injury in young women with decreased endurance fitness. This is consistent with Cahill and Griffith [40] who found that adolescent football players participating in a preseason conditioning program were at significantly decreased risk of knee injury.

Psychosocial factors may also be potentially modifiable. Faelker et al. [75] demonstrate evidence of a dose-response gradient between decreasing socioeconomic status and increased risk of injury. Studies consistently demonstrate a high correlation between injury in sport and life stress [76–79]. These findings are also consistent with the findings for other injury types (i.e. home, fall, and traffic injury) [75, 78, 79].

Less than 40% of high school rugby participants (n = 2,330) completed any preseason training [80]. High rates of injury may be related to decreased endurance and/or strength associated with limited preseason training, as indicated in both adolescent [1, 40, 53, 81, 82] and adult [35, 36, 83] study findings. Some athlete populations (i.e. low-skill division adolescent female soccer players) may benefit from training programs while others (i.e. high-skill division adolescent female soccer players) may not [81]. Proprioceptive balance training, in conjunction with other training techniques, may reduce the risk of specific injury in specific sport [82–84]. The impact of decreased proprioception as a risk factor for injury remains unclear.

Injury Prevention in Pediatric Sport

As seen throughout sport-specific chapters in this book, as well as in the literature at large, there are very few prospective intervention studies addressing prevention strategies to reduce injury in youth sport. A summary of the prospective intervention studies is shown in table 2 [53, 66, 81, 82, 85–89]. These prevention strategies potentially target risk factors, such as limitations in flexibility, strength, endurance, and proprioception/balance. A nonrandomized prospective intervention study shows no effect of a half-time warm-up and stretching program in high school football [66]. Hewett et al. [85] demonstrate in a nonrandomized prospective study that extensive neuromuscular training programs including flexibility, strength, landing skills, and plyometrics may be effective in reducing injury in adolescent basketball, soccer, and volleyball. In soccer, a significant protective effect of a specific education, conditioning and rehabilitation program in adolescent soccer players is found in the low-skilled division only [RR = 0.63 (95% CI; 0.42–0.94)] [82]. Mykelbust et al. [86] also demonstrate a protective effect of a comprehensive sport-specific balance-training program in the reduction of anterior cruciate ligament injuries in elite adolescent female European handball players in a nonrandomized prospective intervention study. There were only four RCTs identified in a youth population. Emery et al. [87] have demonstrated a protective effect of a home-based balance training program using a wobble board in the reduction of all sport-related injuries in high school physical education participants [RR = 0.2 (95% CI; 0.05–0.88)]. Heidt et al. [53] also demonstrate a protective effect of a multifaceted 7-week preseason training program in female high school soccer players [RR = 0.42 (95% CI; 0.2–0.91)]. Wedderkopp et al. [82] demonstrate a significant reduction of injury in adolescent female European handball with the use of a multifaceted training program which included proprioceptive balance training using a wobble board [RR = 0.17 (95% CI; 0.09–0.32)]. In a further study, they also demonstrate the protective effect of balance board training alone in the reduction of injury in female European handball [RR = 0.21 (95% CI; 0.09–0.53)] [88].

As there are relatively few epidemiological studies addressing modifiable risk factors for injury in child and adolescent sport, it is prudent to discuss

Table 2. Studies examining prevention strategies for injury in child and adolescent sport

Author (year)	Study design (country and time frame)	Participants (age)	Prevention strategy	Injury definition	Results (relative risk = RR, odds ratio = OR, provided adequate information is available)
Bixler and Jones [66] (1992)	Non-RCT (USA)	High school football players (5 teams: 3 intervention, 2 control)	1. Intervention: 1/2 time warm-up and stretching exercises 2. Control: no exercises	Injury requiring medical attention	Injury rates between groups not statistically significant (insufficient data to calculate RR)
Emery et al. [87] (2004)	Cluster RCT (Canada)	120 high school physical education students (14–18) (10 schools)	1. Intervention: daily progressive home program using wobble board 2. Control: no treatment	Injury occurring during a sporting activity which required medical attention and/or loss of at least one day of sporting activity	RR = 0.20 (95% CI; 0.05–0.88) RR (ankle sprain) = 0.14 (95% CI; 0.18–1.13). Multivariate analysis + control for cluster randomization. Greatest effect in those with previous injury. Also demonstrated dose-response effect based on improvements in timed static and dynamic balance.
Heidt et al. [53] (2000)	RCT (USA)	300 female high school soccer players (14–18)	1. Intervention: 7 week preseason Frappier acceleration program (cardio-vascular, plyometrics, strength and flexibility) 2. Control: no preseason program	Injury requiring missing at least 1 game or practice	RR = 0.42 (95% CI; 0.2–0.9)

Table 2 (continued)

Author (year)	Study design (country and time frame)	Participants (age)	Prevention strategy	Injury definition	Results (relative risk = RR, odds ratio = OR, provided adequate information is available)
Hewett et al. [85]	Non-RCT (USA)	1,263 high school students (soccer, volleyball and basketball players)	1. Intervention: 366 girls (6-week jump training – 60–90 minutes 3×/week) (includes flexibility, strength, plyometrics, weight training and landing techniques) 2. Control 1: 463 girls 3. Control 2: 434 boys	Serious knee injury (ligament sprain) seen by athletic therapist (>5 days time loss)	14 serious knee injuries (2 intervention, 2 male control, 10 female control) RR = 0.42 (male) RR = 0.17 (female) Significant based on Chi-square analysis ($p = 0.05$). No control for sport type or factors other than gender
Junge et al. [81] (2002)	Non-RCT (Switzerland)	194 soccer players (mean = 16.5)	1. Intervention: included coach and player education, rehabilitation + conditioning program including cardio-vascular, strength, flexibility and plyometrics training 2. Control: ill-defined	Injury resulting in physical complaint >2 weeks or missed session	1. RR = 0.82 (95% CI; 0.58–1.15) 2. RR (high-skilled divisions) = 0.94 (95% CI; 0.58–1.5) 3. RR (low-skilled divisions) = 0.63 (95% CI; 0.42–0.94)
Marshall et al [89] (2003)	Non-RCT	Little League baseball players (5–18)	1. Reduced-impact safety ball vs. traditional ball 2. Faceguard vs. no faceguard		1. RR (safety ball) = 0.72 (95% CI; 0.57–0.91) 2. RR (faceguard) = 0.65 (95% CI; 0.43–0.98)

Myklebust et al. [86] (2003)	Non-RCT over 3 seasons (60, 58, 52 teams/season) (Norway)	Female European team handball players (16–18)	1. Control year 2. 1st intervention season – floor, balance matt and wobble board exercises (15 min) (handout) – video + coach delivered (3×/week for 5–7 weeks and 1×/week for season) 3. 2nd intervention season – as above but physiotherapist delivered at every practice (15 min) (3×/week for 5–7 weeks and 1×/week for season)	Anterior cruciate ligament injury (>1 week time loss = suspected) as assessed by physiotherapist	OR (1st) = 0.87 (95% CI; 0.5–1.52) OR (2nd) = 0.64 (95% CI; 0.35–1.18) OR elite division (2nd) = 0.37 (95% CI; 0.13–1.05)
Wedderkopp et al. [82] (1999)	RCT (Denmark, 1995/96)	237 female European team handball players (16–18)	1. Intervention: practice session training program (warm-up with 2 or more functional large muscle group exercises and proprioceptive ankle disk activity) 2. Control: nonspecific practice session training	Injury requiring player to miss next session or unable to participate without considerable discomfort	RR = 0.17 (95% CI; 0.09–0.32)

Table 2 (continued)

Author (year)	Study design (country and time frame)	Participants (age)	Prevention strategy	Injury definition	Results (relative risk = RR, odds ratio = OR, provided adequate information is available)
Wedderkopp et al. [88] (2003)	Cluster RCT (Denmark)	16 teams female European team handball players (16–18)	1. Intervention: practice session included 10–15 min use of individual ankle disk and warm-up with 2 or more functional large muscle group exercises as in previous study 2. Control group: no ankle disk	Injury requiring player to miss next session or unable to participate without considerable discomfort	OR = 0.21 (95% CI; 0.09–0.53) Multivariate analysis discomfort but no control of cluster randomization in analysis Increased risk with increased time in match play

RCT = randomized controlled trials.

epidemiological evidence in adult sport prior to making recommendations for future research. There is inadequate evidence to support decreased muscle strength, globally, as a risk factor for injury in sport. Emery [34] concludes, based on a systematic review of the literature, that there is evidence of an association between decreased hamstring strength and hamstring strain injury in sport. In a review of the literature, Gleim and McHugh [73] finds no strong evidence that decreased flexibility is associated with injury in sport. There is evidence that decreased sport-specific training in the off-season in professional hockey increased the risk of groin strain injury [RR = 3.38 (95% CI; 1.45–7.92)] [90]. Poor endurance is a risk factor for injury amongst army trainees during the basic training [RR = 2.8 (95% CI; 1.2–6.7) for men and 1.69 (95% CI; 1.2–2.4) for women] [36]. Previous injury appears to be the most significant predictor of sports injury in some studies, with relative risks ranging from 2.88 to 9.41 [17, 35, 84]. Tropp et al. [39] demonstrate that soccer players with functional ankle instability and decreased balance ability were at significantly greater risk of ankle sprain reinjury.

A systematic review of the literature concludes that there are few well-designed studies examining prevention strategies for injury in sport at any age [91]. There are some prospective studies demonstrating the protective effect of equipment in various sports in preventing injury. In baseball and softball, break-away bases reduce sliding injuries significantly [92, 93]. Ankle taping and ankle braces reduce ankle sprain injury in basketball [42, 94]. In ice hockey, full face shields reduce head and face injury [95–98]. Rule modification may also decrease the risk of injuries in some adolescent sports. In football, the elimination of spear tackles significantly reduced the number of head and neck injuries [49, 99]. In ice hockey, fair play rules and making checking from behind illegal significantly reduced overall injury as well as head/neck and back injuries specifically [100, 101]. There is other adult and elite population RCT evidence that balance training in conjunction with other preseason training strategies (i.e. strengthening, endurance training, plyometrics) reduce the incidence of specific injury in specific sports [83, 84, 86, 102–105]. These multifaceted training programs reduce the incidence of ankle sprain injuries and anterior cruciate ligament injuries in some sports. However, balance, endurance, and strength have not been examined as outcome measurements, so it is not clear as to the impact of the training strategies on these potential risk factors.

Protective equipment in many sports (i.e. full face masks and mouth guards in hockey, face shields and safety balls in baseball, shin pads in soccer, helmets in cycling, skiing and snowboarding) exerts a protective effect [89, 95, 106–107]. Regardless, the challenge remains to engage youth in the use of such equipment. Despite the ongoing controversies, educational strategies in combination with legislation or facility/sport association requirements may be the best approach to increasing the use of some protective equipment in some sports.

There is increasing enthusiasm regarding the importance of a preparticipation evaluation by physicians, physiotherapists, and athletic trainers caring for various pediatric athlete populations. The effectiveness of preparticipation evaluation in the prevention of injury in the pediatric population, however, has not been evaluated. Wingfield et al. [108] suggest, based on the results of a systematic review of the literature, that it is difficult to find data to support a specific approach to the preparticipation evaluation or to establish best practices for risk factor identification in any population. As such, standardization of the process is critical prior to attempting to evaluate its effectiveness in any athlete population, including the pediatric population.

Study Limitations in Injury Prevention in Pediatric Sport

To target specific populations of adolescents with those sport-specific training strategies that will have the greatest population health impact; sport participation rates, sports injury rates, and safety behaviors require further examination. Once a specific sport has been targeted for prevention of injury, valid sport injury surveillance systems, including participation exposure and injury data acquisition, require development.

One of the fundamental difficulties in comparing research in sport injury epidemiology is the variability in research design, measurements used to assess exposure and injury, and the variety of risk factors and sports assessed in studies. The research designs reviewed are almost exclusively observational, and intervention studies are not always RCTs. The temporal association between exposure and outcome is often ignored in cross-sectional and case-control studies. For example, Smith et al. [71] examine flexibility in figure skaters already presenting with knee pain, and the temporal association between knee pain and decreased flexibility is unclear.

Injury definition and methods of injury data collection are extremely variable. A major limitation in many studies reviewed is that incidence rates based on number of participants rather than incidence densities based on exposure (i.e. hours or sessions of participation) are used to distinguish high-risk athletes. Clearly, time spent doing an activity is critical in the assessment of risk of injury. Time loss, medical requirements, and reinjury inclusion differ widely between injury definitions. Methods of data collection vary from self-report to therapist or physician report. Only 25–31% of injuries in some studies resulted in a physician consult [5, 23, 24]. Depending on injury definition, some studies may underestimate injury if only those reporting to an emergency room [18, 30, 31, 109], physician, or therapist [37, 51] are included. Other studies may overestimate injury rates if all injuries are reported regardless of reporting source (i.e. parent, coach) [5, 23]. If one relies on self-report, particularly over a longer time frame, incidence rates will likely be underestimated due to recall bias. Bijur et al. [6] demonstrate a 51% increase in self-reported injury over a one-month recall period compared to a 12-month recall period.

Selection bias is of concern in many studies as there is no random selection of participants. Selection bias in which athletes more likely to be injured (i.e. previous injury) and more likely to be in exposure-risk group are selected, may lead to an overestimation of association between risk factor and injury [1, 40, 56, 71, 72, 75, 78, 79, 110]. If there are unreported drop-outs from the study and the reason for drop-out is related to injury, this may lead to an underestimation of association, another form of selection bias. Lack of blinding to exposure status, as with most of the cohort studies examined in this review, may also lead to overestimation of the association.

Poor reliability and validity of exposure measurements (i.e. flexibility, strength) resulting in nondifferential misclassification of exposure (i.e. likelihood of misclassification of exposure is not associated with outcome) will underestimate the association between exposure and injury. This is certainly of concern in studies which demonstrate no association [1, 66, 68–70].

The most noteworthy source of bias in the studies reviewed was a lack of measurement and control for potentially confounding variables. This results most often in an overestimation of association between exposure and injury. When recruitment of subjects is not random, risk factors/training interventions assessed may not be the only difference between groups. Differences in physiological factors, coaching technique, warm-up routines, and equipment may prevail. For example, in Cahill and Griffith's [40] study, a historical cohort, differences attributed to preseason conditioning may be a result of equipment differences, coaching differences, rule changes (i.e. elimination of below the waist blocking in 1973) [111], or physiological factors in the two cohorts, which were not controlled for in the study.

In some RCT studies examining prevention strategies, the intervention was assigned to a team (i.e. cluster), not an individual [53, 81, 82]. If similarities within a team are greater than similarities between teams, these similarities should be controlled for in the analysis (i.e. cluster-adjusted analysis). When clusters are controlled for in an analysis, the effect measure is less precise (i.e. larger 95% CIs) if similarities within each cluster are in fact greater than similarities between clusters [112]. As such, overestimates of the protective effects of training strategies may have been reported as a result of the individual level analyses performed in these intervention studies. In addition, the intervention studies examined identify multifaceted preventative training programs [53, 66, 81, 82]. As a result, it is difficult to identify specific risk factors addressed by the program (i.e. flexibility, strength, endurance, balance) if measurements of these factors are not examined.

External validity of the results in all of the studies examined is limited due to limitations in internal validity. Certainly generalizability beyond the specific sport, age group, level of competition and specific injury type is limited.

In examining Hill's criteria of causation [113], many of the studies reviewed are consistent with the findings in adult population studies. The strength of the associations found between preparticipation training programs and injury are convincing based on the magnitude of the associations found, despite concerns with internal validity and individual level analysis. Specificity, implying that a specific cause leads to a specific effect is difficult to identify when studies often do not control for other risk factors, and injury outcome is often global and poorly defined. Temporal association is clear only in the cohort studies and RCTs reviewed. The only studies providing a clear indication of a dose-response relationship are Faelker's [75], in which injury rate increases with increasing level of poverty and the studies examining increased risk of injury with increasing age [6, 23, 28, 48, 54, 56]. Biological plausibility of risk factors and coherence to existing knowledge has been discussed. Injury prevention studies are few, thus experimental evidence is limited.

Conclusions and Future Research in Injury Prevention in Pediatric Sport

Child and adolescent participation rates in sport are high. High rates of sport injury in this population have a substantial impact on the individual, their parents, and the health care system. Sport injury in children and adolescents may also potentially affect future involvement in physical activity and the future health of our population.

The strength of the evidence for potentially modifiable risk factors for injury in children and adolescents is limited by research design and concerns with internal validity. In case-control and cross-sectional study designs, the temporal association between exposure and outcome is unclear. In many of the cohort studies and nonrandomized intervention studies reviewed, various sources of bias in the selection of subjects, measurement of exposure and outcome variables and lack of control for other potentially confounding variables threaten the internal validity of the studies. There is limited RCT evidence supporting preventative training programs in specific sports in adolescents to reduce the risk of injury. There is more convincing evidence in adult epidemiological studies that decreased endurance, decreased strength, decreased balance, and decreased preseason sport-specific training are associated with sports injury. The consistency of the findings between child and adolescent studies reviewed and the adult population studies is encouraging.

Given the limited number of prospective studies found in the pediatric sport injury literature, it is very likely that other risk factors have not been identified to date, much less evaluated adequately. For example, it is possible that coaching factors (i.e. style, education and certification) may play an important role in injury risk and prevention in various pediatric athlete populations. Other examples may include cross-training, sleep patterns, nutrition, and numerous additional psychosocial factors to those previously identified.

Evidence from descriptive epidemiological studies can be utilized in targeting relevant athlete groups [i.e. high-risk sports such as hockey, basketball, football, soccer (particularly indoor), and gymnastics], age groups (i.e. older adolescents) and skill levels (i.e. low-skill division in female adolescent soccer) in designing future research examining risk factors and prevention strategies in child and adolescent sport. Future studies examining prevention strategies such as preseason conditioning and proprioceptive balance training are warranted. Future RCTs examining optimal sport-specific injury prevention strategies should quantify and control for potential risk factors for injury in child and adolescent sport. It is critical to integrate basic science, laboratory and epidemiological research to maximize the understanding of mechanisms of injury, risk factors for injury, optimal prevention strategies, complete and appropriate treatment (i.e. medical, surgical and rehabilitation), and long-term effects of injury in youth sport. Long-term follow-up studies should be part of the future vision for research in injury prevention in youth sport. These will be critical, quantifying the long-term impact of pediatric sport injuries on future sport participation and the implications for the future health of our population (i.e. development of OA and other disease morbidity and mortality).

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