Contemporary Pediatric and Adolescent Sports Medicine
Series Editor: Lyle J. Micheli

Dennis Caine
Laura Purcell
Editors

Injury in Pediatric and Adolescent Sports

Epidemiology, Treatment and Prevention

Springer

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ISSN 2198-266X ISSN 2198-2678 (electronic)
Contemporary Pediatric and Adolescent Sports Medicine
ISBN 978-3-319-18140-0 ISBN 978-3-319-18141-7 (eBook)
DOI 10.1007/978-3-319-18141-7

Library of Congress Control Number: 2015943349

Springer Cham Heidelberg New York Dordrecht London

Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media (www.springer.com)

The Micheli Center for Sports Injury Prevention

The mission of the Micheli Center for Sports Injury Prevention is at the heart of the Contemporary Pediatric and Adolescent Sports Medicine series.

The Micheli Center uses the most up-to-date medical and scientific information to develop practical strategies that help young athletes reduce their risk of injury as they prepare for a healthier future. The clinicians, scientists, activists, and technologists at the Micheli Center advance the field of sports medicine by revealing current injury patterns and risk factors while developing new methods, techniques, and technologies for preventing injuries.

The Micheli Center had its official opening in April 2013 and is named after Lyle J. Micheli, one of the world's pioneers in pediatric and adolescent sports medicine. Dr. Micheli is the series editor of Contemporary Pediatric and Adolescent Sports Medicine.

Consistent with Dr. Micheli's professional focus over the past 40 years, the Micheli Center conducts world-class medical and scientific research focused on the prevention of sports injuries and the effects of exercise on health and wellness. In addition, the Micheli Center develops innovative methods of promoting exercise in children.

The Micheli Center opens its doors to anyone seeking a healthier lifestyle, including those with medical conditions or illnesses that may have previously limited their abilities. Fellow clinicians, researchers, and educators are invited to collaborate and discover new ways to prevent, assess, and treat sports injuries.

Series Editor Biography

Dr. Lyle J. Micheli is the series editor of Contemporary Pediatric and Adolescent Sports Medicine. Dr. Micheli is regarded as one of the pioneers of pediatric and adolescent sports medicine, a field he has been working in since the early 1970s when he co-founded the USA's first sports medicine clinic for young athletes at Boston Children's Hospital.

Dr. Micheli is now director of the Division of Sports Medicine at Boston Children's Hospital, and Clinical Professor of Orthopedic Surgery at Harvard Medical School. He is a past president of the American College of Sports Medicine and is currently the Secretary General for the International Federation of Sports Medicine. Dr. Micheli co-chaired the International Olympic Committee consensus on the health and fitness of young people through physical activity and sport.

In addition to many other honors, Dr. Micheli has served as Chairperson of the Massachusetts Governor's Committee on Physical Fitness and Sports, on the Board of Directors of the United States Rugby Football Foundation, as Chairman of the USA Rugby Medical and Risk Management Committee, and on the advisory board of the Bay State Games. He has been the Attending Physician for the Boston Ballet since 1977 and is Medical Consultant to the Boston Ballet School.

Dr. Micheli received his undergraduate degree from Harvard College in 1962 and his medical degree from Harvard Medical School in 1966. As an undergraduate student, Dr. Micheli was an avid athlete, competing in rugby, gridiron football, and boxing. Since graduating, Dr. Micheli has played prop for various Rugby clubs including the Boston Rugby Football Club, the Cleveland Blues Rugby Football Club, Washington Rugby Club, and Mystic Valley Rugby Club where he also served as team coach.

Dr. Micheli has authored over 300 scientific articles and reviews related to sports injuries, particularly in children. His present research activities focus on the prevention of sports injuries in children. Dr. Micheli has edited and authored several major books and textbooks.

Co-Editor Biography

Dr. Dennis Caine is Professor Emeritus and former chair of the Department of Kinesiology and Public Health Education at the University of North Dakota. He holds the B.P.E. and B.Ed. from the University of Manitoba, the M.Ed. from the University of British Columbia, and the Ph.D. in growth and development and Certificate in Gerontology from the University of Oregon. His research interests include epidemiology of injury in sport and the effects of injury on growth, maturation and aging. Caine has published 7 co-edited books, more than 70 articles and chapters, and has been invited to address national and international conferences on medicine and science in sport. Over the years he served on editorial review boards for *British Journal of Sports Medicine, Clinical Journal of Sport Medicine, Physician and Sportsmedicine,* and *Research in Sports Medicine* and currently serves as book series co-editor for *Medicine and Sports Science*.

Dr. Laura Purcell is an Associate Clinical Professor in the Department of Pediatrics at McMaster University. She completed her BSc and MSc at the University of Toronto, and her MD at McMaster University. Her pediatric residency training was at Dalhousie University. She completed a sport medicine fellowship at the University of Western Ontario and holds the Diploma of Sports Medicine from the Canadian Academy of Sport and Exercise Medicine.

Dr. Purcell was the founding president of the Paediatric Sport and Exercise Medicine Section of the Canadian Paediatric Society and has authored many position statements and practise points for the CPS journal. She was also the founding chair of the Pediatric Sport and Exercise Medicine Committee of CASEM.

Dr. Purcell has published more than 50 articles and chapters and has been invited to address national and international conferences on pediatric sport medicine issues.

Foreword

I am very pleased to be writing the foreword to this book by Drs. Caine and Purcell.

When we conceived this book series, we wanted prevention of sports injuries in young athletes to receive appropriate recognition. Epidemiology is a pillar of injury prevention. Since shortly after we founded the Sports Medicine Division at Boston Children's Hospital in 1974—the first sports medicine clinic for young athletes in the USA—we have consistently been calling for epidemiological studies of this population group, including clinical registries where injuries in young athletes would be logged.

In 1997 I was proud to chair a Committee on Sports and Children at a joint meeting of the World Health Organization (WHO) and the International Federation of Sports Medicine (FIMS). An outcome of this meeting was a consensus statement in which my fellow authors and I emphasized the need for sports governing bodies internationally to "prepare and maintain statistics of illness and injury for children and adolescents participating in their sports" (FIMS/WHO Ad Hoc Committee on Sports and Children—Micheli LJ (Chair), Armstrong N, Bar-Or O, Boreham C, Chan K, Eston R, Hills AP, Maffulli N, Malina RM, Nair NVK, Nevill A, Rowland T, Sharp C, Stanish WD, Tanner S. Sports and children: consensus statement on organized sports for children. Bulletin of the World Health Organization. 1998;76(5):445-7).

I continue to maintain that strong epidemiology is a prerequisite to preventing sports injury. Indeed, the importance of epidemiology is referenced in the very mission statement of the Micheli Center for Sports Injury Prevention, which was founded in 2013 and stimulated the creation of this book series. Data collection is one of the most important functions of the Micheli Center which will provide the foundation for long-term research into preventing injury.

For all these reasons I am very pleased that we have this exceptional volume devoted to epidemiology as one of the first books in the series. Thanks to the contributions of the chapter authors and the fine editorial work of Drs. Caine and Purcell, it contains a trove of first-rate information and is a significant contribution to the literature.

I urge anyone with an interest in the field of pediatric and adolescent sports medicine to spend time reading the excellent material contained herein so that they might gain a better understanding of this important topic.

Boston, MA, USA — Lyle J. Micheli, MD

Preface

Participation in pediatric and adolescent sports is increasingly popular in Western culture. In the United States, for example, more than 30 million children and adolescents participate in sports each year. Trends over recent decades include increased numbers of participants, increased duration and intensity of training, earlier specialization and year-round training, and increased difficulty of skills practiced. In addition, children and adolescents are increasingly visiting outdoor and wilderness destinations and are participating in a growing number of "extreme sports," such as motocross, mountain biking, and rock climbing.

Physical activity has important and wide-ranging health benefits. However, engaging in sports and recreational activities at a young age also involves risk of injury. Recent data suggest that the risk of sport and recreation injury is high and constitutes a significant public health burden among children and adolescents. The purpose of this book is to provide an up-to-date volume on the nature, distribution, and determinants of injury affecting children and adolescents, as reported in the literature, and further to provide an overview related to treatment of common overuse and acute injuries, a scientific perspective on injury prevention, and recommendations for further research.

Injury in Pediatric and Adolescent Sports: *Epidemiology*, *Treatment*, *and Prevention* is organized into six parts. In Part I, *Introduction*, a chapter on the exceptionality of the young athlete reviews the unique growth and development characteristics of the young athlete and how these characteristics, in turn, may predispose them to increased risk of injury. Part II, *Epidemiology of Injury in Pediatric and Adolescent Sports*, includes chapters on emergency department studies, injury in community-based youth sport organizations, injury in high school sports, injury in adventure and extreme sports, and injury in elite sports. The approach taken in these chapters is to provide a description of what is known about the descriptive epidemiology of injury, including incidence and distribution of pediatric and adolescent sport injuries.

Part III, *Overview of Common Injuries*, includes chapters related to overuse injuries, acute lower extremity injuries, acute upper extremity injuries, and back pain. The purpose of this section is to provide an overview of the nature and treatment of common pediatric and adolescent sports injuries. Part IV, *Potentially Serious Injuries and Outcomes*, focuses on injuries and outcomes that might have serious consequences for children and adolescents and includes chapters related to concussion, acute catastrophic injuries, and psychological injury. The approach taken in these chapters is to provide a perspective of the extent of the problem of these injury types, injury mechanisms, and possible preventive measures.

Part V, *Injury Causation and Prevention*, includes chapters on injury risk factors and injury prevention. The chapter on risk factors critically reviews what is known about injury risk factors in pediatric and adolescent sports. The chapter on injury prevention provides an evidence-based review on what is known about intrinsic and extrinsic injury prevention strategies that have been evaluated in pediatric and adolescent sports. Part VI, *Future Research in Pediatric and Adolescent Sports*, appropriately focuses on future research and concludes with a chapter on recommendations for future research related to pediatric and adolescent sports.

The information in this book will benefit physicians, physical therapists, athletic trainers, sport scientists, sport governing bodies, coaches, parents, and reference librarians. Primary care sports medicine physicians, pediatric and orthopedic surgeons who specialize in sports medicine, and physical therapists and athletic trainers will find *Injury in Pediatric and Adolescent Sports*: *Epidemiology*, *Treatment*, *and Prevention* helpful in identifying problem areas of which to be cognizant and in which appropriate preventive measures can be tested and ultimately implemented to reduce the incidence and severity of injuries. Some sport scientists, as well as health care professionals, will find the information in this book useful as a basis for continued epidemiological study of injuries in various sports, whereas others may find it beneficial as a reference text. We are optimistic that sports governing bodies and coaches will use this information as an informed basis for the development of injury prevention programs related to factors such as exposure, training techniques, equipment modifications, and rules.

In closing, we would like to thank the authors for their outstanding contributions to this book project. The 16 chapters in this book are written by experts in pediatric and adolescent sports medicine. Researching and writing an overview of the literature in each of the topic areas is a very meticulous and time-consuming endeavor. We therefore view the contributions of the authors to this project as generous contributions of their time, effort, and expertise intended to benefit the welfare of all pediatric and adolescent sport participants.

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Part I

Introduction

1

The Exceptionality of the Young Athlete

Dennis Caine and Laura Purcell

Introduction

Participation of children and adolescents aged 5–18 years in sports and recreational activities is increasingly popular and widespread in Western countries. In the USA, for example, more than 38 million children and adolescents participate in organized sports each year [1]. Trends over recent decades include increased number of participants, particularly girls; increased duration and intensity of training; earlier specialization and year-round training; and increased difficulty of skills practiced. Additionally, children and adolescents are increasingly visiting wilderness recreational destinations and participating in a growing number of "adventure and extreme sports" such as skate boarding, rock climbing, mountain biking, and trick blading [2]. It is not uncommon for teens to train 20 or more hours each week at regional training centers, or for children as young as six to play organized sports and travel with select teams to compete against other teams of similar caliber [3].

Physical activity (PA) has important and wide-ranging health benefits. Specifically in children and adolescents physical activity increases physical fitness (both cardiorespiratory fitness and muscular strength), reduces adipose tissue, improves cardiovascular and metabolic disease risk profiles, enhances bone health, and reduces symptoms of depression and anxiety [4]. While PA can help prevent all-cause morbidity associated with a sedentary lifestyle, injuries can become a barrier to participation in physical activity [5]. Inevitably, with increased participation and training come increasing numbers of injuries. The increased sports, recreational and exercise (SRE) activity of children from an early age, and continued through the years of growth, against a background of their unique potential for injury, gives rise to concern about the risk and severity of injury and other health-related problems.

SRE injuries are the leading cause of injury in youth in many countries [5]. Recent data suggest that the risk of SRE injury is high and constitutes a significant public health burden. For example, a recent report [6] found that during 2001–2009, an estimated 2,651,581 children and adolescents aged ≤19 years were treated annually for SRE injuries in the USA. The National SAFE KIDS Campaign estimates that more than 3.5 million children and youth are injured annually playing sports or participating in recreational activities [7].

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D. Caine, L. Purcell (eds.), *Injury in Pediatric and Adolescent Sports*, Contemporary Pediatric and Adolescent Sports Medicine, DOI 10.1007/978-3-319-18141-7_1

Children 15 years of age and younger account for approximately 45 % of all SRE emergency department (ED) visits [8]. SRE injuries were the most common cause of pediatric injuries in other surveys, accounting for 19–29 % of all injuries in this population [9–11]. In addition to the immediate healthcare costs, these injuries may have long-term consequences on the musculoskeletal system, resulting in reduced levels of physical activity and, ultimately, reduction in wellness [12].

The purpose of this chapter is to review the unique growth and development characteristics of pediatric and adolescent athletes and how these characteristics, in turn, may predispose them to increased risk of injury.

Growth- and Maturation-Related Factors

As defined by Malina et al. [13], growth refers specifically to increase in body size or the size attained by specific parts of the body. For example, as children grow, they become taller and heavier, they have increases in lean and fat tissues, and their organs increase in size. Different parts of the body grow at different rates and at different times. The different rates and timing of growth in the body and its parts result in changes in body proportions. The legs, for example, grow faster than the trunk during childhood; hence, the child becomes relatively longer legged.

Maturation refers to the process of becoming mature, or progress towards the biologically mature state [13]. Maturation differs from growth in that, although various biological systems mature at different rates, all individuals reach the same end points of growth, i.e., adult stature. The concept of maturation includes the tempo and timing of progress towards the mature biological state. Timing refers to when specific maturational events occur; for example, age of maximum growth during the adolescent growth spurt. Tempo refers to the rates at which maturation progresses; for example, the timing of the adolescent growth spurt. Timing and tempo vary considerably among individuals. More than 30 years ago, Micheli [14, 15] postulated that growth cartilage and the growth process may predispose the young athlete to an increased risk of overuse injury relative to adults. Specifically, he proposed that growth cartilage (epiphyseal growth plate, joint surface, and apophyseal growth plate) of young athletes is less resistant to repetitive microtrauma than adult cartilage and that this susceptibility was particularly pronounced during growth spurts. A similar hypothesis has been postulated with regard to acute injuries [16, 17]. Other growth-related factors which may predispose the child and adolescent to increased risk of injury include differential growth and maturity-associated variation [18, 19]. It has been proposed that children and adolescents may experience a longer recovery and differing physiological response after concussion [20]. They might also be at risk because of immature or underdeveloped coordination, skills, and perception [21]. Although problems may not ordinarily arise at normal levels of physical activity, the more frequent and intensive participation of young sportspeople today may create conditions under which these potential growth-related risk factors exert their influence.

Children Are Not Miniature Adults

The normal growth pattern is nonlinear: differential growth of the body segments (head, trunk, and lower extremities) occurs throughout growth and influences body proportions accordingly [13]. At birth, the relative contribution of head and trunk to total stature is highest, and this declines through childhood into adolescence. Thus, the child is characterized by a proportionately larger head and trunk, and shorter legs compared with an adult (Fig. 1.1). This "top-heavy" characteristic could predispose the child athlete to increased risk of injuries [19, 22]. Although data are lacking, it seems logical to presume, for example, that a "top-heavy" child would be at increased risk of falling, head first, in sports which involve riding on top of animals such as sheep (mutton-busting), camels (camel-racing), horses, or on top of all-terrain vehicles or bicycles; or at increased risk of overuse injury in sport activities involving substantial running activity [22, 23].

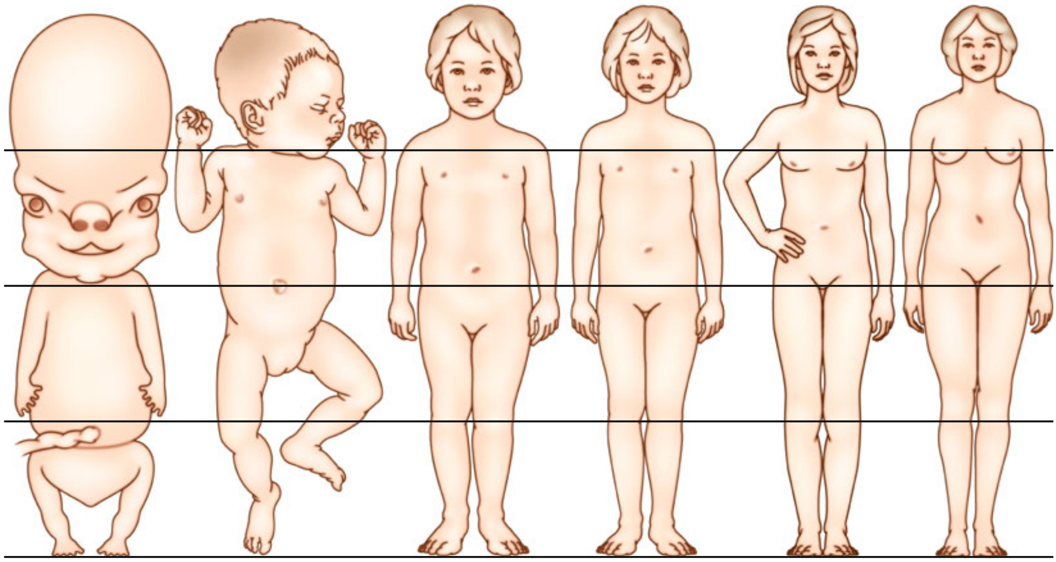

Fig. 1.1 The head, limbs and body grow at different rates, resulting in adults with completely different proportions to those of a fetus and newborn baby. At birth, the relative contribution of head and trunk is highest, declining throughout childhood and adolescence. Therefore, children have proportionately larger heads and trunks and shorter limbs compared with adults

Children's greater head-to-body ratio and weaker neck muscles, combined with their relative nervous system immaturity, lesser myelinization, and thinner frontal and temporal bones, may also make them more vulnerable to head injury and concussion [24, 25]. Child and adolescent athletes may have a more prolonged recovery and are more susceptible to concussion accompanied by catastrophic injury [20, 26]. Concussion in the young athlete is of specific concern because of their continuing cognitive maturation. Whereas the adult brain has achieved its operational skills for everyday life, the child's brain is still developing in areas of concentration, establishing memory patterns, reasoning, problem-solving, and other cognitive skills [26].

Age- and Maturity-Associated Variation

Children and youth of the same chronological age may vary considerably in biological maturity status, particularly during adolescence, and individual differences in maturity status influence growth and performance during this period [13]. The structural, functional, and performance advantages of early-maturing boys in sports requiring size, strength, and power are well known. Similarly, late-maturing girls tend to excel in sports like gymnastics where small stature is beneficial [27]. Bone age, which can be determined using standardized radiographs of the wrist, is one way to assess biological age. Bone age reflects the degree of maturity of the child, but the appearance of bone may differ between various ethnic groups.

Chronological age may add yet another dimension of individual variation, as most pediatric and adolescent sports are categorized by chronological age. Within a single age group (e.g., 13 years of age), for example, the child who is 13.9 is likely taller, heavier, and stronger than the child who is 13.0 years of age, even though both are classified as 13 years of age [18]. Not surprisingly, investigations into a variety of chronologically grouped team sports have reported that elite young athletes were more likely born in the early months of the selection year, a phenomenon known at the relative age effect [28]. Thus, when children are grouped by age, variation is associated with chronological age per se and also with differences in biological maturity [13].

The fear is that an unbalanced competition between early- and late-maturing and/or older and younger boys in contact sports such as football and wrestling contributes to at least some of the serious injuries in these sports. For example, in a study of injury incidence in elite French youth football (soccer) participants, late-maturing boys sustained a significantly greater incidence rate of major injuries than early-maturing boys [29]. There were also differences between maturity groups when patterns of injury location, type, severity and reinjury were analyzed [29]. In contrast, Malina et al. [30] reported that injured and non-injured youth football players did not differ significantly in maturity status. Notably, a noninvasive method for estimating maturity status as a basis for grouping young athletes has recently been proposed [31].

Adolescent Growth Spurt

The adolescent growth spurt is believed to be associated with an increased risk of SRE injury [14, 15, 32]. Height and weight increase during the preadolescent and adolescent years [13]. Girls tend to reach peak height and weight earlier than boys, at about age 15 compared to age 18 or older in boys. The adolescent growth spurt appears to be a time of increased risk for sports injury, including both acute and overuse injury. Some SRE injuries indicate an increased occurrence of injury during pubescence [33, 34]. However, prospective studies are needed to evaluate this relationship further [32]. The results of recent research suggest that increased quadriceps strength, combined with increased knee laxity and no accompanying hamstring strength development during the adolescent growth spurt in girls, might contribute to a decrease in their knee joint stability during landing tasks. These musculoskeletal changes could potentially increase anterior cruciate ligament (ACL) injury risk at a time of rapid height and lower limb growth [35]. In addition, sensorimotor function is not fully mature as children reach adolescence and some mechanisms may actually regress during this period [36]. Deficits in a variety of these sensorimotor mechanisms have been correlated with increased ACL injury risk [37–39]. Notably, three studies reported that neuromuscular control of knee motion and landing forces is significantly worse in females than in males during the transition from prepubertal to pubertal stages, with females showing regressions in control abilities [40–42].

The growth spurt also appears to be a significant factor in the development of overuse injuries [34]. Overuse or repetitive microtrauma can strain the musculotendinous units which may occur more frequently during growth spurts [43, 44]. For example, chronic wrist pain in young non-elite gymnasts is significantly more likely to occur during 10–14 years of age (the expected age of peak height velocity) than either before or after this period [45]. It has been suggested that an explanation for the increased risk of overuse injury during the growth spurt was increased muscle-tendon tightness and accompanying loss of flexibility during the growth spurt [14, 15]. However, the results of several studies have not supported this concept [42, 46–48].

The adolescent growth spurt is also believed to be associated with an increased risk of epiphyseal growth plate injury due to decreased physeal strength [49–51]. During this time, structural changes in growth plate cartilage occur that result in a thicker and more fragile epiphyseal plate [52]. In addition, bone mineralization may lag behind bone linear growth during the pubescent growth spurt, rendering the bone temporarily more porous and more subject to injury [17]. Studies of the incidence of acute physeal injuries in humans indicate an increased occurrence of fractures during pubescence [17, 53–55] and a noteworthy association between peak height velocity and peak fracture rate [17]. Peak adolescent fracture incidence at the distal end of the radius coincides with a decline in size-corrected bone mineral density (BMD) in both boys and girls. Peak gains in bone area preceded peak gains in BMD in a longitudinal sample of boys and girls, supporting the theory that the dissociation between skeletal expansion and skeletal mineralization results in a period of relative bone weakness [56].

Unique Response to Skeletal Injury

Young athletes incur many of the same injuries as their adult counterparts; however, they are at risk of incurring unique injuries not seen in adults because of the different structure of growing bone compared to mature bone [18]. Examples of injuries unique to the young athlete include epiphyseal plate fractures, stress-related epiphyseal plate injury, apophysitis, apophyseal avulsion fractures, and incomplete fractures of the greenstick type. The differences between adult and growing bone are summarized below [14, 15, 18]:

- The articular cartilage of growing bone is a thicker, more plastic layer than in adult bone and can remodel. However, it may also be less resistant to shear force than adult articular cartilage;
- Vulnerability of epiphyseal plates to disruption at the epiphyseal-metaphyseal junction, especially from shearing forces, and resulting in growth plate fractures;
- Vulnerability of apophyses to traction and strong muscle contractions resulting in apophysitis or avulsion injuries; and
- Increased elasticity and resiliency of the metaphysis of long bones which, coupled with the thick periosteum typical of this age group, can result in greenstick or incomplete fractures.

Because of these differences, children and adolescents are more likely to injure bone or avulse an apophysis than to sprain a ligament or tear a muscle or tendon. They are also more likely to injure the articular surfaces of joints, especially during periods of rapid growth. However, it is also possible that the injury mechanism may be of sufficient magnitude and orientation to sprain a ligament or tear a muscle or tendon. Additionally, due to the slower rate of apophyseal growth, athletes in their late teens or early twenties may occasionally incur apophyseal injuries.

Epiphyseal Growth Plate Fractures

Epiphyseal injuries account for between 15 and 30 % of all skeletal injuries in children treated in EDs [57]. A systematic review of the case series literature on epiphyseal plate injuries revealed that 38.3 % of 826 acute cases were sport-related, and among these 45 (14.2 %) were associated with some degree of growth disturbance [58]. These injuries occur in a variety of sports, although gridiron football is most often reported [58].

Most cohort studies reporting on the nature and incidence of pediatric sports injuries do not specify the frequency or severity of epiphyseal plate fractures. Among cohort studies which do report acute epiphyseal injuries, from 1 to 30 % of injuries were reported as epiphyseal fractures [57]. Tabulation of the number of injuries ($n = 3762$) and number of acute epiphyseal injuries ($n = 536$) in these studies reveals that 14.3 % of all injuries were acute epiphyseal injuries. However, these studies report injuries as a percentage of all injuries and do not provide incidence data based on participant exposure.

Stress-Related Epiphyseal Plate Injuries

Epiphyseal growth plate stress injuries are thought to develop when repetitive loading of the extremity disrupts metaphyseal perfusion which in turn inhibits ossification of the chondrocytes in the zone of provisional calcification [59]. The hypertrophic zone continues to widen as the chondrocytes continue to transition from the germinal layer to the proliferative zone [59]. Widening of the physis may be seen radiographically, whereas physeal cartilage extension into the metaphysis has been shown with magnetic resonance imaging (MRI) [60, 61].

Although incidence data are lacking, there is evidence of stress-related epiphyseal growth plate injury affecting young athletes participating in a variety of sports including baseball (proximal humerus), basketball (distal femur/proximal tibia) climbing (phalanages), distance running (proximal tibia, first metatarsal growth plate), rugby (proximal tibia), gymnastics (clavicle, distal radius, proximal humerus), soccer (distal tibia/fibula), and tennis (proximal tibia) [58]. Most of these injuries resolved without growth complication during short-term follow-up. However, there are also reports of partial or complete epiphyseal plate closure in athletes participating in basketball, baseball, dance, gymnastics, football, rugby and tennis [62–69]. These data are consistent with results from animal studies where prolonged intense physical training may precipitate pathological changes in the epiphyseal physis and, in extreme cases, produce growth disturbance [58].

Apophyseal Avulsion Fractures

Apophyseal avulsion injuries occur due to direct trauma or avulsion arising from sudden and violent contraction of muscles in the skeletally immature athlete. These occur at the attachments of ligaments or, more commonly, large tendons to bones [18]. Pain from this injury usually has a traumatic onset, although there are reports of chronic traction injuries leading to avulsion fractures [70–72]. Many patients will describe a "pop" with the onset of discomfort. Most commonly, avulsion fractures occur at the apophyseal attachment of large musculotendinous units.

Common sites for avulsion fractures in the lower extremity are at the attachment of: (1) the sartorious muscle to the anterior superior iliac spine, (2) the rectus femoris muscle to the anterior inferior iliac spine, (3) the hamstring muscles to the ischial tuberosity, (4) the patellar tendon and the tibial tuberosity, and (5) the iliopsoas tendon to the less trochanter of the femur [18]. Common injury locations in the upper extremity include the medial epipcondyle and olecranon apophysis while the vertebral ring apophysis is the site most often mentioned in the spine [18]. Although incidence data are lacking, case reports of sport-related apophyseal injuries abound in the research literature. There are also multiple case series specific to sport [70, 72–77] which attest to the occurrence of this injury type among child and adolescent athletes. Injured subjects are typically males participating in a variety of sports including baseball, football, gymnastics, soccer, running and field events, and wrestling. Treatment has included both conservative (rest and NSAIDS) and surgical (open reduction and internal fixation) options. Timely, accurate diagnosis is imperative so proper treatment can be initiated. However, even though avulsion injury involving the apophyseal growth plate does not normally result in length discrepancy, angular deformity, or altered joint mechanics, it may adversely affect training and performance [18].

Stress-Related Apophyseal Growth Plate Injuries

Stress-related apophyseal injures unique to young athletes cause inflammation at the site of a major tendinous insertion onto a growing bony prominence. These injuries typically occur in active children and adolescents between the ages of 8 and 15 years and usually present as periarticular pain associated with growth, skeletal maturity, repetitive microtrauma and muscle-tendon imbalance [78]. Examples of common stress-related apophyseal injuries include: (1) Sever disease (posterior calcaneus), (2) Osgood–Schlatter Disease (tibial tuberosity), (3) medial epicondylitis (humeral medial epicondyle), (4) Sinding-Larsen–Johansson disease (inferior patellar pole), (5) Iselin disease (base of fifth metaTARSAL), and (6) apophysitis at the hip and pelvis (iliac crest, ischial tuberosity, anterior inferior iliac spine, anterior superior iliac spine).

Case reports of stress-related apophyseal growth plate injuries are abundant in the research literature. There are also several case series specific to sports which attest to the occurrence of this injury type among child and adolescent athletes [72, 79–81], and in the general population [82]. Notably, a 3-season study of the epidemiology of injury affecting middle-school females in basketball, soccer, and volleyball showed that the knee was the most injured body part with Osgood-

Schlatter disease (10.4 %) and Sinding-Larsen-Johansson patellar tendinosis (9 %) occurring with high frequency [83].

Injury Involving the Articular Cartilage

As mentioned above, the articular surface of pediatric and adolescent joints may be less resistant to tensile, shear and compressive forces than adult articular cartilage, especially during periods of rapid growth [49–51]. Osteochondritis dissecans (OCD) affects weight-bearing joints such as the hip, the knee and ankle, but elbow lesions in gymnasts and throwers are also relatively frequent [84]. OCD affects both boys and girls, and may arise from either acute or repetitive injuries; however, it is most common in boys 10–20 years of age, and tends to be a repetitive injury affecting the knee (high-impact landings) and elbow (pitching, throwing, upper extremity weight/bearing). Treatment in children and adolescents is usually nonsurgical, but surgery may be necessary in serious cases. If untreated, OCD can lead to early onset osteoarthritis. The results of one recent study suggest that sport-related OCD, along with epiphyseal plate fractures and apophysitis, are more commonly seen clinically among 5–12-year old patients than 13–17-year-old patients who tend to incur more ACL injuries, meniscal tears, and spondylolysis [85].

Susceptibility to Heat-Related Injury

Heat injury occurs when excessive thermal energy is generated or absorbed by the human body [86, 87]. Between 1995 and 2008, 29 high school football players in the US died from heat stroke [88]; in autumn, 2008 alone, there were four heat-related deaths in US high school football [8]. In the US, more than 9,000 high school athletes are treated each year for heat-related injury [89]. Sports and recreation heat illnesses are most common among males (72.5 %) aged 10–19 years and occur most often during July–September [90].

Reliable data on the incidence of nonfatal heat-related injuries in youth sport are lacking. However, Kerr et al. [91] analyzed the rates and circumstances of exertional heat illness from 2005/2006–2010/2011 and reported a rate of 1.20 per 100,000 athlete exposures. Exertional heat illness occurred mostly in August (60 %) and almost one third (32 %) occurred more than 2 h into the practice session. The rate in football was 11.4 times higher than in all other sports combined.

Compared with adults, exercising children were formerly believed to be inefficient when it comes to thermoregulation [13]. However, more recent studies, in which both groups were exposed to equal relative intensity exercise workloads and environmental conditions while minimizing dehydration, have compared 9–12 year-old boys and girls to similarly fit and heat-acclimatized adults [92]. These newer findings indicate that children and adults have similar rectal and skin temperatures, cardiovascular responses and exercise-tolerance time during exercise in the heat [93–96]. Thus, it may be that children are at an increased risk simply because they are more likely to be exposed to vigorous physical exercise during the warm summer months [86]. It has also been shown that during exercise, children may fail to ingest sufficient fluid to prevent dehydration, because they often do not feel the urge to drink enough to replenish the fluid loss before or following exercise [97].

Sport Readiness

Participating in organized sports can be enjoyable physical activity for many children and adolescents, if the activity is developmentally appropriate. Putting children into sports that are beyond their developmental ability can be frustrating and cause them to drop out of sports altogether [98]. Deciding on an appropriate sport requires knowledge of a child's sport readiness.

Sport readiness means that a child's cognitive, social and motor abilities enable him/her to meet the demands of a particular sport [98–100]. If a young athlete is expected to learn and perform skills that exceed their ability and level of development (motor, sensory, cognitive, socioemotional), there will be little motivation to learn new skills [101]. Young children do not respond to coaching, understand strategy and tactics, or interact with teammates the same way as adults because they lack the social and cognitive skills necessary for competition, appropriate positioning, rapid decision-making and teamwork [98]. To envisage the likely development of a particular motor skill or to suppress one's personal desires for the interests of the team as a whole would require a level of intellectual and psychosocial maturity unavailable to most pre-operational and egocentric children [102].

Motor development is also important for sport participation. Acquiring fundamental motor skills, including throwing, hopping, jumping, kicking and running, is an innate process not dependent on stage of physical maturity or gender [98, 100]. Each fundamental skill is composed of a sequence of stages of development which children progress through at various rates. A child who does not progress through all the stages may be less proficient in sports than a child who has fully developed motor skills. Many children have acquired some motor skills by preschool age; however, most children do not acquire the majority of fundamental motor skills until the age of 6 years. Therefore, organized sports that require performance of motor skills in combination are not recommended until children reach age 6 [98, 100].

Sport activities should be modified to the developmental level of the child by focusing on fun, having shorter games and practices, using smaller equipment and changing positions frequently to increase a child's likelihood of enjoying the activity and achieving success [98, 100]. Readiness to learn certain skills cannot be determined by chronological age, body size or biological maturation alone, but rather can be assessed by determining whether the requisite antecedent skills are sufficient to provide the basis for mastering the new activity [103]. Choosing appropriate sport activities for children can be guided by appreciation of developmental skills and limitations of certain age groups, described in Table 1.1.

Young children are just beginning to learn individual fundamental motor skills and have limited balance, immature visual abilities and short attention spans. Activities should focus on developing fundamental motor skills and emphasize fun and playfulness, avoiding competition [98–100]. As children develop, they are able to master fundamental motor skills and start transitional skills, such as kicking at a target (net) [100]. Improved balance, vision and attention spans make older children ready for entry level team sports such as baseball and soccer, where the emphasis should be on improving fundamental skills and developing transitional skills (Table 1.1). Older children and adolescents are able to perform motor skills in various combinations, and are beginning to appreciate tactics and strategy. More complex team sports, such as basketball, football and ice hockey, are appropriate activities for older children and adolescents (Table 1.1).

Ultimately, choice of sporting activity should be guided by the child's developmental abilities and interests to ensure an enjoyable and successful experience that encourages lifelong participation. A variety of activities should be encouraged to develop multiple skills and decrease chance of injury [98, 100]. Early specialization should also be avoided to minimize risk of injury [98].

Summary

It is well-known that organized sport participation has wide-ranging health benefits for children and adolescents. However, participation in sports also carries risk of injury. Unfortunately, children and youth may be particularly vulnerable to sport injury compared to adults, due to such factors as differential growth, age-and-maturity-associated variation, adolescent growth spurt, unique response to skeletal injury, susceptibility to heat-related injury, and sport readiness. Although problems may not ordinarily arise at normal levels of activity, the more frequent and intensive training and competition of young sportspeople today may create conditions under which these potential growth- and maturation-related risk factors exert their influence.

Table 1.1 Developmental sports skills and sport recommendations during childhood and adolescence

	Early childhood (2–5 years)	Middle childhood (6–9 years)	Late childhood (10–12 years)	Early adolescence (13–15 years)	Late adolescence a 16–18 years)
Motor skills	Limited fundamental sport skills	Mature fundamental sport skills	Improving transitional skills	Tremendous growth but loss of flexibility	Continued growth into adulthood
	Limited balance skills	Better posture and balance	Mastering complex motor skills	Differences with timing of puberty	Mature sport skills
		Beginning transitional skills			
Vision	Not mature until age 6–7 years	Improved tracking but limited directionality	Mature adult patterns	Adult patterns	Adult patterns
	Difficulty tracking and judging speed of moving objects				
Learning	Very short attention span	Short attention span	Selective attention	Improved attention span	Good attention span, memory skills
	Visual, auditory cues important	Limited memory and rapid decision-making	Memory improving	Good memory skills, able to memorize plays and strategize	
Skill emphasis	Emphasize fundamental skills	Emphasize fundamental skills and beginning transitional skills	Emphasize skill development with increasing emphasis on tactics and strategy	Emphasize individual strengths	Emphasize individual strengths
	Emphasize play and experimentation rather than competition				
Suggested activities	Running, tumbling, throwing, catching, riding a tricycle	Entry level soccer and baseball; swimming, running, gymnastics, skating, dance, racquet sports such as tennis, riding a bicycle, martial arts	Entry-level football, basketball, ice hockey	Early-maturing boys: track and field, basketball, ice hockey	All sports depending on interest
				Late-maturing girls: gymnastics, skating	

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Part II

Epidemiology of Injury in Pediatric and Adolescent Sports

Emergency Department Studies

2

Laura Purcell

Introduction

For many young athletes who are injured during sport and/or recreational activities, the emergency department (ED) is the first point of contact with the medical system. More than 40 % of injuries in children and adolescents presenting to Canadian EDs are related to sport and recreational activities, with the highest percentage of injuries occurring in the 10–14 year age group (68 %) [1]. Approximately 2.5–4.61 million children and adolescents with sport and/or recreational activity injuries (SRIs) present to EDs in the USA each year [2–4]. SRIs are the most common cause of musculoskeletal problems in children and adolescents, accounting for 41 % of all musculoskeletal injuries presenting to American EDs and representing 8–9 % of ED visits [2, 5].

In many countries, national databases have been established which document injury statistics from EDs. Countries such as New Zealand, Australia, Greece, Sweden, Norway, the Netherlands, and the UK, as well as many other European countries, have established injury surveillance systems in EDs in an effort to prevent injuries [6].

Within North America, both Canada and the USA have national injury surveillance systems. The Public Health Agency of Canada (PHAC) established an injury surveillance system operating in EDs in 1990. The Canadian Hospitals Injury Reporting and Prevention Program (CHIRPP) collects data from 11 pediatric and 5 general hospitals in Canada [7]. Similarly, in the USA, the National Electronic Injury Surveillance System (NEISS) has been established by the US Consumer Product Safety Commission (CPSC) and represents a national probability sample of hospitals in the USA and its territories [8]. These databases are used in many ED studies about SRIs in children and adolescents in North America [4, 9–36].

Injury surveillance systems are a proactive mechanism to document numbers and characteristics of injuries, including injury cause, mechanism, location and circumstances [6]. Analysis of injury data can reveal trends and patterns of injury, including identification of risk factors, within specific activities that may lead to development of specific strategies and interventions aimed at reducing the frequency of certain injuries [6, 10, 37]. Examples of such interventions include rule changes (no spearing in football) [38], protective equipment recommendations (helmets) [39–41], equipment modifications (padded goal posts in soccer) [42], and specific training programs (FIFA's 11 steps for ACL tear prevention) [43].

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D. Caine, L. Purcell (eds.), *Injury in Pediatric and Adolescent Sports*, Contemporary Pediatric and Adolescent Sports Medicine, DOI 10.1007/978-3-319-18141-7_2

This chapter reviews ED studies evaluating SRIs in children and adolescents. Specific attention is paid to different types of sports and recreational activities, injury rates, types of injuries, anatomic injury sites, age differences, gender differences, mechanisms, circumstances, temporal variations, and outcomes of injuries. It also highlights specific recommendations for injury prevention programs as well as limitations of ED injury surveillance studies.

Sports/Recreational Activities

Sports and recreational activities vary between countries and even between different areas of some countries. One Canadian study using national data found that most SRIs in children and adolescents occurred during soccer (21 %); the least number of injuries occurred in ringuette (0.57 %) [9]. A local study in Canada (Vancouver, British Columbia), however, found that most SRIs occurred in cycling, basketball, soccer, and ice hockey [10]. Another Canadian study looking specifically at SRIs resulting from soccer, found that soccer accounted for 4.5 % of all injuries in children 5–19 years of age in Canada and represented 13 % of all SRIs [11]. Soccer injuries accounted for 21.5 % of SRIs occurring during team sports [11]. In Scotland, the majority of SRIs also occurred during football (soccer) [44].

In the USA, cycling, basketball, playground injuries, and football accounted for the majority of SRIs presenting to EDs based on national data (51 % combined) [2]. Individual sports (cycling, playground injuries, skating/skateboard most common) comprised the majority of SRIs (63 %) compared to group sports (37 %) (basketball, football, baseball/softball most common) [2]. Local studies in the USA found that most SRIs in children and adolescents occurred in football and basketball [5, 12, 45].

A number of ED studies have examined injuries associated with specific sports and activities and have documented injury patterns in these activities [11, 14–27, 46]. The details of these studies are outlined in the following sections.

Injury Numbers and Rates

Annual injury numbers varied by sport and recreational activity (Fig. 2.1) [13–27, 46]. The majority of injuries occurred in bicycling, basketball, football, and soccer.

Some studies calculated injury rates for various sports and recreational activities [13–18, 23–27, 46]. Injury rates describe injury frequency relative to the size of a population and allow for comparisons

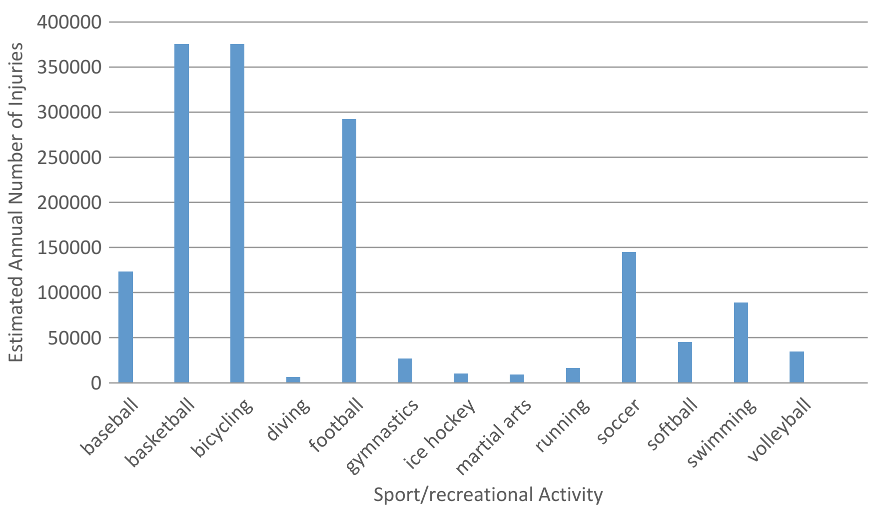

Fig. 2.1 Estimated annual number of injuries in sport and recreational activities

to be made across different sports or within the same sport over time. They can identify high risk sports to help target prevention interventions and guide research studies [47]. Injury rate denominators varied between studies and included population (Fig. 2.2a) [13, 14, 17, 23], children and adolescents [15, 16, 24, 46], and players/participants (Fig. 2.2b) [13, 18, 23, 26, 27].

Types of Injuries

The most common injuries sustained while participating in sports and recreational activity in Canada were fractures, sprains/strains, lacerations, and concussions [9]. The types of injuries varied according to sport or activity [9]. Fractures

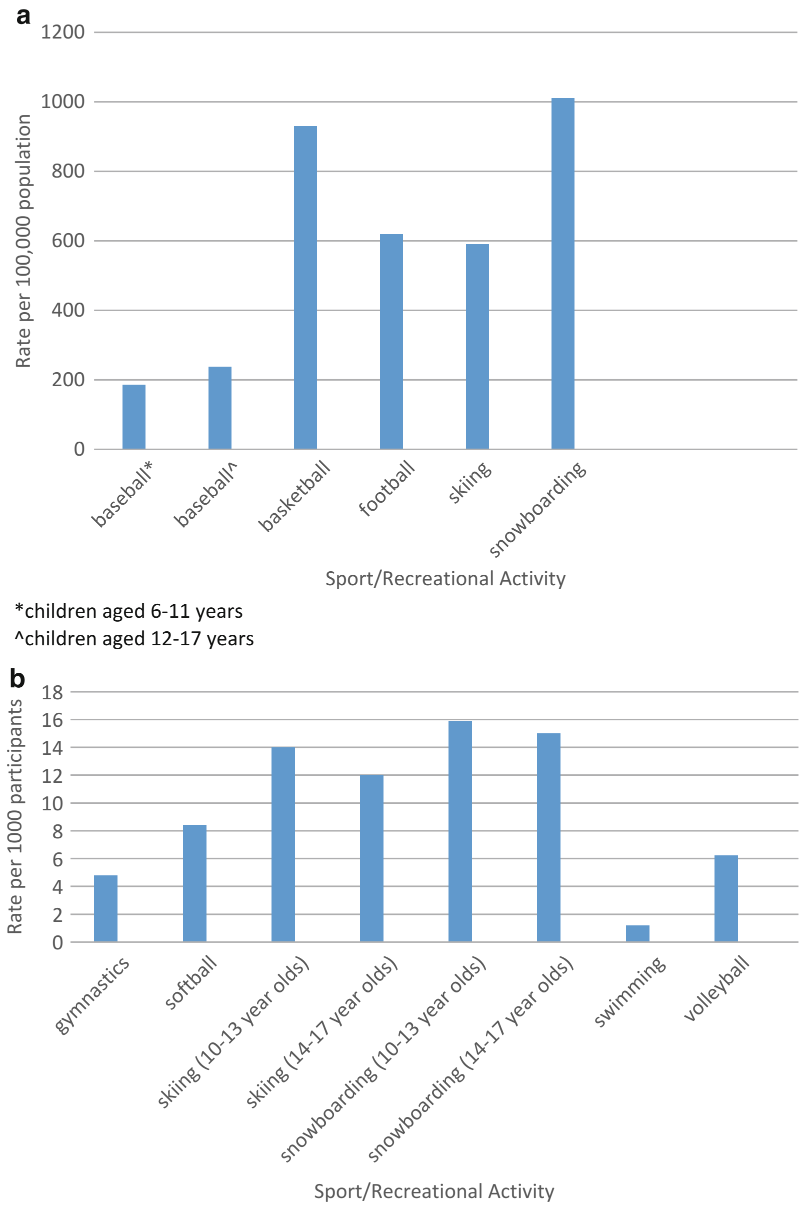

Fig. 2.2 (**a, b**) Injury rates in various sports and recreational activities

were most common in ice hockey, soccer, football, snowboarding, skiing and lacrosse; sprains/strains were most common in basketball and volleyball [9]. National data in the USA indicated that the most common SRI diagnoses were fractures/dislocations (24 %), sprains/strains (20 %), open wounds (17 %), and contusions (17 %) [2]. A study looking at recreational activities found that the most common diagnoses were fractures (28.2 %), contusions/abrasions (24.0 %), lacerations (18.1 %), sprains/strains (14.8 %), and traumatic brain injury (TBI) (6.4 %) [4].

One local study in the USA found that fractures were most common in both football and basketball, followed by closed head injuries (CHI) and lacerations [45]. Another US local study found that the most common SRIs were sprains, contusions, and fractures [5]. In the school setting, sprains/strains were most common (27.7 %), followed by contusions/abrasions (24.7 %) and fractures (16.6 %) [12]. Outside of school, contusion/abrasions (22.5 %) and lacerations (22.2 %) were most common, followed by sprains/strains (20.5 %) [12].

Many studies examined specific injuries and their association with pediatric sports and recreation participation; these are reviewed in detail below [3, 28–35, 48–55].

Abdominal Injuries

There is a paucity of literature regarding pediatric and adolescent sport-related abdominal injuries. One local study in Australia over a 6 year period between 2001 and 2006 identified 6 % of abdominal injuries in children were related to organized sports, 15 % to skateboards/scooters/bike/roller blades and skates, and 21 % to recreational activity [48]. Most injuries occurred in males, aged 11–12 years, and the majority of injuries resulted from rugby, soccer, and bat/ball games [48]. The most common mechanism was collision in males followed by falls in females [48]. Soft tissue injuries and lacerations were the most common diagnoses and the majority (94 %) were minor injuries managed conservatively [48].

Head injuries/Traumatic Brain Injuries

In children and youth aged 10–19 years, more than 40 % of head injuries presenting to Canadian EDs were SRIs [1]. Head injuries include contusions/abrasions, lacerations, and traumatic brain injuries (TBIs), which include skull fractures, hemorrhages and concussions. Head injuries/TBIs occurred most often in males (about 70 %) [28, 49–52] and in children aged 10–14 years participating in most activities [23, 49–52].

In the USA, 6.5 % of all SRIs were TBIs which accounted for approximately 173, 285 ED visits by children annually [28]. Most TBIs were in children and adolescents 10–19 years old (70.5 %) [28]. TBIs were most common in bicycling, football, basketball, and soccer [28, 48]. Admission rates varied from 6.6 to 24 % [28, 49, 51, 52]. Head injuries/TBIs account for varying percentages of injuries in different sports and recreational activities (Fig. 2.3) [14, 18, 20, 23, 28, 46].

The incidence of TBIs has increased in the last 10–15 years. One study found that the incidence of sports-related TBIs increased 62 % from 2001 to 2009 and the estimated rate of injury increased 57 % from 190 per 100,000 population to 298 (likely because of increased awareness and increased ED visits for TBI) [28]. Another study found the incidence of sports-related TBIs increased 92 % over a 10-year period from 2002 to 2011 [48].

Although incidence rates have increased, admission rates for sports-related TBIs have remained stable [52] and injury severity has decreased, as evidenced by decreased mean injury severity score (ISS) from 7.8 in 2002 to 4.8 in 2011 and decreased length of stay (LOS) [52]. In admitted patients, football (24.7 %) and baseball/softball (12.9 %) were the most common sports responsible [49].

Concussions

Sport-related concussions (SRC) are a significant concern in the pediatric and adolescent population. SRCs accounted for half of

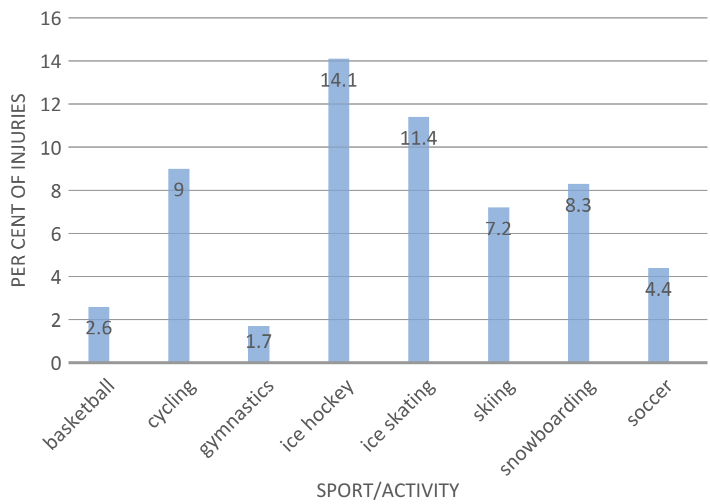

Fig. 2.3 Head injuries/traumatic brain injuries in sports and recreational activities

concussions in the pediatric age group in the USA [29] and resulted in 3–17 % of all injuries in any specific sport [9, 11]. The number of SRCs has been increasing in the last decade: US ED visits for SRCs in 8–13-year-olds doubled from 1997 to 2007 and increased by >200 % in 14–19-year-olds [29]. Admission rates for concussions were one of the highest for all SRIs (24.2 % in one study) [52].

Most SRCs occurred in males (71.6 %) [52]. Sixty percent of SRCs occurred in adolescents aged 14–19 years and 40 % in children aged 8–13 years [29, 52]. One quarter of SRCs occurred during organized team sports (OTS), most commonly football, basketball, soccer, ice hockey and baseball, although 47 % of SRCs in 14–19-year-olds occurred during OTS [29, 52]. Concussion rates per 10,000 participants were highest for ice hockey (10 in 7–11-year-olds, 29 in 12–17-year-olds) and football (8 in 7–11-year-olds, 27 in 12–17-year-olds) [29].

Most SRCs in Canada occurred in males 10–14 years of age playing ice hockey and accounted for 11.4 % of all injuries in hockey in this age group [9]. However, the highest percentage of SRCs was reported in 5–9 year old females in ringuette; SRCs accounted for 17.1 % of all injuries sustained in ringuette [9]. The lowest percentage of SRCs occurred in volleyball [9]. The most common mechanism resulting in SRCs were falls and contact with another person or object [11, 52].

Cervical Spine Injuries

One local US ED study found that 27 % of cervical spine injuries in children were sports-related; 29 % of these injuries resulted from football [53]. Almost all of these injuries occurred exclusively in boys, with an average age of 13.8 years [53]. The majority of SRIs (75 %) showed spinal cord injury without radiological abnormality (SCIWORA) and 75 % involved the upper spine from C1–C4 (75 %) [53]. The worst injuries occurred with diving [58].

Craniofacial Injuries

Craniofacial injuries result in significant severity and morbidity. One study found that 45.5 % of patients were admitted, 15 % of those to the ICU, and 31.1 % required surgery [54]. Ten per cent of craniofacial injuries were SRIs and the majority of these injuries occurred in boys (80.8 %) with a peak incidence between 13 and 15 years (40.7 %) [54]. Nasal (35.9 %), orbital (33.5 %), and skull fractures (30.5 %) were the most common diagnoses [54]. Of SRIs, baseball and softball were the most common sports involved (44.3 %) [54]. The most common mechanisms resulting in injury were throwing, catching or hitting a ball (34.1 %) and collision with other players (24.5 %) [54].

Dental Injuries

SRIs accounted for about 13.8 % of dental injuries, most commonly in baseball (40.2 %), basketball (20.2 %), and football (12.5 %) [30]. The majority of sports-related dental injuries occurred in 13–17-year-olds and 76.6 % of sports-related dental injuries occurred in males [30].

Similar results were found in a local study in Victoria, Australia, which found that 13.5 % of pediatric dental injuries resulted from sports activities, including soccer, cricket, basketball, netball, and hockey [55]. The most common mechanism of sports-related dental injuries resulted from striking or colliding with an object [55].

Eye Injuries

SRIs accounted for 24 % of pediatric eye injuries [31]. Eye injuries were most common in basketball (18 %), baseball and softball (17 %), and football (16 %) [31]. The majority of injuries occurred in males and in the 10–14 year age group [31]. Injury incidence peaked during May, June, July (36 % of SRIs) and were most likely to be the result of contact with another person [31].

Hand Injuries

Approximately 36.4 % of pediatric hand injuries were SRIs [32]. Basketball (28.2 %), football (22.7 %), baseball (5.8 %), and soccer (4.0 %) were the most common sports resulting in hand injuries [32]. Patients aged 10–14 years were most likely to be injured in sports (55.6 %) and in sports/recreational facilities (55.1 %) [32]. The most common diagnosis was fracture (35.0 %); more than 70 % of pediatric hand fractures resulted from sports [32].

Exertional Heat-Related Injuries (EHIs)

Heat-related illnesses are a concern with outdoor sports played during warm weather and are on the rise. Heat-related injuries increased 133.5 % over a 10 year period from 1997 to 2006 [33]. The majority of EHIs in pediatric and adolescent patients occurred during sport or exercise, most commonly football and exercise [33, 34]. The majority of heat-related injuries occurred in males and in adolescents aged 15–19 years and 10–14 years [33, 34]. Admission rates for heat-related illnesses was 7–9.6 % [33, 34].

Knee Injuries

The majority of knee injuries were SRIs and occurred in males [35]. The most common diagnosis was sprains/strains, followed by contusion/abrasions and lacerations/punctures [35]. In patients aged 5–14 years, the most common sports were football, bicycling, and soccer; in patients aged 15–24 years, basketball and football were the most common sports [35].

Violent Injuries

A violent injury is defined as any injury resulting from physical force by one or more persons with the intent of causing harm, injury or death to another person [3]. In the USA, 0.25 % of SRIs in children and adolescents were violent injuries [3]. The highest incidence rate was for 10–14-year-olds (13.6 per 100,000) and the majority were in males (71.6 %) [3]. Most injuries occurred during basketball (20.8 %), and bicycling (19.3 %) [3]. Most violent injuries occurred during bicycling for 10–14-year-olds (26.7 %), and in basketball for 15–19-year-olds (45.3 %) [3]. Most violent injuries were to the head/neck (52.2 %), of which 24.1 % were TBIs, and 23.6 % to the arm/hand [3]. The most common diagnoses were contusions/abrasions (32.7 %), lacerations/punctures (19.3 %), fracture (18.8 %), and concussion (12.6 %) [3]. The mechanism of injury was most commonly being pushed or hit (65.6 %) and most injuries occurred at a sports/recreation place (27.1 %) or at school (25.8 %) [3]. Most injuries were not severe and only 1.2 % of patients were admitted [3].

Patterns of Injuries by Sport/ Recreational Activity

Injury diagnoses vary by sport and recreational activity and anatomic injury sites tend to be sport-specific [5]. The most common anatomic injury sites identified in a local US study included the ankle and foot (20 %), forearm and wrist (17 %), and hand (17 %) [5]. A local Canadian study found that the most frequently injured body parts were the face, head, and digits [10]. Specific injuries and anatomic sites of injury associated with particular sports/activities are outlined below.

Baseball

Soft tissue injuries (34.3 %) and fractures (18.4 %) were the most common diagnoses in baseball [13]. Face (33.5 %) and upper extremity (32.9 %) injuries were most common [13].

Basketball

The most common injuries in basketball were sprains/strains followed by fractures/dislocations [9, 14]. Sprains/strains occurred most often in the lower extremity (30.3 %), most commonly the ankle (23.8 %), whereas fractures/dislocations occurred most often in the upper extremities (15.1 %), mostly in the finger (8.4 %) [14]. In a small local US study, however, fractures were found to be the most common injury in basketball [45].

US national data indicated that the most frequent body parts injured in basketball were lower extremities (42.0 %), upper extremities (37.2 %), and head (16.4 %) [14]. The ankle was injured most often (27.3 %), followed by fingers (20.2 %) [14]. A local US study found that ankle and foot injuries (44 %), hand injuries (21 %) and forearm/wrist injuries (13 %) were most common [5]. Canadian data showed that digits (22 %), ankles (16 %), and head (11 %) were the most frequently injured body parts [10].

Bicycling

Contusions/abrasions (30.4 %), lacerations (29.9 %), and fractures (18.8 %) were the most common injuries [15]. The majority of fractures (78 %) were to the upper extremities. There were 1,965 deaths in children and adolescents resulting from bicycling in the USA between 1990 and 2005, mostly from head injuries in the 15–18 year age group [15].

In a local US study, head (14 %) and forearm/wrist injuries (26 %) were most common [5]. Canadian data found that face (15.3 %), head (13.1 %), and forearm (11.5 %) injuries were most common [10]. US national data showed that the most frequently injured body parts were upper extremities (32.7 %), lower extremities (24.1 %), face (21.4 %), and head (12.4 %) [15]. Another US national study indicated that the most frequent body parts injured were the face (decreased with age), upper extremity (fractures), and skin/soft tissue (increased with age) [46].

Diving

Lacerations (33.9 %) and soft tissue injuries (24.3 %) were the most common diagnoses [16]. Head/neck injuries (38.2 %) and face injuries (21.7 %) were most common [16].

Football

The most common injuries were sprains/strains (31.3 %), fractures/dislocations (28.4 %), and soft tissue injuries (23.7 %) [17]. A US national study found that the upper extremities (49.1 %), lower extremities (26.2 %), and the head/neck/face (16.0 %) were most commonly injured [17]. The most common injury was upper extremity fracture (21.8 % for boys, 24.8 % for girls) [18]. A local US study found that hand injuries were most common (25 %) [5].

Gymnastics

The most common injuries were sprains/strains (44.5 %), fractures/dislocations (30.4 %), and contusions/abrasions (15.6 %) [18]. The most frequently injured body parts were upper extremity (42.3 %), lower extremity (33.8 %), and head/neck (12.9 %) [18].

Ice Hockey

Two US national studies found similar percentages of injuries attributed to contusions/abrasions (23.6–26.9 %), fractures (17.3–17.5 %), and sprains/strains (16. 9–17.3 %) [19, 20]. TBIs accounted for 14.1 % of ice hockey-related injuries [20] and 9 % of injuries in patients 2–18 years of age were concussions [19].

Studies were inconsistent with respect to the most commonly injured body parts in hockey. Canadian data indicated that head and face injuries were most common [10]. One US study using national data found face (19.1 %), wrist/hand/finger (14.1 %), shoulder/upper arm (13.8 %), and lower leg/ankle/foot (11.1 %) injuries were most common [19]. Another US study found that upper extremity (44 %), head (16.3 %), and lower extremity injuries (16.1 %) were most frequent [20].

Martial Arts

In karate, taekwondo and judo, most injuries occurred in karate (79.5 %) [21]. The most common diagnoses in all martial arts were sprains/strains (29.3 %), contusions/abrasions (27.8 %) and fractures (24.6 %) [21], but these varied somewhat within specific types of martial arts. In karate, sprains/strains (30.0 %), contusions/abrasions (28.3 %), and fractures (24.6 %) were most common. In taekwondo, sprains/strains (33.4 %), fractures (28.1 %), and contusions/abrasions (24.3 %) were most common. In judo, fractures (27.3 %), contusions/abrasions (25.4 %), and sprains/strains (24.1 %) were the most frequent injuries [21].

In all disciplines, most injuries occurred to the lower limb/ankle/foot (30.1 %) and hand/wrist (24.5 %) [21]. Anatomic injury sites differed with discipline. In karate and taekwondo, lower leg/ankle/foot (31.0 %/31.8 %), hand/wrist (25.8 %/22 %), and face (9.6 %/10.9 %) injuries were most common [21]. In judo, shoulder/upper arm (19.1 %), lower leg/ankle/foot (16.0 %), and elbow/lower arm (14.9 %) were the most frequently injured body parts [21]. Participants in judo suffered more upper limb/shoulder and neck injuries than in karate and taekwondo [21].

Running

Sprains/strains were the most common injuries (51.5 %) [22]. Lower extremity injuries were the most common (64.4 %), most often the ankle (31.4 %) [22].

Skiing/Snowboarding

The most common injuries were soft tissue injuries (49.0 %/40.5 %), fractures (26.3 %/35.7 %), and TBIs (7.2 %/8.3 %) [23]. The most frequently injured body parts were the knee (22.7 %), head/face (15.7 %), and shoulder (15.6 %) in skiing, and the wrist (17.9 %), arm (16.6 %), and head/face (16.6 %) in snowboarding [23].

Soccer

Sprains/strains (36.7–38 %), fractures/dislocations (23.1–31 %) and contusions/superficial injuries (20.9–23 %) were the most common SRIs [11, 24]. Fractures were most common in the youngest age group, whereas sprains/strains were more common in older age groups [24]. The most common injuries were to the lower extremity, usually ankles and knees, followed by upper extremity and head/face/neck [5, 10, 11, 24]. Females sustained more lower limb injuries whereas males sustained more hand and head injuries [10]. Body parts injured varied depending on age: wrist (12.7 %) and finger (12.4 %) injuries were most common for children 5–9 years of age; ankle (15.7 %) and wrist (13.6 %)

injuries for children aged 10–14 years; ankle (21.9 %) and knee (17.6 %) injuries for the 15–18 year age group [24].

Softball

Sprains/strains (31.3 %) and soft tissue injuries (27.0 %) were the most common diagnoses in softball [25]. Hand/wrist injuries were fractures/dislocations (40.2 %), strains/sprains (26.5 %) and soft tissue injuries (24.6 %), whereas face injuries were mainly lacerations (38.5 %), soft tissue injuries (32.8 %), and fractures/dislocations (22.2 %) [25]. Hand/wrist injuries (22.2 %), of which fingers accounted for 12.6 %, and face injuries (19.3 %) were most common [25].

Swimming

The most frequent injuries were soft tissue injuries (54.7 %), sprains/strains (16.4 %), fractures/dislocations (11.3 %), and submersion (4.9 %) [26]. Children <7 years of age were most likely to be injured by submersion [26]. The most frequently injured body parts were the head/neck (37.0 %) (face most common 43.9 %), and lower extremity (33.3 %) (foot most common 45.5 %) [26].

Volleyball

Sprains/strains represented the majority of injuries (54 %) [27]. Upper extremity (48 %) and lower extremity (39 %) injuries were most common [27]. Of upper extremity injuries, finger injuries were most common (48 %); of lower extremity injuries, ankle injuries were most common (65 %) [27].

Injury Mechanism

Understanding the mechanism of injury can help provide valuable information for injury prevention. A number of ED studies included mechanism data and are detailed below [11, 13, 16, 18, 19, 21–23, 25–27].

Baseball

Being hit by the baseball (46.0 %), hit by bat (24.9 %), and sliding (9.6 %) were the most common mechanisms of injury [13]. Sliding was more likely to result in fracture and admission [13].

Diving

Collision with board/platform (43.9 %) was the main mechanism of injury [16].

Gymnastics

Handsprings/flips (42.3 %) and cartwheels/roundoffs (30.7 %) were the most common mechanisms [18].

Ice Hockey

The most common mechanism were falls (16.5 %), contact with boards (13.6 %) and contact with stick (13.0 %) [19].

Martial Arts

The most common injury mechanisms were being kicked (25.6 %), falling (20.6 %) and kicking (18 %), particularly in karate and taekwondo [21]. In judo, being thrown/flipped (32.7 %) and falling (27.3 %) were more common [21].

Running

One third of injuries resulted from a running-related fall (33.5 %) [22]. Falls resulted in the majority of upper extremity injuries and head injuries, and were more likely to result in soft tissue injuries, lacerations and fractures [22].

Skiing/Snowboarding

Falls on slopes (70 %) was the most common mechanism of injury in both skiing (70 %) and snowboarding (76.4 %) [23].

Soccer

The most common injury mechanisms were contact with other players/people (40.3 %), which resulted in the most fractures (39.1 %), and contact with structures/playing surfaces (33.9 %) [11].

Softball

The most common mechanism of injury was being hit by ball (52.4 %), accounting for the majority of face (89.6 %) and head (75.7 %) injuries [25].

Swimming

Contact with bottom or wall of pool (33.6 % in <7 years, 25.7 % in 7–17 years) and contact with pool deck (18.4 % in <7, 13.1 % 7–17 years) were the most common injury mechanisms [26].

Volleyball

Falls to the ground were the most common mechanism (31 %) followed by contact with the volleyball (20 %) [27]. Contact with net/pole resulted in the most concussions [27].

Injury Circumstances

Many studies documented various circumstances during which injuries occurred, which are detailed below.

Organized vs. Non-organized

Most injuries in football (61 %), martial arts (55 %), and volleyball (gym class 56 %, practice/competition 44 %) occurred during organized events [21, 27, 45]. Head injuries occurred more frequently during organized play than during non-organized play [45]. There were more injuries in basketball and soccer (61.2 %) during non-organized play [11, 45].

Location

School

SRIs sustained in school-aged children were more common at school (29.6–53 %) [10, 12]. Most injuries associated with gymnastics (40.0 %), running (50 %), soccer (41 %), and volleyball (59 %) occurred at school [11, 18, 22, 27]. A number of injuries in football (30.4 %) and soccer (41 %) also occurred at school [11, 17].

Sports/Recreation Place

The majority of baseball (67.3 %), basketball (36.1 %), football (33.6 %), martial arts (57.1 %), soccer (44.4 %), softball (81.2 %), and swimming injuries in 7–17-year-olds (44.6 %) occurred at a sports/recreation place (81.2 %) [11, 13, 14, 17, 21, 25, 26]. The vast majority of skiing (97.2 %) and snowboarding injuries (90.7 %) occurred at ski resorts [23], while the vast majority of diving (90 %) and swimming injuries (96.9 % <7 years, 89.5 % 7–17 years) occurred in swimming pools [16, 26]. More than half of SRCs occurred at parks/playgrounds; a quarter occurred at home and 1/5 occurred at school [52].

Home

The majority of bicycling (47.5 %) (particularly in 1–4-year-olds) and swimming injuries (in children <7-year-olds) (56.3 %) occurred at home [15, 26]

Equipment

Lacerations were less common in athletes wearing a helmet than those not wearing a helmet [45]. Most diving injuries occurred on board/platform (32.3 %) or in-flight (29.8 %) [16]. The odds of colliding with board/platform significantly increased if performing a flipping or handstand maneuver or backward dive [16].

Age Differences

The majority of SRIs in children and adolescents occurred in the 10–14 year age group [5, 9, 11, 12, 15, 16, 21, 23, 25, 36, 45, 46]. Exceptions included rugby, running, and ice hockey, where 15–19-year-olds were most often injured [9, 19, 22]. In one local Canadian ED study, more injuries occurred in the 15–19-year age group in cycling, basketball, soccer, ice hockey, and lacrosse [10]. A US national study also found that most basketball SRIs occurred in 15–19-year-olds [14].

Some studies used different age ranges, looking at 6–11-year-olds and 12–17-year-olds. In football, volleyball, ice hockey, baseball, and gymnastics, the majority of injuries were found in 12–17-year-olds [13, 17, 18, 20, 27].

There were age-related differences in injury patterns. In a number of sports, including soccer and gymnastics, fractures were more common in older children than adolescents, whereas sprains/strains were more common in adolescents [11, 18, 24]. Lacerations were more common in younger children [15]. In ice hockey, 9–14-year-olds sustained wrist/hand/finger injuries most often, whereas 15–18-year-olds injured the upper arm/shoulder most often [19].

Gender Differences

The majority of SRIs overall occurred in males (51–94.9 %) [2, 4, 5, 9–17, 19–26, 36, 44–46]. Exceptions included volleyball, ringuette, gymnastics, and softball, where the majority of injuries occurred in females [9, 18, 25, 27]. In the USA, males were most commonly injured in football and basketball whereas females were more commonly injured in soccer and biking [5]. In Scotland, football (soccer), rugby, and ice-skating accounted for the majority of SRIs in adolescent males, whereas ice-skating, football (soccer), and netball accounted for the majority of SRIs in adolescent females [44]. There was an increasing gender gap for injury risk with age [44].

Females sustained more concussions than males in ice hockey, volleyball, soccer, ringuette, baseball, softball, and rugby, whereas males sustained more concussions in football, basketball, lacrosse, snowboarding, and cycling [9, 19]. Males sustained more fractures and hand injuries than females (31 vs. 22 %; 21 vs. 16 %) [5]. Males were also more likely than females to have a shoulder injury in softball [25]. Females sustained more sprains (44 vs. 36 %) and contusions (37 vs. 33 %), as well as more ankle (26 vs. 20 %) and back (7 vs. 4 %) injuries than males [5].

Temporal Variations

One study looked specifically at temporal variations in SRIs in children and adolescents [4]. Cosinor analysis demonstrated single peaks for month of injury for snow activities (January), trampoline (June), and cycling and water activities (July). Double cosinor peaks were found for skating and playground activities (April and September). Peak week days of injury were Monday for snow activities and trampoline; Wednesday for playground equipment; Saturday/Sunday for skating activities; and Sunday for cycling injuries [4].

A number of sport-specific ED studies included data on temporal variations in injury patterns [10, 11, 13–18, 25–27]. Basketball injuries occurred most commonly between December and March, peaking in January [10, 14]. Bicycling injuries occurred most often (75 %) between April and September [15]. Most baseball and softball injuries occurred between April and June/July [13, 25]. Diving and swimming injuries peaked in June, July and August [16, 26]. Most exertional heat-related injuries occurred in the warmer months of June to September [33, 34]. The majority of football injuries occurred from August through November [17]. Soccer and volleyball injuries peaked in September and October in the USA [10, 27]. In Canada, soccer injuries occurred most often in the summer (33.4 %) followed by the fall (28.3 %) and spring (26.3 %) [11]. Gymnastics injuries occurred throughout the year with peaks in October and March, corresponding to club and school seasons [18].

Injury Outcomes

Admission rates for SRIs were generally low (0–6 %) for all sports [2, 5, 10, 11, 13–24, 26, 27, 36, 46] except for swimming injuries in children <7 years (11 %) [26]. Two local studies, one US and one Canadian, found that the admission rate for bicycling injuries was 8–11.3 % [5, 10]. Orthopedic follow-up in one local US study occurred in 38–43 % of cases [5].

Admission to hospital with SRIs occurred most commonly with head and forearm injuries [10, 21]. There was an increased risk of admission with injuries sustained during alpine skiing, cycling and snowboarding [10]. The most common diagnosis for admission was fractures in martial arts, running, football, volleyball, diving, gymnastics, and baseball [13, 16–18, 21, 22, 27], as well as head injuries/TBIs in baseball, basketball, bicycling, and football [13–15, 17].

Trends Over Time

Overall, injury rates for SRIs have been increasing over the last couple of decades. One study in Wales showed a 54 % increase in SRIs among children and adolescents between 1983 and 1998 [56]. Male–female ratios remained constant (70 % male) and a greater number of sports were responsible for injuries [56]. The increase in injury rates appeared to be increased participation and/or increased risk associated with some sports [10, 56].

Similarly, a Canadian ED study showed a 28 % increase in SRIs between 1992 and 2005 [10]. Head injuries increased from 11.3 to 12.7 % over this period [10]. Soccer injuries doubled and hockey injuries increased 140 % in males and 230 % in females, reflecting the popularity of soccer and hockey in Canada, particularly in females. Injuries in males aged 10–14 years increased significantly ($p<0.001$) over the 14 years [10].

Sport-specific studies have noted increases in injuries over time in martial arts (judo, taekwondo), softball, running (34 % over 14 year period from 1994 to 2007; annual rate of injury increased 21 % over the 14 year period from 1994 to 2007), football (26.5 % over 18 year period from 1990 to 2007), and ice hockey (163 % over 17 year period from 1990 to 2006 among 9–14-year-olds and 85 % among 15–18-year-olds) [17, 19, 21, 22, 25].

Decreases in injuries over time were seen in karate (steady increase between 1990 and 1995 followed by a decrease from 1996 to 2002), bicycling (decreased between 1992 and 2005 from 6.63 per 1,000 children to 3.92 per 1,000 children), gymnastics (25 % from 1990 to 2005), baseball (24.9 % from 1994 to 2006), volleyball (23 % from 1990 to 2009 but annual injury rate remained constant), and basketball (21.8 % from 1997 to 2007) [13–15, 18, 21, 27].

There were also trends identified with specific types of injuries in some studies. In bicycling, contusions and abrasions and injuries to head, face, and lower extremities decreased significantly from 1992 to 2005 [15]. In basketball, the number of TBIs increased by 70 % from 1997 to 2007; the rate of TBIs increased 63.4 % from 11.9 per 1,000 population in 1997 to 19.4 per 1,000 population [14]. There was a significant increase in the number of concussions in volleyball from 1990 to 2009 [27].

Recommendations

ED studies using injury surveillance systems provide valuable information regarding SRIs in children and adolescents. They can identify trends and patterns of injury that allow specific recommendations regarding injury prevention to be made. Injury prevention recommendations and interventions can then be evaluated in the ED using randomized controlled trials, such as the effect of providing a bicycle helmet on subsequent helmet use [57]. The studies reviewed in this chapter offered several recommendations to prevent SRIs in children and youth.

General recommendations included development of injury prevention programs targeted at the 10–14 year age group, particularly males, and specific sports, such as soccer (football) in Canada and Scotland [9, 10, 44]. In addition, pediatric and adolescent training programs, as well as emergency and family medicine training programs, should include more training in diagnosis and treatment of musculoskeletal conditions so that physicians are prepared to properly manage children and adolescents with SRIs [2, 5]. Furthermore, this training is important because knowledge of sports injuries can help direct future research into injury prevention [5]. Ongoing research is particularly important to further elucidate injury trends and patterns, as well as evaluating the effects of injury prevention strategies on injury incidence [5, 17–20, 22, 23].

Further recommendations included that locale of injuries (school vs outside of school), as well as temporal variations in sport injuries, should be considered when planning injury prevention programs to develop more specific interventions [4, 12]. For instance, education programs emphasizing bicycle helmet use should be concentrated just before increase in cycling activity in the spring [4]. In addition, groups involved in injury prevention should be aware that trends in sport injuries may follow media sport popularity, allowing for anticipation of injury prevention based on current popular sports [10].

Consistent recommendations regarding protective equipment and modifications of playing surfaces and environments have been made in several sources. Proper protective equipment should be worn for the sport of participation, including mouth guards [13, 19, 20, 25, 31, 46], proper helmets [15, 19, 20, 23, 25, 30, 31, 46], face shields [13, 19, 20, 25, 30, 31], polycarbonate eyewear [13, 25, 31], and padding [21]. Modifications of playing surfaces/environment include padding soccer goalposts, volleyball net poles and protruding hardware, pool structures and edges, and floors for martial arts; safety/softer/bigger balls in volleyball, baseball, softball, and basketball for younger children; breakaway safety bases in baseball and softball; and adequate hydration, adequate rest breaks, and planning activity during cooler parts of the day (morning/evening) to prevent heat-related illnesses [13, 14, 21, 25–27, 30, 33, 42].

Another important aspect of injury prevention is proper training of coaches and trainers to ensure that athletes are taught sport-specific techniques and safety procedures for their particular sport [3, 15, 16, 18–22, 26, 27, 53] Proper supervision, particularly of young and inexperienced participants, is crucial to reduce injuries [3, 15, 6, 18, 25, 53]. General conditioning and strengthening programs for athletes are also important, as well as proper rehabilitation of injuries [16, 18, 27, 53].

Limitations

Although ED studies using injury surveillance data can provide significant valuable information about SRIs in children and adolescents which can help in the development of injury prevention strategies, there are limitations. ED injury surveillance programs capture mainly acute injuries, severe enough to require emergency treatment. They do not capture more minor injuries or chronic injuries which may present to other medical facilities, such as family doctors or pediatricians, physiotherapists, athletic therapists or chiropractors, or for which no medical treatment is sought. Therefore, these studies likely underestimate the true incidence of SRIs. Additionally, NEISS reports only the most serious injury per patient so patients who have multiple injuries are not captured [3, 4, 12–36].

Moreover, local studies and the CHIRPP program in Canada are not generalizable to the population as a whole, whereas national studies may not be applicable to local areas due to geographical differences in SRIs [5, 9–11, 44–56]. Furthermore, ED injury surveillance systems rely on accurate documentation from ED staff and patients which can result in reporting error and recall bias. In addition, it is often difficult to compare ED studies because of variations in injury definitions, injury details recorded, different populations studied, different age groups and assigned diagnoses and anatomic regions by physicians. Use of standard injury documentation forms can improve data capture and therefore improve injury surveillance [58].

Lastly, accurate injury rates cannot be calculated because participation data and exposure data is generally not available through EDs. Various studies used different denominators in stated rates which make comparisons between sports/activities difficult. Information regarding time lost from sport and injury recovery is also not available through EDs. Therefore, information regarding injury incidence and severity is limited [3–5, 10–56].

Summary

Millions of children and adolescents present to EDs each year with SRIs. ED injury surveillance systems track injury numbers and characteristics which can help identify injury patterns and interventions that may help prevent injuries. These injury surveillance systems can provide a wealth of information about individual sports and activities and allow for comparisons between them. However, there are several limitations, including missed injuries that did not present to an ED for treatment, capturing only moderate to severe injuries requiring emergency treatment, inaccuracies/inconsistencies with documentation and diagnosis, and lack of participation and exposure data to allow for calculation of injury rates. In addition, information regarding recovery times and time lost from sport is not available to allow for accurate assessments of injury severity. Despite these limitations, results of ED studies can be valuable to guide prevention efforts, as well as further research to evaluate specific patterns identified and success of intervention/ prevention efforts.

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3 Epidemiology of Injury in Community Club and Youth Sport Organizations

Todd M. Sabato and Dennis Caine

Introduction

Despite recent evidence indicating a 4 % reduction in participation in the four most popular US team sports (basketball, soccer, baseball, and football) among boys and girls age 6 through 17 years between 2008 and 2012 [1], more than 60 million American youth are involved in organized sport activities—an increase of nearly eight million since 2000 [2]. Clearly, youth sport participation is both extensive and on the rise.

Physical activity and team sport participation during adolescence, however, often declines, although studies show that children who engage in organized sport at an early age have a greater likelihood of remaining active as teens and adults than those who do not [3]. The benefits of physical activity are numerous, which are particularly important with the recent dramatic increase of obesity. The incidence of obesity in children and adolescents has doubled over the past 30 years, and affects one-third of all children by the third grade [4]. Sport and physical activity play an impactful role in helping children maintain a healthy weight. Similarly, physical activity delays the development of chronic diseases such as hypertension, heart disease, type-2 diabetes, and osteoporosis [3, 5, 6]. Participation further leads to higher levels of cardiorespiratory fitness, and stronger muscles and bones [5].

Sport has also been found to positively impact emotional, social, and psychological development. Youth participants have shown improved academic achievement, greater self-esteem, fewer behavioral problems, and healthier psychological adjustments [2]. In addition, young athletes learn valuable skills transferrable to future life experiences, such as emotional control, the value of teamwork, and the ability to show initiative [7].

In recent years, more youth have undertaken intense training at younger ages or participated in multiple sports, often simultaneously. It is not uncommon for teens to train at regional centers for 20 or more hours per week, or for children as young as 6 to play organized hockey or soccer, and travel with select teams to compete on a regular basis [8]. Given this trend toward early and multifaceted training, frequent competition and single sport specialization, injuries are quite common [6, 9]. From 2002 to 2009, an estimated 2,651,581 children and adolescents under 20 years old were treated annually for sports- and recreation-related injuries in the USA [10].

Minimizing the risk of athletic injury requires a thorough understanding of the extent of injury among youth, the causative agents and viable

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D. Caine, L. Purcell (eds.), *Injury in Pediatric and Adolescent Sports*, Contemporary Pediatric and Adolescent Sports Medicine, DOI 10.1007/978-3-319-18141-7_3

preventive measures. Knowledge of each of these elements may assist athletes, coaches, and parents in generating proactive approaches to injury prevention, treatment, and care [11]. Quantifying injury occurrence with respect to *who* is affected by injury, *where* and *when* injuries occur, and *what* their outcome is, is referred to as descriptive epidemiology. Explaining *why* and *how* injuries occur and identifying control and prevention strategies is referred to as analytical epidemiology [12].

Several comprehensive reviews of pediatric sports injuries have been published [8, 13, 14]. The present chapter expands upon previous reviews with more recently published work. The primary focus of the chapter is the application of descriptive epidemiology to sport-related injuries sustained by children and youth participating in non-school community-based settings, including privately owned clubs. This is particularly important, given that participants in these venues often do not have similar access to immediate health care such as that found in high schools in the USA, where athletic trainers are typically employed.

Descriptive Epidemiology

Descriptive epidemiology is the most common type of epidemiological research in pediatric and adolescent sports injury. Although there has been a transition from descriptive to etiologically based approaches, and to increased translational research, large gaps remain in the available descriptive epidemiological literature on injury related to some pediatric and adolescent sports. For example, while competitive swimming and figure skating attract large numbers of participants, few published epidemiological studies on youth injury in these sports exist.

Figure 3.1 illustrates important aspects of the descriptive epidemiology of youth sports-related injuries. Addressed below, these elements highlight a respective contribution to the epidemiology of community-based sports injury.

Injury distribution reflects person (who), place (where), time (when), and injury outcome (what) factors, and provides descriptive characteristics of injuries. Assessing each of these factors, individually and in context with others, is paramount to identifying injury patterns.

Person Factors

Sport Affiliation

Tables 3.1 and 3.2 summarize studies reporting overall (i.e., practice and competition combined) injury rates for girls' and boys' sports, respectively. Girls' incidence rates per 1,000 h and/or per 1,000 athlete-exposures (AEs) are shown for alpine skiing [15], artistic gymnastics [16–21], rhythmic gymnastics [22], soccer [23–30], softball [28], TeamGym [31], and tennis [32]. Incidence rates for boys' sports are reported for alpine skiing [15], baseball [28], gridiron football [33], artistic gymnastics [17], rugby [34], soccer [26–28, 30, 35, 36],

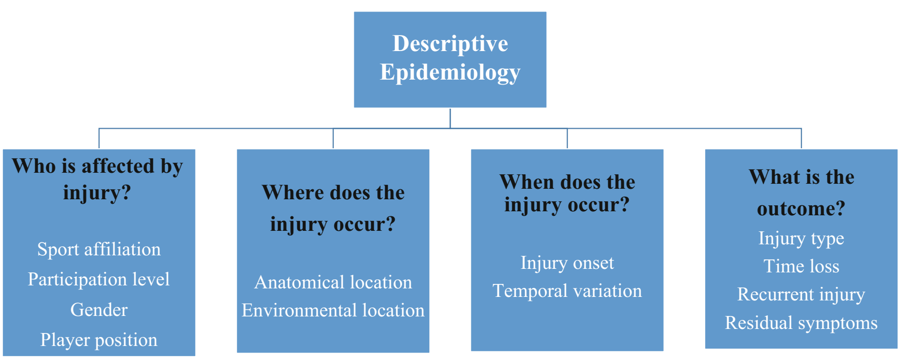

Fig. 3.1 A schema of the descriptive epidemiology of youth sport injuries. Reproduced with permission from [8]

Table 3.1 A summary of exposure-based incidence rates in girls' sports

Study	Study design[a]	Data collection[b]	Study duration	Level of play	No. of injuries	No. of exposures (hours)	No. of exposures (AEs)[c]	Rate: # Inj/1,000 h	95 % CI	Rate: # Inj/1,000 AEs
Alpine skiing										
Westin [15]	PR	Q	5 years	Ski high school	150			1.77	1.5–2.04	
Artistic gymnastics										
O'Kane [16]	CS	Q	1 season	Club	216			Acute: 1.3	1.0–1.7	
								Overuse: 1.8	1.5–2.2	
Kolt [17]	P	Q	9 months	Club	57			5.3		
Caine [18]	P	Q	3 years	Club	192	76,919.5	22,584	2.5		8.5
Bak [19]	P	Q	1 year	Club	41			1.4		
Lindner [20]	P	QI	3 seasons	Club	90	173,263		0.5		
Caine [21]	P	I	1 year	Club	147	40,127		3.7		
Rhythmic gymnastics										
Cupisti [22]	P	Q	8 months	Club	49			1.08		
Soccer										
Clausen [23]	P	DM	1 season	15–18 years	424	27,746		15.3	13.1–17.8	
Soligard [24]	P	DM	1 season	13–17 years	376			3.9	3.4–4.0	
Steffin [25]	P	DM	1 season	15.4 (SD=0.8)	526	142,721		3.7	3.4–4.0	
Kucera [26]	P	Q	3 seasons	12-18 years	320	60,166		5.3	4.7–6.0	
Emery [27]	P	DM	1 seasons	U14–U18	2,256			5.6		
Radelet [28]	P	Q	2 seasons	14–19 years	16		1,637			23.0
Soderman [29]	P	DM	1 season	U14–U18	79			6.8		
Backous [30]	P	Q	1 week	6–17 years				10.6		
Softball										
Radelet [28]	P	Q	2 years	Community	37		3,807			10.0
TeamGym										
Harringe [31]	P	DM	1 season	Club-level				2.2	1.4–3.0	
Tennis										
Spinks [32]	P	DM	12 months	5–12 years		1.1				

[a]Design: *P* prospective cohort, *R* retrospective cohort, *CS* cross-sectional
[b]Data collection: *DM* direct monitor, *IR* insurance records, *RR* record review, *Q* questionnaire
[c]An AE is one athlete participating in one practice or competition

Table 3.2 A summary of exposure-based incidence rates in boys sports

Study	Design[a]	Data collection[b]	Study duration	Level of play	No. of injuries	No. of exposures (hours)	No. of exposures (AEs)[c]	Rate: # Inj/1,000 h	95 % CI	Rate: # Inj/1,000 AEs	95 % CI
Alpine skiing											
Westin [15]	PR	Q	5 years	Ski school	162			1.62	1.36–1.88		
Baseball											
Radelet [28]	P	Q	2 years	7–13 years	128		6,913			17.0	
Gridiron football											
Malina [33]	P	DM	2 seasons	Youth grades 4–8	259					10.4	9.2–11.8
Gymnastics											
Bak [17]	P	Q	1 year	Club	26			1.0			
Rugby											
Garraway [34]	P		1 season	Under 16	26			3.4			2.1–4.8
				16–19	72			8.7			6.5–10.8
Soccer											
Brito [35]	P	DM	Pre-season	12–19	53	23,364		2.5			
Emery [27]	P	DM	1 season	U14–U18	39	7,024		5.5			
Kucera [26]	P	Q	3 years	U12–U16	467			5.3	4.7–6.0		
Radelet [28]	P	Q	2 years	7–13 years	47		2,799			17.0	
Junge [36]	P	DM	1 year	14–18 (Alcace)	57			2.3			
				14–18 (Chech)	130			2.6			
Backous [30]	P	Q		6–17 years						7.3	
Tennis											
Spinks [32]	P	DM	12 months	5–12 years	10			1.3			

[a]Design: *P* prospective cohort, *R* retrospective cohort
[b]Data collection: *DM* direct monitor, *Q* questionnaire
[c]An AE is one athlete participating in one practice or competition

and tennis [32]. Girls participating in artistic gymnastics (range=0.5–5.3) and soccer (range=3.7–15.3), and boys participating in rugby (range=3.4–8.7) and soccer (range=2.3–5.5) reported the highest rates of injury per 1,000 h exposure. When using AEs, injury rates among girls were highest in soccer (23.0), softball (10.0), and gymnastics (range=1.3–8.5), while in boys injury rates were highest in baseball (17.0) and soccer (range=4.3–17.0). Most of these sports involve contact, jumping, sprinting, or pivoting, actions often involved in the mechanism of sports injury.

Participation Level

Some data indicate that injury rates may vary by participation level. For example, advanced-level club female gymnasts may experience greater risk of injury compared to beginning-level counterparts, particularly in competition [18]. Increased daily and accumulated exposure to injury risk among advanced-level gymnasts, and an increased difficulty of skills practiced and performed, may explain this.

Data among girls' soccer players are mixed. Emery et al. [27] reported lower rates of injuries among U14 soccer players compared to U16 and U18 players (p=.01), whereas McNoe et al. reported higher rates among senior (>17 years) vs. junior (<=17 years) players in matches and training (p<.05) [37]. Soderman et al. reported that the highest incidence was seen in the 16-16.9 age group [29].

In a variety of sports, including football [33], lacrosse [39], rugby [40], and soccer [37], older boys experience higher injury rates than younger boys. In contrast, Brito et al. reported the highest incidence of injury among U17 soccer players followed by U15, U19, and U13 [35]. Older boys are heavier and stronger, and thus generate greater force on contact, enhancing the risk of injury. Other factors, such as maturity- and chronological age-associated variation, as well as intensity and duration of training, may also relate to risk of injury [41].

Gender

Gender-based differences in sports injuries are inconsistent. Several studies report higher injury rates for males, yet greater injury severity among females [42–44]. Higher injury rates are reported for females relative to males in skiing [15], gymnastics [17], and soccer [27, 37] (Tables 3.1 and 3.2). By comparison, in tennis, males had higher injury rates than females [32]. In tournament sports, higher taekwondo injury rates were reported for girls in one study and for males in another study [45, 46]. For karate, males had a much higher rate of injury [47].

Player Position

Minoe et al. [37] found little difference in the incidence rates by playing position for both males and females. However, injury incidence (per 1,000 h) for young female team handball players in practice was highest for goalkeepers (6.7), followed by backs (3.7), wings (3.2), and line (2.9). The highest incidence of injury in games, however, was sustained by backs (54.8) followed by line (54.3), goalkeepers (30.6), and wings (23.6) [48].

Place Factors

Anatomical Location

Identification of commonly injured anatomical sites is important, as it alerts health-care professionals to sites in need of special attention during pre-participation screenings [49]. Such information is also relevant in considering effective prevention strategies. For example, the impact of neuromuscular training on the incidence of knee injury among adolescent soccer, volleyball, and basketball players revealed that untrained female athletes had a 3.6-fold greater incidence of knee injury than trained female athletes ($P<0.05$) [50].

The proportion of injuries by body region may vary by gender within a sport and between sports. Male gymnasts, for example, experience a greater proportion of upper extremity (UE) injuries (e.g., shoulder or wrist) than female gymnasts, likely reflecting the skills practiced and apparatus used in men's gymnastics [51]. Similarly, variable techniques and competition rules for young martial artists are clearly reflected in the body regions and parts injured. In judo, for example, UEs are more frequently injured, whereas in karate the head/face incur most of the injuries [52].

Comparisons of commonly injured anatomical locations by region, body part, and sport are summarized in recent reviews [50–57]. Across sports, the lower extremity (LE) is most commonly injured, ranging from 21.7–85.1 % of all injuries [16, 23, 37, 50–59]. Adolescents involved in acrobatics [60], alpine skiing [15], and TeamGym [31] also indicate the LE as the most commonly injured body region.

The ankle and/or knee are the most commonly injured LE sites in most sports. Injuries to both joints increase a young athlete's risk of developing early onset osteoarthritis [61], subsequently creating a societal burden through indirect and direct costs [62]. Exceptions, however, include taekwondo, in which injuries occur primarily to the foot and toes [50]; skiing, where injuries are mainly to the knee and lower leg [15, 54]; rugby, where the thigh is most frequently injured [56]; and track and field where LE injuries primarily affect the lower and upper leg [57].

UE injuries are more common in sports such as baseball, gymnastics, judo, ice hockey, and snowboarding, and likely reflect the sport-specific upper body demands. In baseball, for example, most injuries involve the throwing arm, particularly among pitchers, with the strongest correlation to injury being the number of pitches thrown [63].

Only one sport (karate) reported head and facial injuries, most specifically tooth injuries, as the most common injury site [52]. Rugby injuries are most common to the head and neck [56]. Several studies examining TeamGym [31], soccer [37, 53], and taekwondo [50] indicate the head or head/neck as the second or third most common anatomical location for injury. Chapter 11 in this volume is dedicated to concussions affecting child and adolescent athletes.

In addition, some studies report incidence rates for specific body locations, thus permitting statistical comparison of anatomical location rates across sports, gender, or environmental locations [18, 27, 34, 58, 64, 65]. Lystad et al.'s review in taekwondo revealed that the LE incurred the highest injury rates, with 35.74 injuries per 1,000 AEs (95 % CI: 29.05–43.51), followed by the head and neck (12.65; 95 % CI: 8.80–17.57) and UE (7.22; 95 % CI: 4.41–11.15) [58]. In youth rugby, head injuries had the highest incidence per 1,000 game hours (8.1; 95 % CI: 7.1–9.1), followed by the face (7.8; 95 % CI: 5.1–10.4) and neck (3.3; 95 % CI: 2.7–4.0) [66].

Environmental Location

Much of the limited literature on environmental location has focused on injury frequency in practice and competition. Studies reporting practice and competition incidence rates for girls in gymnastics [21], ice hockey [67], martial arts [43–45, 58], lacrosse [38], netball [68], rugby [69], soccer [23, 24, 27–29, 37], softball [28], and team handball [46, 70, 71], and for boys in baseball [28], football [33, 73] ice hockey [67], lacrosse [38], martial arts [43–45, 66], rugby [68, 69, 74, 75], soccer [27, 35, 37, 59], team handball [70, 71], and TeamGym [72] are summarized in Tables 3.3 and 3.4, respectively. As a result of greater exposure time, the proportion of injuries in most girls' and boys' sports is greater in practice than in competition. However, incidence rates are typically higher during competition. For example, in gymnastics the vast majority of injuries (71.0–96.6 %) occur in training compared to competition (3.4–21.0 %) [16, 76]. Significantly higher injury rates in competition relative to practice were reported in girls gymnastics ($p < .001$) [18] and soccer ($p = .0009$) [24, 27, 36], and in boys baseball ($p < .05$) [28] and football ($p < .05$) [28, 33]. Competitors are more likely to be participating at greater intensity and speeds in competition and tournaments than in practice, thus increasing the risk of sustaining injury [27].

Table 3.3 A summary of exposure-based game/practice incidence rates in girls' sports

Study	Study design[a]	Data collection[b]	Duration of injury surveillance	Team type or age(s)	Practice rate (# Inj. per 1,000 h	Game rate (# Inj. per 1,000 h	P-Value and rate ratio (RR)[c]	Practice rate (# Inj. per 1,000 AEs)[d]	Game rate (# Inj. per 1,000 AEs)[e]
Gymnastics									
Caine [21]	P	DM	3 years	Club	2.35	7.43	RR: 2.69		
Ice hockey									
Roberts [67]	P	DM	1 season	Pee Wee		50.5			12.2
Martial arts									
Lystad [66]	P	DM	Tournament	10–18					52.83 (38.08–71.41)
Beis [43]	P	Q	1 season	Taekwondo					41.3
Pieter [44]	P	Q	1 season	Taekwondo					56.6
Tuominen [45]	P	Q		Karate					50.0
Lacrosse									
Lincoln [38]	P	DM	10 weeks	Recreational lacrosse					3.4 (1.5–6.7)
Netball									
Pringle [68]	P	DM	4 weeks	6–15 years		13.0			
Rugby									
Bird [69]	P	DM	1 season	<18 years				0	4.7
Soccer									
Clausen [23][f]	P	DM	1 season	15–18 years	2.3	19.6			
McNoe [37]	P	Q	1 season	13–17 years	7.0	51.7	$p < .05$		
Soligard [24][g]	P	DM	1 season	13–17 years	1.9 (SD = 0.2)	8.55 (SD: 0.5)	RR = 3.26, CI: 1.51–7.81		
Emery [27]	P	DM	1 season	U14–U16	2.62	8.55	RR = 3.26, CI: 1.51–7.81		
Radelet [28]	P	Q	2 years	7–13 years	9.0	41.0	$p < .009$		
Soderman [29]	P	DM	1 season	14–19 years	1.5	9.1			
Softball									
Radelet [28]	P	DM	2 years	7–13 years				7.0	11.0
Team handball									
Olsen [70][g]	P		1 season	15–18 years	1.0 ± 0.19	10.4 ± 1.50			

(continued)

Table 3.3 (continued)

Study	Study design[a]	Data collection[b]	Duration of injury surveillance	Team type or age(s)	Practice rate (# Inj. per 1,000 h	Game rate (# Inj. per 1,000 h	P-Value and rate ratio (RR)[c]	Practice rate (# Inj. per 1,000 AEs)[d]	Game rate (# Inj. per 1,000 AEs)[e]
Wedderkopp [46]	R		1 season	16.-18 years	3.4	40.7			
Nielsen [71]	P		1 season	7–18 years	2.2	11.4			
TeamGym									
Lund [72]	P	DM	1 season	10 years and older		[4.2–8.4] and [4.2–8.4]			6.3, CI: 4.2–8.4

[a]Study design: Design: *P* prospective cohort; *R* retrospective cohortPl
[b]Data Collection: *DM* direct monitor, *Q* questionnaire
[c]*RR* Relative Risk
[d]AE: 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
[e]Ratio: Incidence density ratio (IDR) = game injury rate over practice injury rate
[f]Acute injuries
[g]Coach report data for acute injuries

Table 3.4 A summary of exposure-based game/practice incidence rates in boys' sports

Study	Study design[a]	Data collection[b]	Duration of injury surveillance	Team type or age(s)	Practice rate (# Inj. Per 1,000 h) (range)	Game rate (# Inj. per 1,000 h) (range)	*P*-value and rate ratio (RR)[c]	Practice rate (# Inj. per 1,000 AEs)[d] (range)	Game rate (# Inj. per 1,000 AEs) (range)	*P*-value and rate ratio[c]
Baseball										
Radelet [28]	P	Q	2 years	7–13 years			$p < .05$	6.0	24.0	$P = < 0.05$,
										IDR = 3.1[e]
										SD = 0.20
Football										
Malina [33]	P	DM	2 seasons	Grades 4–8				8.7	18.6	IDR = 2.1[e]
Radelet [28]	P	Q	2 years	7–13 years		117.3	$p < .05$	7.0	43.0	$P = < 0.05$
Stuart [73]	P	DM	1 season	Grades 4–8					8.8	
Ice hockey										
Roberts [67]	P	DM	Tournament	12–19 years		117.3			26.4	
Lacrosse										
Lincoln [38]	P	DM	10-week season						8.7 (5.6–13.0)	
Martial arts										
Lystad [66]	P	DM	Tournament	10–18					62.78 (52.22–74.86)	
Beis [43]	P	Q	1 season	Taekwondo					26.4	
Pieter [44]	P	Q	Tournament	Taekwondo					58.3	
Tuominen [45]	P	Q		Karate					133.1	
Rugby										
Gabbett [74]	P	DM	4 seasons			56.8;				
						CI: 42.6–70.9				
Pringle [68]	P	DM	4 weeks	6–15 years	15.5			0.9	6.2	
Bird [69]	P	DM	1 season	<19 years		19.8				
Sparks [75]			1950–59	13–18 years						

(continued)

Table 3.4 (continued)

Study	Study design[a]	Data collection[b]	Duration of injury surveillance	Team type or age(s)	Practice rate (# Inj. Per 1,000 h) (range)	Game rate (# Inj. per 1,000 h) (range)	*P*-value and rate ratio (RR)[c]	Practice rate (# Inj. per 1,000 AEs)[d] (range)	Game rate (# Inj. per 1,000 AEs) (range)	*P*-value and rate ratio[c]
Soccer										
Brito [35]	P	DM	Pre-season	12–19 years	1.8	6.08	*P* = 0.02			
					0.9–2.7	2.9–10.6				
McNoe [37]	P	Q	1 season	13.17 years	6.8	36.8				
Timbka [59]	P	Q	1 season	13–16 years	3.9	2.4	CI: 1.7–3.2			
Emery [27]	P	DM	1 season	U14–U16	2.94	87.57	RR = 2.57			
							CI:2.57–6.2			
							P = 0.009			
Team Handball										
Olsen [70][e]	P		1 season	15–18 years	0.6 ± 0.28	8.6 ± 2.29				
Nielsen [71]	P		1 season	7–18 years	1.7	8.9				
TeamGym										
Lund [72]	P	DM	1 season	10 years and older		57.6			7.8	
						CI: 33.5–81.7			CI: 4.5–11.0	

[a]Study design: Design: *RCT* randomized control trial, *P* prospective cohort, *R* retrospective cohort
[b]Data collection: *DM* direct monitor, *Q* questionnaire
[c]*RR* rate ratio
[d]AE: 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
[e]Incidence density ratio (IDR) = game injury rate over practice injury rate; RR = relative risk

Environmental location also considers factors such as the type and condition of competition surface, and indoor and outdoor venues. Although the incidence of acute injuries among young female football players on artificial turf and grass did not differ significantly with respect to match injuries (RR 1.0, 95 % CI: 0.8–1.3; $p=0.72$) or training injuries (RR 1.0, 95 % CI: 0.6–1.5, $p=0.93$), in matches the incidence of serious injuries was significantly higher on artificial turf (RR 2.0, 95 % CI: 1.3–3.2; $p=0.03$) [25]. Steffen et al. hypothesized that more severe injuries, such as ligament sprains to the knee and ankle, occur when the player is off-balance while the loaded leg is fixed to the ground [25].

Another study reported a higher incidence of injury for indoor compared to outdoor soccer [77]. In contrast, Emery and Meeuwisse reported no significant difference between indoor and outdoor soccer injury rates except at the elite level, where incidence was greater in outdoor soccer (RR = 3.22, CI = 1.8–6.12) [27]. In girls' gymnastics, the event associated with the highest proportion and incidence of acute injury is floor exercise, which may be explained by the high volume of landings [16, 18].

Time Factors

Injury Onset

Few studies provide a breakdown of injuries by onset, and some studies report acute injuries only. As expected, the proportion of acute injuries tends to be very high in competition or tournaments. For example, 92.9 % of injuries were traumatic in young female players in team handball tournaments [46].

The relative proportion of acute or overuse injuries varies considerably by sport. In a study of adolescent soccer players, 66 % of injuries were traumatic [29]. Similarly, 78 % of youth team handball injuries (including practice and matches) were acute [70]. In adolescent female soccer players over one season, 63.9 % of injuries were acute, and 34.1 % were overuse [23]. Among female club gymnasts, there was an overuse injury rate of 1.8 per 1,000 h (56.6 %) and an acute injury rate of 1.3 per 1,000 h (43.4 %) [16].

The paucity of reported data on overuse injuries is concerning given estimates indicating half of youth sport injuries are due to overuse, and that the incidence of such injuries may be increasing [78]. Additionally, overuse injuries may be associated with substantial time loss and risk of reinjury [21]. Finally, in most studies, data on acute and overuse types are combined for analytical purposes, a problem given that injury risk factors may relate differently to categories of injury onset [8, 79].

Temporal Variations

An understanding of temporal variations in injury may guide childhood injury prevention programs, and provide opportunities to monitor improvements in targeted prevention programs [80]. Cosinar analyses have demonstrated significant monthly injury peaks for a variety of recreational activities, including snow and water activities, trampoline, and scooters [80]. A large soccer tournament study found that the number of heat-related illnesses was related to ambient temperature [81]. The aggregate rate of heat illness was 0.6 cases/1,000 player-hours under "normal" conditions compared to 2.8/1,000 player-hours during "hot" years.

Few studies of community-based child and adolescent sports provide information on temporal variations in injury. Yet, information on time elapsed in a practice and competition or time of season may provide a unique perspective into cause of injury. Gutgesell reported that most injuries occurred in the last half of preadolescent basketball games, indicating fatigue as a possible contributor [82]. Three gymnastics studies report a relatively high frequency of injury early in practice, perhaps due to an inadequate warm-up [18, 20, 21]. A rugby study noted more injuries in the first and fourth quarters [75]. In TeamGym, the majority of injuries occurred at the end of the gymnastics session, when gymnasts were likely fatigued [31].

Studies involving female gymnasts indicate a higher rate of injury following periods of reduced training, such as a short vacation [18, 21]. Studies of rugby injuries also report a higher incidence of injury at the beginning of the season [34, 40] and after winter vacation [34], suggesting a lack of fitness contributes to injury. A study of youth soccer players similarly found injury incidence to be highest at the outset of the competitive season ($p < .01$) [37]. The greatest proportion of TeamGym injuries occurred at the end of the season [31]. Intervention-based research involving adolescent athletes, indicating the effectiveness of sport-specific neuromuscular training warm-up programs at reducing the risk of injury, may hold promise for those returning from out-of-season or reduced training experiences [83–85].

Injury Outcome

Injury outcome refers to the severity of the injury and can range from abrasions to fractures to injuries that result in severe permanent functional disability or even death. Aspects related to acute catastrophic injuries are covered in Chapter 12.

Injury Type

Identifying common injury types is essential, as it alerts health care professionals to areas of special need, and directs researchers in identifying potential risk factors and developing preventative measures. Most studies discuss injury types in general terms, such as contusions or fractures, presenting few specifics on types of injuries or injury grade. This is troubling, given the types of injuries that are often unique to children. Epiphyseal injuries, for example, account for 15–30 % of all emergency room skeletal injuries in children. More than a third of these injuries are sport-related [86], and among these almost 15 % were associated with some degree of growth disturbance [18].

Most injuries reported across community/club sports are sprains, strains, and contusions [50–57]. Sprains and/or strains are the most common injuries for most sports, and are among the three most common injuries in lacrosse [38], taekwondo [58], girls' gymnastics [16], soccer [25, 39, 43], team handball [51], and rugby [77]. Other common injuries include abrasions, contusions, fractures, inflammation, and lacerations. Notably, the same injury mechanism causing a sprain in an adult may cause an epiphyseal fracture in a child [52].

Most studies report injuries as a percentage of all injuries sustained, although several recent studies report incidence rates for specific injury types, thus permitting comparison of rates across studies. The highest rate (relative to 1,000 AEs) of injury in taekwondo was contusions (43.33; CI: 35.92–51.80), followed by sprains (6.14; CI: 3.58–9.83) [58]. In lacrosse, Lincoln et al. reported 2.8 contusion/laceration injuries per 1,000 AEs followed by dislocations/fractures (0.9 per 1,000 AEs) [38].

Time Loss

Most studies reporting time loss use days lost from practice or competition as a measure of injury severity. Time loss data are often categorized by time periods (e.g., 7 days or less = minor) to indicate the degree of severity. However, subjective factors such as personal motivation, peer influence, or coaching staff reluctance/encouragement may determine if and when players return to play (RTP) [8]. Accessibility to health care professionals and location and type of injury may also impact decisions regarding RTP. Additionally, amount of time loss corresponding to each severity category may vary both within and between sports, making cross-study comparisons difficult at best. For example, multiple definitions have been used to indicate a moderate injury: 1–4 weeks [37], 8–21 days [18], and 7–30 days [40].

The available data indicate that most pediatric sports injuries, measured by time loss, are relatively minor [8]. Several studies report time loss or severity of injury as an incidence rate. Lystad et al. reported a rate of 36.62 injuries per 1,000 AEs for minor (<1 week) taekwondo injuries and a rate of 12.27 injuries per 1,000 AEs for moderate injuries [58]. Steffen et al. reported the highest rate of injuries in soccer were minor, or 1–7 days lost (4.0/1,000 h), followed by moderate injuries (2.6/1,000 h) [25].

Recurrent Injury

One unfortunate outcome of many injuries is recurrent injury. Injury history is an independent risk factor for sustaining a sport-related injury. Young participants may experience recurrent injuries for several reasons, including premature return to activity, inadequate rehabilitation, and underestimation of the severity of the primary injury. A previously injured athlete who returns to participation has a changed injury risk profile, particularly if the injury has not been properly rehabilitated.

There are few studies of recurrent injury. Studies of recurrent injuries in young female gymnasts report a range between 24.5 and 32.3 % [18, 20, 21]. In 6–15 year olds playing rugby or netball, 27 % reinjured the same anatomical location [68]. In young female team handball players 35 % incurred an injury at the same site before acquiring a major injury, and 30 % with a moderate injury experienced previous injury at the same location [46].

Some studies have reported the proportion of recurrent injuries specific to an anatomical location. For example, 33.8 % of ankle injuries were recurrent injuries among young female football players [25] and nearly one-third of club gymnasts reported a history of concussion [16]. Clearly, it is important to provide sufficient time for recovery before a gradual RTP is allowed.

Residual Symptoms

Few studies have evaluated the long-term participation and health-related outcomes of pediatric sports injury [87]. However, as many as 8 % of youth may drop out of sports annually due to injury [88]. A public health concern regarding long-term consequences of youth sports injury is the premature development of osteoarthritis (OA) [89, 90]. Although OA more commonly affects older adults, post-traumatic OA has been observed in former athletes who are young adults and can be linked to injury incurred during participation in youth sports [90].

The knee in particular is the most common site for OA [8]. Anterior cruciate ligament (ACL), meniscus, and articular cartilage injuries are closely linked to early onset OA [91–93]. In a study of female soccer players with a confirmed ACL injury before 20 years of age, radiographic evidence of OA was present in 51 % of the injured knees after 12 years, compared with 8 % in the uninjured knees [94]. In follow-up studies of young athletes with meniscus surgery, more than 50 % had early onset knee OA and associated pain with functional impairment [95–97].

Young athletes are also at risk of incurring epiphyseal injuries, accounting for between 15–30 % of all skeletal injuries in youth [86]. At least 5 % of these injuries may be associated with growth disturbance [47]. There are also multiple reports of stress-related epiphyseal plate injuries, some of which have resulted in growth disturbance [98]. Disturbed physeal growth as a result of injury can result in limb length discrepancy, angular deformity, or altered joint mechanics, and may cause significant long-term disability, including OA [99].

There is also preliminary evidence that the development of cam-type deformity (excess bone at the upper surface of the femoral head) secondary to stress-related alteration in the proximal femoral epiphysis during adolescence may be influenced by impact sports such as soccer, basketball, and ice hockey [100–103]. Cam-type abnormality in young athletes may be a consequence of an alteration of the growth plate secondary to high-level sports activity during growth [100, 104]. Individuals with cam-type deformity may be at increased risk of developing secondary coxarthrosis and femoral acetabular impingement (FAI) [103].

Study Limitations

Methodological shortcomings and study differences limit their interpretation and comparison of findings. Variability in study populations, data collection time, sample sizes, injury definitions, response rates, and data collection procedures, as well as selection, recall and response motivation bias hampers generalizability. The reader must interpret the literature in light of such limitations, while recognizing the difficulty of collecting data in more controlled ways. Lastly, our search was limited to published studies reporting incidence rates relative to exposure hours or AEs.

Summary

This review underscores the value of quality data in identifying the nature and extent of athletic injury among children and adolescents participating in non-school community-based settings, including privately owned clubs. Reliable descriptive data highlight the type or level of sport, as well as anatomical and environmental location, where injuries are most likely to occur. They also provide valuable information on temporal factors and outcome of injuries sustained in various sports. This information, in turn, may assist in development of preventive measures to reduce the number and severity of injuries.

Above all, this overview underscores the need for well-designed descriptive epidemiological studies to determine the nature and extent of the public health burden imposed by child and youth sport-related injuries in non-school community-based settings. Data on recurrent injury are particularly lacking. The lack of quality descriptive data in some sports is concerning, given the increased levels of participation and training characterizing child and adolescent sports today. The need for national organizations to take the lead in developing guidelines and incentives for research into the epidemiology of injury is paramount.

We further recommend that community-based sport organizations include in their budgets sufficient funds to hire an athletic trainer or physical therapist to provide an appropriate standard of care for young athletes. In addition to the immediate care of injuries, the functions of this individual should include early detection of developing stress injuries and liaison with other health care professionals regarding injury detection, treatment, and surveillance, and timely return to practice and competition.

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Epidemiology of Injury in High School Sports

4

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Introduction

The popularity of high school sports has increased over each of the past 25 years with almost 7.8 million student-athletes participating during the 2013/2014 academic year [1]. The most popular high school sports in terms of number of participants include football, track and field, basketball, baseball, soccer, wrestling, cross country, tennis, golf, and swimming and diving for boys and track and field, basketball, volleyball, soccer, softball, cross country, tennis, swimming and diving, competitive spirit squads, and lacrosse for girls [2]. Participating in high school sports, a means of incorporating daily physical activity into a healthy lifestyle, can provide adolescents with multiple health and social benefits [3–8]. However, as with any physical activity, participation in high school sports carries a risk of injury. To reduce that injury risk to the lowest possible level targeted, evidence-based injury prevention efforts must be developed, implemented, and evaluated. This requires an understanding of the epidemiology of high school sports-related injuries including injury rates and patterns, something best achieved through analysis of data from long running sports injury surveillance programs such as the National High School Sports-Related Injury Surveillance Study (High School RIO). In this chapter, data from High School RIO will be used to evaluate the epidemiology of injury in high school sports.

Who Is Affected by Injury?

The most appropriate way to evaluate injury risk by sport is to compare injury rates between sports, calculating injury rates by dividing the number of injuries sustained over the course of a sport season by some unit of athletic exposure accumulated during that sport season. The same definitions of injury and athletic exposure must be applied across each sport to enable direct comparisons. In High School RIO, injury rates

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D. Caine, L. Purcell (eds.), *Injury in Pediatric and Adolescent Sports*, Contemporary Pediatric and Adolescent Sports Medicine, DOI 10.1007/978-3-319-18141-7_4

for each sport are calculated by dividing the number of injuries sustained during the sport season by the number of athletic exposures (AE) with one student athlete participating in one practice or competition equaling one AE. Injuries captured in High School RIO (1) occur during school-sanctioned practices or competitions, (2) require care from an athletic trainer (AT) or physician, and (3) restricted the athlete's participation in the sport for at least 1 day or, beginning in the 2007/2008 academic year, include any concussion, fracture, or dental injury regardless of whether it resulted in participation restriction. Injury rates are calculated by sport and, within each sport, by type of athletic activity (i.e., competition and practice).

Sport

Overall, injury rates vary widely by sport (Table 4.1). Not surprisingly among boys, full-contact sports (i.e., football, wrestling, ice hockey, lacrosse) have the highest total injury rates followed by sports where athlete-athlete contact occurs relatively frequently although too much contact is in violation of the rules of the sport (i.e., basketball, soccer), followed by sports where athlete-athlete contact is rare (i.e., baseball, cross country, swimming and diving, track and field, volleyball). Similarly, among girls, sports with more frequent athlete-athlete contact (i.e., soccer, basketball, field hockey, lacrosse) have higher total injury rates than sports with little athlete-athlete contact (i.e., volleyball, softball, track and field, cross country, swimming and diving). The exceptions to this among girls' sports are gymnastics, which has a relatively high injury rate despite a complete lack of athlete-athlete contact and cheerleading (actually a co-ed sport although girls participate at much higher rates than boys at the high school level) which has a relatively low injury rate although athlete-athlete contact occurs with some frequency (e.g., between bases and fliers during stunts).

Injury rates also vary across sports by type of athletic activity, with most sports having higher injury rates in competition compared to practice (Table 4.1). The difference between competition and practice injury rates is greater in some sports than others. For example, in boys' ice hockey the competition injury rate is eight times higher than the practice injury rate (rate ratio [RR] = 8.2) while the other full-contact sports, football (RR = 5.4), lacrosse (RR = 3.6), and wrestling (RR = 2.0), each had smaller disparities between competition and practice injury rates. In fact, although it has the second highest competition injury rate of all boys' sports, ice hockey has one of the lowest practice injury rates. Thus, ice hockey could provide a model for efforts to reduce practice injury rates in the other boys' full-contact sports. Conversely, some non-contact sports had higher practice injury rates than competition injury rates although total injury rates in these sports are very low relative to other sports.

In most sports, injury rates have either remained relatively stable over time or decreased slightly (Table 4.1). However, this should be put into context given the intense focus on concussion by clinicians, policy makers, the media, and young athletes' parents over the past decade. Concussion injury rates increased significantly from the 2005/2006 through the 2012/2013 academic years with the sharpest increases beginning in 2008/2009 [9]. This increase in concussion rates has influenced total injury rates, masking a small decrease in the rate of all other injuries in most sports. In fact, injury rates in high school sports under surveillance from 1995 to 1997 were twice as high as injury rates in the same sports in 2005/2006 [10]. Thus, high school sports appear to have become safer over time. That said, efforts to decrease the incidence and severity of injuries among high school athletes should be continued.

Gender

Across gender-comparable sports, girls have higher total injury rates than boys (Table 4.1). Although injury rates in boys' lacrosse are higher than those in girls' lacrosse they are not considered gender-comparable sports given differences in the rules by which they play (e.g., boys are allowed to body check while girls are not) and the

Table 4.1 Injury rates per 1,000 athletic exposures by sport and year, national high school sports-related injury surveillance study, USA, 2005/2006–2013/2014

Injury rates per 1,000 athletic exposures by academic year										
	2005/2006	**2006/2007**	**2007/2008**	**2008/2009**	**2009/2010**	**2010/2011**	**2011/2012**	**2012/2013**	**2013/2014**	**All years[a]**
Boys' sports										
Football total	4.4	4.45	4.18	3.65	4.02	3.61	3.66	3.86	3.91	4.05
Competition	12.1	13.52	12.77	11.28	12.72	12.22	11.83	12.14	11.03	12.48
Practice	2.5	2.68	2.47	2.06	2.29	1.90	2.08	2.17	2.35	2.32
Wrestling total	2.5	2.51	2.27	2.20	2.28	2.18	2.21	2.11	2.20	2.34
Competition	3.9	3.80	3.70	3.25	3.40	3.77	3.33	3.17	3.73	3.67
Practice	2.0	2.06	1.76	1.83	1.87	1.65	1.81	1.72	1.68	1.88
Ice hockey total	–	–	–	2.23	2.56	2.21	2.03	2.02	2.19	2.33
Competition	–	–	–	6.08	5.56	5.63	4.18	5.15	5.30	5.65
Practice	–	–	–	0.49	1.09	0.58	0.88	0.49	0.48	0.69
Lacrosse total	–	–	–	2.20	2.48	1.90	2.31	1.86	1.68	2.12
Competition	–	–	–	4.33	4.89	3.83	4.33	3.74	3.65	4.24
Practice	–	–	–	1.28	1.35	1.07	1.39	1.00	0.84	1.18
Soccer total	2.4	2.27	1.75	1.64	1.79	1.67	1.71	1.43	1.53	1.79
Competition	5.2	4.31	3.63	3.54	3.58	3.52	3.67	3.07	3.22	3.69
Practice	1.1	1.45	0.96	0.82	1.00	0.89	0.91	0.72	0.80	0.98
Basketball total	1.9	1.75	1.39	1.46	1.54	1.37	1.37	1.51	1.49	1.57
Competition	3.0	2.87	2.23	2.47	2.82	2.33	2.57	2.61	2.44	2.65
Practice	1.5	1.28	1.04	1.04	1.00	0.95	0.88	1.02	1.07	1.10
Baseball total	1.2	1.25	0.93	0.82	0.93	0.83	0.87	0.85	1.06	0.99
Competition	1.8	2.01	1.37	1.33	1.51	1.44	1.26	1.32	1.67	1.55
Practice	0.9	0.82	0.68	0.55	0.63	0.52	0.64	0.61	0.73	0.69
Cross country total	–	–	–	–	–	–	–	0.65	0.72	0.70
Competition	–	–	–	–	–	–	–	0.78	0.89	0.86
Practice	–	–	–	–	–	–	–	0.62	0.89	0.67
Track and field total	–	–	–	0.91	0.86	0.57	0.74	0.55	0.62	0.72
Competition	–	–	–	1.50	1.64	1.09	1.16	1.08	1.15	1.30
Practice	–	–	–	0.78	0.67	0.45	0.64	0.42	0.50	0.58

(continued)

Table 4.1 (continued)

Injury rates per 1,000 athletic exposures by academic year										
	2005/2006	**2006/2007**	**2007/2008**	**2008/2009**	**2009/2010**	**2010/2011**	**2011/2012**	**2012/2013**	**2013/2014**	**All years[a]**
Swim and diving total	–	–	–	0.20	0.35	0.18	0.17	0.11	0.23	0.21
Competition	–	–	–	0.14	0.19	0.07	0.08	0.05	0.17	0.12
Practice	–	–	–	0.21	0.39	0.21	0.21	0.13	0.24	0.24
Volleyball total	–	–	–	–	0.90	0.81	0.53	–	–	0.73
Competition	–	–	–	–	1.33	0.45	1.07	–	–	0.93
Practice	–	–	–	–	0.68	0.99	0.22	–	–	0.62
Girls' sports										
Soccer total	2.4	2.51	2.35	2.26	2.11	2.11	2.46	2.33	2.59	2.42
Competition	5.2	5.43	5.15	4.75	4.48	4.53	5.46	5.71	5.74	5.36
Practice	1.1	1.31	1.16	1.18	1.04	1.00	1.20	0.86	1.20	1.14
Basketball total	2.0	2.09	1.61	1.64	1.55	1.81	1.78	1.95	1.89	1.88
Competition	3.6	3.60	3.30	3.37	2.61	3.59	3.51	3.47	3.68	3.55
Practice	1.4	1.44	0.90	0.90	1.08	1.02	1.06	1.25	1.08	1.16
Field hockey total	–	–	–	1.81	1.80	1.77	1.77	1.48	1.36	1.73
Competition	–	–	–	2.78	2.71	2.90	2.50	2.12	2.10	2.62
Practice	–	–	–	1.38	1.39	1.23	1.45	1.17	1.02	1.31
Lacrosse total	–	–	–	1.72	1.62	1.40	1.23	1.24	1.11	1.45
Competition	–	–	–	2.67	2.91	2.20	1.55	2.41	1.75	2.39
Practice	–	–	–	1.30	1.04	1.04	1.09	0.67	0.83	1.03
Gymnastics total	–	–	–	2.15	2.38	1.51	1.09	–	–	1.89
Competition	–	–	–	3.46	3.87	2.41	1.83	–	–	3.19
Practice	–	–	–	1.82	2.05	1.30	0.94	–	–	1.60
Volleyball total	1.6	1.37	1.22	1.01	1.01	0.93	1.07	1.02	1.16	1.16
Competition	1.9	1.40	1.43	1.08	1.01	1.16	1.37	1.18	1.46	1.36
Practice	1.5	1.36	1.12	0.97	1.01	0.80	0.92	0.94	1.01	1.06
Softball total	1.1	1.11	1.29	1.22	1.15	0.97	1.56	1.17	1.15	1.22
Competition	1.8	1.96	1.86	1.90	1.68	1.52	2.30	1.87	1.44	1.83
Practice	0.8	0.65	0.98	0.87	0.87	0.70	1.16	0.81	1.00	0.91
Track and field total	–	–	–	1.06	1.19	0.90	0.93	0.86	0.85	0.99

Injury rates per 1,000 athletic exposures by academic year

	2005/2006	2006/2007	2007/2008	2008/2009	2009/2010	2010/2011	2011/2012	2012/2013	2013/2014	All years[a]
Competition	–	–	–	1.28	1.39	1.35	1.07	1.09	0.91	1.21
Practice	–	–	–	1.01	1.14	0.79	0.89	0.81	0.83	0.93
Cross country total	–	–	–	–	–	–	–	1.10	0.76	0.94
Competition	–	–	–	–	–	–	–	1.13	0.48	0.84
Practice	–	–	–	–	–	–	–	1.09	0.81	0.96
Swim and diving total	–	–	–	0.34	0.37	0.27	0.38	0.26	0.28	0.32
Competition	–	–	–	0.32	0.19	0.38	0.14	0.48	0.28	0.31
Practice	–	–	–	0.34	0.41	0.24	0.43	0.21	0.28	0.33
Co-ed										
Cheerleading total	–	–	–	–	0.66	0.59	0.57	0.73	0.72	0.71
Competition	–	–	–	–	0.67	0.54	0.67	1.13	0.82	0.85
Practice	–	–	–	–	0.69	0.64	0.58	0.77	0.81	0.76
Performance	–	–	–	–	0.57	0.37	0.46	0.45	0.37	0.49

[a]All years' rate was calculated by dividing the sum of all injuries captured over all years the sport was under surveillance divided by the sum of all athletic exposures captured during all years the sport was under surveillance

protective equipment they wear (e.g., boys are required to wear helmets, shoulder pads, etc. while girls are required to wear only mouth guards and protective eyewear). In both soccer and basketball the difference between competition and practice injury rates is greater among girls (RR = 4.7 and RR = 3.1, respectively) than among boys (RR = 3.8 and RR = 2.4, respectively) while the difference between competition and practice injury rates is slightly greater in baseball (RR = 2.2) than softball (RR = 2.0). Further research is needed to determine if the observed gender differences in injury rates reflect true differences in injury risk (i.e., reflect bio-pathological differences that result in differences in injury incidence) or if these differences are instead due to sociocultural effects (i.e., reflect differences in injury diagnosis and reporting rather than true differences in injury incidence).

Participation Level

Among the 20 sports under surveillance in High School RIO in 2013/2014, injuries were relatively evenly distributed overall by year of school for both boys (freshman sustained 23.1 % of all injuries, sophomores 24.5 %, juniors 24.1 %, and seniors 28.3 %) and girls (freshman 27.7 %, sophomores 26.5 %, juniors 24.9 %, and seniors 20.9 %). Similar patterns exist when comparing overall injury patterns between varsity, JV, and freshman-level competition. However, for some specific injuries there are differences by age and gender. For example, the distribution of overuse injuries increased with year in school for boys (freshman sustained 20.7 % of all overuse injuries, sophomores 24.4 %, juniors 26.4 %, and seniors 28.5 %) while the opposite was true for girls (freshman 30.7 %, sophomores 26.1 %, juniors 23.4 %, and seniors 19.8 %) [11].

Position

In some sports the position an athlete plays is associated with the likelihood of injury as well as the types of injury sustained while in other sports few patterns of injury by position exist. For example, in 2013/2014 football running backs/slot backs sustained 19 % of all competition injuries and 13 % of practice injuries while linebackers sustained 14 % of competition injuries and 16 % of practice injuries. Similarly, in 2013/2014 in volleyball outside hitters sustained 37 % of all competition injuries and 42 % of practice injuries while middle blockers sustained 22 % of competition injuries and 18 % of practice injuries. Thus, athletes playing these positions in these sports sustain a disproportionate number of injuries. Conversely in soccer, injuries are more evenly distributed by position. For example, in 2013/2014 among boys 39 % of all competition injuries were sustained by midfielders, 30 % by forwards, and 25 % by defenders and among girls 38 % of all competition injuries were sustained by midfielders, 27 % by forwards, and 26 % by defenders. Gender differences in positions most frequently injured exist in some sports as well. For example, in 2013/2014 baseball pitchers sustained 14 % of all competition injuries and 25 % of practice injuries while softball pitchers sustained 9 % of all competition injuries and 10 % of practice injuries.

What Type of Injuries Occur?

Anatomical Location

The body sites most commonly injured vary by sport (Table 4.2). In sports under surveillance in 2005/2006 the body sites most commonly injured during competition largely reflect the primary activities of the sport. For example, in sports with a large amount of running incorporating rapid accelerations, decelerations, and changes in direction (e.g., football, basketball, and soccer) the ankle and knee were the most commonly injured body sites while in wrestling, a combat sport incorporating grappling and throws, the most commonly injured body site was the shoulder. Interestingly given the gender differences in injury rates discussed above, in sports played by both genders the body sites most frequently injured were largely consistent (Table 4.2).

Table 4.2 Most commonly injured body site by sport, national high school sports-related injury surveillance study, USA, 2005/2006–2013/2014

Body site most commonly injured (% of all injuries) by type of athletic exposure in the first year the sport was included in surveillance and the most recent year the sport was included in surveillance

	Year	Competition	Practice	Year	Competition	Practice
Boys' sports						
Football	2005/2006	Knee (17 %)	Ankle (15 %)	2013/2014	Head/face (28 %)	Head/face (24 %)
Wrestling	2005/2006	Shoulder (21 %)	Knee (16 %)	2013/2014	Head/face (35 %)	Head/face (34 %)
Ice hockey	2008/2009	Head/face (31 %)	Head/face, hand/wrist, and ankle (18 %)	2013/2014	Head/face (45 %)	Head/face (36 %)
Lacrosse	2008/2009	Head/face (23 %)	Knee and hip/thigh/upper leg (each 13 %)	2013/2014	Head/face (34 %)	Head/face (19 %)
Soccer	2005/2006	Ankle (21 %)	Hip/thigh/upper leg (29 %)	2013/2014	Head/face (31 %)	Hip/thigh/upper leg (27 %)
Basketball	2005/2006	Ankle (37 %)	Ankle (45 %)	2013/2014	Ankle (34 %)	Ankle (35 %)
Baseball	2005/2006	Shoulder, head/face, and hip/thigh/upper leg (15 % each)	Shoulder (20 %)	2013/2014	Head/Face (17 %)	Shoulder (24 %)
Cross country	2012/2013	Ankle (29 %)	Lower leg (34 %)	2013/2014	Ankle (33 %)	Lower leg (30 %)
Track and field	2008/2009	Hip/thigh/upper leg (74 %)	Hip/thigh/upper leg (38 %)	2013/2014	Hip/thigh/upper leg (56 %)	Hip/thigh/upper leg (39 %)
Swim and diving	2008/2009	Shoulder, trunk, and head/face (each 33 %)	Shoulder (40 %)	2013/2014	Shoulder, knee, and hand/wrist (each 33 %)	Shoulder (42 %)
Volleyball	2009/2010	Ankle (71 %)	Ankle (57 %)	2011/2012	Ankle (50 %)	Ankle (67 %)
Girls' sports						
Soccer	2005/2006	Ankle (25 %)	Ankle (30 %)	2013/2014	Head/face (34 %)	Ankle (25 %)
Basketball	2005/2006	Ankle (35 %)	Ankle (34 %)	2013/2014	Head/face (35 %)	Ankle (28 %)
Field hockey	2008/2009	Head/face (35 %)	Hip/thigh/upper leg (20 %)	2013/2014	Head/face (36 %)	Hip/thigh/upper leg (22 %)
Lacrosse	2008/2009	Head/face (39 %)	Ankle (22 %)	2013/2014	Head/face (30 %)	Ankle (26 %)
Gymnastics	2008/2009	Knee (36 %)	Ankle and arm/elbow (each 21 %)	2011/2012	Trunk (50 %)	Trunk and ankle (each 27 %)
Volleyball	2005/2006	Ankle (30 %)	Ankle (44 %)	2013/2014	Head/face (33 %)	Ankle (26 %)
Softball	2005/2006	Ankle and Hand/Wrist (16 % each)	Head/Face (22 %)	2013/2014	Head/Face (28 %)	Head/Face (22 %)
Track and field	2008/2009	Hip/thigh/upper leg (44 %)	Hip/thigh/upper leg (32 %)	2013/2014	Hip/thigh/upper leg (51 %)	Hip/thigh/upper leg (39 %)
Cross country	2012/2013	Hip/thigh/upper leg (36 %)	Lower leg (40 %)	2013/2014	Ankle (27 %)	Lower leg (27 %)
Swim and diving	2008/2009	Shoulder and arm/elbow (each 25 %)	Shoulder (55 %)	2013/2014	Shoulder and head/face (each 33 %)	Shoulder (54 %)
Co-ed						
Cheerleading	2009/2010	Ankle (36 %)	Head/face (29 %)	2013/2014	Head/face (32 %)	Head/face (44 %)

Some gender differences appear when anatomic location of injury is evaluated in more detail however. For example, for all sports under surveillance in 2013/2014 knee injuries among males were most commonly medial collateral ligament injuries (30.6 % of all knee injuries) and patella/patellar tendon injuries (22.0 %) while among females knee injuries were most commonly patella/patellar tendon injuries (32.2 %) and anterior cruciate ligament injuries (27.3 %). In many sports, the body sites most commonly injured have changed over time (Table 4.2). For example, among high school football players in 2005/2006 the most commonly injured body site in competition and practice were the knee (17 % of all injuries) and ankle (15 %) but in 2013/2014 the most commonly injured body site in both competition and practice was the head/face (28 % and 24 %, respectively). In many sports by 2013/2014 the head/face had become the most commonly injured body site during competition. However, it is unknown if this change over time reflects the increased emphasis on concussion, resulting in more concussion injuries that were sustained being diagnosed and reported rather than going unrecognized, or if it reflects true changes in body sites injured over the past decade.

Diagnosis

The most common diagnosis of injury across sports, genders, and types of activity (i.e., competition and practice) has overwhelmingly been strain/sprain (Table 4.3). Additionally, despite the significant increase in concussion rates over time, strains/sprains have remained the most common diagnosis of injury in 2013/2014 in both competition and practice for most sports (Table 4.3). Exceptions include boys' ice hockey where concussion was the most common diagnosis in both competition (42 % of all injuries) and practice (36 %) and girls' field hockey where concussion was the most common diagnosis in competition (28 %). While strains/sprains accounted for 40 % of competition injuries and 43 % of practice injuries in all sports under surveillance in 2013/2014 fractures represented 9 % of competition injuries and 6 % of practice injuries and concussions represented 26 % of competition injuries and 17 % of practice injuries.

Specific Types of Injury

Changes in injury patterns over time are most apparent when evaluating specific types of injury (i.e., the specific body site and diagnosis combinations). For example, ankle strain/sprain was the most common specific injury sustained in competition for eight of the nine sports under surveillance in 2005/2006 with the exception being wrestling where shoulder strain/sprain was most common (Table 4.4). By 2013/2014 concussion was the most common specific injury sustained in competition in eight of these nine sports with the exception being boys' basketball where ankle strain/sprain remained the most common injury. For the majority of sports, during their first year under surveillance the most common specific injury sustained during competition and practice were consistent. This was true across genders as well. However, in 2013/2014 while there was consistency in the most common specific injury sustained in competition and practice for seven of the ten boys' sports under surveillance, the most common specific injury sustained in competition and practice differed for seven of the nine girls' sports under surveillance. Again, it is currently unclear if these gender patterns represent true differences in the specific types of injuries sustained by boys and girls in practice or if this is some artifact of recognition and/or reporting of injuries.

Injury Severity

In the High School RIO surveillance system injury severity is measured in three ways: time loss from sports participation (Fig. 4.1), injuries resulting in a medical directive to end sports participation (Fig. 4.2), and injuries resulting in surgical repair (Fig. 4.3). In most sports, athletes return to play within a week of injury over a third of the time in 2013/2014 (Fig. 4.1). Similarly, in nearly all sports athletes return to play within

Table 4.3 Most common injury diagnoses by sport, national high school sports-related injury surveillance study, USA, 2005/2006–2013/2014

Most common injury diagnosis (% of all injuries) by type of athletic exposure in the first year the sport was included in surveillance and the most recent year the sport was included in surveillance						
	Year	**Competition**	**Practice**	**Year**	**Competition**	**Practice**
Boys' sports						
Football	2005/2006	Strain/sprain (43 %)	Strain/sprain (50 %)	2013/2014	Strain/sprain (36 %)	Strain/sprain (37 %)
Wrestling	2005/2006	Strain/sprain (42 %)	Strain/sprain (43 %)	2013/2014	Strain/Sprain (34 %)	Strain/sprain (29 %)
Ice hockey	2008/2009	"Other" (29 %)	"Other" (27 %)	2013/2014	Concussion (42 %)	Concussion (36 %)
Lacrosse	2008/2009	Strain/sprain (36 %)	Strain/sprain (46 %)	2013/2014	Strain/sprain and concussion (each 31 %)	Strain/Sprain (44 %)
Soccer	2005/2006	Strain/sprain (44 %)	Strain/sprain (65 %)	2013/2014	Strain/sprain (38 %)	Strain/sprain (53 %)
Basketball	2005/2006	Strain/sprain (55 %)	Strain/sprain (62 %)	2013/2014	Strain/sprain (49 %)	Strain/sprain (54 %)
Baseball	2005/2006	Strain/sprain (40 %)	Strain/sprain (44 %)	2013/2014	Strain/sprain (37 %)	Strain/sprain (46 %)
Cross country	2012/2013	Strain/sprain (59 %)	"Other" (63 %)	2013/2014	Strain/sprain (63 %)	"Other" (58 %)
Track and field	2008/2009	Strain/sprain (82 %)	Strain/sprain (61 %)	2013/2014	Strain/sprain (73 %)	Strain/sprain (57 %)
Swim and diving	2008/2009	Laceration (34 %)	Strain/sprain (40 %)	2013/2014	Strain/sprain, fracture, and "other" (each 33 %)	Concussion (47 %)
Volleyball	2009/2010	Strain/sprain (72 %)	Strain/sprain (71 %)	2011/2012	Strain/sprain (62 %)	Strain/sprain (67 %)
Girls' sports						
Soccer	2005/2006	Strain/sprain (51 %)	Strain/sprain (69 %)	2013/2014	Strain/sprain (41 %)	Strain/sprain (50 %)
Basketball	2005/2006	Strain/sprain (58 %)	Strain/sprain (66 %)	2013/2014	Strain/sprain (45 %)	Strain/sprain (57 %)
Field hockey	2008/2009	Strain/sprain (34 %)	Strain/sprain (50 %)	2013/2014	Concussion (28 %)	Strain/sprain (49 %)
Lacrosse	2008/2009	Strain/sprain (38 %)	Strain/sprain (47 %)	2013/2014	Strain/sprain (51 %)	Strain/sprain (47 %)
Gymnastics	2008/2009	Strain/sprain (65 %)	Strain/sprain (69 %)	2011/2012	Strain/sprain and "other" (each 50 %)	Strain/sprain (34 %)
Volleyball	2005/2006	Strain/sprain (77 %)	Strain/sprain (72 %)	2013/2014	Strain/sprain (46 %)	Strain/sprain (58 %)
Softball	2005/2006	Strain/sprain (41 %)	Strain/sprain (40 %)	2013/2014	Strain/sprain (35 %)	Strain/sprain (44 %)
Track and field	2008/2009	Strain/sprain (75 %)	Strain/sprain (61 %)	2013/2014	Strain/sprain (67 %)	Strain/sprain (53 %)
Cross country	2012/2013	Strain/sprain (64 %)	"Other" (58 %)	2013/2014	Strain/sprain (46 %)	"Other" (60 %)
Swim and diving	2008/2009	Strain/sprain and "other" (each 24 %)	Strain/sprain (44 %)	2013/2014	"Other" (50 %)	"Other" (57 %)
Co-ed						
Cheerleading	2009/2010	Strain/sprain (46 %)	Strain/sprain (46 %)	2013/2014	Strain/sprain (35 %)	Strain/sprain (34 %)

Table 4.4 Most common specific injury by sport, national high school sports-related injury surveillance study, USA, 2005/2006–2013/2014

Most common specific injury (% of all injuries) by type of athletic exposure in the first year the sport was included in surveillance and the most recent year the sport was included in surveillance						
	Year	**Competition**	**Practice**	**Year**	**Competition**	**Practice**
Boys' sports						
Football	2005/2006	Ankle strain/sprain (14 %)	Ankle strain/sprain (13 %)	2013/2014	Concussion (27 %)	Concussion (22 %)
Wrestling	2005/2006	Shoulder strain/sprain (11 %)	Head/face "other" and knee "other" (8 % each)	2013/2014	Concussion (29 %)	Concussion (18 %)
Ice hockey	2008/2009	Concussion (20 %)	Concussion and ankle strain/sprain (14 % each)	2013/2014	Concussion (42 %)	Concussion (36 %)
Lacrosse	2008/2009	Concussion (19 %)	Ankle strain/sprain (13 %)	2013/2014	Concussion (31 %)	Concussion (15 %)
Soccer	2005/2006	Ankle strain/sprain (18 %)	Hip/thigh/upper leg strain/sprain (26 %)	2013/2014	Concussion (26 %)	Hip/thigh/upper leg strain/sprain (21 %)
Basketball	2005/2006	Ankle strain/sprain (35 %)	Ankle strain/sprain (43 %)	2013/2014	Ankle strain/sprain (31 %)	Ankle strain/sprain (35 %)
Baseball	2005/2006	Ankle strain/sprain (13 %)	Shoulder strain/sprain (11 %)	2013/2014	Hip/thigh/upper leg strain/sprain (11 %)	Shoulder strain/sprain (13 %)
Cross country	2012/2013	Ankle strain/sprain (24 %)	Lower leg "other" (28 %)	2013/2014	Ankle strain/sprain (3 %)	Lower leg "other" (22 %)
Track and field	2008/2009	Hip/thigh/upper leg (67 %)	Hip/thigh/upper leg (34 %)	2013/2014	Hip/thigh/upper leg strain/sprain (51 %)	Hip/thigh/upper leg strain/sprain (37 %)
Swim and diving	2008/2009	Shoulder "other," head/face "other," and trunk "other" (33 %)	Shoulder strain/sprain and shoulder "other" (20 %)	2013/2014	Shoulder strain/sprain, knee "other," and hand/wrist fracture (each 33 %)	Shoulder "other" (26 %)
Volleyball	2009/2010	Ankle strain/sprain (71 %)	Ankle strain/sprain (57 %)	2011/2012	Ankle strain/sprain (50 %)	Ankle strain/sprain (67 %)
Girls' sports						
Soccer	2005/2006	Ankle strain/sprain (22 %)	Ankle strain/sprain (27 %)	2013/2014	Concussion (32 %)	Ankle strain/sprain (22 %)
Basketball	2005/2006	Ankle strain/sprain (34 %)	Ankle strain/sprain (32 %)	2013/2014	Concussion (31 %)	Ankle strain/sprain (25 %)
Field hockey	2008/2009	Ankle strain/sprain (17 %)	Hip/thigh/upper leg strain/sprain (18 %)	2013/2014	Concussion (28 %)	Hip/thigh/upper leg strain/sprain (22 %)
Lacrosse	2008/2009	Concussion (37 %)	Ankle strain/sprain (19 %)	2013/2014	Concussion (28 %)	Ankle strain/sprain (23 %)
Gymnastics	2008/2009	Ankle strain/sprain (29 %)	Ankle strain/sprain (21 %)	2011/2012	Trunk "other" (33 %)	Ankle strain/sprain (20 %)
Volleyball	2005/2006	Ankle strain/sprain (29 %)	Ankle strain/sprain (43 %)	2013/2014	Concussion (31 %)	Ankle strain/sprain (25 %)

Softball	2005/2006	Ankle strain/sprain (13 %)	Ankle strain/sprain and concussion (12 % each)	2013/2014	Concussion (20 %)	Ankle strain/sprain (16 %)
Track and field	2008/2009	Hip/thigh/upper leg strain/sprain (37 %)	Hip/thigh/upper leg strain/sprain (31 %)	2013/2014	Hip/thigh/upper leg strain/sprain (43 %)	Hip/thigh/upper leg strain/sprain (35 %)
Cross country	2012/2013	Hip/thigh/upper leg strain/sprain (27 %)	Lower leg "other" (27 %)	2013/2014	Ankle strain/sprain (27 %)	Lower leg "other" (23 %)
Swim and diving	2008/2009	Shoulder "other" (25 %)	Shoulder strain/sprain (33 %)	2013/2014	Shoulder "other" and concussion (each 33 %)	Shoulder "other" (36 %)
Co-ed						
Cheerleading	2009/2010	Ankle strain/sprain (36 %)	Concussion (19 %)	2013/2014	Concussion (24 %)	Concussion (38 %)

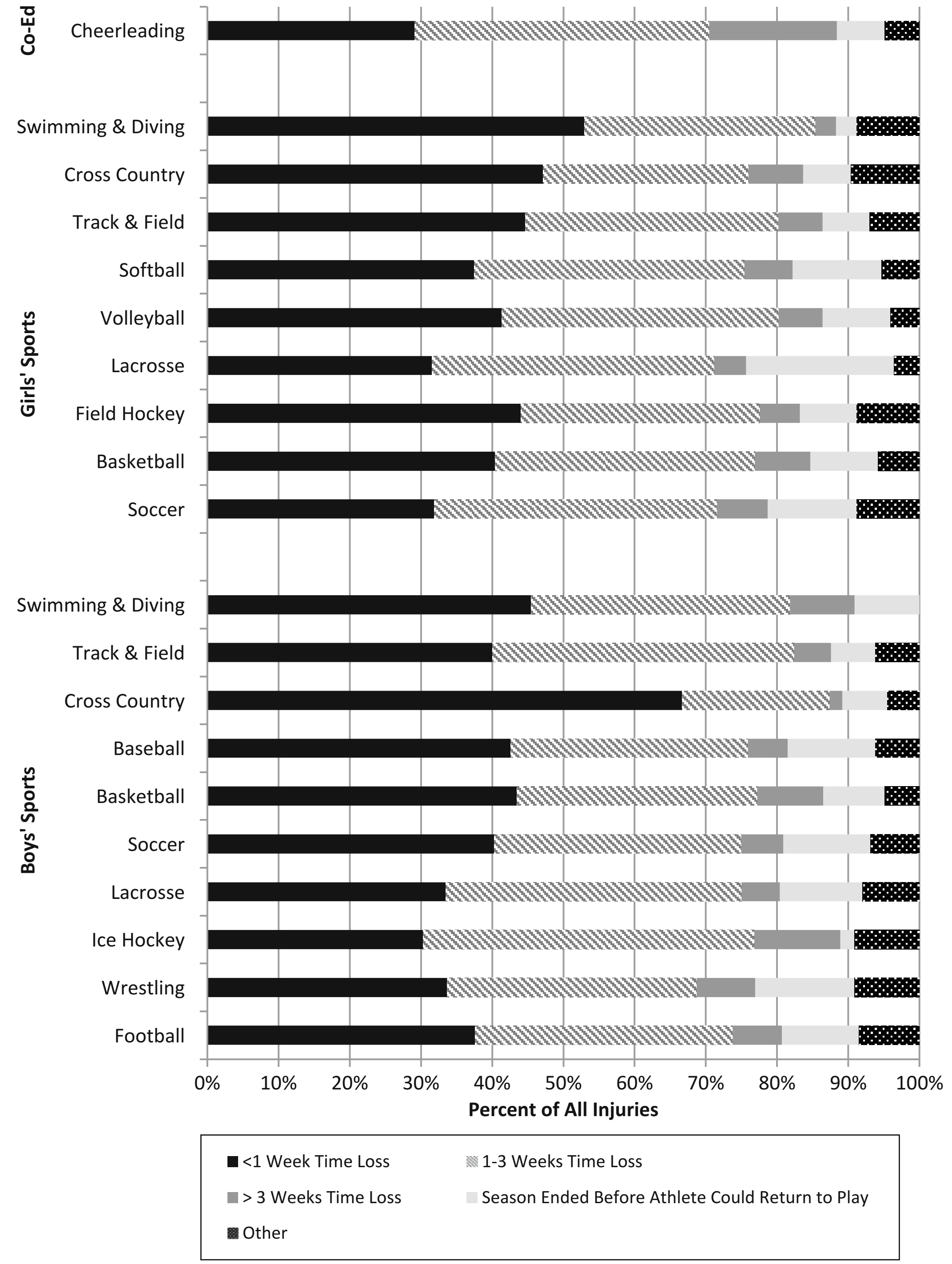

Fig. 4.1 Time loss by sport, national high school sports-related injury surveillance study, USA, 2013/2014. Definition: "Other" includes athlete choose not to continue despite no medical DQ, medical DQ for season, medical DQ for career, athlete released from team for not medical reasons, and "other"

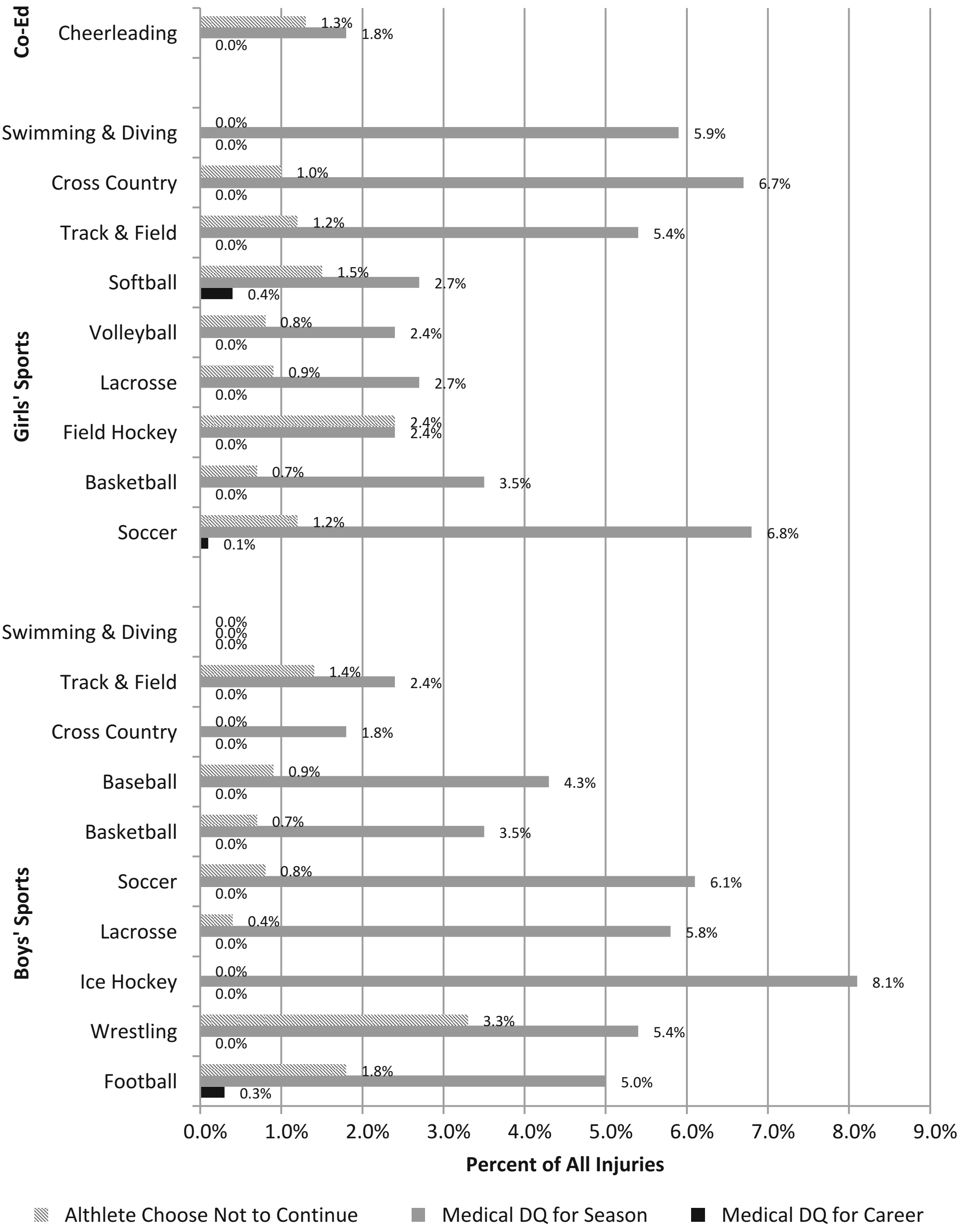

Fig. 4.2 Injuries from which athlete did not return to play, national high school sports-related injury surveillance study, USA, 2013/2014. Definitions: (1) "Athlete Choose Not to Continue" represents athletes who discontinued sports participation despite absence of a medical professional providing that recommendation, (2) "Medical DQ for Season" represents athletes who received recommendation from a medical professional to discontinue sports participation for the remainder of the season in which they were injured, and (3) "Medical DQ for career" represents athletes who received recommendation from a medical professional to discontinue sports participation permanently

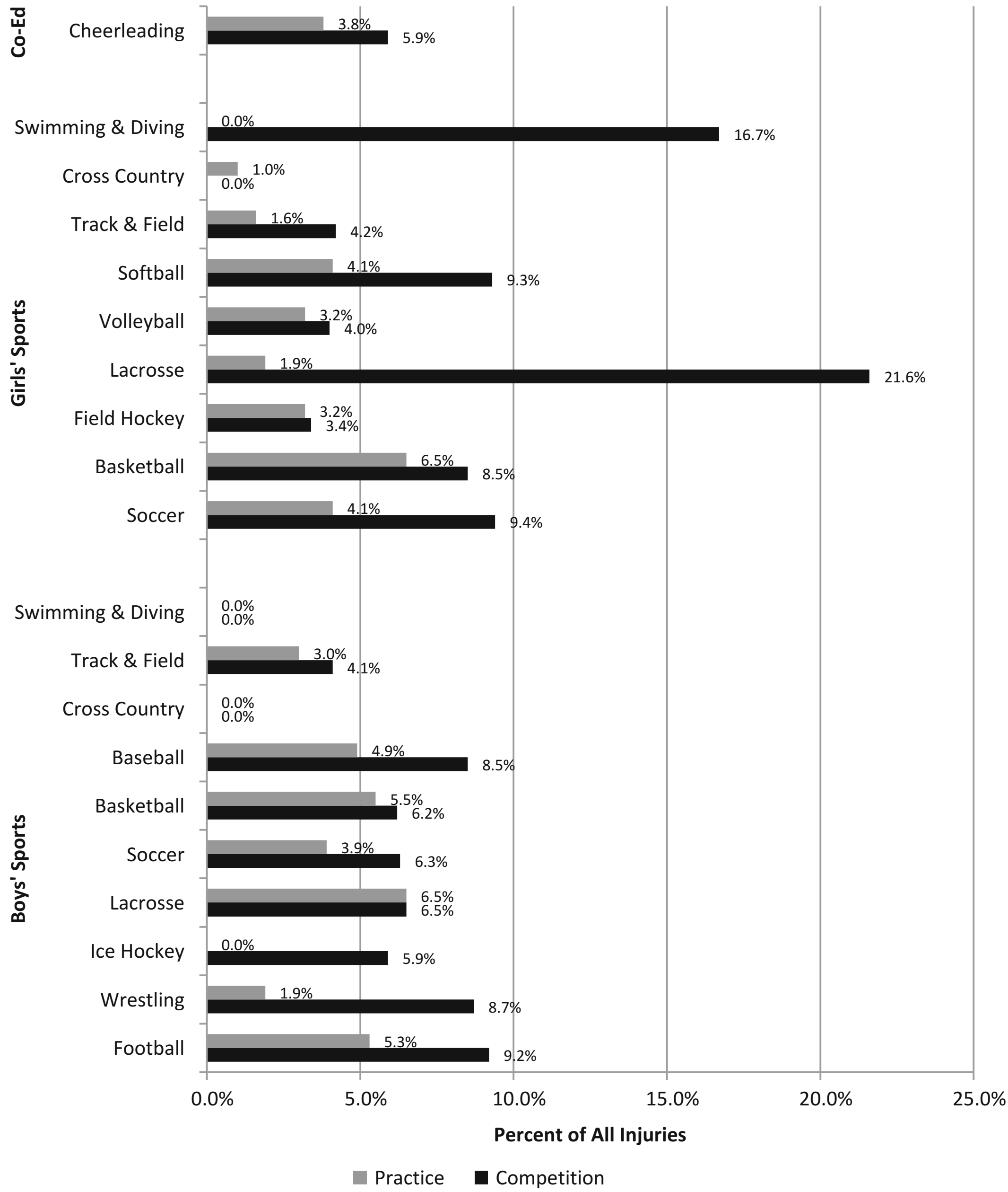

Fig. 4.3 Injuries which resulted in surgical repair by sport and type of athletic activity, national high school sports-related injury surveillance study, USA, 2013/2014. In this figure cheerleading "competition" represents injuries sustained during both competition and performances

3 weeks of injury over 70 % of the time. However, there are sport-specific differences when the more severe injuries from which athletes do not return are considered. While injuries resulting in career medical disqualification are extremely rare (less than 0.5 % of all injuries in any sport), these severe injuries were reported in girls' softball, football, and girls' soccer in 2013/2014 (Fig. 4.2). Injuries resulting in medical disqualification for the season are more common. Among boys' sports ice hockey (8.1 % of all injuries), soccer (6.1 %), lacrosse (5.8 %), wrestling (5.4 %), and

football (5.0 %) had the most injuries resulting in medical disqualifications for the season. Among girls' sports soccer (6.8 %), cross country (6.7 %), swimming and diving (5.9 %), and track and field (5.4 %) had the most injuries resulting in medical disqualifications for the season. Boys' wrestling (3.3 %) and girls' field hockey (2.4 %) were the only sports with over 2 % of all injuries resulting in the athlete discontinuing sports participation despite no medical directive to do so in 2013/2014. In 17 of the 20 sports under surveillance in 2013/2014 a higher proportion of competition injuries resulted in surgical repair compared to practice injuries (Fig. 4.3). In each of the gender comparable sports, a higher proportion of competition injuries resulted in surgical repair in girls than boys. The boys' sports with the highest proportion of competition injuries resulting in surgical repair were football (9.2 %), wrestling (8.7 %), and baseball (8.5 %). The girls' sports with the highest proportion on competition injuries resulting in surgical repair were lacrosse (21.6 %), swimming and diving (16.7 %), soccer (9.4 %), and softball (9.3 %).

One indicator of economic burden of injury captured in High School RIO is the diagnostic tools applied during injury evaluation. For the 20 sports under surveillance in 2013/2014, of all injuries 32.3 % had X-ray confirmation of diagnosis, 9.7 % had MRI, and 2.9 % had CT scan. Although not specifically a surrogate of injury severity, it is worth noting that 90 % of all injuries sustained in the 20 sports under surveillance in 2013/2014 were new injuries with 4 % being recurrences of injuries sustained previously in the same academic year and 6 % being recurrences of injuries sustained prior to the same academic year (recurrence is defined as the same diagnosis to the same body site as a prior injury).

Where, When, How Do Injuries Occur?

Location of Injury

Across all sports under surveillance in High School RIO competition injuries are sustained with approximate equal frequency at home and away. In most sports the location of injury in the playing field mirrors the amount of time play is centered in various parts of the playing field. For example, in 2013/2014 in football competitions 76.8 % of all injuries occurred between the 20 yard lines, 21.1 % in the red zones, 1.7 % in the end zones, and 0.4 % off the field. Similarly, in 2013/2014 in boys' soccer 34.7 % of all competition injuries occurred on the offensive side of the field between the goal box and center line, 22.5 % on the defensive side of the field between the goal box and center line, 12.6 % in the defensive goal box, 11.8 % in the offensive goal box, 9.2 % on the sides of the defensive goal box, 7.3 % on the sides of the offensive goal box, and 1.9 % off the field and in girls' soccer 34.3 % of all competition injuries occurred on the offensive side of the field between the goal box and center line, 21.8 % on the defensive side of the field between the goal box and center line, 15.6 % in the defensive goal box, 11.1 % on the sides of the defensive goal box, 8.2 % in the offensive goal box, 7.1 % on the sides of the offensive goal box, and 1.8 % off the field.

Timing of Injury

Although injury rates are significantly higher in competition than practice, incidence of injury is evenly split with 50.3 % of all injuries occurring in competition and 49.7 % occurring in practice in the 20 sports under surveillance in 2013/2014. Regarding time in season, 23.4 % of all injuries reported in 2013/2014 occurred during preseason, 72.8 % during regular season, and 3.8 % during postseason. However, there are some injuries with important differences in seasonal patterns of injury. For example, 90.4 % of exertional heat illnesses occur during fall sports' preseason [12]. Regarding time in practice, 11.8 % of all injuries in the 20 sports under surveillance in 2013/2014 occurred in the first ½ h of practice, 20.3 % in the second ½ h, 58.8 % 1–2 h into practice, and 9.1 % >2 h into practice. Timing of injury in competition is sports specific. For example, in 2013/2014, 0.9 % of football competition injuries occurred in pregame warm-ups, 13.3 % in the first quarter, 31.0 % in the second quarter, 29.6 % in the third quarter, 25.0 % in the fourth quarter, and 0.2 % in overtime. In boys' soccer 3.1 % of competition injuries occurred in pregame warm-ups, 33.3 % during the first half, 62.5 % in the second half, and 1.0 % in overtime. Similarly, in girls' soccer 3.3 % of competition injuries occurred in pregame warm-ups, 34.2 % in the first half, 62.2 % in the second half, and 0.2 % in overtime. In other gender-comparable sports timing of injury was also relatively consistent.

General Mechanisms and Sport-Specific Activities Associated with Injury

The most common mechanism of injury is athlete-athlete contact in sports such as boys' and girls' soccer, boys' and girls' basketball, girls' lacrosse and girls' field hockey, as well as the full-contact sports of football, ice hockey, boys' lacrosse, and wrestling. Athlete-athlete contact injuries even occur in "non-contact" sports such as volleyball (e.g., when opponents land on each other's feet at the net) and swimming (e.g., when multiple swimmers are warming up in the same lane swim into each other). Understanding sport-specific patterns is essential to injury prevention however. For example, in 2013/2014 in football tackling and being tackled account for 56.9 % of all competition injuries and 40.8 % of all practice injuries and, more specifically, for 63.8 % of all concussions, 53.4 % of all fractures, and 39.9 % of all strains/sprains. In some gender-comparable sports patterns are quite similar. For example, in 2013/2014, heading the ball accounted for 10.7 % of all competition injuries, 2.4 % of practice injuries, and, more specifically, 24.2 % of concussions in boys' soccer and 10.7 % of all competition injuries, 6.7 % of practice injuries, and, more specifically, 28.9 % of concussions in girls' soccer. However, in basketball some gender patterns are evident, perhaps reflecting the fact that boys' basketball is now frequently played "above the rim" with athletes leaving the ground to attempt dunks and shot blocking and subsequently landing from heights of several inches to feet. For example, in 2013/2014 rebounding accounted for 36.6 % of all competition injuries, 26.1 % of practice injuries, and, more specifically, 37.1 % of strains/sprains, 36.4 % of concussions, and 22.2 % of fractures in boys' basketball and 24.8 % of all competition injuries, 14.1 % of practice injuries, and, more specifically, 23.3 % of strains/sprains, 23.1 % of concussions, and 11.5 % of fractures in girls' basketball. Gender differences in boys' and girls' lacrosse emphasize the fact that, given differences in rules of play and required protective equipment, these are not gender-comparable sport. Among boys' lacrosse players the most common mechanism of injury is athlete-athlete contact (40.9 % of all injuries) while among girls' lacrosse players the most common mechanisms of injury are no contact (i.e., rotation around a planted foot) (26.2 %) and athlete-apparatus contact (i.e., ball, crosse) (24.0 %). More specifically, among boys 74.4 % of concussions were associated with contact with another athlete while among girls 63.8 % of concussions were associated with contact with a ball or crosse [13].

Summary

As demonstrated in this chapter, the epidemiology of injury among high school athletes varies by sport. Thus, targeted injury prevention efforts should be based on an understanding of sport-specific injury rates and patterns as these differences mean that more general prevention programs are less likely to be effective. Understanding differences in injury rates and patterns by sport can help clinicians, policy makers, coaches, and parents assess the relative safety of different sports and work together to make all sports as safe as possible for young athletes.

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5 Epidemiology of Pediatric and Adolescent Injury in Adventure and Extreme Sports

Dennis Caine and Omer Mei-Dan

Introduction

During the last two decades there has been an explosion in both the popularity and participation in adventure and extreme sports (AES) [1, 2]. According to the Sporting Goods Manufacturing Association (SGMA) analysis of the Sports and Fitness Participation Report (2011 edition), AES are an appealing recreation and athletic option for millions of Americans [3]. The growing popularity of these activities has been driven by youth culture [4, 5] as is evidenced by television networks' investment in AES programming and their coverage of sports events like the X-games, an Olympic-like competition showcasing the talents in extreme sporting events.

AES, by definition, involve elements of increased risk, and are usually performed in beautiful, exciting, and remote locations or in extreme environments [4]. They tend to be individual sports that are performed by adventurous elite athletes as well as the recreational adventure sports enthusiast in both competitive and noncompetitive settings. These activities often involve speed, height, a high level of physical exertion, and highly specialized gear or spectacular stunts.

Examples of popular AES include BMX; rock and ice climbing; hang-gliding and paragliding; scuba diving; surfing (including wave, wind, and kite surfing); personal watercraft; whitewater canoeing, kayaking, and rafting; BASE jumping and skydiving; extreme hiking; skateboarding; mountain biking; in-line skating; ultra-endurance races; alpine skiing and snowboarding; and ATV and motocross sports [4, 6]. Of these, the more radical and dangerous versions of AES, such as outdoor rock and ice climbing, high-grade white water kayaking, and BASE jumping, are considered "extreme sports" [7].

Participants in AES often train or compete in variable environmental conditions that are weather and terrain related, including wind, snow, water, and mountains [8]. These activities often take place in remote destinations or recreational facilities with little or no access to immediate medical care [9]. Even if medical care is available it usually faces challenges related to longer response and transport times, access to few resources, limited provider experience due to low patient volume, and more extreme geographical and environmental challenges [10].

Mass media showcasing breathtaking stunts and the inclusion of skateboarding, in-line sports,

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D. Caine, L. Purcell (eds.), *Injury in Pediatric and Adolescent Sports*, Contemporary Pediatric and Adolescent Sports Medicine, DOI 10.1007/978-3-319-18141-7_5

and rock climbing showcased in the 2014 Youth Olympics in Nanjing, and mountain biking at the 2000 Games in Sydney, are all helping to drive the popularity of AES among youth. In the USA, children and adolescents, aged 6–17 years, recorded 2.8 billion annual outdoor recreation outings during 2007–2012, or 92 average outings per participant [11]. The most popular outdoor activities for this age group were road, mountain, and BMX biking (27 % of American youth/13.4 million participants) [11]. In addition, as early as 2002, children and adolescents <17 years were thought to make up 25 % of all backpackers and wilderness campers in the USA [12].

Physical activity in children and adolescents increases physical fitness (both cardiorespiratory fitness and muscular strength), reduces body fat, improves cardiovascular and metabolic disease risk profiles, enhances bone health, and reduces symptoms of depression and anxiety [13]. However, engaging in sports and recreational activities at a young age also involves a risk of injury [14]. By their very nature, participation in AES involves performance in variable and often unpredictable environmental conditions that may be associated with increased injury risk. While we strive for an active population, participation in any physical activity must consider the risk of injury and measures for injury prevention.

Young participants may be particularly vulnerable to injury due to such growth-related factors as the adolescent growth spurt, susceptibility to growth plate injury, differences in maturity status, nonlinearity of growth and, relative to adults, longer recovery and differing physiological response after concussion, and slower acclimatization to extreme weather conditions [15–17]. They might also be at risk because of decreased neuromuscular control, strength, emotional maturity, and judgment compared with adults [18]. The unusual and sometimes risky physical demands of AES may create conditions under which these potential risk factors can more readily exert their influence.

Recent data suggest that the risk and severity of injury in some AES are high [19]. For example, researchers reviewed 2000–2011 National Electronic Injury Surveillance System (NEISS) data for seven popular sports featured in the Winter and Summer X Games: surfing, mountain biking, motocross, skateboarding, snowboarding, snowmobiling, and snow skiing [20]. Of the four million injuries reported for extreme sports participants, 11.3 % were head and neck injuries. Of all head and neck injuries, 83% were head injuries and 17% neck injuries.

This chapter illuminates the epidemiologic approach to understanding the incidence and characteristics of injury affecting pediatric and adolescent AES participants, and what is known about risk factors and preventive measures with the hope of generating understanding and further research. It is beyond the scope of this chapter to provide an in-depth review of the incidence and distribution of injury in AES.

Epidemiology of Injury

Injury epidemiology is the study of the distribution and determinants of varying rates of injuries in human populations for the purpose of identifying and implementing measures to prevent their development and spread. A model outlining the epidemiologic approach to sports injury prevention was first proposed by Willem van Mechelen and his colleagues [21]. First, research establishes the extent of injury, including both incidence and severity. Second, research explores its etiology (i.e., the causes and implications of injury). Third, research creates a prevention strategy to reduce the injury burden. Last, research evaluates the effectiveness of the implemented prevention strategy by reexamining the extent of injury.

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 (step 1), for the purpose of explaining *why* and *how* injuries occur (step 2) and identifying strategies to control and prevent them (steps 3 and 4) [22]. 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 identification and implementation of preventive strategies is referred to as analytical epidemiology [23].

Descriptive Epidemiology

Descriptive reports represent the most common type of epidemiologic research published in the AES injury literature and arise from anecdotal reports and case series. Much of the available data on injury in AES arise from aggregate records kept by professional associations, hospital trauma registries, hospital admissions, competitive events, and national injury registries. Observational studies, including surveys and cohort studies are infrequent. Analytical research is sparser. The important aspects of the descriptive epidemiology of sports-related injuries are discussed below with the purpose of highlighting their various contributions to understanding the distribution of AES injuries [24].

In descriptive epidemiology the researcher attempts to quantify the occurrence of injury. We often first learn of a youth injury or fatality suffered through participation in AES in media reports. For example, on July 27, 2014, a New Zealand newspaper reported a 16-year-old mountain biker who received multiple injuries after falling on a mountain-bike track and was air-lifted to a regional hospital [25]. On August 29, 2010, ESPN news reported that Peter Lenz, motorcycle racer, had been run over and killed by a 12-year-old motorcycle racer during an accident at the Indianapolis Motor Speedway [26]. Reports like these are not uncommon in the news media. However, typically no information is provided on the frequency of such events.

Case reports/series are often used to report unusual injuries sustained by an individual or a group of individuals. For example, an 18-year-old male sustained multiple fracture/dislocations of his left foot while practicing parkour, an extreme sport that is gaining popularity in the USA [27]. Participants of this sport, known as *parkouristes*, try to overcome obstacles in their environment by simply jumping or scaling an obstacle, but sometimes this is done in a very acrobatic manner [27].

The most basic measure of injury occurrence is a simple count of injured persons or fatalities. For example, in May 2014, the Division of Hazard Analysis, US Consumer Product Safety Commission, reported that during January 2010 to August 2010 there were 169 ATV-related injuries affecting children and adolescents <16 years of age, or 25.8 % of all ED-treated ATV-related injuries [28]. These count data are useful in providing an estimate of the relative frequency of injuries as well as an estimate of the morbidity load on a clinic. However, they have limited epidemiologic utility and should not be confused with rates [29].

In order to investigate the rate and distribution of injuries it is necessary to know the size of the source population from which the injured individuals were derived, or the population at risk. The two most commonly reported rates in the sports injury literature are *prevalence* and *incidence*. Prevalence pertains to the total number of cases, new or old, that exist in a population at risk at a specific period of time. For example, 47 % of the German Junior National climbing team and 28 % of recreational climbers had stress reactions in the fingers [30]. A limitation of prevalence data is that only injuries present during the time of the survey period are registered, and thus data are not necessarily representative of all injuries in a population.

The two types of injury incidence most commonly reported in the sports injury literature are *clinical incidence* and *incidence rates*. *Clinical incidence* refers to the number of incident injuries divided by the total number of athletes at risk and usually multiplied by some k value (e.g., 100) [31]. For example, Flores et al. [32] reported an annual rate of 72.1 outdoor recreational injuries per 100,000 population (95 % CI = 38.6–105.6). The injury rate was highest in the 15- to 19-year age group (214.0 per 100,000 population, 95 % CI = 98.2–329.7). While clinical incidence may serve as an indication of clinical or resource utilization, it does not account for the potential variance in exposure of participants to risk of injury [31]. For example, the 15–19-year-old age group in the Flores et al. [32] may have been differentially exposed to the risk of injury.

Incidence rate (IR) refers to the number of incident injuries divided by the total time-at-risk and usually multiplied by some *k* value (e.g., 1,000) [31]. It is the preferred measure of incidence in research studies because it can accommodate variations in exposure time of individual participants. Different units of time-at-risk, varying in precision, have been used to calculate incidence rates in the AES literature. These include reporting the number of injuries per *k* time exposures (one time exposure is typically defined as one individual participating in 1 h of activity in which there is the possibility of sustaining a sport-related injury) and per *k* element exposures (one element exposure is defined as one individual participating in one element of activity in which there is the possibility of sustaining an athletic injury). Examples of exposure elements used in AES include climbs, summits, surfing days, personal watercrafts (PWC) in operation, (scuba) dives, and (BASE) jumps.

A difficulty that arises in comparing incidence rates from different studies relates to the injury definition employed. A review of the AES literature reveals that few common operational definitions exist for injury both within and between sports. Definitions include such criteria as presence of a new symptom or complaint, decreased function of a body part, decreased athletic performance, time loss, and consultation with medical or training personnel [19]. Clearly, if injury is defined differently across studies, a meaningful comparison of injury rates is compromised due to different criteria for determining numerator values.

Who Is Affected by Injury?

As might be expected, injury rates are most often categorized according to sport participation (e.g., sport climbing, ice climbing) and the way in which participants are organized for sports (e.g., recreational or competitive). Two recent edited texts on AES provide limited data on the incidence of pediatric and adolescent injury across a range of activities [4, 19]. Most of the data reported arise from estimates of clinical incidence. For example, in 2004–2005, the 15–19-year-old (214 injuries/100,000 population; 95 % CI: 98.2–329.7) and 10–14-year-old (187.1 injuries/100,000 population; CI: 84.3–289.9) age groups recorded the highest injury rates in outdoor recreational activities treated in EDs in the USA, followed by the 20–24-year-old group (121.1 injuries/100,000 population; CI: 72.9–169.3) [32].

IR data arising from a retrospective cross-sectional study have recently been reported for youth rock climbers, aged 11–19 years [33]. An overall IR of 4.44 injuries per 1,000 climbing hours (95 % CI: 3.74–5.23) was reported for elite and recreational climbers. Recreational climbers incurred a rate of 4.71 per 1,000 climbing hours (95 % CI: 3.64–6.09) compared to 4.27 per 1,000 h among elite climbers.

Where Does Injury Occur?

Determination of "where" injury occurs involves identification of the anatomical and situational locations of injury. Identifying the anatomical location highlights the body parts that are more likely to be injured which can, in turn, assist in the development of preventive measures to reduce the number and severity of these injuries [34]. Anatomical locations include body region of injury (e.g., upper extremity) as well as specific body parts (e.g., shoulder, ankle). For example, a common injury site associated with skateboarding is the wrist, accounting for 32 % of all hospital-reported skating injuries, and 25 % of all wrist injuries are fractures [35]. Notably, 76.7 % of patients in this study were elementary and high school students.

Environmental location provides information on the distribution of injury by where in the environment the injury occurred. Environmental locations reported in AES injury literature include surface or terrain on which the activity takes place, for example indoor or outdoor climbing or grade of terrain associated with mountaineering; geographical location, for example public areas versus skate parks for skateboarders; proximity to others or obstacles (e.g., overcrowding among personal watercraft riders); and whether the injury occurred in practice or competition. Information on high-risk settings is of course useful in identifying important targets for further study, including application of preventive measures. For example, IRs for youth rock climbing reveal a higher risk for indoor (4.31 per 1,000 h; 95 % CI: 3.59–5.13) vs. outdoor climbing (2.94 per 1,000 h; 95 % CI: 1.2–5.79) [32]. Notably, several hospitals reported an increase in the frequency of skateboarding injuries when a skate park was opened [36, 37].

When Does Injury Occur?

The next characteristic of injury distribution is the *when* of injury occurrence. Temporal factors are typically expressed in terms of injury onset and timing of injury. There are two broad categories of injury onset that differ markedly in etiology. Injuries that occur suddenly are termed acute or sudden impact injuries and are usually the result of a single, traumatic event. For example, loss of balance and irregularities encountered in the riding surface account for the majority of skateboard-related injuries and related fractures [38]. Overuse injuries are more subtle and develop gradually over time. They are the result of repetitive micro-trauma to the tendons, bones, and joints.

Most epidemiological studies in the AES injury literature either report acute injuries only or otherwise do not distinguish between acute and overuse injuries. This is, in part, due to the source of the injury data (e.g., hospital data). However, distinction between overuse and acute injuries is important, particularly in studies that analyze risk factors since risk factors for overuse and acute injuries are not necessarily the same. The importance of identifying injury onset is also important given the growing evidence of overuse problems in sport, particularly among child and adolescent participants [39]. For example, the most common mechanism of injury was repetitive overuse in a group of adolescent rock climbers [33].

Examples of timing of injury include time into training, time of day, and time of season or year when injury occurs. It stands to reason that if rates are higher during a particular time period, then efforts to better understand the risk factors for the elevated risk are in order and appropriate preventive measures should be applied to reduce risk during this time. For example, a report on pediatric motocross injuries found that the majority of patients presenting for medical evaluation sustained the injury at a formal course [40]. Additionally, it would be expected that a greater proportion of skateboard injuries would be seen during the spring and summer months when conditions would be more favorable; however, few papers acknowledge this likelihood [38].

It is also of interest to consider changes in incidence and distribution of injury over time. For example, despite statements from medical societies against the use of ATVs by children and adolescents under 16 years of age, injury rates for this population from ATV accidents have increased 240 % since 1997, and the spinal injury rate has increased 476 % over the same time frame [17].

What Is the Outcome?

Injury outcome in AES can span a broad spectrum from abrasions to fractures to those injuries that result in severe permanent functional disability (i.e., catastrophic injuries) or even death. In the epidemiologic literature on sports injuries, injury severity is typically indicated by one or more of the following: injury type, time loss, residual symptoms, and economics cost. Assessment in each of these areas is important to understanding the individual and public health impact of injuries.

Injury Type

Most AES studies report injury types in general terms such as contusion or fracture, with few specifics on type of fracture, grade of injury, and so forth. Injury types are generally reported as frequency or percent values. For example, patients aged 14–19 years treated for mountain-biking injuries treated in EDs in the USA, 1994–2007, sustained a greater proportion of traumatic brain injuries (8.4 %) than did patients aged 8–13 years and ≥20 years combined (4.3 %) [41]. The three most common injury types reported among youth rock climbers were sprain (0.72 per 1,000 h; 95 % CI: 0.46–1.08), strain (0.69 per 1,000 h; 95 % CI 0.43–1.04), and tendonitis (0.34 injuries per 1,000 h; 95 % CI: 0.17–0.62) [33].

Injury Severity

Not surprising, there is an increased risk of severity of injury in AES, particularly in extreme sports [5]. A useful measure of injury severity is the duration of restriction from athletic performance subsequent to injury. Some studies reporting time loss use total or average number of days lost from practice, competition, or work as a measure of injury severity. For example, the median amount of time loss among a group of youth rock climbers was 14 days, including ongoing injuries where participants had not yet returned to full activity [33]. In addition to length of hospital admission and level of care required, a number of hospital studies of injury related to AES have used the Injury Severity Score (ISS), while others merely describe severity in basic terms such as mild, moderate, and severe [38]. A mean ISS of 10.5 was found in a population-based analysis of severe skateboard injuries, which compares favorably with in-line skating (10.6) and cycling (12.7) [42].

Clinical Outcome

Clinical outcome includes such factors as re-injury, nonparticipation, residual effects, and fatalities. An unfortunate outcome of many injuries, at all levels of sport, is re-injury. It is believed that unresolved residual symptoms from previous injury predispose an athlete to recurrent injury at the same site [43]. Restricted joint motion leads to muscle atrophy and increased compensatory stress on other areas, thus predisposing to injury at other sites. An athlete with previous injury who returns to participation is characterized by a changed injury risk profile, particularly if the original injury was not properly rehabilitated. Unfortunately, few studies of pediatric and adolescent AES injuries provide data related to the frequency or incidence of re-injury.

Perhaps the most important question related to injury severity relates to long-term effects of injury. However, with the exception of catastrophic injuries (including fatalities), surprisingly little is known about the long-term outcomes of pediatric and adolescent AES injuries, such as rates of posttraumatic osteoarthritis, sequelae of head injuries, and other trauma. However, one study reported osteoarthritic changes in the hand of 3.2 % of German Junior National Climbing team and 6 % in junior recreational climbers; in contrast, 28 % of adults with ≥15 years of climbing experience presented with osteoarthritic changes of the hand [44].

The data on catastrophic injuries, like most injury data for AES, arise primarily from hospital and ED data, trauma registries, national injury registries, sport associations and commissions, emergency services, and search and rescue reports. As a result, most of the data on catastrophic injuries, including fatalities, are count data. For example, over a 5-year period there were 40 wilderness recreational deaths involving children and adolescents in five contiguous counties in Washington State [45]. Similarly, over a 4-year period, a total of nine catastrophic injuries in Canada related to skateboard activity, eight of which involved males between 11 and 20 years of age, were reported [46].

Economic Cost

Financial costs may be either direct or indirect. Direct costs are those incurred in conjunction with medical treatment (e.g., treatment, medication), and indirect costs are those associated with the loss of productivity because of increased morbidity and mortality levels. For example, Bentley et al. [47] reported on the cost of adventure tourism and adventure sports injury in New Zealand over a 12-month period. Younger male claimants comprised the largest proportion of adventure injuries. In the 16–20 year age group there were 2,081 injury claims amounting to 862,424 NZ$.

Hospital costs have also been provided for children and adolescents admitted to US hospitals. For example, the total hospital charges in 2006 for ATV-injured children and adolescents were $116.4 million for all injuries and $12.8 million for spinal injuries [17].

Analytical Epidemiology

Analytical epidemiology focuses on *why* and *how* injuries occur (step 2) and identifying strategies to control and prevent them (steps 3 and 4).

In recent years, there has been a promising and observable transition in sports injury epidemiology to research approaches etiologically rather than descriptively based to make participation safer for all participants. Preventive measures supported by research include ankle bracing, helmets, face shields, and use of mouth guards [14]. Multiple interventions using warm-up, balance training, and neuromuscular control strategies have also been shown to be effective in preventing youth sport injuries [14]. However, in AES injury epidemiology literature, the approaches have been primarily descriptive, with few studies designed to test risk factors or to determine the effectiveness of preventive measures.

Risk Factors

The epidemiological research examining injury risk factors in pediatric and adolescent AES include primarily reports on in-line skating, youth rock climbing, skiing and snowboarding, and ATV use. For example, a case–control study of in-line skaters determined that the odds ratio for wrist injury, adjusted for age and sex, for those who did not wear wrist guards, as compared with those who did, was 10.4 (95 % CI, 2.9–36.9) [35]. Cross-sectional analyses showed three risk factors for injury among youth rock climbers: older age (15–19 years vs. 11–14 years; OR=11.30, 95 % CI 2.33–54.85); injury in a sport other than climbing (OR = 6.46, 95 % CI 1.62–25.68); and preventive taping (OR = 5.09, 95 % CI 1.44–18.02 [33]). In a hospital study of mountain biking-related injuries, patients aged 14–19 years sustained a greater proportion of hand injuries than did patients aged 8–13 years and ≥ 20 years combined (IPR, 2.0, 95 % CI, 1.6–2.5) [41]. However, these analyses are based on clinical incidence data and may not reflect the true exposure of participants to risk of injury.

Inciting Events

Although risk factors may render the sport participant more susceptible to injury, they are not usually sufficient for an injury to occur. An inciting event is more obviously (or visually) related to the injury than a risk factor and may be viewed as a precipitating factor associated with the definitive onset of injury [48]. Examples of inciting events reported in the general AES literature include falling, collision with stationary objects or others in the environment, rapid ascent and out-of-air (during scuba diving), vehicle rollovers, equipment failure, and awkward landings.

There are few data which relate specifically to inciting events related to injury in child and adolescent AES. The most commonly reported mechanism of injury among youth rock climbers was repetitive overuse, followed by falls, and those incurred during strenuous moves [33]. In skateboarding, loss of balance and irregularities in the riding surface account for the majority of injuries [38]. Presumably, these led to falls from the skateboard, although this is only mentioned in one study [49].

Injury Prevention

Once the analytical evidence points to an association between certain risk factors and injury, thereby establishing a degree of predictability for those participants who are likely to sustain injury, the next step in epidemiologic research is to seek ways to prevent or reduce the occurrence of such injury. Testing the suggested preventive measure to determine its effectiveness is an important aspect of the analytical epidemiologic process and fulfills the ultimate goal of epidemiology—that is, prevention. Ideally, the effectiveness of an injury prevention measure should be tested prior to recommending its general implementation.

The results of recent investigations of sports injury prevention strategies have been encouraging. However, there is a paucity of research designed to determine the effectiveness of injury prevention measures in AES. Most recommendations are intuitive in nature with conclusions drawn from descriptive data; few studies have actually tested preventive measures [6]. However, one study reported that the use of hip pads lowered overall risk of common snowboarding injuries (OR = 0.84; 95 % CI, 0.75–0.95) [50]. Similarly, use of helmets has been shown to reduce the risk of head injury among skiers and snowboarders [51]. Ethical, cost, and feasibility issues no doubt combine to preclude some types of experimental research.

Summary

This chapter provides an epidemiologic perspective on injury in pediatric and adolescent AES. Few studies provided specific information on the incidence and distribution of AES injury in this population. Most of the available data on AES injuries among children and adolescents arise from a variety of databases where data are presented in aggregate form, or combined across age groups and gender.

Given the life-changing impact injury can have in sports, the current paucity of well-designed epidemiological studies specifically targeting pediatric and adolescent AES is a concern, but perhaps understandable considering the nature of these sports and the fact that so many of them are new and recently evolved. Most AES lack quality descriptive injury data, which provides the essential building block for analytical epidemiological studies. Few studies address injury risk factors and even fewer evaluate preventive measures. The importance of denominator-based longitudinal data collection in obtaining an accurate picture of injury risk and severity and as a basis for testing risk factors and evaluating preventive measures cannot be overemphasized.

There is also an urgent need for sport governing bodies to provide incentive and guidance for epidemiological research. And finally, there is a need for translational research to examine factors which impact the likelihood of a prevention strategy being adopted by the target population.

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6 Epidemiology of Injury in Elite Youth Sports

Kathrin Steffen

Introduction

A physically active lifestyle and active participation in sport are undoubtedly important for all age groups [1, 2]. However, participation in sport involves the risk of overuse and acute injuries, and injuries may have significant negative side effects on both the short and long term [3, 4]. Youth have high participation rates in sports, and participation in sport activities is described as the leading cause of youth injury in many countries [5, 6]. Data from a Canadian report states that 33–41 % of youth have had at least one serious sport injury they had to seek medical attention for [7]. The optimal window on when to choose sport is discussed in many countries. Young talented athletes start specializing in their sport early and often train 15–20 h a week from an age of 12–13 [8]. This increased involvement in sports from an early age through the years of growth raises concern about both immediate and long-term health [3]. Also, injuries are referred to as one of the major reasons why athletes drop out of sports. As a consequence, many talented athletes choose or are forced to give up their promising sports careers.

At the elite level, international sporting federations organize competitions in various age classes ranging from as low as under-13 up to under-21, depending on the sport. These competitions also represent important showgrounds for young athletes. In some sports, this is often where talented athletes are identified for a future professional career [9]. Thus, to maximize the health benefits of lifelong sports and exercise, and to minimize the direct and indirect costs associated with injury, identifying athletes at high injury risk early and providing them with targeted tools to prevent sports injuries is a significant goal. Following the 4-stage model of van Mechelen et al. [10], injury epidemiology is the first step in the development of effective injury prevention strategies.

As a new initiative to address the next generation of future Olympic athletes at an early stage in their career, the International Olympic Committee (IOC) created a sporting event for these young talented athletes. The first Summer Youth Olympic Games (YOG) were held in Singapore in 2010, and the first Winter Youth Olympic Games in Innsbruck, Austria, in 2012 [11]. The program of the YOG includes all the sports scheduled at the 2012 London and 2014 Sochi Olympic Games, but with a limited number of disciplines and events (Table 6.1). These Youth Olympic Games brought together around

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D. Caine, L. Purcell (eds.), *Injury in Pediatric and Adolescent Sports*, Contemporary Pediatric and Adolescent Sports Medicine, DOI 10.1007/978-3-319-18141-7_6

Table 6.1 Summer and winter sports on the program of the Youth Olympic Games in Singapore (2010), Innsbruck (2012), and Nanjing (2014)

Summer sports			
Aquatics	Archery	Artistic gymnastics	Athletics
Badminton	Basketball	Beach volleyball	Canoeing
Cycling	Diving	Equestrian	Fencing
Field hockey	Football	Golf	Handball
Judo	Modern pentathlon	Rhythmic gymnastics	Rowing
Rugby	Sailing	Shooting	Swimming
Table tennis	Taekwondo	Tennis	Triathlon
Volleyball	Weightlifting	Wrestling	
Winter sports			
Alpine skiing	Biathlon	Bobsleigh	Cross-country skiing
Curling	Figure skating	Freestyle skiing	Ice hockey
Luge	Nordic combined	Short track	Skeleton
Ski jumping	Snowboard	Speed skating	

1,100 (winter YOG) and 3,600 athletes (summer YOG), aged 14–19, from all over the world to participate in high-level competitions.

Little is known about the injury risk of the young athlete competing at high-level sports [12]. Consequently, a comprehensive injury and illness surveillance, based on the IOC model for previous Olympic Games, was initiated during the 10 days of the 2012 first Winter Youth Olympic Games [11]. Continuous injury and illness surveillance during major sporting events will build a foundation for providing evidence useful for the development of injury prevention program [13]. This book chapter summarizes the current knowledge on injury risk of children and adolescent elite athlete competing in sports presented on the program for Youth Olympic Summer and Winter Games.

Varying Injury Risk

A literature search of injury surveillance among children and adolescent elite athletes competing in Olympic summer and winter sports identified a total of 22 studies, representing 17 of the selected 49 (35 %) sports on the program of the Summer and Winter Youth Olympic Games.

Tables 6.2 and 6.3 summarize the injury risk expressed as the number of injuries per athlete per season, per participating athletes, and injury incidence as injuries per 1,000 h or athlete exposures for male and female elite young athletes competing through regular seasonal activities [14–26], training camps and national tournaments [27–30], or major sports events [11, 31–34].

Summer Sports

The literature search yielded 11 seasonal studies [15–17, 19–26] and 8 studies [27–34] presenting data from training camps or tournament play, representing a total of ten sports. Of these, most studies were on football players [19–22, 27, 31–34], while the others captured rugby union [15], track and field [16], handball [17], rowing [23], badminton [24], gymnastics [25, 26], wrestling [29], field hockey [28], and tennis [30]. Keeping the varying length of study periods in mind, all from some days during a tournament up to 10 years [21], the number of included participants and injuries varied, too, with a small sample size in most cases. Almost all studies chose a prospective study design [15–17, 19–22, 25], and "time loss" was generally a criteria in their data collection procedures [15–17, 19–29, 31, 32]. Injury risk was lower during seasonal activities than during tournament play.

Table 6.2 Summer sports

Reference Country, season, follow-up period	Population	Sport	No of all injuries	Injury recording, injury definition	Injuries per athlete per season	Injury incidence per 1,000 h Competition	Training	Total
Seasonal activities								
Palmer-Green et al. [15] England, 2006–2008, 2 years	Male $n=250$ 16–18 years	Rugby Union	109	Prospective, time loss	0.44	47.0		
Jacobsson et al. [16] Sweden 2009–2010, 1 year	Female + male $n=126$ 17 years	Track and field	170	Prospective, medical attention	1.35			Female: 3.1 Male: 3.9
Møller et al. [17] Denmark, 2010–2011, 31 weeks	Female + male $n=194$ U16	Handball	148	Prospective, time loss	0.76			6.0
Møller et al. [17] Denmark, 2010–2011, 31 weeks	Female + male $n=152$ U18	Handball	117	Prospective, time loss	0.77			5.8
Johnson et al. [19] UK, 2001–2007, 6 years	Male $n=292$ 9–16 years	Football (Soccer)	476	Prospective, ?	0.27	10.5	1.4	
Le Gall et al. [20] France, 1998–2006, 8 years	Female $n=119$ 15–19 years	Football (Soccer)	619	Prospective, time loss	0.65	22.4	4.6	6.4
Le Gall et al. [21] France, 1993–2003, 10 years	Male $n=528$ 13–15 years	Football (Soccer)	1,152	Prospective, time loss	0.22	11.2	3.9	4.8
Price et al. [22] UK, 1999–2001, 2 years	Male $n=4,773$ 9–19 years	Football (Soccer)	3,805	Prospective, time loss	0.40			
Smoljanovic et al. [23] World Cup athletes, 2006–2007, 1 year	Male $n=231$ 18 years	Rowing	209	Retrospective by survey, time loss	0.90		2.0[a]	
Smoljanovic et al. [23] World Cup athletes, 2006–2007, 1 year	Female $n=167$ 18 years	Rowing	184	Retrospective by survey, time loss	1.10		2.4[a]	

(continued)

Table 6.2 (continued)

Reference Country, season, follow-up period	Population	Sport	No of all injuries	Injury recording, injury definition	Injuries per athlete per season	Injury incidence per 1,000 h Competition	Training	Total
Yung et al. [24] Hong Kong, 2003, 1 year	Male + female $n = 11$ 16–21 years	Badminton	37	Retrospective by survey, time loss	3.36	5.9	2.8	3.1
Kolt and Kirkby [25] Australia, 19??, 1½ years	Female $n = 24$ 11–19 years	Gymnastics	151	Prospective, time loss or modification of gymnastics sessions	4.19		2.6	
Kolt and Kirkby [26] Australia, 19??, 1 year	Female $n = 47$ 11–19 years	Gymnastics	111	Retrospective by survey, time loss	2.36		1.6	
Training camps and tournaments								
Ergün et al. [27] National training camps, Turkey, 2005–2008, 3 years	Male $n = 52$ U17–19	Football (soccer)	29	Prospective, time loss	Not relevant	30.4	7.4	12.1
Hägglund et al. [31] U19 European Championships, 2006–2008, 3 years	Female $n = 433$ 18 years	Football (soccer)	43	Prospective, time loss	Not relevant	11.7–28.2	1.1–7.4	4.9–13.5
U19 European Championships, 2006–2008, 3 years	Male $n = 436$ 18 years	Football (soccer)	38	Prospective, time loss	Not relevant	16.3–27.8	1.5–2.1	6.4–13.0
U17 European Championships, 2006–2008, 3 years	Male $n = 433$ 16 years	Football (soccer)	40	Prospective, time loss	Not relevant	20.7–28.6	1.2–5.6	8.4–13.3
Yard and Comstock [29] National tournament, USA, 2006	Male $n = 3,000$ 16–19 years	Wrestling	138	Prospective, time loss	Not relevant			5.8 (per 1,000 athlete matches)

Waldén et al. [32] U19 European Championships, 2005	Male $n=144$ 18 years	Football (soccer)	17	Prospective, time loss	Not relevant	30.4	2.9	13.4
Junge and Dvorak [33] U19 World Championships, 2002, 2004, 2 years	Female $n=432$[b] 16–19 years	Football (Soccer)	?	Prospective, tissue (expected time loss)	Not relevant	68–85 (20–49)		
Junge et al. [34] U17 World Championships, 1999, 2001, 2 years	Male $n=576$[b] 16 years	Football (Soccer)	146	Prospective, tissue (expected time loss)	Not relevant	51.0–88.1 (19.2–32.7)		
Rishiraj et al. [28] Canada, 1996–2000, 5 years	Female $n=75$ 18 years	Field hockey	192	Prospective, time loss	Not relevant	67.5[a]	68.0[a]	67.9[a]
Hutchinson et al. [30] USA, 1986–1988, 1990–1992, 6 years	Male $n=1{,}440$?? yrs	Tennis	304	Prospective, physical or medical assistance	Not relevant			

Risk of injuries expressed as the number of injuries per athlete per season and injury incidence and for adolescent elite athletes of different sports (if not otherwise specified)
[a]Per 1,000 athlete exposures
[b]Based on a squad of 18 players for 12 (female) and 16 (male) qualified teams for each tournament, U16 = under age 16

Table 6.3 Winter sports

Reference						Injury incidence per 1000 h		
Country, season, follow-up period	**Population**	**Sport**	**No of all injuries**	**Injury recording, injury definition**	**Injuries per athlete per season**	**Competition**	**Training**	**Total**
Seasonal activities								
Decloe et al. 2014 [14] Canada, 2008–2009, 1 year	Female $n = 41$ 15–17 years	Ice hockey	20	Prospective Medical attention	0.49			2.9
Westin et al. 2012 [18] Sweden, 2006–2011, 5 years	Female $n = 216$ Male $n = 215$ 15–17 years	Alpine skiing	Female: 102 Male: 91	Prospective Time loss	Female: 0.09 Male: 0.08			Female: 1.8 Male: 1.6
Training camps and tournaments					*Injuries per participating athletes*			
Ruedl et al. 2012 [11] Youth Olympic Games, Austria, 2012, 10 days	Female + male $n = 1{,}021$ 14–18 years	Alpine skiing Curling Ice hockey Ice-track sports Nordic skiing Skating Snowboard	32 2 26 8 7 15 21	Prospective Medical attention	0.19 0.03 0.13 0.06 0.03 0.10 0.42			

Risk of injuries expressed as the number of injuries per athlete per season and injury incidence and for adolescent elite athletes of different sports (if not otherwise specified)

Winter Sports

For winter sports and young elite athletes, significantly fewer studies exist on injury surveillance: two studies on male and female alpine [18] and female ice hockey athletes [14] with a population follow-up period between 1 and 5 years. In addition, Ruedl et al. [11] published injury data through the 10 days of the first Winter Youth Olympic Games, including 1,021 athletes, aged 14–19. Data from this multisport event were presented for alpine, curling, ice hockey, ice track, Nordic skiing, skating, and snowboard athletes. All three studies followed their populations prospectively [11, 14, 18], and two of them applied the "medical attention injury definition" to their data collection [11, 14]. Injuries varied between cohorts and were chosen to be described by either "injuries per season per athlete" [14, 18], per 1,000 h of exposure to sport [14, 18], or per participating athletes [11], making direct comparisons on injury risk across sports difficult.

To sum up: Among the present studies, a total of four were designed to register data retrospectively by using surveys [23–26], and seven data collections (published in five studies) monitored fewer than 80 athletes [14, 24, 27, 31, 32]. In other words, the quality and generalizability of these studies can be questioned. Additionally, comparisons of incidence rates across studies should be interpreted with caution due to methodological shortcomings, different data collection procedures, and injury definitions, including their verification, of studies included in this review. Still, it is obvious that injury risk varies across sports.

Most of the sports with a presumably higher risk, such as football, field hockey, badminton, rugby, skiing and snowboard, and gymnastics, are all characterized by a high rate of player-to-player contact, high speed, jumping, and or pivoting activities, all likely known to be involved in the mechanism of injuries [35, 36]. In comparison relatively low injury rates were registered for rowing athletes [23], the Nordic skiing athletes [11], and curling [11], sports, which are characterized by involving long training and competition sessions and placing repetitive stress to the different body structures with a risk of overload.

Data on injury risk in seasonal football revealed surprisingly high injury rates for 15–19-year-old French female football players [20]. These figures reflect similar or even higher injury rates than recorded in adult elite female football players [37, 38]. The incidence of match injuries [20] was also markedly higher than match injury rates found among male youth and adolescent football players [21, 39], suggesting that adolescent elite female football players are at high injury risk.

Reflections

Protection of the athletes' health is a clearly articulated objective of the IOC [13]. Longitudinal surveillance of injuries and illnesses can provide valuable data that may identify high-risk sports and disciplines. Monitoring health risk in youth elite sports is gaining momentum as an important step towards formulating injury prevention measures.

This review on injury epidemiology among children and adolescent elite athletes competing in the 49 selected sports illustrates that there are few well-designed injury surveillance studies targeting this population. As shown in Tables 6.2 and 6.3, most studies involved adolescent athletes with only a few studies involving children elite athletes. These findings confirm the result of a previous review on the same topic, published in 2010 [12]. While injury risk is well documented for the young elite football player, using a methodology comparable to senior-level play, little or no information on injury risk is available for children and adolescent elite athletes competing in the remaining Summer and Winter Olympic sports.

In both summer and winter sports, many of the injuries occurred as a result of athlete-to-athlete contact, typical for team sports characterized by tackling or checking. Many injuries that occur during the Winter Olympics involve high speeds. The low injury risk for athletes competing in the Nordic skiing disciplines, as compared to the alpine events of freestyle and snowboard athletes, is not surprising as Nordic competitors are not exposed to high speeds on icy surfaces with minimal protection [35, 40–42]. In freestyle and snowboard cross, for example, athletes race while passing challenges such as turns, jumps, and waves. Combined with the speed component, competing in heats may promote an additional risk-taking attitude for the athletes [40, 41]. Parallels can be drawn with velodrome and road cycling when the athletes position themselves for the final sprint.

Mismatches in biological maturity between young athletes may also have implications for an increased injury risk, specifically in sports that are characterized by physical contact between teammates and opponents, for example in ball team sports and martial arts. Competing regularly against older, more mature, and heavier opponents may lead to a higher incidence of injury in younger athletes [20, 39]. In addition, many of the most talented athletes are competing for several teams or in higher age groups, which leads to a mismatch between competition participation and training/recovery and presumably to an increased injury risk [43].

Overuse injuries may represent as much of a problem as do acute injuries in many sports [44], and this is the case not just among elite athletes but also recreational athletes, runners, and other "weekend warriors." Overuse injuries constitute a high proportion of injuries in sports as swimming [45], athletics events [16, 46], beach volleyball [44, 47], and cycling [48]. Identifying overuse injuries, including their injury mechanisms through the current injury surveillance methodology, has been a challenge [44, 49], and looking into the recent literature, overuse injuries have largely been neglected so far. Although a consensus was reached on how to record and report data in epidemiological studies on injuries [50], the Oslo Sports Trauma Research Center (OSTRC) has recently shown that this standard methodology does not capture overuse injuries. As a first step, the OSTRC has therefore developed and now validated new methods to quantify overuse injuries, taking advantage of new digital technology to record data directly from the athlete. These studies include a selection of team sports and endurance sports at different levels of participation. The second step is to employ this novel methodology to conduct prospective studies to measure the magnitude of key overuse problems in selected sports and at the same time study their risk factors [49, 51]. Such studies are ongoing, using handball as a model, where shoulder problems and low back pain are prevalent.

Practical Implications

Introducing and implementing successful preventive measures relies, in part, on the proper characterization of risk factors and mechanisms [52].

To reach this goal, comprehensive injury surveillance studies have been conducted for top-level adult athletes in single elite events including football [53–55], rugby [56–58], handball [17, 59], athletics [46, 60, 61], beach volleyball [47], and swimming [45]. Injury surveillance studies have also been performed in large multisport events, as the Olympic Games in Athens 2004 [34], in Beijing 2008 [62], in Vancouver 2010 [63], and in London 2012 [64], and the applied methods to collect injuries have been shown to be reliable and feasible.

Results from the Summer Olympics Games 2008 and 2012, for instance, revealed that in relation to the number of registered athletes, the risk of incurring an injury was highest in football (soccer), taekwondo, field hockey, team handball, weight lifting, and boxing (all ≥15 % of the athletes) and lowest for sailing, canoeing/kayaking, rowing, synchronized swimming, diving, fencing, and swimming (all ≤5 % of the athletes) [62, 64].

With these systematic injury registrations, high-risk sports will be identified, including their most common and most severe injuries. As, however, injury risk and patterns of young elite athletes may vary from their older professional counterparts, injury surveillance of young elite athletes is needed to gain knowledge about the injury risk among this highly competitive population.

The second step in the development of injury preventive strategies is to map the causes of injuries and to identify their risk factors and mechanisms [10]. With increased knowledge on intrinsic and extrinsic risk factors, as well as the inciting event, athletes at high injury risk may be identified earlier in their careers and targeted to individualized injury prevention strategies. As a consequence, the risk of additional injuries, possible serious long-term health consequences, and dropouts from sports can be decreased. However, apart from football [65–71], handball/basketball [36], and skiing/snowboarding [35, 41], this basic information on injury epidemiology is lacking for most of the elite sports that were selected for this review. This lack in the current literature together with already established youth elite sports events across sports and international federation will justify introducing comprehensive injury surveillance systems at the youth and adolescent elite sports level. As an example, injury surveillance has been introduced in the FIS (Fédération Internationale de Ski) World Cup disciplines over more than six seasons aimed to identify, describe, and analyze over time the injury risks and injury patterns in skiing and snowboarding with a view to use this knowledge to reduce the risk of injuries among the top-level athletes, and several studies have addressed injury mechanism and potential preventive strategies to reduce injury risk are out for testing [35, 41, 72, 73].

Based on the experiences from former injury surveillance during major multisports events, as the 2008 and 2012 Summer Olympics [62, 64], the 2010 Winter Olympics [63], and, recently, the Winter Olympics in Sochi 2014 [74], arenas as the new sports event for elite youths, the Youth Olympic Games, should be evaluated for establishing systematic injury surveillance in this population. The key to a meaningful epidemiology study lies in an organized data collection process with a coordinated effort from the sports medicine professionals, the coaches, and the athletes, and finally systematic analyses. However, while studies performed at high-level competition provide essential information on injury risk, these time-limited observation and data collection periods are not sufficient for understanding the general picture of load and injury risk as exposure to risk situations varies substantially during an entire season [75]. Well-designed prospective injury recording methods are strongly emphasized to minimize recall bias, and the monitoring of injury risk should ideally cover all training and competition activities throughout the year. Longitudinal cohort studies are also needed to examine the long-term consequences of joint injury in youth, including posttraumatic osteoarthritis [3], in addition to not limit the focus on acute injuries, but also on overuse complaints [44, 49, 51].

Summary

Injury surveillance in elite sports events is an important task to ensure safety, to preserve the health of the athlete, and to allow high lifelong activities in sports. The young elite athlete seems to be subjected to a high injury risk. However, the current knowledge on injury risk for this population is, apart from football, based on few and for the most part small studies. Large prospective investigations are needed in most sports, and still, little knowledge is available on injury epidemiology among young elite athletes competing in sports that are programmed for the Summer and Winter Olympic Games. Considering all sports presented at the Olympic level, most knowledge has been assembled through the initiatives of the international football organization. Systematic injury surveillance studies should be established in major multisport events as the Youth Olympics Games to monitor injury trends, identify high-risk sports, and ensure new knowledge on injury trends which can form the basis for further research on injury risk factors, mechanisms, and, in the final step, injury prevention. By acquiring new knowledge on injury (and illness) trends, future research on risk factors, mechanisms, and finally, prevention, can be optimized. The key to a meaningful study of epidemiology lies in a well-organized procedure for data collection with coordinated efforts from sports medicine professionals, coaches, and athletes, combined with systematic subsequent analyses.

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Part III

Overview of Common Injuries

Overuse Injuries of the Extremities in Pediatric and Adolescent Sports

7

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Introduction

Children and adolescent sports have become more competitive. Short-term benchmarks such as being selected for a local travel team may be perceived as imperatives for children and adolescents whose goals may include collegiate athletic scholarships, national teams, and professional contracts. Seeking to gain an edge for their children, parents may employ personal sport coaches and fitness instructors and send their children to sports camps and showcases. Many parents and coaches also encourage children to specialize in a single sport at a very young age, although there is little data to support that this is necessary for long-term success [1]. With an estimated 60 million children and adolescents between 6 and 18 years of age involved in organized sports [2], a multitude of businesses have emerged promoting a youth sport culture focused on higher intensity training and nearly year-"round competition" [3].

In this setting, overuse injuries are common. Several studies indicate that approximately 50 % of youth sports injuries are due to overuse [4–6]. Given that approximately 3.7 million injuries resulting in time loss from sports occur at the high school level, overuse injuries account for an estimated 1.85 million injuries annually [7]. The actual incidence is likely much higher as this estimate does not include injuries occurring in grade school athletes. In addition, most studies of pediatric and adolescent sports injuries define injury as requiring time loss from sport, yet many young athletes continue to participate despite injury [8, 9].

This chapter discusses risk factors for overuse injuries of the extremities, and describes the clinical assessment of common overuse injuries including apophysitis and bone stress injuries (BSI). Injuries that are notoriously difficult to treat and can cause long-term consequences are also reviewed.

Risk Factors for Overuse Injuries

Risk factors have often been classified as either "intrinsic" or "extrinsic" (Table 7.1). Intrinsic factors are individual physical, physiologic, or psychological characteristics. Extrinsic factors include training methods, sport technique, and sporting environment. In many cases, a combination of risk factors results in injury [10–12].

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D. Caine, L. Purcell (eds.), *Injury in Pediatric and Adolescent Sports*, Contemporary Pediatric and Adolescent Sports Medicine, DOI 10.1007/978-3-319-18141-7_7

Table 7.1 Risk factors for overuse injury

Intrinsic risk factors
Growth-related factors
Susceptibility of growth cartilage to repetitive stress
Adolescent growth spurt
Previous injury
Previous level of conditioning
Anatomic factors
Menstrual dysfunction
Psychological and developmental factors—athlete specific
Extrinsic risk factors
Training workload (rate, intensity, and progression)
Training and competition schedules
Equipment/footwear
Environment
Sport technique
Psychological factors—adult and peer influences

From: DiFiori et al. [1]; with permission

Of all overuse injury risk factors, a previous injury is the strongest predictor [13–22]. This may indicate that a prior injury did not receive complete and comprehensive treatment, creating a susceptibility to repeat injury at the same site. Alternatively, such a situation could alter force dissipation, leading to injury at another site along the kinetic chain.

Characteristics unique to skeletally immature athletes also play a role. Growth cartilage is more vulnerable to injury than mature bone [23–27], particularly during the adolescent growth spurt [27]. In addition, a reduction in size-adjusted bone mineral density that develops before peak height velocity occurs is associated with acute fractures [28]. These factors may also apply to overuse injuries. Injuries such as chronic wrist pain in young gymnasts and proximal humeral physeal stress injury coincide with the expected age range for the adolescent growth spurt [29, 30].

Moreover, asynchronous changes occur during rapid growth that affect the relationships between growth and strength [31]. When combined with the mechanical stresses of training, a milieu distinct to young athletes exists that heightens the risk for overuse injuries.

Amenorrhea is also an established risk factor for overuse injury, specifically BSI [32–37]. The catalyst appears to be inadequate caloric intake leading to a state of hypoestrogenemia resulting in lower bone mineral density, thus lowering the threshold for BSI [38].

Other proposed intrinsic factors such as anatomic alignment, inflexibility, and joint hypermobility have all been cited as risk factors for overuse injury. However, there is little data to substantiate a causal relationship between these factors and injury [39–49].

Among extrinsic factors, training workload has repeatedly been linked to overuse injury.

Both training volume and intensity are significant factors [42, 50–53]. In particular, training more than 16 h per week results in more overuse injuries [51, 54, 55]. A high ratio of workload to rest may also be a specific factor. This can occur during youth sport showcase events and tournaments that include multiple competitive events per day, often over more than 1 day. Studies evaluating this concept are needed [1]. Other extrinsic factors, such as strength and conditioning as well as equipment fit and suitability, may play a role, but lack specific data [1].

Apophysitis

The secondary ossification center where a muscle-tendon unit inserts is known as an apophysis. Apophysitis is an overuse condition causing pain, inflammation, and microtrauma to the apophysis due to traction of the attaching tendon [56]. The skeletally immature athlete is unique in that the apophysis is the weak link in the muscle-tendon-bone unit. There is a lack of data on the actual incidence of apophyseal injuries. These injuries are more common in young athletes participating in running and jumping sports, such as soccer, basketball, and football, especially with use of cleats.

General principles for all apophysitises are described below. Table 7.2 provides a list of common apophyseal injuries.

History and exam: Pain onset is usually insidious. If a sudden onset of pain is described, an avulsion injury should be suspected. Physical examination

Table 7.2 Common apophyseal injuries

Apophysis	Eponym	Age (y)	Anatomic site	Exam findings	Treatment specifics (non-avulsion injuries)
Calcaneal	"Sever's disease"	8–12	Calcaneus, Achilles tendon	TTP at calcaneal insertion of the Achilles tendon	Heel cup
Fifth metatarsal	"Iselin's disease"	8–14	Lateral aspect of the base of fifth metatarsal, peroneus brevis	TTP at base of fifth MT	Avoid tight footwear
Tibial tubercle	"Osgood-Schlatter disease"	8–14	Tibial tubercle, patellar tendon	TTP at distal insertion of patellar tendon	Counterforce brace over patellar tendon
Inferior pole of the patella	"Sinding-Larsen-Johansson syndrome"	8–12	Inferior patellar pole, patellar tendon	TTP at proximal insertion of patellar tendon	Counterforce brace over patellar tendon
Pelvic		9–16	Multiple: ASIS, AIIS, iliac crest, ischial tuberosity, lesser trochanter, greater trochanter	TTP at tendon attachment of the specific apophysis	Relative rest
Medial epicondyle	"Little League elbow"	8–14	Medial epicondylar apophysis, flexor-pronator	TTP at medial epicondyle	Cessation of throwing initially

**TTP* tenderness to palpation

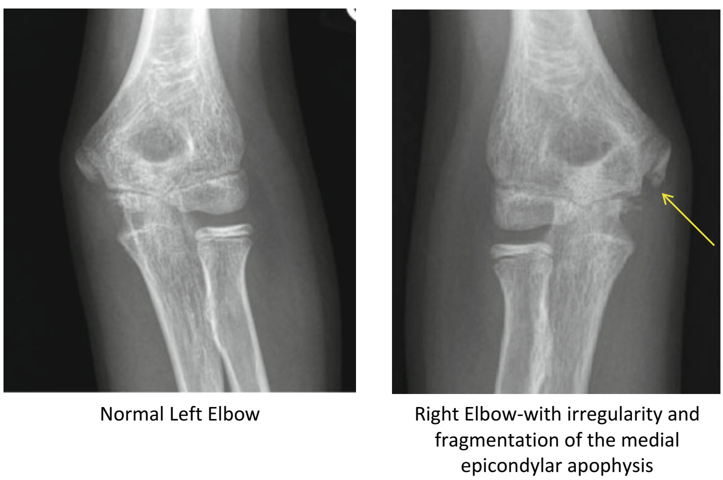

Fig. 7.1 Images from a 12-year-old pitcher with a 2-month history of medial elbow pain when throwing. (**a**) Normal left elbow. (**b**) Right elbow showing irregularity and fragmentation of the medial epicondylar apophysis

demonstrates focal tenderness to palpation, and often soft tissue swelling, at the apophysis.

Imaging: Imaging is usually not necessary unless there is concern for another injury (avulsion fracture, stress fracture). X-rays will show irregularity and possibly fragmentation of the apophysis, as well as soft tissue swelling (Fig. 7.1). X-rays should be obtained for injuries of the fifth metatarsal to rule out fracture. A key point in interpreting radiographs is that the normal lucency of the apophysis runs parallel to the long axis of the metatarsal while a fracture line runs perpendicular to the long axis.

Treatment: The cornerstone of management of apophyseal injuries is relative rest. Pain should be used as a guide to the amount of activity that is acceptable. If the athlete is limping or has pain with walking, a walking boot, stiff-sole shoe, or crutches should be used until pain resolves and gait normalizes. Ice cup massage and over-the-counter pain relievers can be helpful for pain management. Physical therapy to work on improving flexibility and strength can be helpful. Modalities such as iontophoresis may be useful adjuncts to allow a safe return to sports. In milder cases a home exercise plan can be implemented instead of a formal physical therapy program. Surgical consultation is recommended for avulsion injuries with 2–3 cm of displacement.

Return to play: Young athletes may return to play when they are pain-free with activities of daily living and exercise, have full strength of the involved muscles, and have no evidence of an altered gait during or after activity. They should continue to perform their rehabilitation exercises to maintain strength and flexibility.

Prevention: Incorporating flexibility, strength, and proprioceptive exercises may be preventative. In addition, proper shoe selection for the athlete's specific foot type may be helpful for some conditions. Following proposed overuse prevention guidelines should be encouraged [1, 6, 57].

Osteochondrosis of the Elbow

Osteochondrosis is defined as "a focal disturbance of endochondral ossification" [58]. It has a multifactorial etiology, with no single factor accounting for all aspects of the disease. Etiologic factors include heredity, rapid growth, anatomic conformation, trauma, and dietary imbalances; however, only heredity and anatomic conformation are well supported by the literature [58].

Incidence: Osteochondrosis of the elbow, also known as Panner's disease, occurs in young athletes between the ages of 5 and 10 years. It is more common in athletes who play sports that involve throwing (i.e., baseball) or weight-bearing on the upper extremities (i.e., gymnastics).

Mechanism of injury: It is believed to occur from an injury to the blood supply of the epiphysis in growing athletes. This leads to fragmentation of the capitellum and eventual resorption followed by reorganization of the epiphysis.

Signs and symptoms: Lateral elbow pain with activities, relieved by rest: Elbow stiffness and lack of full extension may develop, and possibly decreased pronation or supination. However, locking does not occur. On physical examination tenderness over the lateral elbow and capitellum is found [59].

Imaging: Radiographs will show flattening of the capitellum with irregular surfaces and radiolucent lesions. Over time (9–18 months) X-rays will show resolution of the condition with restoration of a rounded capitellar epiphysis.

Management: Treatment involves rest from aggravating activities and symptom control (i.e., pain management). Time alone will allow the epiphysis to revascularize and reorganize [59]. Repeat X-rays should be performed in 6–12 weeks to assess healing.

Return to play guidelines: The athlete may return to throwing activities or upper extremity weight-bearing activities when symptoms have resolved and there is radiographic healing of the capitellum. Plain radiographs may lag behind the clinical examination.

Prevention: Since the etiology is multifactorial, this condition may not be completely preventable. However, repetitive throwing and upper extremity weight-bearing are modifiable, so pitch count recommendations and general guidelines for periodic rest from sport should be followed.

Clinical pearls: It is important to differentiate this condition from osteochondritis dissecans (OCD) of the elbow. OCD occurs in a slightly older age group, may result in loose body formation causing mechanical symptoms of locking, and has a very different treatment and prognosis.

Bone Stress Injuries

Table 7.3 lists common bone stress injuries and their key exam findings. General principles for BSI are discussed below.

Incidence: Stress reactions and stress fractures, known collectively as BSI, occur in young athletes. Prevalence is sport specific. A study of Australian track and field athletes reported that 20 % developed a stress fracture [60], while among US collegiate track and field athletes, 16 % developed a BSI [61]. A study at a national tennis training center demonstrated that 12.9 % of players had a stress fracture [62]. Importantly this study found that junior tennis players were more likely to have these injuries than adult players. In another study, BSI in adolescent and exercising women (mean age 18 y/o) were 30–50 % more likely when risk factors for female athlete triad were present [63].

Mechanism of injury: BSI may occur along a spectrum. Initially, periosteal and bone marrow edema occurs without cortical involvement. Stress reactions may progress to involve the cortex resulting in a stress fracture. Such injury may occur in otherwise healthy bone exposed to high-volume and biomechanical loads. Non-traumatic fractures occurring with modest biomechanical load or volume suggest that the bone is unhealthy (from diminished bone density or other metabolic factors). Complications of BSI include non-union or complete fracture. Specific anatomic regions, such as the femoral neck, the anterior cortex of the tibia, and the metaphyseal/diaphyseal junction of the fifth metatarsal, have an increased propensity for nonunion in part based on total stress, and vascular supply.

Table 7.3 Common bone stress injuries of the extremities

Location	Exam
Metatarsals	Focal TTP metatarsal shaft
Media tibial stress syndrome	TTP spans several cms of the posteromedial tibial border
Tibia	Focal TTP, most commonly at the junction of middle and distal thirds of tibial shaft
Fibula	TTP of fibular shaft
Physis	Exam is usually unremarkable
Proximal humerus	Pain occurs only with throwing
Distal radius	Pain occurs with weight-bearing on the wrist

**TTP* tenderness to palpation

Imaging: X-rays are recommended for any young athlete suspected of having a BSI. The sensitivity of plain radiographs may be as low as 10 % if done very early. A negative X-ray does not exclude BSI. X-rays may be repeated, though may never reveal the injury. If X-ray is non-confirmatory, additional imaging such as MRI should be considered. Sensitivity and specificity of BSI are highest for MRI and may allow for better staging of some BSI [61]. MRI staging includes grades 1–4, with grade 1 having mild periosteal edema only on T2 images with no fracture line progressing to grade 4 with severe periosteal edema on T2 images, marrow edema on T2 and T1 images, and a visible fracture line [61]. Other imaging modalities, including bone scan and CT scan, are falling out of favor for initial diagnosis as they expose young athletes to higher amounts of radiation.

Management: While management of BSI should be individualized, general principles of treatment include reduction of impact loading to allow for healing. Immobilization, protected weight-bearing (e.g., use of a walking boot, or long pneumatic splint), or non-weight-bearing with crutches may further reduce loading and control pain occurring with routine walking and weight-bearing. Cross-training with nonimpact activities such as biking or swimming to maintain cardiovascular fitness is recommended.

Return to play: When pain resolves, there is adequate bone healing, and no tenderness over the area of the stress fracture, the athlete may begin weight bearing activities followed by controlled impact and sport specific training. Return to play should occur with a structured on-field or on-court progression with intermittent participation and gradually increasing volumes. In a prospective study of collegiate track and field athletes, higher grade BSI were associated with a longer return to play [61]. Specifically, grade 1 and 2 injuries returned at approximately 13 weeks, while grade 3 and 4 injuries returned at approximately 24 weeks.

Prevention: Young athletes should have appropriate caloric intake, as well as calcium and vitamin D intake. Girls who develop menstrual dysfunction should be assessed for the female athlete triad, caloric insufficiency, and/or overtraining. All young athletes with recurrent BSI should be considered for evaluation for underlying bone metabolic disorders. Training volume should be carefully monitored. A gradual increase in training is necessary to prevent re-injury.

High-Risk Bone Stress Injuries

Overuse injuries may not be benign. Some present significant treatment challenges, with the potential to alter an athletic career and cause long-term health consequences. These injuries are listed in Table 7.4 and discussed in detail below.

Femoral Neck Stress Fracture

Incidence: Stress fractures to the femoral neck are rare in adolescents [64, 65].

Mechanism of injury: BSI occurs due to repetitive and rapid increases in training, or underlying bone health deficiencies.

Signs and symptoms: There should be a high index of suspicion for this injury in athletes who present with anterior hip pain or groin pain with running or other weight-bearing activities. Pain with a single-leg hop localizing to the groin is concerning. Pain with passive internal rotation or resisted external rotation may also be present.

Imaging: Hip X-rays should be performed with attention paid to the femoral neck for periosteal reaction or lucency. Since X-rays are frequently negative, MRI should be performed to determine if there is bone marrow edema, cortical involvement, or a fracture line. The location of a femoral neck stress fracture is critical to determining its appropriate treatment.

Management: Compression-sided (inferior) femoral neck stress fractures without displacement can be treated non-operatively with non-weight-bearing on crutches for approximately 6 weeks. Cross-training involving no weight-bearing may be considered prior to 6 weeks if there is no pain. Patients with tension-sided (superior) femoral neck stress fractures should be strictly non-weight-bearing and promptly referred to an orthopaedic surgeon for possible surgical fixation, since these stress fractures are at risk for nonunion and progression to complete fracture [65].

Return to play guidelines: For compression-sided injuries, after 6 weeks of non-weight-bearing, limited weight-bearing exercises may

Table 7.4 High-risk bone stress injuries of the extremities

Location	Exam	Imaging
Femoral neck-tension side	Pain with passive hip internal rotation	Frequently only seen on MRI
Anterior tibial cortex	Focal TTP of anterior tibia	X-ray may reveal the defect of anterior tibial cortex (“dreaded black line”)
Tarsal navicular	TTP over mid-dorsal navicular (“N” spot)	MRI or CT
Fifth metatarsal at metaphyseal/ diaphyseal junction (“Jones fracture”)	TTP at proximal fifth metatarsal	May see cortical defect on X-ray. MRI if X-ray negative

**TTP* tenderness to palpation

be introduced, followed by gradual progression to full weight-bearing exercises over another 6-week period. Repeat MRI is recommended by the authors to ensure resolution prior to full impact training.

Prevention: Similar to that described above for other BSI.

Clinical pearls: A high index of suspicion is critical to a timely diagnosis. Any athlete who develops anterior hip or groin pain in the setting of high training volumes should be removed from weight-bearing exercise and evaluated for a femoral neck stress fracture.

Stress Fracture of the Anterior Tibial Cortex

When treating exertional leg pain in young athletes, clinicians should be aware of a higher risk tibial stress fracture involving the anterior tibial cortex. These injuries occur on the tension side of the tibia and are notoriously difficult to treat. Tenderness on exam is localized to the anterior tibia, as opposed to the posteromedial tibial border in low-risk tibial BSI. Lateral radiographs may demonstrate a defect of the anterior tibial cortex (referred to as a "dreaded black line") (Fig. 7.2). If X-ray is negative, MRI or CT scan with thin cuts should be obtained [66]. Limited weight-bearing and immobilization with pulsed

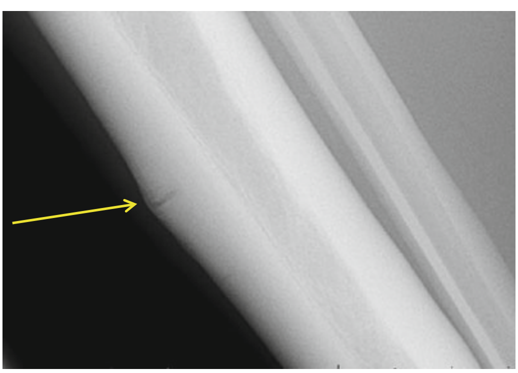

Fig. 7.2 "Dreaded black line": Stress fracture of the anterior tibial cortex

electrical stimulation for 3–6 months have been described [67]. However, even with prolonged non-weight-bearing healing is not predictable. Therefore, surgical consultation is recommended. Surgical treatment with intramedullary nailing has been successful in adolescents, with an average of 4 months for return to sports [68].

Navicular Stress Fracture/Reaction

Incidence: Incidence of tarsal navicular stress fractures in young athletes has not been documented; however it was the most common lower extremity stress fracture in elite tennis players at a national tennis training center, with junior players being at greatest risk [62]. A case report of a 13-year-old female cross-country runner has also been reported [69].

Mechanism of injury: Increased load and stress to the medial mid-foot with excessive training. The midportion of the navicular has the higher risk, because this area is relatively avascular.

Signs and symptoms: Young athletes with insidious onset of medial mid-foot pain should raise concern for a tarsal navicular stress reaction or stress fracture. This may be associated with limping and/or swelling. Physical examination may include focal tenderness over the mid-dorsal portion of the navicular ("N" spot).

Imaging: X-ray is recommended, but is typically non-diagnostic. MRI is often needed to make the diagnosis. Subsequent CT scanning can establish the extent of the fracture.

Management: A systematic review of tarsal navicular stress fractures found that immobilization with non-weight-bearing on crutches for approximately 6 weeks had a similar favorable outcome (96 % success rate with return to play in 5 months) compared to surgical treatment (86 % success rate with a similar time to return to play), and is thus recommended as first-line treatment for non-displaced stress fractures [70]. Protected weight-bearing is not effective, as only 42 % of patients returned to sports activity at an average of 5.7 months [70]. After non-weight-bearing and immobilization, protected weight-bearing may then be considered for another 4–6 weeks, followed by rehabilitation and return to activity. Because these injuries are difficult to heal, consultation with orthopaedic surgery should be considered. There is no clear data regarding follow-up imaging (e.g., repeat CT scans) to guide return. Failure to heal with non-weight-bearing management or imaging findings of displacement or nonunion clearly warrant surgical consultation.

Return to play guidelines: When there is no tenderness over the area of the stress fracture, the athlete may start sport-specific running, cutting, and jumping. Return to play should occur with a structured on-field or on-court progression with intermittent participation and gradually increasing volumes.

Prevention: Careful monitoring of training volume, scheduled rest days, and a gradual increase in training are recommended.

Clinical pearls: Nutritional and caloric intake should be reviewed. Evaluation of bone density may be considered, especially if there is a history of prior stress fractures, or if features of the female athlete triad are present.

Jones Metatarsal Stress Fracture

Recognition of BSI of the metaphyseal/diaphyseal junction of the fifth metatarsal is important due to its relative morbidity. Pain and tenderness over the base of the fifth metatarsal should be evaluated for this potential high-risk stress fracture. X-ray may show a lucency of the cortex ("dreaded black line") or a periosteal reaction in the proximal metaphyseal/diaphyseal junction of the fifth metatarsal. However, a normal X-ray does not exclude a BSI. MRI should be obtained if initial X-rays are negative.

Management: Immobilization and non-weight-bearing for extended periods (up to 19 weeks) is recommended. In high-level athletes, surgical screw fixation may be preferred to reduce the risk of nonunion and shorten the duration of treatment (14 weeks of non-weight-bearing) [71].

Physeal Stress Injuries

BSI can affect the growth plate (physis). Such injuries occur at a number of sites of the upper and lower extremities, most commonly involving the proximal humeral physis and the distal radial physis.

Little League Shoulder (Epiphyseolysis of the Humeral Physis)

Incidence: Incidence of proximal humeral epiphyseolysis ("Little League shoulder") is not known but has been reported primarily in baseball pitchers and overhand athletes. It has also been reported in numerous other sports in adolescent athletes [72].

Mechanism of injury: This condition usually develops from excessive volume of overhand activities with excess traction or rotational stresses to the proximal humeral epiphysis. This may result in widening of the physis which is essentially a stress-related Salter I fracture. Complications of growth arrest are rare [72].

Signs and symptoms: Pain occurs with throwing or other repetitive overhead activities, and is usually relieved with rest. Diminished performance may be noted.

Imaging: Plain X-rays may show widening and/or irregularity of the proximal humeral physis. A comparison film of the non-dominant shoulder should be obtained. If X-rays are negative, MRI may establish the diagnosis.

Management: Cessation of throwing is recommended for a minimum of 6 weeks, but up to 3 months may be necessary. An upper extremity strengthening program focusing on the scapula, rotator cuff, and shoulder-stabilizing muscles is necessary. These exercises are best performed in functional planes (i.e., throwing/serving/pitching) that involve the eccentric component and incorporate the lower body/trunk and on the deceleration phase as well.

Return to play guidelines: A structured throwing program progressing from long tosses to pitching is recommended prior to full participation. Close attention should be paid to following USA youth baseball pitch count recommendations and appropriate rest periods.

Prevention: Monitoring pitching volumes may be helpful. There is increased risk of overuse injuries in young baseball players who have shoulder pain with pitching, shoulder fatigue, pitch >8 months/year, or pitch excessive volumes [50]. A young pitcher or overhand athlete should not continue to participate when shoulder pain persists or recurs with each outing.

Clinical pearls: Since the physical exam is frequently non-diagnostic, this injury should be suspected when an athlete presents with recurrent shoulder pain when throwing, in the absence of any trauma. Imaging is needed to establish the diagnosis.

Stress Injury of the Distal Radial Physis

Incidence: This injury occurs among competitive gymnasts. Wrist pain in young gymnasts is common, affecting 46–79 % [73]. A subset of those with wrist pain will display radiographic findings of distal radial physeal stress injury. The incidence is unknown, since negative radiographs do not exclude the injury, and there are no controlled studies using MRI.

Mechanism of injury: Repetitive loading of the wrist during weight-bearing (such as floor exercise and pommel horse) is thought to disrupt metaphyseal perfusion of the physis. This interferes with normal endochondral ossification, resulting in accumulation of chondrocytes, and widening of the physis.

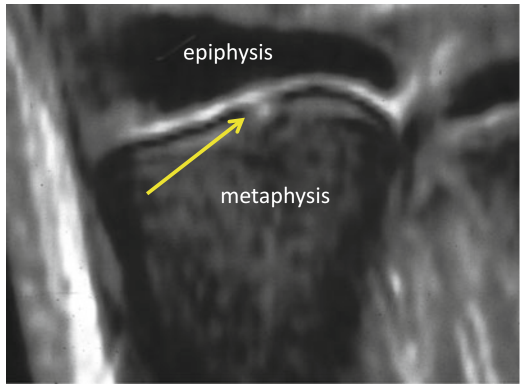

Fig. 7.3 Stress injury of the distal physis in a 10-year-old gymnast with wrist pain provoked with weight-bearing on the wrist. This coronal GRE image of the distal radius demonstrates physeal cartilage (high signal, *arrow*) extending into the metaphysis (adapted from DiFiori and Mandelbaum [78])

Signs and symptoms: Gymnasts describe dorsal wrist pain with weight-bearing when the wrist is extended. Physical exam is usually unremarkable, though pain may be reproduced by passively or actively loading the wrist in extension.

Imaging: Radiographs of the wrist may demonstrate widening of the physis, a beaked appearance of the metaphysis, irregularity of the physeal borders, and/or haziness within the normally lucent physis. MRI is more sensitive and specific, and may show physeal cartilage extension into the metaphysis (Fig. 7.3).

Management: An initial 6-week period of rest from upper extremity weight-bearing is recommended. If radiographs were abnormal, repeat images should be obtained to document healing. Bracing is rarely necessary, but should be considered if the athlete has pain provoked with daily activities.

Return to play: A gradual resumption of limited repetitions of training elements including weight-bearing on the wrist is initiated, with ongoing symptom assessment. If the athlete remains pain-free, both training volume and number of wrist loading elements can be increased on a weekly basis.

Prevention: Monitoring training volume, particularly during the adolescent growth spurt, is recommended. Although many gymnasts prefer to wear dorsal wrist braces, there is no evidence that they reduce injury incidence.

Clinical pearls: This injury can alter growth of the distal radius. Thus, it is important to have a high index of suspicion when young gymnasts present with wrist pain. If radiographs are negative, MRI should be obtained.

Patellofemoral Pain

Incidence: Patellofemoral pain has a 15–20 % incidence in young athletes [74]. It is the most common cause of non-traumatic knee pain in young athletes. In one sports medicine clinic study, patellofemoral pain was the single most common diagnosis [75].

Mechanism of injury: Many biomechanical factors may play a role, including lateral patellar alignment, increased patellar mobility, pes planus, hip abduction or quadriceps weakness, increased Q angle, knee valgus alignment, and femoral anteversion. Increased flexion-based training typically contributes to this condition. Early sport specialization may be another modifiable risk factor [76].

Signs and symptoms: The pain is typically described as anterior, or "behind the kneecap" [77]. Pain can occur with running, squatting, and climbing and/or descending stairs. Pain may also occur with prolonged sitting with the knee flexed ("theater sign"). The pain is frequently difficult to localize. When asked to point to the area of pain, patients may instead draw a circle over the patellar region, referred to as the "circle sign" [77]. Tenderness over the patellar facets, a positive inhibition sign, and pain with a single-leg squat may be present [77]. A key aspect of the clinical exam is that this condition does NOT cause an effusion [77].

Imaging: Imaging is not required initially; however, X-ray may be considered for persistent or long-standing knee pain. An initial weight-bearing X-ray with a notch view and an axial view is recommended to evaluate for malalignment and other conditions that may cause knee pain such as osteochondritis dissecans, or even bone tumors.

Management: Initial reduction in activities that load the patellofemoral joint, combined with a functional rehabilitation program is recommended. Rehabilitation should focus on strengthening the quadriceps and hip abductors, as well as functional strengthening in sport-specific patterns. Flexibility of the hamstrings, quadriceps, and iliotibial band should be addressed as necessary. Other interventions, such as addressing biomechanical factors such as knee valgus alignment, pes planus (with orthotics), lateral patellar tilt with patellofemoral bracing, or patellofemoral taping, can be considered, though data supporting their effectiveness is not consistent. Surgery involving realignment of the extensor mechanism can be considered for recalcitrant cases, but is rarely needed as the vast majority of patients recover fully with a tailored rehabilitation program.

Return to play guidelines: Pain-free single-leg squat, tolerance to single-leg hop tests, and other functional tests may be used to gauge progression of sports-specific activities. Many athletes may continue to participate with training modifications combined with an ongoing rehabilitation program. Return to pre-injury levels should occur with a structured and gradual progression of training volumes.

Prevention: Addressing biomechanical flaws, particularly with knee valgus and poor neuromuscular control in developing young athletes, may help prevent patellofemoral pain. Monitoring training volume carefully, along with gradual return to training, is necessary. Limiting early sports specialization and promoting diversification may improve developmental progression and appropriate neuromuscular control.

Clinical pearls: Presence of a knee effusion on physical examination is not consistent with patellofemoral pain, and should prompt imaging with radiographs. If radiographs are negative, MRI should be obtained to evaluate for osteochondritis dissecans or other conditions.

Summary

Overuse injuries are common in children and adolescents. These injuries occur due to multiple factors, particularly factors unique to growth and development, such as reduction in size-adjusted bone mineral density and asynchronous biomechanical changes. Recovery time can be significant. Some overuse injuries such as tension-sided stress fractures of the femoral neck can be difficult to treat, and may result in long-term sequelae. Understanding the factors that contribute to these injuries and providing a comprehensive management approach are central in ensuring successful outcomes. Finally, being familiar with higher risk overuse injuries is important to make an accurate and timely diagnosis, and to prevent long-term consequences.

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Acute Lower Extremity Injuries in Pediatric and Adolescent Sports

8

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Introduction

The number of children and adolescents participating in sports has greatly increased in the last decades. In the USA, 25 % of girls and 50 % of boys between 8 and 16 years of age participate in sports, while in Europe up to 79 % of children participate in organized sports [1]. The age of initiation of intense training is decreasing and programs exposing children to excessive amounts of exercise increase the risk of injury [2]. This chapter reviews acute lower limb injuries which most commonly affect young athletes, such as physeal fractures and apophyseal avulsion fractures, as well as knee, ankle, and foot injuries. Muscular injuries and acute compartment syndrome are also discussed.

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Epidemiology

About 34 % of children and adolescents participating in sports in the USA sustain an injury during sports [3]. A large epidemiological study of 16 different sports reported that more than 50 % of all sports injuries involve the lower limb, with the knee and ankle accounting for the majority [4]. Ankle ligament sprains were the most common injuries over all sports, accounting for 15 % of all reported injuries, while the knee was the most common severely injured, accounting for 44.6 % of all surgeries, with more than 21 days' loss.

The incidence of injury is affected by different factors, such as increasing age, gender, sport, and participation level. Sports injuries differ by age in diagnosis, type, and body area. One study reported that children aged 5–12 years sustained more traumatic injuries, and more commonly in the upper extremity [5]. Adolescents aged 13–17 years sustained injuries more frequently in the chest, pelvis, lower limbs, and spine. Soft tissue and overuse injuries are also more frequent in these patients [5]. A recent study suggests that gender is an important variable [6]. Female athletes seem to have a higher percentage of overuse injuries (62.5 %) compared with traumatic injuries (37.5 %), especially in the lower extremity. The knee is the most commonly injured body part in pediatric patients (73.9 %). The percentage of

D. Caine, L. Purcell (eds.), *Injury in Pediatric and Adolescent Sports*, Contemporary Pediatric and Adolescent Sports Medicine, DOI 10.1007/978-3-319-18141-7_8

males and females who sustained an anterior cruciate ligament (ACL) injury was almost equal [7].

The incidence and pattern of injury vary according to sport. Epiphyseal growth plate fractures are frequent injuries in contact sports, most often American football. A systematic review revealed that 38.3 % of acute growth plate injuries were sport related, and 14.2 % were associated with growth disturbance [8]. Ankle physeal injuries account for 15–38 % of all physeal injuries.

It is unclear if activity level influences the rate of injury. Some authors reported a high rate of lower limb injuries in out-of-season practice activities [4], while others reported that young elite athletes have low rates of injury [5]. This may reflect a different subpopulation or injury prevention programs and better support. However, even if little research has evaluated the effectiveness of injury prevention in children and youth sports, initial results are promising [9, 10].

Growth Plate Injuries

The bones of children and adolescents are less mineralized, more vascularized, more porous, and more elastic than adult bones, so they absorb more energy before they fracture, heal more quickly, and produce greater callus. Another important difference is the presence of the growth plate or physis, which is the area of growing tissue near the epiphysis. The growth plate cartilage is the weakest link in the bone of skeletally immature patients, and is 2–5 times weaker than the surrounding tissue, especially during periods of rapid growth. Physeal fractures are common, accounting for 15–30 % of all skeletal injuries in children treated in emergency departments (ED). The most common physeal fractures occur in the distal femur, distal tibia, proximal tibia, and distal radius [2]. Epiphyseal growth plate injuries occur frequently in baseball, gymnastics, and distance running in which the tolerance limits of the physis may be exceeded by the mechanical stresses. American football is most often associated with acute physeal fractures.

Epiphyseal injury may clinically present with acute pain, visible anatomic deformity, and inability to move or weight bear on the injured side. Plain radiographs can diagnose and classify the fracture. Comparison views of the contralateral side are useful to evaluate minimally displaced or nondisplaced fractures, or to delineate ossification patterns. A computerized tomography (CT) scan is recommended for intra-articular fractures to define the fracture pattern and aid in surgical planning [11]. Ultrasonography can visualize the cartilaginous epiphyses that are not demonstrated on radiographs [12, 13]. Magnetic resonance imaging (MRI) can determine the "health" status of the physis [14].

The Salter-Harris classification system for physeal injuries is most commonly used. This was developed on a radiographic basis: type I (complete separation of the epiphysis from the metaphysis without any metaphyseal bone involvement) to type V (a compression of the growth plate) (Fig. 8.1). The most common injury is type II, in which the line of separation extends along the growth plate, including a portion of the metaphysis. In minimally displaced type I and II fractures, prognosis is good and treatment may be necessary only in the presence of symptoms; immobilization is indicated only if the fragments are displaced. Type III and IV fractures have a favorable prognosis if vascularization is good and the fracture is not displaced. Surgery with internal fixation may be necessary to restore the joint surface to normal, avoiding the risk of early osteoarthritis. Type V injuries have a poor prognosis because they produce a partial or complete growth arrest if the growth plate is not completely realigned (Fig. 8.2). Injuries of the epiphyseal growth plate can result in limb length discrepancy, angular deformity, or altered joint biomechanics with possible long-term disabilities [8].

Distal femoral fractures in adolescents result either from high-energy trauma or a sports-related injury. A careful neurovascular examination of the injured extremity is necessary. For nondisplaced Salter-Harris Type I and II physeal fractures, conservative management with a long leg cast is usually adequate. For displaced Salter-Harris Type I or II fractures with a small metaph-

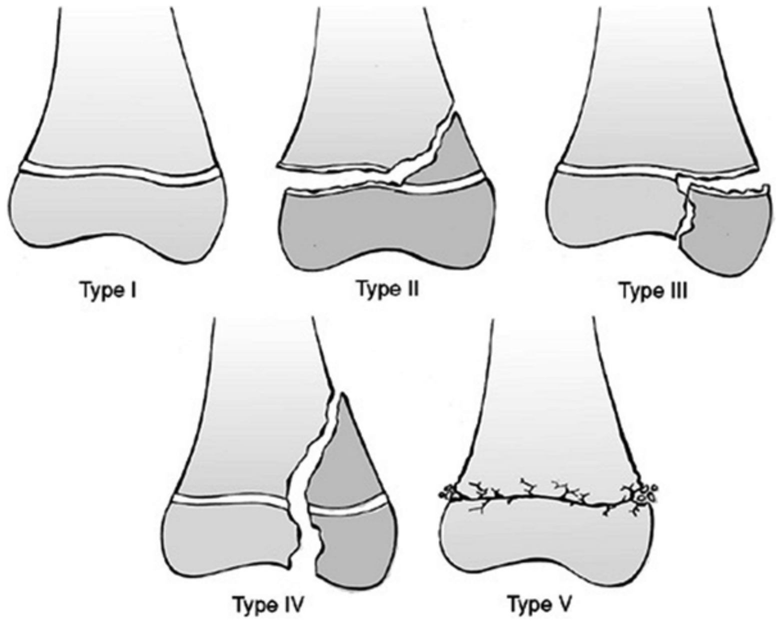

Fig. 8.1 Salter-Harris classification system

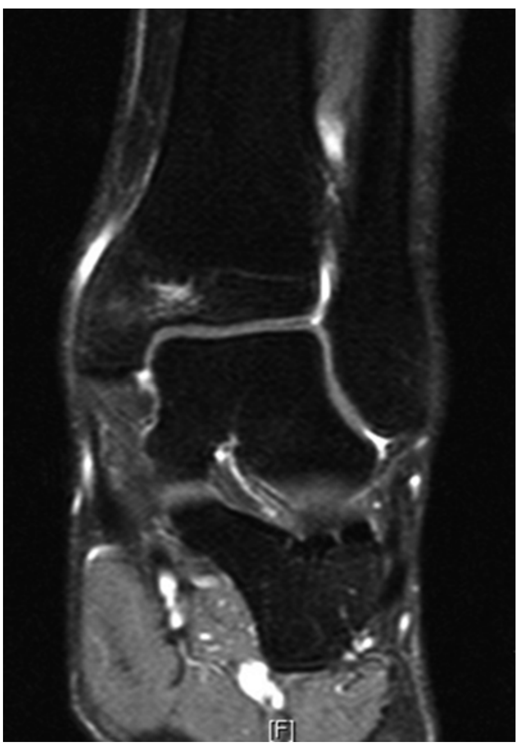

Fig. 8.2 Type V Salter-Harris lesion of the distal tibia of a 22-year-old athlete

yseal fragment, closed reduction and stabilization with percutaneous pins or Kirschner wires is indicated. Displaced Salter-Harris Type III and IV fractures warrant anatomic reduction and fixation [15]. Cannulated compression screws placed across the fracture and parallel to the physis are commonly used. Even after proper treatment, up to 50 % of distal femoral physeal fractures may result in growth disturbance [16]. A high risk of limb length discrepancy or angular deformity has been reported after Salter-Harris Type II injury [16].

Proximal tibial physeal fractures occur with valgus or hyperextension force on a fixed knee. The principles of treatment are similar to those for distal femoral physeal fractures. A CT scan is recommended for Salter-Harris Type III and IV fractures involving the tibial plateau. Neurovascular injuries and compartment syndromes are not uncommon, and they should be kept in mind.

Ankle physeal injuries account for 15–38 % of all physeal injuries. Injury patterns are a consequence of the physeal anatomy and the patient's age [17]. The distal tibial physis appears by 1 year of age and closes by 12–14 years of age in girls and by 15–18 years of age in boys. The distal fibular physis appears by 2 years of age, and closes by 19–20 years of age. The medial malleolar ossification center appears at 1–2 years of age and closes by age 12 years [18]. The distal tibial physis closes in a circular pattern from the center to medial to lateral. During normal development, the medial and posterior tibial physeal plates close first, followed by the anterolateral areas. The fracture patterns reflect the areas of the physis that are still open.

The Tillaux fracture is a Salter-Harris Type III fracture of the anterolateral portion of the distal tibial epiphysis (Fig. 8.3). It occurs late in adolescence when the medial and posterior plates have closed and the anterior growth plate is still open. The mechanism of injury is forceful external rotation. As the ankle is stressed medially, the pull of the anterior tibiofibular ligament results in an avulsion fracture of the anterolateral aspect of the distal tibial epiphysis over the area of the physeal plate that is still not ossified. As Tillaux fracture occurs toward the conclusion of physeal closure, symptomatic growth arrest is rare [15]. A Tillaux fracture appears on anteroposterior radiographs as a vertical line through the epiphysis. It can be managed nonsurgically, with a closed reduction in internal rotation of the foot, but these fractures often require open reduction internal fixation (ORIF) to restore the joint surface and prevent articular degeneration.

A triplane fracture is a multiplanar Salter-Harris Type IV fracture of the ankle, which involves all three planes of the distal tibia. Patients are usually younger than those with a Tillaux fracture. A CT scan is useful to assess the fracture pattern, plan surgery, and obtain anatomical reduction of the joint surface [15, 19].

Apophyseal Avulsion Fractures of the Hip and Pelvis

Apophyseal avulsion fractures occur in growing teens involved in sports, particularly sprinters, distance runners, and soccer and tennis players. They usually result from a sudden forceful concentric or eccentric contraction of the muscle attached to the apophysis, which is an area of growth cartilage where muscles and tendons attach. Soccer and gymnastics have documented the highest number of avulsion fractures [20]. Although apophyseal avulsion fractures of the hip and pelvis usually affect adolescents, with a mean age of 13 years, they can occur in older patients, as the apophyses close at 25 years old (range 4–25 years) [21]. The most common locations were the ischial tuberosity (IT—54 %), anterior inferior iliac spine (AIIS—22 %), anterior superior iliac spine (ASIS—19 %), superior corner of pubic symphysis (PS—3 %), and iliac crest (IC—1 %) [20]. Apophyseal avulsion fractures of the greater trochanter have also been reported, and although rare, bilateral avulsion fractures can occur [22, 23].

Apophyseal injuries of the pelvis are usually acute. The young athlete feels shooting pain

Fig. 8.3 Tillaux fracture

referred to the involved tuberosity. The clinical exam reveals pain and local tenderness during movement of the affected limb or during abdominal movements, as well as restricted range of motion and weakness. However, they can also be the result of a neglected and/or misdiagnosed injury and, if not properly diagnosed and treated, they can result in a chronic, debilitating problem. Plain radiographs are usually sufficient for diagnosis [20]. Classification is usually based on the location and amount of displacement.

Most patients can be managed conservatively. After a short period of rest, ice, and analgesics, patients can start gentle passive and active motion. Once 75 % of motion is regained, patients may progress to guided resistance exercises, usually at 3 weeks after injury. Approximately 1–2 months after injury, patients can begin stretching and strengthening exercises with an emphasis on sports-specific exercises. They should return to competitive sports no earlier than 2 months after injury. Surgical intervention is indicated for displacement of 2–3 cm, painful nonunion, inability to return to competitive sports, and exostosis formation [24]. Kautzner et al. reported faster recovery and better compliance with rehabilitation protocols in patients with fragment displacement treated surgically [25]. They concluded that the indication for surgical treatment is the grade of fragment displacement and the patient's sporting activity.

Knee Injuries

Anterior Cruciate Ligament Injuries

In skeletally immature patients the collagen fibres of the ACL form a strong connection between the ligament, the perichondrium, and the epiphyseal cartilage. As ligaments are stronger than growth plates, knee injuries most often result in physeal injuries or tibial spine avulsion (80 % of children under 12 years old with ACL trauma) [26]. However, as the number of children and adolescents participating in competitive sports is growing, ACL tears are becoming more common, up to 90 % of cases in children older than 12 years old [26]. Recent reviews reported ACL injury in about 50–70 % of cases of knee hemarthrosis [27].

Several authors reported that young female athletes are at greater risk of sustaining ACL injuries, probably because of differences in joint laxity, hormones, anatomy (narrow notch width), neuromuscular function, and training [28, 29]. Up to 50 % of ACL ruptures in elite female athletes occurred during the menstrual phase of their cycle [30]. However, more recent research with more patients did not show any statistically significant difference in the proportion of male and female athletes who sustained an ACL tear [6].

Plain radiographic evaluation is essential to exclude bone injuries, while MRI can confirm a diagnosis based on an accurate clinical examination.

The management of ACL lesions in this age group is controversial. Conservative management with extensive rehabilitation and return to activities wearing a brace until skeletal maturity and growth plate closure followed by delayed anatomic ACL reconstruction to allow an anatomical adult-like reconstruction was the treatment traditionally preferred [31]. However, early surgical treatment is now advocated for ACL-deficient and unstable knees [32]. Longitudinal studies found that about 70 % of young athletes who suffered an ACL injury developed moderate knee osteoarthritis within 10–15 years [33]. A recent meta-analysis showed that conservative treatment can result in severe instability, high rate of meniscal tears, early degenerative osteoarthritis, and poor recovery in sports [34]. Delay of as little as 5 months between ACL injury and surgery was associated with high risk of a medial meniscal tear, which increases steadily in frequency more than 1 year after ACL injury [35]. Therefore, the importance of early surgical ACL reconstruction has recently been emphasized [36].

When ACL surgical reconstruction is performed, there is potential risk for iatrogenic injury to the physis. This could lead to growth disturbance, as the proximal tibia contributes 55 % to the growth of the leg, and the distal femoral physis contributes 70 % to the growth of the femur. Many different surgical techniques have been described to minimize risks and complications to the physis, and extra-physeal reconstruction or partial/complete transphyseal techniques are available [37]. Transphyseal repair involves a tunnel being drilled across both the tibial and femoral physis. This procedure allows ideal tunnel placement, and improves graft longevity and knee function, but the incidence of growth disturbance may increase, especially in very skeletally immature children [37]. Partial transphyseal techniques avoid the distal lateral femoral physis, providing more isometric tibial graft positioning, and provide excellent stability and return to sport. More anatomic physeal-sparing reconstruction techniques seem to be promising, but are technically demanding [2].

Conservative treatment can be considered for partial ACL tears. Good outcomes have been reported in patients younger than 14 years with a partial ACL tear and a stable knee treated conservatively [38–40]. One series reported that only 31 % of such patients required reconstruction [38].

Prevention of injuries is very important. Training programs during the preseason focused on strengthening, neuromuscular, and proprioceptive training supervised by qualified personnel seem to be effective to prevent ACL lesions [41].

Posterior Cruciate Ligament Injuries

The posterior cruciate ligament (PCL) is the primary restrain to posterior tibial translation and is a secondary restraint to external rotation. PCL injuries are less common than ACL injuries. Three mechanisms have been proposed for PCL tears: a direct blow to the anterior surface of the tibia, hyperflexion, and hyperextension. Noncontact injuries, such as forced hyperflexion, have been reported to be the most common isolated PCL injury mechanism in athletes [42]. PCL injuries can be classified according to severity (grades I–III), timing (acute versus chronic), and presence of associated injuries (isolated versus combined) [43].

Avulsion fractures are frequently associated with PCL injuries in children and adolescents, so plain radiographs are necessary. The attachment site may not yet have ossified; thus, avulsion of the PCL, especially from the femur, may not be appreciated on plain films. In the skeletally immature knee, MRI can accurately differentiate between intrasubstance and complete tears and determine associated chondral or meniscal disease. Partial ligament tears can be difficult to distinguish, even with MRI. In this case arthroscopy and examination under anesthesia remain the most accurate means of diagnosis [44].

PCL injuries are not as benign as previously thought [39]. Nonoperative treatment with the knee immobilized in a cast in full extension to reduce posterior translation was considered the first-line approach to PCL injuries in the pediatric population because of the high risk of physeal injury leading to growth arrest or angular deformity. However, treatment should consider the type of ligamentous injury (partial or complete), the site (avulsion or midsubstance), the grade (partial or complete), and the presence of any associated injuries (meniscal or chondral injuries). Soft tissue PCL avulsions from the femur or tibia should be repaired primarily with transosseous (intraepiphyseal) sutures through drill holes. Bony avulsions can be repaired with either screw or transosseous suture fixation. Isolated midsubstance PCL tears can be managed conservatively in skeletally immature patients with good results [45], particularly those with less than 8 mm of posterior displacement on stress radiographs [45]. PCL reconstruction is a viable treatment option in patients with multi-ligament injuries or those with isolated PCL injury who have failed conservative treatment, with outcomes related to the severity of the initial injury.

Medial and Lateral Collateral Ligament Injuries

Isolated medial and lateral collateral ligament (MCL, LCL) injuries are uncommon in pediatric athletes, but are more frequently associated with an ACL tear and multilayer knee instability [1]. MCL tears occur after a valgus or rotatory stress to the knee. Injuries of the MCL are well evaluated with MRI, which can show a ligament tear, lateral bone marrow edema due to the valgus stress forces, and medial bone marrow edema due to the microavulsive injury [46]. Injuries of the MCL are commonly classified according to Hughston classification as grades 1–3 [47]. Avulsion fractures of the proximal MCL are called Pellegrini-Stieda lesions [47]. Incomplete and isolated tears of the MCL are commonly treated nonoperatively with early functional rehabilitation with good results, but when ACL tear and multilateral knee instability are associated, they require surgical reconstruction [48].

Isolated LCL injury is very rare in the pediatric population, but can be associated with tears of the ACL and injuries to the posterolateral corner structures [49]. A Segond fracture is an avulsion fracture of the lateral tibial plateau and is commonly associated with ACL injury [49]. The management of isolated LCL tears is conservative. Failure to recognize and repair the posterolateral corner injuries is the reason for failure of ACL reconstruction and persistent knee instability [49].

Meniscal Tears

Meniscal injuries involve 5 % of patients younger than 15 years, particularly children and adolescents participating in football, soccer, and basketball. Isolated meniscal tears most frequently involve the medial meniscus, while the lateral meniscus is frequently injured in case of ACL injury with an unstable knee and discoid meniscus [50]. Discoid meniscus is abnormally shaped with different histological and mechanical properties from the normal meniscus. The ultrastructure of discoid meniscus is significantly different and the collagen fibrils are less in number and misaligned [51]. Discoid menisci cannot control the coordination of the tibiofemoral joint, absorb shock, or reduce mechanical pressure on articular cartilage; thus they quickly become worn and the incidence of tears is increased [52].

Young athletes may describe a “pop” heard or felt after a twisting event. Symptoms include pain, effusion, snapping, giving way, and less frequently locking. However, the diagnosis can be difficult because clinical exam is often subtle and nonspecific, leading to possible delay in diagnosis and/or misdiagnosis. Physical examination may reveal joint line tenderness and effusion. The McMurray test is considered positive when the child feels pain with provocative rotation at 30–40° of flexion. The differential diagnosis is discoid meniscus, popliteal tendinopathy, patellofemoral pain, and osteochondritis dissecans. Radiographs can exclude bone lesions or tumors. MRI can detect meniscal pathology when clinical evaluation is inconclusive.

Treatment of meniscal tears in children and adolescents is controversial. Current literature suggests surgical treatment but recent studies showed poor outcome after partial or total meniscectomy [53], with 75 % remaining symptomatic and 80 % showing radiographic signs of osteoarthritis at 5-year follow-up [54]. Therefore, meniscal repair has been suggested.

Arthroscopic meniscal repair is the treatment of choice [55, 56]. Factors shown to correlate with increased healing of meniscal injuries include younger age, peripheral tears (within 3 mm of meniscal rim), lateral meniscus tears, concomitant ACL reconstruction, surgery within 8 weeks of injury, and tear length less than 2.5 cm [57]. Partial meniscectomy is indicated for more complex meniscus injuries.

Acute Patellar Dislocations

Traumatic patellar dislocation is common in young athletes, and accounts for approximately 3 % of all knee injuries [58]. It occurs about 2/3 of the time in active patients under the age of 20 years. Girls are more likely to sustain a patellar dislocation than boys. Patellar dislocations are often the result of a direct blow or fall onto the knee, but can also occur without contact. A common example is a right-handed baseball player who rotates on his foot while swinging the bat.

The medial patellofemoral ligament (MPFL) is the primary passive restraint to lateral patellar translation at 0–30° of knee flexion [59]. The MPFL is commonly injured after acute patellar dislocation. MRI studies demonstrated an MPFL injury in up to 100 % of patients [60], and is, together with medial retinacular tears, the major cause of hemarthrosis. Osteochondral fractures are common after patellar dislocations, occurring in nearly 25 % of cases [61].

Imaging should include plain radiographs and MRI. Standard plain radiographs and Mercer-Merchant view with the patient supine and the knee flexed 45° can show an osteochondral fracture of the medial facet of the patella. MRI can evaluate osteochondral injuries of the patellofemoral joint and the location and extent of soft tissue damage to the medial patellar stabilizers, including the medial retinaculum, MPFL, and vastus medialis obliquus.

Primary patellar dislocation is usually managed nonoperatively, with acute surgical repair indicated for chondral lesions or fractures [62]. Recurrent dislocations are relatively common, with recurrence rates up to 45 % [63]. In up to 80 % of patients, recurrent instability is attributed to predisposing factors, such as immature physis and trochlear dysplasia [63]. Surgical treatment for traumatic patellar dislocation is still debated. Some studies found no statistically significant differences in the incidence of re-dislocation and functional scores between nonoperative and operative treatment [64]. Other authors reported lower functional results in case of osteochondral fracture [59, 62]. For these reasons a gold standard treatment is still not available [63]. Treatment should be individualized based on preoperatory findings and the patient's activity level.

Ankle Injuries

Ankle injuries are the most common injuries sustained by high school athletes, accounting for 16 % of all sports-related injuries [65], and 10 % of all injuries seen in EDs [66]. Ankle sprains are the most common (88.7 % of all ankle injuries), and lateral sprains are more common than isolated medial ligament injuries, accounting for 85 % of injuries. American football accounted for most high school ankle sprains (24.1 %), followed by soccer (15–18 %), basketball (12 %), and volleyball (10 %) [67]. Even though the overall rate is comparable between the two sexes, in gender-comparable sports such as soccer, volleyball, and basketball, ankle sprain rates were higher in girls than boys [6].

Patients with acute ankle sprains usually respond to nonoperative measures, including physical therapy and functional rehabilitation. One study showed that functional rehabilitation in patients engaged in regular activity allowed earlier resumption of sports training with fewer symptoms compared to cast immobilization [68]. Most ankle sprains cause athletes to miss less than 7 days of activity (51.7 %), with 33.9 % causing 7–21 days lost, and 10.5 % causing more than 22 days lost. Injuries involving multiple ligaments resulted in more time lost. Only 0.5 % of ankle sprains were treated surgically.

Although ankle sprains are commonly treated with a high rate of success, they may result in pain and disability in the short term; recurrent sprains, chronic ankle instability, decreased sport activity, and early retirement from sports in the midterm; and secondary injuries and early osteoarthritis in the long term. Recurrent ankle sprains accounted for 15.7 % of ankle injuries. Sports with the highest proportion of recurrent ankle sprains were cheerleading (20.8 %), boys' basketball (20.1 %), and girls' gymnastics (20.0 %) [66]. Talar dome injuries are complications of lateral ankle sprains, and occur in up to 6.5 % of cases. They should be suspected if there is ongoing pain and persistent effusion or occurrence of intermittent swelling of the joint.

The high number of ankle sprains demonstrates the need for targeted injury prevention strategies. Ankle braces can reduce the incidence but not the severity of acute ankle injuries [69, 70].

Foot Injuries

Foot fractures account for 5–13 % of pediatric fractures [18]. Metatarsal fractures are common in children and adolescents participating in sports. These usually occur indirectly as a result of torsional forces and avulsions or from direct trauma. The incidence of first metatarsal fractures is highest in children under 5 years of age. This has been called the "bunk bed fracture" because of its common mechanism [71]. The fifth metatarsal is the most common metatarsal fracture in children, occurring 45 % of the time and in 90 % of children greater than 10 years of age [66]. It occurs after an inversion-type injury, when the peroneus brevis tendon is avulsed from its attachment at the base of the fifth metatarsal. The treatment is usually conservative, with a short leg walking cast for 3–5 weeks. If displacement is greater than 2–3 mm, surgical reduction and internal fixation are needed [72]. However, only a few level I evidence-based studies are published; therefore, the treatment is often empiric and based on surgeon personal experience.

The Jones fracture is a transverse fracture at the junction of the diaphysis and the metaphysis of the fifth metatarsal without extension distal to the fourth intermetatarsal articulation. The average age of occurrence involves 15–21-year-old athletes, who usually describe a large adduction force applied to the forefoot while the ankle is plantar flexed [66]. These fractures are associated with high rates of delayed union, nonunion, and refracture because of poor blood supply. Therefore this fracture poses a difficult problem for the competitive athlete, for whom an early return to sport is important. A systematic review suggested that a nonoperative approach with non-weight-bearing immobilization resulted in a longer time to union and a higher number of delayed unions or nonunions compared with operative treatment [73]. A level I study comparing early screw fixation with casting for acute Jones fractures showed a statistically different union rate between the operative group (94 %) and the nonoperative group (67 %), and a median time to return to sports of 15 weeks in the cast group and 8 weeks in the screw group [74]. Treatment should be based on the personality of fracture and the patient. Nondisplaced Jones fracture can be treated conservatively with a non-weight-bearing cast for 6–8 weeks, while surgical reduction and internal fixation with a cannulated screw is the gold standard treatment in case of displacement. In case of nonunion, a plate fixation with autologous bone graft is indicated [66].

Lisfranc's joint injuries are common in adolescents playing football. The keystones of Lisfranc's joint are the first and second metatarsals articulating with the first and second cuneiforms. Stronger ligaments connect the plantar surfaces of the joint. The Lisfranc's ligament is the stronger ligament and stabilizes the medial cuneiform with the II and III metatarsal bones; the transverse ligaments connect the plantar surfaces of the bases of the lateral four metatarsals. The most common mechanism of injury is an axial loading through the foot with the foot in forceful plantar flexion and slight rotation, which causes the proximal second metatarsal to dislocate dorsally [18]. The typical presentation involves an athlete with pain over the dorsum of the midfoot associated with swelling and an inability to bear weight, particularly on the tiptoes. Weight-bearing radiographs are needed to make the diagnosis. Lisfranc's injuries can be treated in a cast boot for 4–5 weeks when the first and second metatarsal bones are not disrupted more than 2 mm with weight-bearing images. If there is widening of more than 4 mm surgery should be considered. A large reduction forceps is placed with the tips on the medial cuneiform and lateral second or third metatarsal base to reduce the dislocation. The dislocation is then fixed with a percutaneous screw fixation from the medial cuneiform to the second or the third metatarsal base [75]. Postoperative care is 4–6 weeks with boot immobilization and return to sports typically takes more than 4 months.

Hallux fractures occur most commonly in soccer [18] (Fig. 8.4). Closed injuries were diagnosed in 92 % of patients; 8 % of children presented with open fractures. The vast majority of children (86 %) were treated conservatively with rest and taping, while displaced fractures require reduction and percutaneous fixation with K-wire [18]. Because of the first toe's role in weight bearing, balance, and pedal motion, deformity, decreased range of motion, and degenerative joint disease can impair a patient's functional ability.

There is an increasing incidence of "turf toe," a sprain of the plantar capsule ligaments, in young athletes playing on synthetic surfaces and using lighter, more flexible shoes. The first metatarsal-phalangeal joint capsule is reinforced by a fibrocartilaginous plate, which is formed by

Fig. 8.4 Type V Salter-Harris fracture of the hallux in a young soccer player

the flexor hallucis, adductor hallucis, abductor hallucis tendons, and deep transverse metatarsal ligament (Fig. 8.5). The sesamoid bones are contained within the fibrocartilaginous plate. The usual mechanism of turf toe is hyperextension with the foot in slight dorsiflexion. Less common mechanisms of injury are hyperflexion, which occurs when the ball carrier is tackled from behind, and valgus stress [76]. The Lachman test of the first toe is useful to determine the stability of the plantar plate. Stress X-rays can show a proximal migration of the sesamoids, and MRI is used to confirm the plantar plate injury. For sprains of the plantar plate, with minimal or no retraction of the sesamoids, management includes planter flexion taping of the hallux and a walking boot for 2–3 weeks. Partial weight bearing is allowed at 3 weeks and full weight bearing at 4 weeks as symptoms allow. Surgical reconstruction is indicated if there is a complete tear of the plantar plate [77].

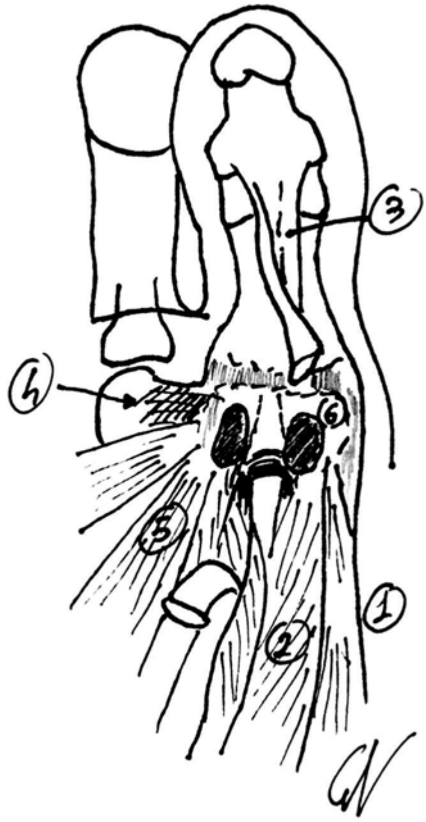

Fig. 8.5 Plantar plate of the first metatarsophalangeal joint. (*1*) Abductor hallucis. (*2*) Flexor brevis hallucis. (*3*) Flexor longus hallucis. (*4*) Deep transverse intermetatarsal ligament. (*5*) Adductor hallucis. (*6*) Sesamoid bones

Muscle Injuries

Muscle injuries are common in athletes. They are less frequent in young athletes than adults: the injury incidence is 1.19 per 1,000 h of training activity/6.6 per 1,000 h of competition in soccer players younger than 22 years, and 1.63/9.5 for those older than 30 years [78]. The muscles most frequently involved are the hamstrings, rectus femoris, and medial head of the gastrocnemius. The main site of injury is the musculotendinous junction [79]. Muscle injuries may be distinguished as direct or indirect. Contusion and laceration are direct injuries. If there is no impact, injury is the consequence of an indirect trauma. A recent study classified indirect injuries as non-structural and structural, according to the integrity of muscle fibres [80]. The structural damage to muscle fibres may be caused by a single contraction or by the cumulative effect of several contractions. An eccentric contraction is a major cause of injury, probably as a consequence of the greater forces produced by eccentric contractions compared to isometric or concentric contractions [81, 82].

Most muscle injuries respond well to conservative treatment. Due to the paucity of studies focusing on muscle injuries in the pediatric population, treatment should follow the protocols designed for adult athletes. Guidelines for the treatment of muscle injuries have been recently published [83]. The management of muscle injuries follows different stages. The aim of the first stage (first 48–72 h after injury) is to relieve pain. Different protocols including PRICE (protection, rest, ice, compression, elevation) and POLICE (protection, optimal load, ice, compression, elevation) are commonly used. Ice, low-level laser therapy, and pulsed ultrasound therapy are effective during the first phase to reduce pain. Nonsteroidal anti-inflammatory drugs inhibit the initial inflammatory process and may alter the natural course of muscle healing. Therefore they are not recommended in this phase [84]. At the second stage, the patient can begin training and rehabilitation protocols supervised by an expert physiotherapist. It is fundamental that every exercise or protocol must be administrated in the absence of pain. Muscle stretching; isometric, isotonic, concentric, and eccentric exercises; core stability exercises; and physical therapy (laser therapy and ultrasound) are used in this stage. The third stage includes functional rehabilitation and general athletic reconditioning, followed by gradual return to competition. Surgery is indicated in cases of subtotal or complete muscle laceration or tendon avulsion [83].

Compartment Syndrome

Compartment syndrome (CS) of the lower leg is a rare but serious complication following either fractures or soft tissue injuries and does not always present classically in the pediatric population, making clinical diagnosis uniquely challenging. Compartment syndrome is defined as elevated pressures in a confined osseofascial space, ultimately resulting in ischemia and necrosis.

The pathophysiology of the condition remains uncertain and several theories have been proposed. Circulation of blood from high-pressure arteries to low-pressure veins is dependent on the pressure differential (arteriovenous gradient—Δp). When Δp gradient is diminished, rates of delivery of oxygenated arterial blood and drainage of deoxygenated venous blood decrease, resulting in extrusion of fluid into the third compartment, causing tissue edema and exacerbating the intracompartmental pressure (ICP) rise. This establishes a vicious cycle leading to collapse of lymphatic vessels and eventually of the arterial supply, causing ischemia and irreversible necrosis. Nerve symptoms such as paraesthesiae and tingling begin as early as 30 min from the onset of ischemia and irreversible damage may occur as early as 12 h post-onset [85].

Fractures are the most common cause of acute CS (95 %) [86]. Open fracture does not decrease the risk of acute CS, because small fascial tears resulting from open fractures do not adequately decompress the compartment [87].

Diagnosis in children is more difficult than in adults, as children may have limited communication and can have varying clinical presentations of pain. The clinical hallmarks, or the "five P's," of compartment syndrome (pain, pallor, paresthesia, paralysis, and high intra-compartment pressure) are inconsistently found in children, especially those with "silent" compartment syndrome [88]. Pulselessness is not a diagnostic criterion because peripheral pulses are usually present. Currently, diagnosis is made on the basis of physical examination and repeated ICP measures [89]. The normal compartment pressures in the lower leg of healthy children (13–16 mmHg) is significantly higher than those of adults (0–10 mmHg), because children are in a stage of muscle growth and this increasing volume due to muscle hypertrophy may press against the surrounding fascia [90].

Immediate surgical decompression by fasciotomy of the affected compartments is crucial to prevent long-term damage. ICP measurement is recommended in young children, unconscious patients, and patients with regional nerve blocks and when the clinical signs are equivocal. Fasciotomy is indicated when compartment pressure exceeds 30 mmHg or when compartment pressure rises more than 10–30 mmHg above the diastolic blood pressure. However, ICP measurement may not be necessary if the diagnosis is clinically evident [91].

Summary

More than 50 % of all sports injuries involve the lower limb, and include physeal fractures, apophyseal avulsion fractures, knee ligament and meniscal tears, patellar dislocations, ankle sprains, and foot injuries. Physeal fractures are common in children and adolescents, particularly the distal femur and distal tibia, and can lead to growth disturbances and lower limb deformities. Apophyseal avulsion fractures can occur in growing teens involved in sprinting and distance running. Most patients can be successfully managed conservatively, but displaced fractures may need surgical treatment. Acute knee injuries can be severe injuries requiring surgical intervention. The incidence of ACL tears, in particular, has increased. Traumatic patellar dislocation is associated with a high incidence of osteochondral fractures, requiring MRI evaluation. Ankle sprain is the most common injury sustained by young athletes. Excellent results have been reported with physical therapy and functional rehabilitation. However, ankle sprain may result in ongoing pain and disability, recurrent sprain, and ankle instability. Foot fractures account for 5–13 % of pediatric fractures. Metatarsal fractures are common in children participating in sports and the vast majority are treated conservatively. Muscle injuries of the leg are quite common in young athletes. Acute compartment syndrome can occur commonly with tibial fractures.

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9 Acute Upper Extremity Injuries in Pediatric and Adolescent Sports

Jonathan Watson, Kian Setayesh, and Mark R. Hutchinson

Introduction

Participation in pediatric and adolescent sports continues to gain in popularity. This increase in level of participation has led to a rise in the incidence of acute upper extremity injuries among young athletes. Some of the most common shoulder injuries specific to adolescent athletes include medial clavicular physeal separations, which can be confused with clavicle fractures, shoulder dislocations, clavicle fractures, and proximal humerus fractures. Ulnar collateral ligament (UCL) tears of the elbow are common among throwing athletes, such as baseball pitchers. Trauma about the elbow can occur, with supracondylar, lateral condyle, and medial epicondyle the most common subtypes of elbow fractures. Hand and wrist injuries occur as well, including nail bed injuries, metacarpal or phalanx fractures, and interphalangeal joint dislocations. Similar to other aspects of pediatric orthopaedics, the majority of these injuries can be treated nonoperatively. Accurate diagnosis and treatment are necessary in order to expedite return to play. This chapter reviews these common upper extremity injuries in young athletes.

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Shoulder and Arm

Sternoclavicular Joint

Sternoclavicular (SC) joint injuries are very uncommon in the pediatric population. Injury can vary from a simple sprain to dislocation of the joint [1]. A simple sprain consists of a tear or stretching of the sternoclavicular ligaments; a moderate sprain can involve subluxation of the joint; and a complete tear of the ligaments can result in dislocation. SC joint dislocations in children are also extremely rare, with only a few case reports existing in the literature [1–3]. Dislocations can be either anterior or posterior, and the mechanism of injury is either from a direct or indirect force, with compression and rolling backward of the shoulder. Both X-ray and computed tomography (CT) can aid in diagnosis. The serendipity view is used to image the SC joint as well. This is obtained by imaging the patient supine with a 40° cephalic tilt to the beam. Urgent closed reduction is necessary, especially in cases with compression of the great vessels, trachea, or esophagus [4]. Open reduction is necessary in cases of delayed presentation or failed closed reduction. A mild

D. Caine, L. Purcell (eds.), *Injury in Pediatric and Adolescent Sports*, Contemporary Pediatric and Adolescent Sports Medicine, DOI 10.1007/978-3-319-18141-7_9

sprain can be treated with ice, brief rest, and progressive advancement of activity. Moderate sprains can be treated with a figure of eight brace in order to prevent recurrent subluxation.

Medial clavicular physeal injuries can often present with similar mechanism, signs, and symptoms to SC dislocations [5]. The epiphysis at the medial portion of the clavicle is the last to appear and the last to close in the body. Fusion with the clavicular shaft does not occur until approximately 23–25 years of age. This is important because this injury can be confused with SC dislocation. Open or closed reduction is performed for posterior displacement of medial clavicular physeal injuries in the same way as SC dislocations. Anterior displacement can often be treated without reduction maneuvers secondary to remodeling of that injury [6, 7]. Return to noncontact sports can be attempted at 6 weeks if the patient regains full painless range of motion (ROM). Contact sports should be avoided for an additional 4–6 weeks to allow the clavicle to remodel.

Clavicle Fractures

The clavicle is one of the most frequently broken bones in the pediatric population, accounting for ~10–15 % of fractures, 90 % of which occur in the midshaft region. The mechanism is usually secondary to a fall on an outstretched upper extremity, but occasionally can occur with a direct blow to the clavicle. Patients will have pain and tenderness about the clavicle, and usually children will avoid use of the affected arm. There will sometimes be obvious skin tenting or deformity at the fracture site secondary to the lack of soft tissue around the clavicle. Clavicle fractures can be seen on standard chest radiographs; however, a dedicated anteroposterior (AP) view should be obtained as well.

The majority of fractures will heal with nonoperative management using a sling, followed by progression of activity to include ROM and strengthening. The figure of eight brace is no longer recommended secondary to discomfort without improvements in outcomes [8]. Operative indications include open fractures, neurovascular compromise, and skin tenting or impending open injury. Surgical treatment options include plate fixation and intramedullary devices. Sports are usually avoided until clinical evidence of union, approximately 6–8 weeks [9]. Nonoperative treatment results in union in approximately 10 weeks, with a slight improvement with operative intervention at 7.5 weeks [10].

Acromioclavicular Joint

Similar to the SC joint, injuries to the acromioclavicular (AC) joint in children are very rare. Rather than a true AC separation, children typically sustain a distal clavicle physeal fracture secondary to closure of the physis in the mid-20s [11]. Common signs or symptoms typically include point tenderness about the AC joint or a bony prominence or bump secondary to displacement. The mechanism of injury is typically a direct blow to the area. Standard shoulder or clavicle X-rays can be of diagnostic value. The Zanca view is a dedicated X-ray for the AC joint. It is taken with the patient standing and a 10–15° cephalic tilt of the beam with 50 % penetrance in order to better visualize the joint.

Nonoperative treatment is usually sufficient with sling immobilization for 1–2 weeks followed by gradual ROM and return to play. Operative intervention is required for open injuries and those with significant displacement or skin tenting. This involves replacement of the clavicle back into the periosteal sleeve, suture of the sleeve closed, and internal fixation. This is usually achieved with a coracoclavicular screw or transacromial fixation, which is then removed at 4–6 weeks postoperatively [12].

Glenoid, Scapula, and Coracoid Fractures

Glenoid, scapula, and coracoid fractures in younger athletes are extremely rare [11]. Glenoid fractures can be secondary to a fall on an outstretched arm, while scapula fractures usually denote a higher energy injury. Children and adolescents with these fractures will have pain and will resist movement of the affected extremity. Scapular fractures can be seen on a routine chest radiograph. For glenoid fractures, a dedicated series of shoulder X-rays is helpful in diagnosis. Coracoid fractures are best seen on a Stryker notch view, in which the patient lies supine with the palm on the forehead and the beam tilted 10° cephalad. CT scan can also be used to further delineate fracture anatomy.

Very few studies have been published regarding management of these injuries in children and adolescents. Similar to adults, isolated scapular, glenoid, and coracoid fractures can be treated nonoperatively with a sling and progression of activity when pain free. Operative indications include floating shoulder, greater than 3 cm displacement of the glenoid fracture, and instability related to the fracture [11].

Shoulder Dislocations and Instability

Shoulder dislocations are an infrequent occurrence in the pediatric and adolescent populations. Approximately 40 % of patients who sustain a dislocation are younger than 22 years old [9]. The majority of these dislocations are anterior and secondary to a traumatic event, often in contact sports such as football or rugby. A fall on an outstretched arm can also lead to a dislocation. Anterior dislocations often occur with the arm abducted and externally rotated. Patients usually present after a single inciting event that may or may not require closed reduction.

On physical exam patients will have pain in the shoulder region along with an obvious deformity secondary to the dislocation. A neurovascular exam should always be performed to rule out any injuries caused by the dislocation, specifically examination of axillary nerve function. This can be examined by asking the patient to activate their deltoid by flexing, abducting, or extending their shoulder. Imaging of the shoulder should always include at minimum two orthogonal views to determine the presence or absence of dislocation and the direction. An AP, axillary lateral, and scapular Y view should be performed. In some instances, the patient cannot tolerate an axillary lateral, so a Velpeau lateral can be obtained. In this case, the patient can be maintained in the sling and lean backwards approximately 30° with the beam originating directly superior.

In some cases, the patient may have sustained a dislocation that spontaneously reduced; however, in others a closed reduction may need to be performed. There have been several maneuvers described and it is usually the treating physician's preference [13]. The patient is then immobilized in a sling and strengthening of the shoulder stabilizers is performed.

However, the recurrence rate of shoulder instability in the young population is very high [14]. Surgical treatment is indicated in cases of recurrent instability. Both open and arthroscopic techniques have been described. Although previously open stabilization has been considered the gold standard, current arthroscopic techniques have obtained equivalent results [15, 16]. The length of immobilization and rehabilitation following surgery are highly variable. The athlete must have full range of motion and protective strength without apprehension prior to return to play [17].

Rotator Cuff Tears

The incidence of rotator cuff injuries in adolescent athletes has increased with the increasing participation in throwing sports, with one study quoting as high as 12.2 % [18]. The majority of these injuries are partial-thickness rotator cuff tears secondary to internal impingement and repetitive throwing motions [9]. Patients typically have pain over the anterolateral aspect of their shoulder that is aggravated by throwing or overhead activities. It can be associated with weakness or a decrease in throwing velocity. Physical exam findings often include a decrease in active motion with preservation of passive motion, positive impingement signs, such as Neer or Hawkins, and positive rotator cuff signs, including the empty can test or resisted external rotation of the arm. X-rays should be taken to rule out any concomitant pathology; however, MRI is the most accurate diagnostic method.

Intra-articular contrast should be used in cases of suspected labral pathology.

Nonoperative treatment will resolve the majority of cases and involves rest and cessation of throwing activity, ice, and anti-inflammatory medication. Physical therapy with focus on stretching of the posterior capsule and strengthening of the rotator cuff musculature, scapular stabilizers, and core is beneficial. Rarely, these injuries require operative management, which usually consists of arthroscopic debridement of the rotator cuff tear. Postoperatively, patients are initiated in a physical therapy program similar to that mentioned above with a gradual return to throwing program. Limitation of pitch counts is a key concept in prevention of shoulder pain in the young athlete [19]. Posterior capsular stretching, core strengthening, flexibility, and strengthening of the scapular stabilizers are all very important in prevention in order to maintain proper throwing mechanics.

Labral Tears

Labral tears are part of the collection of findings associated with internal impingement in throwing athletes [9]. The repetitive throwing motion and increase in external rotation and abduction lead to posterior capsular tightness and a shift of the center of the humeral head more posterior and superior. This in turn leads to contact with the superior labrum and can result in tearing. Patients have a similar presentation to those with rotator cuff tears, with positive provocative maneuvers for superior labrum anterior posterior (SLAP) tears and biceps pathology being positive, such as Obrien's, Kim, labral shear, speed, and Jurgenson tests. An MRI arthrogram is the most specific test for diagnosis of a SLAP tear. The vast majority of these cases can be treated nonoperatively with the same therapy program mentioned above for rotator cuff injuries. Operative management is indicated after failure of nonoperative measures and includes arthroscopic debridement or possible repair of labral pathology. Return to play after a graduated therapy and throwing program is possible.

Proximal Humerus

Fractures of the proximal humerus account for less than 1 % of all pediatric fractures [20]. The proximal humeral physis accounts for ~80 % of humeral growth and physeal closure occurs between ages 14 and 18 years. The mechanism of injury is usually a direct blow or fall on an outstretched hand. Comparable to most fractures, patients will present with pain, swelling, and possible deformity of the fracture site. A standard shoulder X-ray series is necessary, with orthogonal views to rule out any dislocation. The majority of fractures are treated nonoperatively with sling immobilization for 3–4 weeks and progressive ROM. Operative indications include open fractures, neurovascular compromise, skin tenting, and displacement greater than 50 %, or angulation greater than 40° [3]. Treatment methods include closed reduction and pinning, intramedullary nail placement, and open reduction internal fixation (ORIF) if soft tissue interposition prevents closed reduction. Patients can return to practice activities when full ROM is regained and competitive sports once their strength has returned [21].

Humeral Shaft Fractures

Fractures of the humeral shaft represent less than 10 % of humerus fractures in children [22]. Injuries typically occur with a direct blow to the arm or an indirect injury due to throwing. Signs and symptoms include pain, swelling, ecchymosis, tenderness over the fracture site, and refusal to move the extremity. A neurovascular exam is essential, given the possibility of radial nerve injury with these fractures. AP and lateral radiographs of the humerus should be obtained to confirm the diagnosis. Nonoperative treatments include a sling and swathe, coaptation splint, hanging arm cast, and functional bracing. Operative treatments include ORIF and intramedullary nailing. Indications for surgery include open fractures, polytrauma, bilateral injuries, compartment syndrome, failed closed reduction, and ipsilateral upper extremity injuries [22].

Athletes should avoid contact sporting activities for 1 month after discontinuation of any cast or brace.

Elbow and Forearm

Ulnar Collateral Ligament Injuries

The increased prevalence of youth baseball has led to an increase in incidence of rupture of the UCL of the elbow. The mechanism of injury can be secondary to a fall with a valgus load to the elbow or repetitive valgus stress leading to attrition and finally rupture of the ligament. Patients commonly have medial elbow pain exacerbated by throwing or overhead activities. On examination, they will have tenderness just distal to the medial epicondyle and pain with valgus stress. Specific maneuvers include the moving valgus stress test, where a valgus stress is applied through full arc of motion, and the milking maneuver, in which the elbow is flexed at 90° and the thumb is pulled with the forearm supinated to create a valgus stress. Acute ruptures can be accompanied by swelling and ecchymosis. X-rays can be obtained to rule out any bony pathology; however, an MRI arthrogram is the best test to diagnose.

Nonoperative therapy is initiated with rest, ice, compression, and elevation (RICE) therapy in addition to cessation of overhead activity. Partial injuries may be amenable to strengthening of the flexor-pronator muscles and gradual increase in throwing. Acute complete tears require surgical reconstruction with tendon graft in order to return to competition for overhead athletes and those who require upper extremity weight bearing, such as gymnasts. Several different techniques have been described [23]. UCL reconstruction is a successful procedure, with return to play rates ranging from 70 % to greater than 90 % [23]. Patients typically return to competition from 9 to 12 months postoperatively.

Prevention of UCL injuries is important in the youth population. Core strengthening, kinetic chain coordination, throwing mechanics, and pitch counts should all be monitored [24].

Lateral Collateral Ligament Rupture

Injuries to the lateral collateral ligament of the elbow are not as common as the medial side. The mechanism of injury is usually secondary to a fall on an outstretched arm or forced hyperextension of the elbow with the forearm supinated. Patients usually complain of lateral elbow pain as well as instability or popping in a position of extension and supination. This can be tested or exacerbated with the patient attempting to rise from a chair using his or her arms. Radiographs of the elbow should be obtained to rule out any associated fractures. Varus stress X-rays may reveal an increased opening when compared to the contralateral side. MRI can be obtained to confirm a ligament rupture.

Treatment of this injury is usually nonoperative. Patients are placed into a sling with guarded ROM allowed. Progression of activity can begin when the patient has pain-free ROM. Recurrent instability or failure of nonoperative management are indications for surgery, which involves either ligament repair or reconstruction. Postsurgically patients undergo rehabilitation for approximately 2 months, when they are reassessed. If they have full extension of the elbow with equal strength to the contralateral side, progression of activity to return to sport can begin.

Distal Humerus and Supracondylar Fractures

Supracondylar fractures typically occur in the first decade of life and account for approximately 30 % of all limb fractures in children under seven [25, 26]. The mechanism of injury is usually a fall on an outstretched hand. Extension-type fractures occur over 96 % of the time, and flexion-type fractures comprise the remainder [27]. Nerve injury can occur in a relatively high proportion of children, estimated between 7 % and 16 % of fractures, and are more common with displaced fractures. An obvious deformity is present with displaced fractures and the neurovascular status of each child should be examined. A standard series of elbow X-rays are obtained to confirm diagnosis as shown in Fig. 9.1. The ossification centers in a skeletally immature elbow are shown in Fig. 9.2. Non-displaced fractures can be treated in a long arm posterior mold splint if the posterior angulation is less than 20 %. Displaced fractures need closed reduction with percutaneous pinning and immobilization of approximately 3–4 weeks. Once the pins are removed children generally have no restrictions [28].

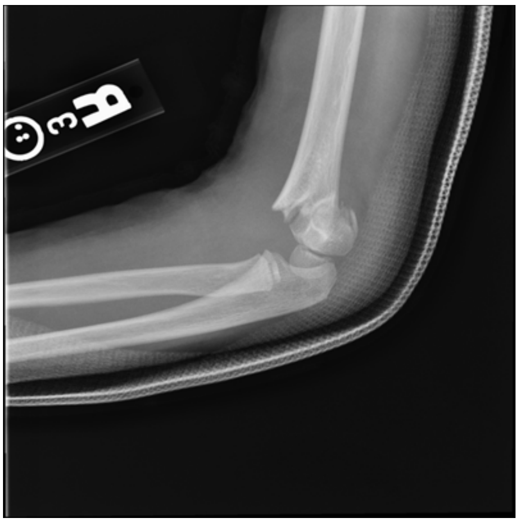

Fig. 9.1 Lateral X-ray of the elbow showing a supracondylar fracture

Lateral Condyle Fractures

Lateral condyle fractures are the second most common fractures of the elbow in pediatrics [26]. They can occur with a fall on an outstretched, supinated hand, transmitting a force to the lateral condyle through the extensors of the forearm. Contrary to supracondylar fractures, displaced fractures may only present with pain and swelling. The skin and neurovascular function should be examined in each child. Traditional elbow radiographs are helpful in diagnosis, with the internal oblique view being the most accurate. Figure 9.3 demonstrates a lateral epicondyle fracture seen on X-ray. Non-displaced fractures can be treated with immobilization, while fractures displaced 2–4 mm and fractures displaced greater than 4 mm and rotated require ORIF. There is a risk for displacement in these fractures, so close follow-up with X-rays every 1–2 weeks is necessary. After bony healing and resolution of pain, the athlete can return to play.

Medial Epicondyle Fractures

Medial epicondyle fractures occur in approximately 10 % of all pediatric elbow fractures, the majority of which occur in children and

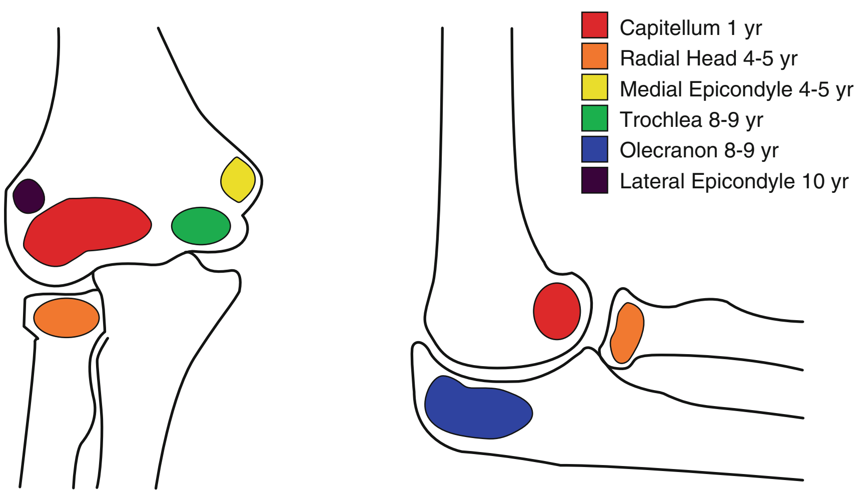

Fig. 9.2 Ossification centers in a skeletally immature elbow

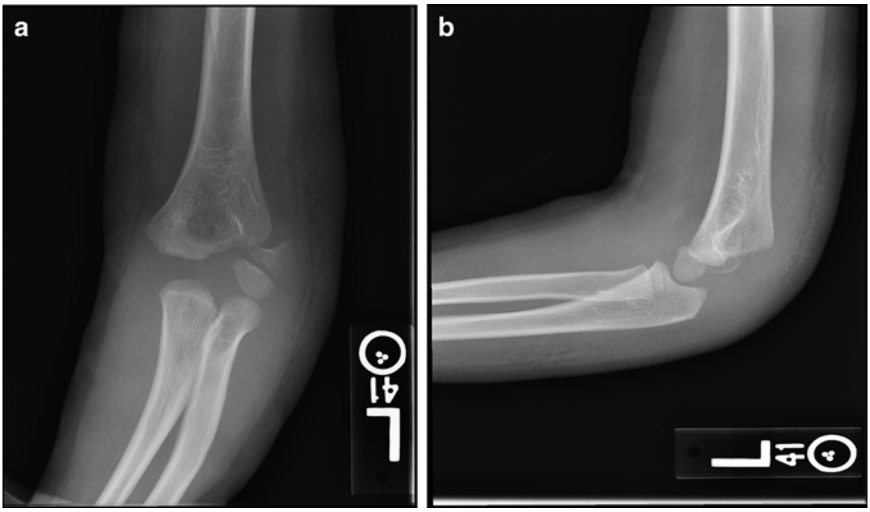

Fig. 9.3 AP (**a**) and lateral (**b**) X-rays of a lateral condyle fracture

adolescents aged 10–14 years. They occur more commonly in males compared to females, with a ratio of 3 to 1. These fractures can be associated with elbow dislocation [27]. The medial epicondylar apophysis can be avulsed by the attachments of the flexor-pronator mass and the medial collateral ligament (MCL). This can be seen with traumatic avulsions and in throwing athletes [29]. The mechanism is a valgus stress in combination with the contraction of the flexor mass. A fall on an outstretched hand is also a common mechanism.

On physical exam, patients have pain and swelling over the medial elbow and can have associated valgus instability. AP, lateral, and oblique X-rays of the elbow are essential for diagnosis (Fig. 9.4). Non-displaced fractures and fractures with less than 5 mm of displacement can be treated in immobilization with the elbow in flexion for 1–3 weeks. Fractures with greater than 5 mm displacement, especially in the throwing athlete, require operative intervention. Similar to other pediatric elbow injuries, athletes can return to play after fracture healing and resolution of symptoms.

Fig. 9.4 AP X-ray of medial epicondyle fracture

Forearm Fractures

Forearm fractures are very common in pediatric patients. The mechanism is typically a fall on the outstretched hand. Single-bone forearm fractures can be associated with a distal or proximal radioulnar articulation injury. These are classified as either the Monteggia or Galeazzi variants, and the different variations are shown in Fig. 9.5. The Monteggia variant fracture involves the ulnar shaft with radial head dislocation [30]. Galeazzi variant fractures occur with radial shaft fracture and associated distal radioulnar joint (DRUJ) dissociation [31]. On physical exam, these fractures are often displaced and carry an obvious deformity. AP and lateral X-rays of the forearm are necessary, as well as wrist and elbow X-rays to rule out any associated injuries as described

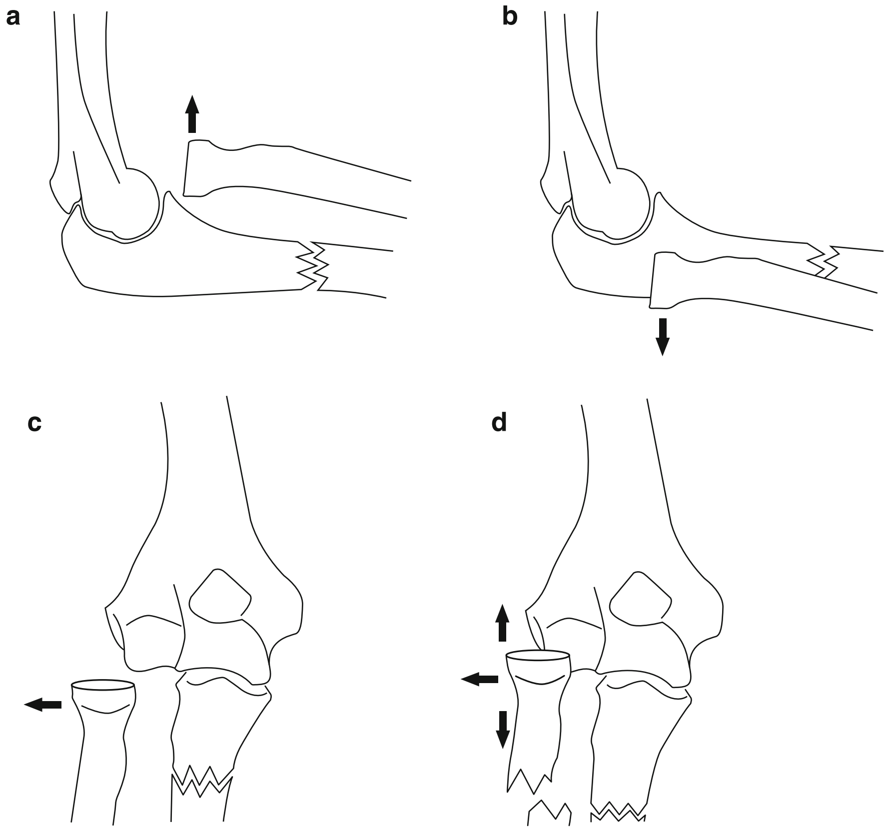

Fig. 9.5 Monteggia fracture variants: (**a**) type I, (**b**) type II, (**c**) type III, and (**d**) type IV

above. Most pediatric forearm fractures can be treated nonoperatively in a cast for 6–12 weeks. Displaced fractures require surgical intervention with pins, intramedullary nails, or plate and screws. Return to activity can begin with evidence of fracture union.

Wrist and Hand

Distal Radius and Ulnar Fractures

The distal radius is the most common fracture of childhood, and can be associated with DRUJ disruption, although this is not common [26, 32]. Patients will present with pain and swelling of the wrist. There can be a deformity associated with displaced fracture patterns. Imaging should involve X-rays of the wrist as well as the affected elbow to rule out other associated pathology. Physeal injuries and fractures through the growth plate are common, as these areas are weaker than the surrounding bone. Salter-Harris fractures occur through the growth plates. Typically closed reduction with longitudinal traction is enough to reduce the fracture and splinting with transition to a cast over 4–6 weeks is indicated. Children younger than 10 years old can tolerate sagittal alignment less than 15° and dorsal angulation of 30°, whereas children 10 years and older can only tolerate sagittal misalignment less than 10° and dorsal angulation less than 20° [26]. Fractures exhibiting larger displacement and angulation may require closed reduction with percutaneous pinning, with pins in place for 3–4 weeks with casting and radiographic evaluation for healing [27]. Once the fracture has healed, patients can progress their activity as tolerated and return to sports.

Triangular Fibrocartilage Complex Injuries

The most common mechanism of triangular fibrocartilage complex (TFCC) injuries is a fall on an extended wrist with the forearm pronated or traction to the ulnar aspect of the wrist. This usually manifests as ulnar-sided wrist pain, and pain in the wrist with ulnar or radial wrist deviation or painful pronation and supination of the wrist [33, 34]. Patients often have pain when attempting to rise from a seated position using the wrist to push off. X-rays of the wrist should be taken to rule out any fractures. MRI is the gold standard to diagnose a tear and has largely replaced arthrography, although wrist arthroscopy is the most accurate means of diagnosis. Acute injuries to the TFCC are treated with nonsteroidal anti-inflammatories (NSAIDs), immobilization in a cast or brace, and, in some instances, steroid injections. Arthroscopic debridement can be performed in instances where initial treatment fails [27]. Direct surgical repair should be performed for more peripheral tears, and acute tears have better surgical outcomes than chronic tears. In the case of an ulnar-positive variance, an ulnar shortening osteotomy should be considered in order to address the potential cause of TFCC issues [26]. Therapy is usually started about 6 weeks postoperatively and continued for 6 weeks, after which the athlete is allowed to return to activities.

Carpal Fractures

The scaphoid is the most common carpal bone fractured in children and adolescents, and is also the most common carpal bone fractured during athletic activity. The incidence can be as high as 1 in 100 football players per year [33, 35]. The mechanism is usually a forced dorsiflexion with the wrist in ulnar deviation [26, 27]. Scaphoid fractures are characterized by degree of displacement and location, such as at the distal pole, waist, and proximal pole. Fractures at the waist are most common and displacement of over 1–2 mm can place patients at risk for nonunion [26]. Avascular necrosis (AVN) or osteonecrosis is a complication associated with scaphoid fractures secondary to frequent disruption of its blood supply at the time of injury.

The other carpal bones are injured with less frequency. Capitate fractures are less common than scaphoid fractures; however, they can also be associated with AVN. The capitate is usually fractured from a direct blow to the dorsum of the wrist or a forced dorsiflexion or volar flexion; however, they can be seen with perilunate and lunate dislocations as well [26]. The pisiform is a sesamoid carpal bone which rarely can be fractured with direct trauma to the volar and ulnar aspect of the wrist. Triquetrum fractures can result from hyperextension injuries with impingement of the distal ulna on the triquetrum, causing an avulsion from the dorsal cortex. Hamate fractures occur most commonly at the hook associated with direct force from a fall or impact with a bat, club, or racquet. Patients usually present with pain in the hypothenar eminence and occasionally will develop ulnar neuropathy as both the ulnar nerve and artery pass nearby in Guyon's canal [25–27]. Hamate body fractures are less common but can be seen with dorsal dislocation of the ring and small finger metacarpal bones [26].

A standard wrist radiograph series is usually sufficient; however, scaphoid fractures require an additional scaphoid view, and hook of hamate fractures require a carpal tunnel view for diagnosis. Nonoperative treatment consists of cast immobilization. Operative intervention is reserved for displaced fractures. Patients are allowed to return to athletic activity when the wrist is non-tender on examination.

Metacarpal Fractures

Hand fractures are increasingly common in adolescent athletes. In some literature, upper extremity injuries accounted for over 80 % of all injuries sustained [33]. Basketball, baseball, football, and inline skating demonstrate the highest incidence of hand injuries. Some studies found that hand injuries accounted for 40 % of football and skating injuries, and that 29 % of all

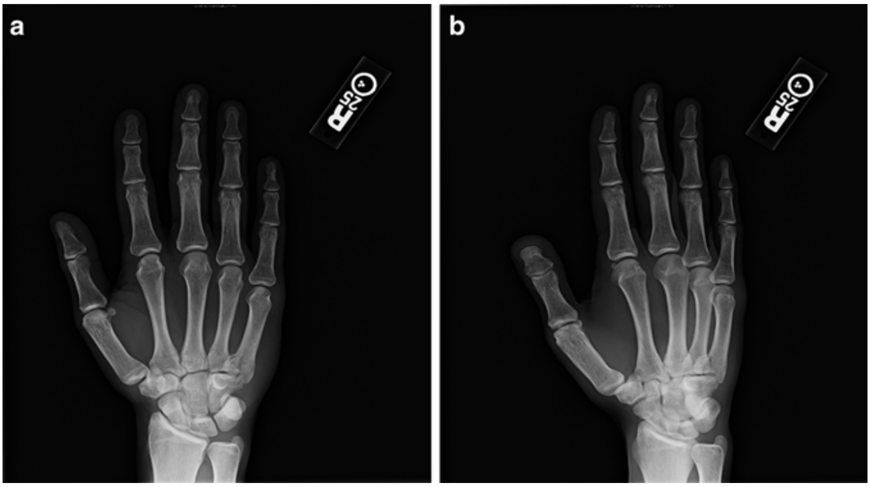

Fig. 9.6 AP (**a**) and oblique (**b**) X-rays of small finger metacarpal base fracture

sport-related fractures occurred in the phalanges, while 13 % occurred in the metacarpals [6, 26, 35]. Combined, the phalangeal and metacarpal fractures account for 41.2 % of fractures [35]. Other sports also place the metacarpal bones at risk, such as skiing and snowboarding, football, rugby, and boxing [33].

Physical exam reveals swelling and tenderness over the affected digit. AP, lateral, and oblique X-rays of the hand are essential for diagnosis. The majority of fractures can be treated nonoperatively. Operative indications include open injuries, unstable fracture patterns as in the fracture pattern in Fig. 9.6, malrotation of the digits, and multiple metacarpal fractures. Early motion is initiated and the pins are usually removed at 4 weeks. Return to play is allowed with resolution of tenderness and bony union.

Thumb Collateral Ligament Injuries

Acute UCL rupture of the thumb metacarpal phalangeal (MCP) joint, or skier's thumb, is typically seen in skiers and snowboarders who fall on an outstretched hand with the thumb extended [27]. A valgus stress is placed on the thumb causing rupture to the UCL [36]. Swelling and tenderness are present on the ulnar aspect of the thumb. Valgus stress X-rays may be used to diagnose UCL ligament injury as well [36]. Occasionally, a Stener lesion can occur as the torn ligament becomes interposed between the adductor pollicis, preventing healing of the ligament. This can be seen on MRI and requires urgent surgical intervention to correct, as the ends of the torn tendon are unable to attach to one another due to the gapping with the interposed adductor muscle [27]. Surgical intervention in pediatric patients involves direct ligament repair with immobilization for 4–6 weeks in a thumb spica cast and ultimately a removable splint [25–27]. After the cast is removed, motion is begun and the athlete can return to sport at approximately 3 months.

Phalanx Fractures, Nail Bed Injuries

In toddlers, the finger is most likely injured with a crush injury, such as in a door, but as children get older fractures are usually secondary to recreational sports [26]. With crush injuries to the distal phalanx, partial or distal tip amputations may occur. Nail bed and plate injuries are associated with distal phalangeal fractures; however, the growth plate is typically not involved except in the case of a Seymour's fracture [26, 27, 37]. In a Seymour's fracture, the germinal matrix of the nail becomes interposed between the physeal fracture and prevents reduction. Treatment

Fig. 9.7 AP X-ray of intra-articular phalanx fracture

Fig. 9.8 Lateral X-ray of a dorsal dislocation of the DIP joint

involves removal of the nail plate, delicate removal of the nail bed with repair using absorbable suture, reduction of the fracture, and placement of the nail plate back between the cuticle and the nail bed to keep the interval open until a new nail forms [27, 37].

Phalangeal neck fractures may exhibit a component of malrotation and are unstable; they may redisplace after closed reduction. They can be intra-articular involving the PIP as shown in Fig. 9.7. These fractures are typically stabilized with pins for 3–4 weeks. Intra-articular fractures require joint congruity in order to avoid posttraumatic arthritis [25, 26]. Patients can return to play after hardware removal and resolution of tenderness on exam.

Interphalangeal Joint Dislocations

Finger dislocations or "jammed" fingers occur frequently in sports requiring the participant to catch a ball. A force on the distal phalanx is the mechanism of injury; an axial load is transmitted to the proximal interphalangeal joint (PIP) with hyperextension and subsequent subluxation [33, 38, 39]. Patients can present with obvious deformity or dislocation as well as tenderness. Radiographs should be obtained of the affected finger. Dorsal dislocations are more common than volar dislocations, and have a subsequent volar plate injury [26, 27]. Figure 9.8 demonstrates dorsal dislocations at the DIP joint seen on X-ray. Volar dislocations can be associated with central slip injury. Central slip injuries can be diagnosed with Elson's test, which flexes the PIP to 90° while the examiner resists extension. The DIP joint will remain supple if the central slip is intact, while a ruptured central slip causes the DIP joint to be rigid [27]. Dislocated PIP joints can be closed reduced and splinted in slight flexion or buddy taped for 2–4 weeks. Prolonged splinting can cause stiffness and a course of occupational therapy may be required; however, this is uncommon. Return to play is initiated after active ROM is initiated and the patient has painless motion. IP joint mechanisms of dislocation are pictured in Fig. 9.9.

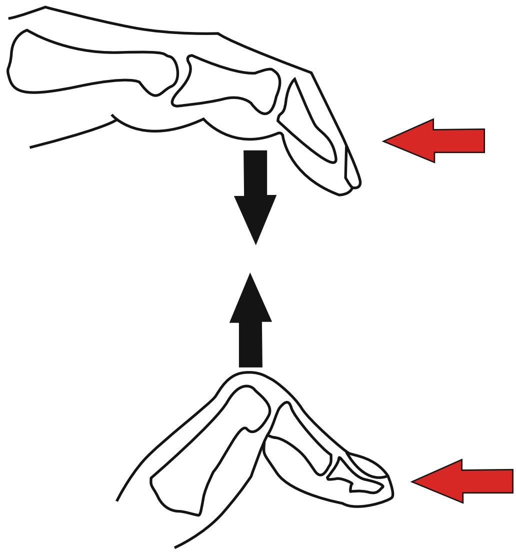

Fig. 9.9 Mechanism of injury of DIP and PIP joint dislocations

Jersey Finger

Flexor digitorum profundus (FDP) avulsions, also known as "jersey finger," are typically seen in sports involving tackling such as rugby and football. The ring finger is most involved and the mechanism is a forced distal interphalangeal joint (DIP) extension against a flexed FDP causing eccentric loading [33, 36, 40]. Patients present with inability to flex the affected finger. Radiographs should be taken to rule out any bony fragments. Purely tendinous avulsions can retract into the palm and need surgical intervention within a week as the blood supply is disrupted [27]. Tendon ruptures associated with a bony fragment have less surgical urgency but should still be repaired. Tendon repairs typically require several weeks of immobilization followed by extensive therapy. Return to play is allowed after functional motion is obtained.

Mallet Finger

Mallet fingers are an extensor tendon injury at the insertion onto the distal phalanx sometimes associated with a fracture, as the metaphyseal fracture

Fig. 9.10 Lateral of bony mallet injury to the distal phalanx

piece is avulsed by the extensor tendon [33]. This can be seen in 16 in. softball, baseball, or basketball as the athlete will attempt to corral a ball and be struck on the fingertip, causing a hyperflexion injury [38, 39]. Patients can have an obvious deformity of the finger with inability to actively extend the DIP joint. Radiographs should be taken to rule out a fracture, as shown in Fig. 9.10. Typically splinting in extension is an effective treatment for non-displaced mallet fingers; however, displaced fractures or bony avulsions involving 50 % of the articular surface can require ORIF or closed reduction and percutaneous pinning [26, 36]. Nonoperative treatment requires splinting for 3 months. Patients can return to play after hardware removal or splinting.

Summary

Upper extremity injuries are common in pediatric and adolescent sport. Common injuries include medial clavicular physeal separations, proximal humeral injuries, shoulder instability, UCL rupture, medial epicondylar fractures, and supracondylar fractures. The majority of the injuries discussed can be treated nonoperatively; however, accurate diagnosis is needed in order to advance the athlete's recovery and return to play.

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Back Pain in the Young Athlete

10

Patrick M. Riley Jr, and Lyle J. Micheli

Introduction

Back pain is one of the most common reasons an adult will seek medical attention, but it was believed that children rarely experienced back pain [1]. It also was believed that, in comparison to adults, a child with back pain was more likely to have a neoplasm or infection. However, recent studies have shown the incidence of back pain to be relatively common in young people, ranging between 23 and 37 % [2, 3].

Back pain in children and adolescents is likely more common now due to increasing participation in organized sports. There is potential for acute spine trauma in sports, but more commonly back pain results from overuse. Due to increased competition and the desire to obtain a "competitive edge," more young athletes are participating in a single sport year round. This continuous repetitive stress in the same regions of the musculoskeletal system without rest leads to overuse injuries. In the low back this can result in spondylolysis. Although most back pain can be attributed to muscular strain, spondylolysis is the most common bony reason for back pain in young athletes [4].

Clinicians treating young athletes must be cognizant of the most common etiologies of back pain in this at-risk population. While up to 48 % of adults with back pain will have a discogenic etiology, 47 % of back pain in adolescents is due to spondylolysis and 25 % to hyperlordosis [4]. Clinicians with knowledge of common diagnoses in this population should be able to make the correct diagnosis by obtaining a sport-specific history, performing a careful physical exam, and using appropriate imaging. The ability to correctly diagnose young athletes with back pain may prevent further disability and allow an earlier return to sports and activities.

This chapter reviews acute and chronic causes of back pain in young athletes, including physical exam findings, imaging, and management.

Epidemiology and Risk Factors

Back pain in young people is common and lifetime prevalence approximates adult levels around 18 years of age [5]. By 20 years of age, half of adolescents have experienced low back pain (LBP). The prevalence of LBP doubles between the ages of 12 and 15 years [6, 7]. Additionally, LBP in childhood results in a fourfold increase in LBP as an adult [8].

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D. Caine, L. Purcell (eds.), *Injury in Pediatric and Adolescent Sports*, Contemporary Pediatric and Adolescent Sports Medicine, DOI 10.1007/978-3-319-18141-7_10

Risk factors for LBP include gender, anthropomorphic factors, certain sports, and age. Several studies have shown that females have more back pain than males [5, 9, 10]. Although it was believed that males had a higher incidence of spondylolysis, recent data suggests equal prevalence [11]. Certain female-dominated sports, however, have an increased risk of spondylolysis, including gymnastics, ballet, and figure skating [9, 12–16]. Spondylolisthesis occurs more frequently in girls [16–19]. Female athletes are particularly at risk because of the “female athletic triad”: negative caloric balance, decreased estrogen production, and overtraining. Athletes with the triad may be predisposed to lower bone density and associated increased risk for stress fractures.

In addition, anthropomorphic factors can predispose young athletes to back pain, including tight hip flexors, weak abdominal muscles, malalignment of the lower extremities, and pelvic/sacral morphology. Athletes with tight hip flexors and weak abdominal muscles may have excessive lordosis, increasing stress on the posterior elements. Malalignment of the lower extremities may cause improper transfer of ground forces to the lower trunk. Finally, abnormalities in pelvic and sacral morphology, particularly the pelvic incidence (PI), have shown a relationship with the development of spondylolisthesis [20].

Another risk factor for LBP is the sport played. Sports that require repetitive hyperextension, such as football, wrestling, and gymnastics, cause microtrauma to the posterior elements and predispose young athletes to back injuries. The prevalence of back pain in football lineman may be as high as 50 % [21], while wrestlers have a 59 % incidence of LBP compared with 31 % for age-matched controls [19, 22]. Gymnasts practicing for greater than 15 h per week have an increased risk of spinal injury [12] (Fig. 10.1). In addition, sports requiring repetitive rotational movements such as bowling, baseball, and swimming increase the risk for intervertebral disc injury. Finally, weight lifting, snowboarding, rowing, and collision sports have a risk of fractures and herniated discs secondary to flexion and axial loading.

Furthermore, age is a risk factor for LBP. During adolescence, the spine is at risk of spondylolysis because growth cartilage is more susceptible to deforming forces than ligament or bone. Compressive forces on vertebrae can rupture cartilaginous end plates, causing Schmorl nodes to form, or the ring apophysis to produce limbus vertebrae. Conversely, tensile forces can result in vertebral body apophysitis or apophyseal avulsions. Also, as linear skeletal growth occurs, mineralization of bone is delayed and is more susceptible to fracture [23, 24]. Additionally,

Fig. 10.1 It is clear to see why gymnasts may have a higher rate of spondylolysis

rapid growth during the adolescent growth spurt increases muscle-tendon tightness resulting in decreased flexibility and increased risk of injury.

History and Physical Exam

History

A careful history in young athletes with back pain will usually lead to a correct diagnosis. Duration, intensity, and location of symptoms should be elicited. The location of symptoms is important as a more localized area of pain is more suggestive of an identifiable cause as opposed to vague, diffuse back pain. Clinicians should determine which sports he/she plays, position of play, and volume of training, as certain sports have a significantly increased risk of back injury. Similarly, certain positions in sports, such as offensive linemen in football, have a higher incidence of spondylolysis [21]. Additionally, volume of training may suggest overtraining as a cause for back injury.

It is important to determine if pain is localized to the back or whether there are radicular symptoms. Radicular pain, numbness, or dysesthesias suggest nerve compression. It is also critical to inquire about cauda equina symptoms such as bowel or bladder dysfunction, saddle anesthesia, or severe bilateral lower extremity pain, which indicate a surgical emergency.

Onset of pain may also give clues to diagnosis. Pain associated with sports may occur during or after activity. Night pain may indicate a more serious condition and presence of weight loss, fevers, or generalized malaise should be determined. A nutritional history is critical, especially in female athletes in which there are concerns for the "female athlete triad," as this population is more susceptible to stress fractures [25].

Physical Exam

A thorough physical exam is as important as the history in obtaining the correct diagnosis. Observation should always be the first part of the exam, particularly noting overall body habitus and posture. A pale, cachectic patient may suggest an underlying malignancy, infectious disease, or nutritional disorder. Coronal and sagittal alignment should be evaluated for trunk imbalance, scoliosis, lordosis, or kyphosis. Patients may present with a "sway-back" deformity indicating excessive lumbar lordosis and associated hip flexion contracture. Additionally, the examiner should look for cutaneous abnormalities such as café au lait spots, sacral dimples, hemangiomas, or hair patches.

Palpating the spine and paraspinal musculature can help delineate bony injury versus muscular strain. Tenderness along spinous processes may indicate fracture, ligamentous injury, or apophysitis. If the sacroiliac joints are tender, a flexion abduction external rotation (FABER) maneuver of the hips may help confirm sacroiliitis. Finally, the greater trochanters should be palpated laterally for tenderness, indicating bursitis or gluteus medius tendinitis, and in the posterior peritrochanteric region, indicating piriformis syndrome or other short external rotator inflammation.

Range of motion in flexion and extension should be assessed as well as whether pain is elicited during flexion or extension. Flexion pain is less specific in young athletes but can suggest disc pathology. A patient with a disc herniation may be apprehensive about lumbar flexion and the Valsalva maneuver [26]. Limited flexion may be secondary to pain or tight hamstrings. An Adams forward bend test should be performed to assess for a rib hump or asymmetry which suggests scoliosis. Although scoliosis is not typically painful, a left-sided thoracic curve may represent an underlying spinal cord abnormality. Extension pain is more specific for spondylolysis or posterior element pathology. Stork testing (single-leg hyperextension) can increase specificity and can localize laterality of the spinal abnormality.

A complete neurological exam is essential for any patient with LBP, particularly those with radicular or nerve-like complaints. This should include sensory and motor exam of nerve roots L2 to S1 [27]. A good start to the motor exam is to ask the patient to heel walk and toe walk. If they can do this without difficulty it indicates gross motor integrity of L4 and S1, respectively. Reflexes and signs of upper motor neuron irritability (i.e., clonus, Babinski testing, abdominal reflexes) should be tested. Nerve tension tests including straight leg raise, contralateral straight leg raise, Lasegue sign, and prone femoral stretch should be performed to assess for nerve root irritation.

A lower extremity exam may indicate contributing factors to LBP. In particular, an increased popliteal angle, indicative of tight hamstrings, can cause LBP but can also result from spondylolisthesis. A positive Thomas test, indicating hip flexor contracture, may be present in those with excessive lumbar lordosis.

Acute Injuries

Fractures

Pediatric thoracolumbar trauma accounts for approximately 0.6–0.9 % of all spine fractures, with sports accounting for 21–53 % of these [28–30]. Athletes involved in sports with axial loading, such as diving and snowboarding, and contact sports such as hockey and wrestling, have an especially high risk for fractures.

Patients with suspected thoracolumbar fracture should be managed according to advanced trauma life support (ATLS) protocol. Proper spine boarding technique should always be performed to prevent additional injury. A careful exam including palpation for bony tenderness or step-off, as well as a detailed neurologic exam, is critical.

Plain radiographs, historically, have been the first line in imaging. However, computed tomography (CT) has become quicker and easier, frequently becoming the initial imaging choice in adults. In pediatric patients, however, radiation exposure must be considered, as a single CT scan results in a theoretic 13–25 % median excess relative risk of thyroid cancer induction [31]. When interpreting spinal X-rays, Denis' three column theory can aid in description of the injury and stability of the fracture [32]. Although a two-column injury typically indicates instability, there are two column fractures that are stable (i.e., stable burst fractures). If neurologic findings are present, magnetic resonance imaging (MRI) should be obtained to evaluate for herniated discs, hematoma, neuroforaminal encroachment, ligamentous injury, or spinal cord edema.

Younger children (<9 years old) may have a higher incidence of neurological injury without skeletal abnormality, known as "spinal cord injury without radiographic abnormality" (SCIWORA). This occurs because the immature spine is more elastic, allowing for greater ranges of motion and displacement without fracture. SCIWORA occurs in 30–40 % of spinal cord injuries in pediatric patients [33, 34] and 23 % of SCIWORA patients may have a delayed presentation of neurologic injury ranging from 6 to 72 h after injury [35].

Most pediatric thoracolumbar fractures are stable and do not result in neurological injury or long-term problems. Spinous process and transverse process fractures account for 23 % of all spine fractures in young athletes, while compression fractures represent 48 %. Isolated spinous process and transverse process fractures usually result from blunt trauma and can be managed with pain control and return to activities as tolerated. Compression fractures can be treated with activity modification, a thoracolumbarsacral orthosis (TLSO) for 6–8 weeks and gradual return to sports.

Burst fractures occur from an axial load injury and are classified as stable or unstable. Stability of burst fractures is controversial, but in contrast to adults, the percentage of canal compromise does not necessarily correlate with the risk of neurologic injury. This may be because the immature spine has a larger canal diameter with respect to the spinal cord [36, 37]. Stable burst fractures can be managed in a hyperextension cast or TLSO brace for 8–12 weeks. Unstable fractures are treated with posterior pedicle screw implantation with or without arthrodesis and with or without decompression.

Apophyseal Fractures and Herniations

Apophyseal ring fractures occur in children and adolescents aged 10–14 years and result from a separation of the vertebral apophysis from the spongiosa layer of the vertebral body. This injury, seen almost exclusively in the skeletally immature, is analogous to a herniated disc in adults. The apophysis can herniate into the spinal canal or into the neural foramen causing nerve root impingement. The apophysis may spontaneously reduce, however, and X-rays may appear normal. If X-rays are carefully scrutinized, a small bony fleck may be seen posterior to the vertebral body. MRI is important to determine how much injury has occurred. Adolescent athletes involved in weight lifting or gymnastics are at increased risk. The classic presentation is an adolescent with radicular pain after weight lifting. Ninety percent of apophyseal ring fractures occur at the L4–5 level.

Treatment consists of anti-inflammatories, activity modification, and 8 weeks in a TLSO, if there are no significant neurologic findings or very mild radicular symptoms. Surgical decompression to remove the limbus is warranted if neurologic deficits are present.

Acute Disc Herniation

Discogenic causes for back pain, including disc herniation, account for 11 % of LBP in young athletes [4]. The majority of disc herniation occurs after 12 years of age and 92 % occur at the L4–5 or L5–S1 levels. Athletes involved in collision sports or weight lifting are at increased risk. Between 30 and 70 % of adolescents with acute disc herniation have vertebral anomalies such as scoliosis, transitional defects (lumbarization and sacralization), schisis, and canal narrowing [38]. Genetic and familial factors may contribute to early disc disease [39, 40]. Finally, there is increased incidence of acute disc herniations in patients with growth cartilage abnormalities of the lumbar spine, such as Schmorl nodes and Scheuermann's disease.

Patients with a herniated disc may have apprehension with lumbar spine flexion or Valsalva maneuver. A scoliotic posture may be assumed as a compensatory mechanism to relieve pressure off a compressed nerve root. Additionally, straight leg raise will be positive two-thirds of the time [41].

First-line treatment of an acute herniated disc is nonsurgical, including rest, anti-inflammatories, and physical therapy with gradual return to activities. More aggressive non-operative treatment could include a rigid brace and epidural steroid injections. Unfortunately, conservative therapy is less effective in adolescents when compared to adults [42, 43]. One study of surgically treated lumbar disc herniations in children and adolescents revealed that as few as 40 % of adolescents with herniated lumbar discs responded to conservative therapy and recurrence was common [44].

Sprains, Strains, and Contusions

Although common, muscular strains, ligamentous sprains, and contusions are diagnoses of exclusion. Ligamentous sprains and muscular strains account for 20 % of back pain in adolescent athletes [4]. Injury to the interspinous ligament is the most common sprain [45]. A contusion occurs after blunt trauma to soft tissues and may cause hematoma formation.

Sprains, strains, and contusions cause acute pain in the first 24–48 h and are often associated with spasms and localized, palpable tenderness over the affected area. Imaging will be negative except MRI, which will show localized edema within the soft tissue area of injury. Recurrences can be common and may become chronic. Acute management includes rest, ice, and anti-inflammatories. Physical therapy should target core muscular imbalances, core strengthening, and hamstring stretching. Modalities including electrical stimulation, massage, and ultrasound may provide some benefit. Gradual return to sports occurs as symptoms resolve.

Chronic/Overuse Injuries

Spondylolysis and Spondylolisthesis

Spondylolysis is an anatomic defect of the pars interarticularis without displacement of the vertebral body. It usually results from a chronic cyclic loading of the inferior articular facet onto the pars interarticularis of the inferior vertebrae during repetitive hyperextension [46]. The most common vertebrae involved is L5 and the defect may be unilateral or bilateral. Patients with L4 spondylolysis are more frequently symptomatic [47].

Spondylolisthesis refers to the translation of one vertebra relative to the adjacent caudal vertebral segment. The most common location for spondylolisthesis in children and adolescents is at L5–S1. Dysplastic spondylolisthesis is more likely to progress (32 %) compared to the isthmic type (4 %) and is more likely to need surgery [48–50]. Although many patients with isthmic spondylolysis present with some degree of spondylolisthesis, <4 % of children and adolescents show slip progression in adulthood [48, 51]. Patients diagnosed before the adolescent growth spurt, females, and slips >50 % have a higher likelihood of progression [52].

The prevalence of spondylolysis is age dependent. A prospective study of 500 children followed from first grade for 45 years found a prevalence of spondylolysis of 4.4 % among 6-year-olds and 6 % in adults [53]. Although relatively uncommon in the general population, spondylolysis is more prevalent in athletes due to repetitive forces on the back.

Spondylolysis is the most common cause for back pain in young athletes, comprising 47 % of back pain in this population [4]. Once believed to be more common in boys, recent studies have shown equal prevalence [25]. Certain female-dominated sports have an increased risk, including gymnastics, ballet, and figure skating [9, 12–16]. Spondylolisthesis, however, is more common in females [11, 16, 17, 19].

There may be a genetic predisposition in developing spondylolysis. In family studies of patients with isthmic spondylolysis and spondylolisthesis, 22–26 % of first-degree relatives had similar radiographic changes, but most were asymptomatic [54, 55]. Children of European descent have two to three times the risk of developing spondylolysis and spondylolisthesis compared with those of African descent [53].

Back pain associated with spondylolysis becomes worse with activity; hyperextension with rotation is particularly painful. Physical exam typically reveals hamstring tightness and pain with "stork" testing. Patients with slips may have paresthesia, neurologic deficit (particularly L5), and positive tension signs.

Initial imaging for spondylolysis and spondylolisthesis include standing posterioanterior (PA) and lateral radiographs. Traditionally, supine oblique radiographs would be included to show the classic "scotty-dog" sign. However, obliques are only 32 % sensitive for spondylolysis while doubling the radiation exposure [56]. Additionally, there is no increase in sensitivity or specificity in detecting spondylolysis when comparing two-view versus four-view radiographs [57]. Lateral images are important for detecting a pars defect and documenting the degree of spondylolisthesis [58]. Slip angle can also be measured on the lateral radiograph. A slip angle >50° is associated with greater risk of progression, instability, and postoperative pseudoarthrosis [52]. Additionally, pelvic incidence (PI) can be measured on lateral X-rays (Fig. 10.2). Recent studies have shown a direct linear relationship between PI and severity of spondylolisthesis, suggesting that pelvic anatomy may directly influence the development of isthmic spondylolisthesis. PI was significantly higher in patients with low- and high-grade isthmic spondylolisthesis compared with controls [59]. Increased PI results in increased lordotic stress on the lumbar spine.

When radiographs are normal but clinical suspicion is high, single-photon emission computed tomography (SPECT) is the most sensitive method for detecting spondylolysis [60]. SPECT may also show osseous healing potential as increased signal uptake correlates with metabolically active bone [61]. Additionally, decrease in tracer uptake on serial SPECT scans has been correlated with improvement in signs and symptoms [46]. MRI can also be used when radiographs are normal but suspicion is high. In addition to avoiding radiation, MRI can detect bone marrow edema suggestive of a "pre-spondylolysis" [62]. Detection of "stress reaction" in the pars may increase the rate of bony union because early treatment can prevent frank fracture. One study comparing MRI and CT in detection of spondylolysis found that MRI was 92 % sensitive in detection of pars defect and found 11 lesions in

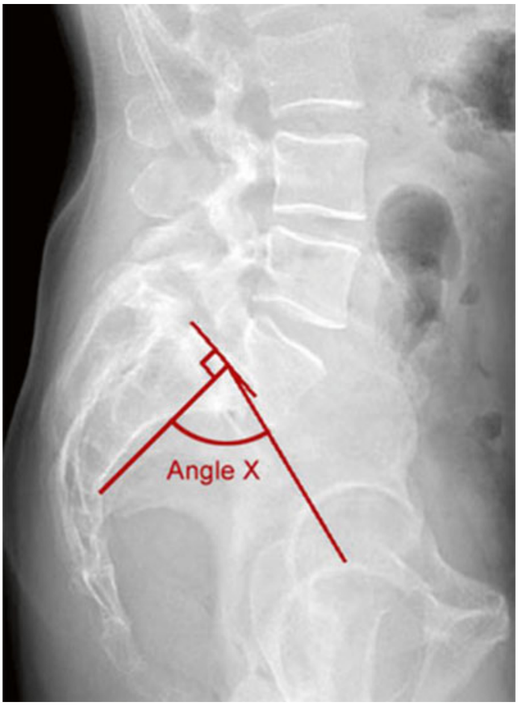

Fig. 10.2 When performing measurements on spinopelvic radiographs, pelvic incidence (PI) most closely correlates with the isthmic spondylolisthesis grade. It is measured by taking the angle subtended by an initial line from the center of the femoral head to the midpoint of the sacral end plate and a second line perpendicular to the center of the sacral endplate. PI is relatively constant during childhood (~47°), increases during adolescence, and remains constant in adulthood (~57°). Unlike many other parameters of pelvic morphology, PI is not affected by changes in posture. A low PI indicates low shear forces at the lumbosacral junction and less lumbar lordosis (reprinted from Hanson et al. [59]; with permission)

9 patients that had negative CT scan [63]. However, MRI for evaluation of back pain has a high false positive rate and positive predictive value [64]. One study showed that MRI detected pars abnormalities in 6 of 22 asymptomatic elite rowers [65]. Another study in young asymptomatic elite tennis players showed that only 4 % had no MRI abnormality [66].

Once spondylolysis has been diagnosed, thin-cut CT, performed with a reverse gantry angle, is the best imaging modality to define bony anatomy (Fig. 10.3). It can reveal sclerosis of the pars and size of the gap in the pars defect, which may assist in determining healing potential. CT is the test of choice to follow healing of spondylolysis using serial imaging [67].

Initial management of spondylolysis is non-operative with activity modification and activity restriction for 3–6 months. Physical therapy is important to stretch hamstrings, strengthen core musculature, and perform specific anti-lordotic exercises, which have been shown to decrease pain and disability [68].

Although bracing is controversial, a lumbar brace, such as the modified Boston brace, has been shown to be superior to activity modification alone [11]. The brace is molded in 0°–15° of anti-lordotic flexion and worn for 24 h a day for the first 4–6 weeks, followed by weaning. Return to sports begins once there is painless extension and rotation of the lumbar spine. As the athlete returns to play, the brace is worn only during sports and is discontinued once the athlete has remained pain free for 3–4 months. This regimen has resulted in good to excellent results in 78 % of patients [69] with a 72–89 % rate of successful return to sports [51, 70]. Other studies have shown bony healing with use of a rigid brace, a soft brace, or no brace [71–74].

Resolution of symptoms does not necessarily indicate bony union of a pars defect. If pain resolves but thin-cut CT reveals a persistent pars defect then a fibrous union has occurred. Fibrous union frequently leads to a good clinical result [51, 61]. A meta-analysis showed only a 28 % rate of bony healing of spondylolytic defects despite an 84 % success rate in patients treated non-operatively; 71 % of unilateral defects healed while only 18 % of bilateral defects healed [75].

Most young athletes with spondylolysis or spondylolisthesis can be treated conservatively. Surgical treatment is reserved for progressive spondylolisthesis, neurologic deficit, or painful nonunion and persistent back pain [76]. If modification of sporting activities is unacceptable then pros and cons of surgery need to be thoroughly discussed. Patients should be reminded that long-term prognosis of spondylolysis without surgery is favorable and that continuing sports, although painful, will not necessarily worsen the spondylolysis. Many athletes may choose to tolerate some pain and continue sports; other athletes are

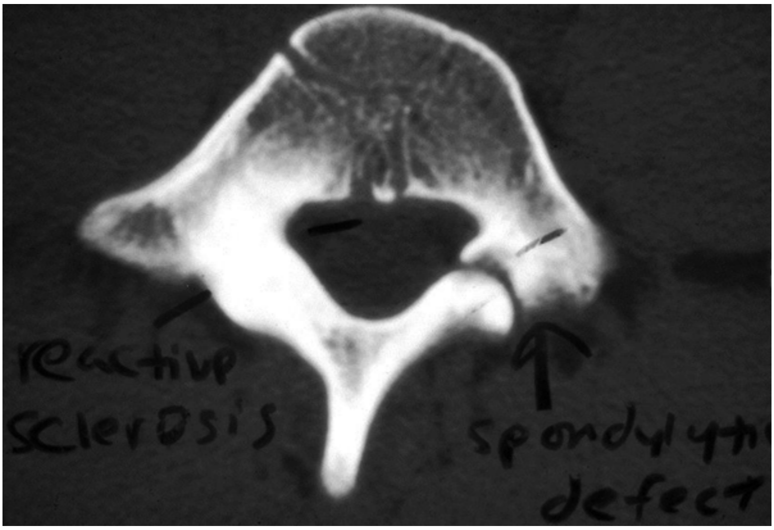

Fig. 10.3 CT scan is the imaging test of choice to define structural anatomy and follow serially to assess bony union

unwilling to accept any activity limitations and would prefer surgical management [77].

Surgical options for spondylolysis are direct repair versus posterior lumbar fusion. Direct repair is performed at levels above L5, while for L5 itself, debridement of fibrous tissue and in situ fusion with autogenous iliac crest bone graft are the gold standard. Methods for achieving union include posterior wiring of the transverse process and spinous process, pedicle screw and hook techniques, or Buck translaminar interfragmentary screws. Results from Buck fusion are the most studied with a painless union rate of 88 % and return to sports of 82 % [78, 79]. Fusion is indicated if there is spondylolisthesis or a degenerative disc at L5–S1. Pedicle screw instrumentation with rods is the currently preferred method [80].

Lordotic Low Back Pain

Lordotic back pain is the second most common cause of LBP in young athletes [4]. During the adolescent growth spurt, the thoracolumbar fascia and interspinous ligaments may tighten and decrease flexibility, resulting in lordotic LBP. Pain may result from traction apophysitis or impingement of the spinous processes [4] (Fig. 10.4). Another possible cause of pain is excessive stress on the facet joints. In addition, Bertolotti syndrome, characterized by anomalous enlargement of the transverse processes of the most caudal vertebra,

Fig. 10.4 Bone scan in a patient with lordotic low back pain reveals increased uptake in the spinous process. This patient was diagnosed with spinous process impingement

which may articulate or fuse with the sacrum or ilium and cause L4/5 disc disease, may also cause extension-based back pain [81].

Physical exam is similar to that for spondylolysis, including pain with hyperextension and tight hamstrings, so spondylolysis must be ruled out with imaging. Thus, lordotic LBP is a diagnosis of exclusion. Imaging in lordotic LBP may reveal increased signal within the posterior elements and a possible effusion in the facet joints (Fig. 10.4).

Treatment includes anti-lordotic exercises such as abdominal strengthening and hamstring/hip flexor stretching. Gradual return to sports is allowed once pain with extension maneuvers subsides. If symptoms persist, an anti-lordotic back brace may be beneficial. Patients with facet joint inflammation or a pseudoarthrosis of a transitional vertebra may benefit from a localized corticosteroid injection into the facet joint capsule or into the pseudoarthrosis.

Degenerative Disc Disease

Discogenic back pain is relatively rare in inactive adolescents. However, in active young athletes, it may represent up to 11 % of back pain [4]. There appears to be earlier disc degeneration in sports requiring frequent trunk rotation such as gymnastics, soccer, and weight lifting [82–84], and increased disc degeneration in swimmers and baseball players compared with non-athletes [11]. An MRI study comparing elite athletes and non-athletes found that 90 % of athletes had degenerative disc disease [85]. Although MRI findings are more common in athletes, clinicians must be cautious in treating MRI findings that do not correlate with the history and physical exam. For instance, an MRI study of young asymptomatic elite tennis players showed that 62 % had degenerative disc disease [66].

The adolescent growth spurt is the most vulnerable time for disc degeneration of the lumbar spine. A 15-year MRI follow-up study showed that most degenerative lumbar disc abnormalities found on final follow-up were present on initial MRI obtained in late adolescence/early adulthood [85].

Treatment of degenerative discs in this age group is nonsurgical. Relative rest with temporary restriction from sports is generally successful. Anti-inflammatories can be used for pain relief while a lumbar corset may also help. Physical therapy focused on flexibility of the lumbar paraspinals and hamstrings is essential. Core strengthening is critical to reestablishing balance and symmetry around the lumbar spine. For those who fail non-operative modalities, microdiscectomy or lumbar interbody fusion may be necessary.

Scheuermann's Kyphosis

Scheuermann's kyphosis is the most common cause of structural kyphosis in adolescents. It is a disorder of endochondral ossification that affects the vertebral end plates and results in intervertebral disc herniation, anterior wedging of consecutive vertebrae, and a fixed thoracolumbar kyphosis. Scheuermann's kyphosis is diagnosed between 13 and 17 years of age and is more common in boys. It is rare in patients younger than 10 years. Patients with Scheuermann's kyphosis may complain only of a cosmetic deformity; it is painless in approximately 80 % of patients. Higher demand athletes, however, may complain of back pain with activity. If there is pain it is usually at the apex of the curve and is aggravated by prolonged sitting, standing, or activities.

Examination reveals a round back appearance of the thoracic spine most prominent with forward flexion. It is important to distinguish Scheuermann's kyphosis from postural kyphosis. While postural kyphosis is usually reducible with hyperextension or lying supine, Scheuermann's kyphosis is not reducible with these movements. Thoracic kyphosis may be accompanied by a compensatory lumbar hyperlordosis, associated with a higher rate of back pain and an increased risk of spondylolysis.

In Scheuermann's kyphosis there is hyperkyphosis of at least 40° of the thoracic spine, usually between T7 and T9, due to anterior wedging of multiple vertebrae. Diagnosis is made on a lateral radiograph in which there are at least three consecutive vertebrae with wedging of 5° or more, typical vertebral end-plate changes, Schmorl nodes, and apophyseal ring fractures [86].

Treatment of juvenile kyphosis is controversial. Some advocate that Scheuermann kyphosis is self-limited with a benign course not requiring treatment. However, thoracolumbar braces are often used to stabilize progression of deformity in skeletally immature patients with a kyphosis of 50° or more. When worn for 12–24 months until maturity, Milwaukee and DuPont braces may limit progression of deformity, and in some cases may lead to improvement [87].

Surgical management is reserved for persistent pain and curves greater than 75°. Restrictive lung disease is typically not seen in curves less than 100°. If the curve is rigid with marked anterior wedging, the treatment of choice is anterior release and interbody fusion followed by posterior fusion with compression instrumentation. Patients whose kyphosis corrects to less than 55° with hyperextension can be treated by posterior-only approaches.

Atypical Scheuermann's Kyphosis

Atypical Scheuermann's kyphosis is an uncommon cause of back pain. It usually consists of one or two vertebral bodies, anterior Schmorl node herniations, and disc space narrowing at the thoracolumbar junction [88], likely resulting from repetitive flexion of the thoracolumbar spine. Patients have kyphosis of the thoracic spine and hypolordosis of the lumbar spine, collectively known as "flat-back syndrome." MRI may reveal end-plate changes, Schmorl nodes, and apophyseal ring fracture. Treatment consists of physical therapy including extension-based exercises. Occasionally, lordotic bracing is utilized.

Summary

Back pain is relatively frequent in children and adolescents, particularly those involved in sports or fitness training. Practitioners with knowledge of the most common etiologies of back pain in young athletes can make a correct diagnosis by obtaining a detailed history, performing a focused physical exam, and utilizing appropriate imaging.

In contrast to adult back pain, where degenerative changes are frequent pain generators, back pain in young athletes is usually attributed to overuse and can be resolved with symptomatic treatment. Activity modification, structured physical therapy programs, and possibly a brace are effective treatments for most causes of LBP in young athletes. It is important to educate the patient and family that most conditions causing back pain in young athletes are not dangerous and that playing sports, although painful, is generally safe. Physical therapy focusing on flexibility and core strengthening with a therapist who has experience with young athletes is critical to a successful return to activities. Although controversial, bracing in certain conditions has proven effective in healing and resolution of symptoms. Patients who fail conservative measures may be candidates for corticosteroid injections or surgery, depending on the etiology.

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Part IV

Potentially Serious Injuries and Outcomes

11 Concussion in Young Athletes

Laura Purcell

Introduction

Concussions are a significant concern in sports at all levels and have garnered a wealth of media attention in recent years. Reports of long-term consequences, including depression, marital discord and season- and career-ending injuries, have generated popular interest in sport-related concussions (SRCs) [1, 2]. SRCs are of particular concern in young athletes participating in sports and recreational activities because the majority of concussions (66 %) occur in children and adolescents [3] and because of the potential for detrimental effects on developing brains [4–13]. Another reason for concern is that the number of SRCs has been increasing in the last decade. Emergency department (ED) visits in the United States (US) for SRCs in 8–13 year olds doubled between 1997 and 2007, and increased by >200 % in 14–19-year-olds [14].

SRCs in pediatric athletes have also alarmed governments in North America and governments have become increasingly cognizant of the need for concussion awareness and concussion education. In the US, the Lystedt Law recommending concussion education for coaches, athletes, and parents was passed in 2009 [15]. Since then, concussion legislation has been passed in all 50 states throughout the USA as well as the District of Columbia [16, 17]. In Ontario, Canada, the Ministry of Education has mandated that all school boards in the province develop and implement concussion policies [18]. In addition, the federal government of Canada has funded a nation-wide concussion project to reduce the incidence and severity of concussions in youth sports [19].

This chapter reviews the epidemiology, diagnosis, and management of concussion in young athletes. It also reviews management of persistent concussion symptoms and prevention.

Epidemiology

More than 40 % of brain injuries in children and adolescents between 10 and 19 years of age treated in Canadian EDs result from sports and recreation activities [19]. In the US, approximately 175,000 children and adolescents are treated every year in EDs for sport-related head injuries (SR-HI) [20]. The rate of SR-traumatic brain injuries (TBIs) among patients 19 years of age and younger increased by 57 % between 2001 and 2009 [20]. One local Canadian study found that in patients 0–14 years of age, 82.4 % of SR-HI were diagnosed as concussion [21].

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D. Caine, L. Purcell (eds.), *Injury in Pediatric and Adolescent Sports*, Contemporary Pediatric and Adolescent Sports Medicine, DOI 10.1007/978-3-319-18141-7_11

Table 11.1 Concussions by sport and age in males and females

	Females			Males		
	Age Group, # (%)			Age Group, # (%)		
Sport/activity	5–9 years	10–14 years	15–19 years	5–9 years	10–14 years	15–19 years
Ringette	6 (20.7)	36 (17.5)	12 (4.8)	N/A	N/A	N/A
Ice hockey	–	74 (12.5)	52 (16.3)	56 (9.1)	580 (11.4)	257 (9.5)
Rugby	0 (0.0)	11 (14.5)	53 (11.9)	0 (0.0)	30 (10.0)	87 (10.6)
Snowboarding	–	21 (4.4)	24 (7.1)	6 (6.7)	89 (6.4)	76 (8.7)
Skiing	5 (2.4)	24 (5.2)	20 (13.6)	12 (4.6)	40 (6.2)	17 (6.9)
Football	0 (0.0)	12 (3.8)	6 (3.7)	9 (2.5)	178 (5.3)	140 (7.3)
Sledding	13 (3.5)	17 (4.8)	6 (10.2)	36 (3.5)	17 (4.8)	–
Cycling	35 (3.2)	40 (3.8)	8 (3.7)	54 (2.8)	152 (4.4)	67 (5.4)
Lacrosse	–	0 (0.0)	0 (0.0)	–	13 (5.2)	–
Soccer	8 (1.5)	96 (3.2)	107 (7.0)	39 (2.7)	110 (2.8)	53 (3.5)
Baseball	–	18 (6.6)	–	–	15 (2.2)	6 (2.3)
Basketball	–	33 (1.8)	23 (3.2)	6 (1.6)	76 (2.7)	31 (1.7)
Volleyball	0 (0.0)	15 (2.6)	5 (1.5)	0 (0.0)	7 (2.3)	–

Adapted from Fridman et al. [24]

In the US, 144,000 children and adolescents aged 0–19 years are treated for concussion annually [22]. SRCs accounted for about 25–50 % of concussions in children and adolescents [14, 22, 23]. In children 8–13 years old, 58 % of all concussions were SRCs while 46 % of all concussions in 14–19-year-olds were SRCs [14]. Most SRCs occurred in males (69–72 %) [22, 23].

SRCs comprised 0–17 % of all injuries in any specific sport [24–33]. The rates varied by sport, age and gender (Table 11.1) [24–35]. Overall, 25 % of SRCs occurred during organized team sports (OTS), most frequently football, basketball, soccer, ice hockey and baseball [14, 23]. In 14–19-year-olds, 47 % of SRCS occurred during OTS [14, 23]. Concussion rates per 10,000 participants were highest for ice hockey (10 in 7–11-year-olds, 29 in 12–17-year-olds) and football (8 in 7–11-year-olds, 27 in 12–17-year-olds) [14]. Cycling was the most common individual/leisure activity resulting in concussion [14].

Gender differences in SRCs have been documented. SRCs were more common in females than males in gender-comparable sports [34, 35]. In football (soccer), basketball, and ice hockey, SRCs were more common in females than males [34, 35]. It is not clear from the literature whether the concussion incidence data showing a consistent increased risk in females compared with males in similar sports is a true difference or reflects a reporting bias, as females tend to be more honest in reporting injuries than males [34, 35].

All of these statistics are likely underestimations of the true incidence of SRCs among children and youth as most studies using ED injury surveillance systems only capture patients presenting to EDs for treatment. Patients who sought care at another medical facility such as an urgent care center, a family doctor or pediatrician's office, walk-in clinic, physiotherapist or chiropractor, and those patients who did not seek medical care are not captured by ED-based injury surveillance systems [3, 14, 20–33]. Another reason for underestimation of concussion incidence results from some athletes not reporting concussions because of a fear of being taken out of play [14, 36].

Guidelines

The 2012 Zurich consensus statement on concussion is the most recognized and followed guideline for sport-related concussions [4]. The Zurich statement deals primarily with concussions in adults, although they do address pediatric and adolescent issues. The Canadian Paediatric Society has had concussion guidelines since 2006 which have been most recently updated in 2014 [5]. The American Academy of Pediatrics has had guidelines since 2010, and have specific guidelines for students returning to school following a concussion [6, 37]. Most recently, the Ontario Neurotrauma Foundation has published pediatric-specific concussion guidelines [10]. All of the pediatric guidelines are based on the Zurich principles.

Definition

Concussion is defined as "a complex pathophysiological process affecting the brain, induced by biomechanical forces" [4]. This process results "in the rapid onset of short-lived impairment of neurological function that resolves spontaneously" [4]. In some cases, symptoms and signs may evolve over minutes to hours following the injury. A direct hit to the head/face/neck or elsewhere on the body which transfers an impulsive force to the head can cause a concussion, resulting in a range of clinical symptoms that typically resolve in a sequential course. The majority of concussions do not involve a loss of consciousness. The acute symptoms of concussion are indicative of a functional injury to the brain (i.e., how the brain works) rather than a structural injury, such as a hemorrhage or contusion [4].

Traumatic brain injury (TBI) and head injury (HI) are often used interchangeably with concussion in the literature which can be confusing [4]. TBI and HI are not specific conditions and refer to a group of brain injuries of varying types and severity resulting from variable causes [12]. Concussion is a specific medical diagnosis and is a subset of TBI and HI, which also include skull fracture and intracranial hemorrhage [4, 20, 38].

Signs and Symptoms

There are many clinical signs and symptoms that may develop following a concussion. Features of SRCs are summarized in Table 11.2 and include symptoms/physical changes, behavioral changes, cognitive impairment, and sleep disturbances [4–6]. The cognitive effects of concussion, such as impaired attention, concentration and memory; slowed processing speed; and decreased ability to learn, can negatively affect a student's scholastic achievements [7–9].

If a head injury is suspected and an athlete exhibits one or more of these components, a concussion should be assumed and appropriate management initiated [4–6, 10]. In younger children, signs and symptoms may be more subtle and more difficult to elicit because of limited ability to communicate [5, 39]. Concussion signs and symptoms may evolve over minutes to hours following injury [4]. Typically symptoms resolve in 10 days in adults and older adolescents [4], but children and younger adolescents typically take longer, often 3–4 weeks or longer [4, 7–9, 40–47].

Evaluation of Acute Concussion

On Site

Any child or adolescent who sustains a head injury while participating in a sport or recreational activity should immediately stop and be removed from the activity. If medical personnel are present, the athlete should be assessed using accepted emergency management procedures (airway, breathing, circulation). In an unconscious athlete, a cervical spine injury must be assumed and appropriate c-spine precautions should be initiated, including immobilization with board and collar and emergent transfer to hospital [4–6, 10, 48].

A conscious athlete should be assessed for signs and symptoms of concussion by medically trained personnel using a sideline assessment tool, such as the Sideline Concussion Assessment Tool 3 (SCAT3) for ages 13 years and older or the Child SCAT3 for ages 5–12 years [4, 49, 50]. The Child SCAT3 allows for parental input in the assessment of younger children.

The assessment of concussion should include a neurological exam and evaluation of cognitive function, including memory, attention, and

Table 11.2 Features of sport-related concussion

Symptoms/physical signs	Behavioral changes	Cognitive impairment	Sleep disturbances
Headache Nausea/vomiting Dizziness Visual disturbances Photophobia Phonophobia Loss of consciousness Amnesia Loss of balance or poor Coordination Decreased playing ability	Irritability Emotional lability Sadness Anxiety Inappropriate emotions	Slowed reaction times Difficulty concentrating Difficulty remembering Confusion Feeling in a fog Feeling dazed	Drowsiness Trouble falling asleep Sleeping more than usual Sleeping less than usual

Adapted from Purcell [5]

concentration. If the athlete is deemed to be stable, he/she should not be left alone and should be closely observed for signs of deterioration [4–6, 10, 48]. The athlete should not return to play (RTP) on the day of injury and should not return to full participation until symptoms have completely resolved and clearance has been obtained by an experienced medical professional [4–6, 10, 48].

If medical personnel are not available on site, a responsible, trained adult, ideally the coach, trainer, or parent, should assess the injured athlete using the Concussion Recognition Tool (CRT) [4, 5, 51]. Urgent medical assessment should be arranged and the athlete should not return to play until medically cleared [4–6, 10].

In Office/ED

Many child and youth sport activities and recreational activities occur without medical personnel on site. Therefore, the office or ED is the first point of contact for many injured athletes. A comprehensive medical assessment of a potentially concussed athlete should include a detailed history and thorough neurological exam. The history should elicit potential risk factors for prolonged recovery, such as previous head and facial injuries, including previous diagnoses of concussion; history of headaches/migraines in the patient and family; sleeping difficulties; learning disabilities or attention deficit/hyperactivity disorder (ADHD); and mental health issues [4–6]. The neurological exam should assess mental status, cognitive function, gait and balance. An important part of the assessment is the determination of the need for urgent imaging and management of other injuries [4]. The SCAT3 and ChildSCAT3 can be used in the office/ED setting for both initial and serial follow-up assessments [4–6, 49, 50].

If stable following initial assessment, an injured athlete should be observed at home by a responsible adult for the next 24–48 h for signs of deterioration, such as vomiting, decreased level of consciousness, worsening headache, or seizure activity. Patients should not be woken during the night, unless there are signs of deterioration, as sleep is an important part of concussion recovery. Signs of deterioration could indicate a more severe injury than a concussion that may require emergent medical management. The presence of any of these signs requires emergent reevaluation in the ED [5, 6].

Investigations

Diagnostic Imaging

Routine neuroimaging tests, such as skull X-rays, computed tomography (CT) scans, and magnetic resonance imaging (MRI), are not required for diagnosis of concussion. As concussion is a functional injury, not a structural injury, X-rays, CTs, and MRIs usually do not indicate any structural injury. Diagnostic tests should only be obtained if there is suspicion of a structural injury (decreased level of consciousness or prolonged loss of consciousness, seizure, focal neurological deficits) [4–6, 52].

There are specialized imaging techniques, such as functional MRI (fMRI), single-photon emission computed tomography (SPECT), and positron emission tomography (PET), which may indicate functional and physiological abnormalities associated with concussion. However, these techniques are not routinely available and are largely experimental [4].

Neuropsychological Testing

Neuropsychological (NP) testing in various forms has been shown to be beneficial in assessing cognitive status in the setting of concussion [4, 53, 54]. It can be helpful in concussion management, particularly with respect to return to play decisions [4]. When used, NP testing is usually done once the patient is clinically symptom-free [4]. If NP testing is performed, it should be viewed as one component of the assessment process, in addition to clinical assessment and judgment, and not used as the sole basis for making management decisions [4, 5].

Pre-injury baseline testing may be helpful in the management of concussion; however, universal baseline testing is not recommended because of a lack of evidence to support this assertion [4, 48, 54, 55]. Particularly in children and adolescents, where rapid cognitive improvements between the ages of 9 and 15 years can confound NP results, the cost and lack of availability/resources make widespread pre-injury baseline testing impractical [4, 5, 39, 55, 56].

In certain cases, formal age-appropriate NP testing by a trained neuropsychologist may be necessary to aid the management of concussion [4, 5]. For instance, in athletes who have sustained multiple concussions or who are experiencing prolonged symptoms, formal NP testing may identify specific cognitive deficits that may help with educational planning [4, 5, 48, 54].

Management

Consensus agreement is that rest, both cognitive and physical, is the key to management of concussion, although there is little evidence regarding the optimal length and type of rest [4–6, 10]. One study in high school and college athletes did find that physical and cognitive rest immediately after injury, as well as later during recovery, improved concussion symptoms and performance on computerized NP tests [57]. Physical rest includes avoiding sports participation, exercise, physical education classes, and recreational activities such as cycling or playfighting with friends or siblings. Cognitive rest involves limiting activities that require mental exertion, such as reading, video games, television, and school/homework. As symptoms begin to resolve, usually within 24–48 h, athletes can gradually increase cognitive tasks, including school, and social activities, as long as symptoms are not worsened by these activities [4–6, 9, 10, 58].

Medications

No medications have been studied in the treatment of acute concussion in children and adolescents. Acetaminophen and/or ibuprofen may help decrease the severity and duration of headache following concussion [5, 6, 10]. Medications have been used to treat specific prolonged symptoms of concussion, such as sleep disturbances, headache and mental health issues [5, 10, 59]. Medications that can mask the signs and symptoms of concussion should not be taken when returning to sport participation [4, 5].

Return to Learn

In order to facilitate cognitive rest and allow concussion symptoms to diminish, injured student athletes may require a brief absence from school (usually a couple of days at most) [5, 6,

Table 11.3 Graduated Return to Learn (RTL) protocol*

Stage	Tasks
Cognitive rest	Decrease and limit cognitive tasks and screen time at home. No school
Increase cognitive tasks	As symptoms improve, slowly increase cognitive tasks at home in 15–20 min increments
Resume modified school attendance	As symptoms continue to improve, resume school attendance. Start with half-days or only certain classes (avoid gym, music, shop). Limit homework assignments to 15–20 min blocks
Increase school attendance	Gradually increase school attendance to full days as symptoms allow. Specific accommodations may be required to avoid symptom exacerbation (See Table 11.4). Tests should be limited to one per day in a quiet area, with unlimited time and frequent breaks
Return to Play protocol (RTP)	Once symptom-free and back to full-time school attendance without accommodations, the student can start with graduated RTP (Table 11.5)

*If symptoms worsen at any stage, decrease activity until they improve
Data from Purcell [5], Halstead and Walter [6], Kirkwood et al. [48], Sady et al. [60], McGrath [61], and Centers for Disease Control and Prevention [62]

10, 37]. Once symptoms start to improve and students can increase cognitive tasks without exacerbating their symptoms, a gradual return to school can be initiated, starting with half days or only certain classes (Table 11.3) [5, 6, 10, 37, 48, 58, 60–62]. Students do not need to be completely symptom-free before returning to school; however, modifications and/or accommodations to their schedule and/or workload may be required (Table 11.4) [5, 6, 37, 48, 58, 60–62]. Students must return to a full academic load prior to returning to sports [5]. If a prolonged absence from school is required because of severe, persistent symptoms, referral to a specialist with experience in concussion and/or a neuropsychologist may be necessary to aid with education planning [5].

Return to Play

Returning to sports and activities after a concussion should be a gradual process that only starts once all symptoms have resolved at rest and with some light exercise [4–6, 10]. There should be NO return to activity on the day of injury [4–6]. Consensus opinion states that RTP in child and adolescent patients should be more cautious and conservative than in adults [4–6, 63].

Once symptoms have resolved and a patient has been symptom-free for 7–10 days, the student can start a medically supervised stepwise exertion protocol (Table 11.5) [4–6, 58, 63]. Each step of the protocol should take a minimum of 24 h and an athlete should only progress to the next step if they remain asymptomatic at the current step. If symptoms recur, they should rest for 24–48 h until symptoms resolve, and attempt to progress again starting at the previous asymptomatic step. If symptoms do not recur with progression through these steps, an athlete would take approximately 1 week to complete the full rehabilitation protocol and resume full sport participation [4–6, 58, 63].

Modifying Factors

Concussion management may need to be modified in the presence of specific factors that may require additional investigation, such as formal NP testing or neuroimaging, or treatment, such as specific medications [4, 59]. In certain cases, these modifying factors may predict the possibility of persistent or prolonged symptoms following concussion [4, 59]. These modifying factors include prolonged loss of consciousness; younger age; presence of comorbidities, such as headaches/migraines,

Table 11.4 Academic accommodations for concussed students

Postconcussion symptom	Effect of school attendance	Accommodation
Headache	Difficulty concentrating	Frequent breaks, quiet area, hydration
Fatigue	Decreased attention, concentration	Frequent breaks, shortened day, only certain classes
Photophobia/phonophobia	Worsening symptoms (headache)	Sunglasses, ear plugs or headphones, avoid noisy areas (cafeterias, assemblies, sport events, music class), limit computer work
Anxiety	Decreased attention or concentration, overexertion to avoid falling behind	Reassurance and support from teachers about accommodations, reduced workload
Difficulty concentrating	Limited focus on schoolwork	Shorter assignments, decreased workload, frequent breaks, having someone read aloud, more time to complete assignments and tests, quiet area to complete work
Difficulty remembering	Difficulty retaining new information, remembering instructions, accessing learned information	Written instructions, smaller amounts to learn, repetition

Data from Purcell [5], Halstead et al. [6, 37], and Kirkwood et al. [48]

Table 11.5 Graduated return to play (RTP) protocol for athletes with concussion*

Rehabilitation stage	Functional exercise at each stage of rehabilitation	Objective of each Stage
1. No activity[a]	Symptom-limited physical and cognitive rest	Recovery
2. Light aerobic exercise	until symptom-free Walking, swimming, or stationary cycling No resistance training	Increase heart rate
3. Sport-specific exercise	Skating drills in ice hockey, running drills in soccer. No impact activities	Add movement
4. Non-contact training drills	Progression to more complex training drills (e.g., passing drills in football and ice hockey) May start progressive resistance training	Exercise, coordination, and cognitive load
5. Full-contact practice	Following medical clearance, participate in normal training activities	Restore confidence and assess functional skills by coaching staff
6. RTP	Normal game play	

*Children and adolescents should remain at this step until symptom-free for 7–10 days
Data from McCrory et al. [4]

Table 11.6 Targeted treatments for persistent postconcussion symptoms

Symptom	Treatment
Persistent headache	Lifestyle adjustments (proper hydration, adequate sleep, regular exercise) Avoidance of acetaminophen/ibuprofen overuse Prophylactic medications (e.g., for migraines) Neurology referral
Neck pain	Physiotherapy
Balance problems/dizziness	Vestibular rehabilitation
Sleep disturbances	Sleep hygiene reinforcement Medications (e.g., melatonin)
Depression/anxiety	Referral to a mental health professional; addressing social isolation or withdrawal Medications

Data from Purcell [5], Zemek et al. [10], Makdissi et al. [59], Blume [67], and Alsalaheen et al. [68]

mental health issues, learning disabilities, or attention deficit hyperactivity disorder (ADHD); high-risk sport or activity; and a history of multiple concussions, particularly if the concussions are temporally close together or recovery after concussion is taking longer [4, 59]. If modifying factors are a concern, management may require referral to a specialized multidisciplinary concussion team, including physicians with specific concussion expertise [4, 5].

In an athlete with a history of multiple concussions, consideration may need to be given to possible retirement from sport or changing to a less risky position to reduce the risk of recurrent head injury. Retirement should be considered if concussions occur with less force, result in more severe symptoms, if there is a concomitant learning disability, ADHD or persistent cognitive symptoms, or the risk is quite high because of a player's sport, position or playing style [5, 48, 63].

Persistent Symptoms

In up to 30–40 % of cases, concussed child and adolescent athletes do not recover in 3–4 weeks and may experience significant concussion symptoms for weeks to months [41, 42, 44, 45, 64]. Risk factors for persistent concussion symptoms and prolonged recovery include history of previous concussion, particularly multiple previous concussions and more recent prior injury [44, 64, 65]; higher initial post-concussion symptom score (PCSS) [45]; older children [64]; presence of loss of consciousness, headache, nausea, vomiting, and/or dizziness [43, 64, 66];decreased reaction time, verbal memory, and visual memory when combined with presence of headache, dizziness, and nausea [43]; and presence of premorbid conditions including learning difficulties or behavioral problems [64].

When concussion symptoms persist, other etiologies for these symptoms, which are often nonspecific and may result from other entities, should be ruled out [5, 10, 59]. Part of the workup for other etiologies may warrant investigations, including neuroimaging and formal NP testing [5, 10, 59]. Targeted treatments beyond cognitive and physical rest, such as medications, referral to medical subspecialists, active rehabilitation with subthreshold exercise, vestibular rehabilitation, and physical therapy, may be necessary to manage symptoms (Table 11.6) [5, 10, 59, 67–69]. Patients experiencing prolonged symptoms should be managed by a multidisciplinary team with concussion expertise [4, 5, 10]. Pediatric-specific guidelines for concussion management, with particular attention to management of persistent symptoms, have been recently published [10].

Prevention

Because of the potential long-term detrimental effects of concussion, prevention of injury is very important. Although helmets and mouth guards do not prevent concussion, certified helmets and appropriate mouth guards should be worn in every high risk sport (equestrian, snowboarding, skiing, bicycling, football, ice hockey) to prevent other head and mouth injuries [4–6, 70–73]. Protective equipment should be properly fitted, worn according to instructions and be well-maintained. Damaged or old equipment should be replaced promptly [74].

Education of athletes and coaches of the limitations of protective equipment and the lack of protection against concussion may help deter athletes from adopting a more aggressive playing style (risk compensation) and reduce risk of head injury [4, 5, 75]. Practicing fair play, good sportsmanship and following the rules of the sport can also help reduce the incidence of concussion and other injuries. Ensuring that athletes are taught proper sporting techniques, including heading in soccer, tackling in football, and body-checking in hockey, can help minimize injury risk as well [4, 5]. In addition, rule enforcement and rule changes, such as the ban of spearing in football, as well as modifications to the playing environment, such as padded soccer goalposts, can help reduce the incidence of concussion in sport [4, 5, 75, 76].

Another vital component of concussion prevention is education of athletes, coaches, parents, officials, teachers, health care providers, and anyone else involved in youth sports about the signs and symptoms of concussion and the principles of management. Coaches and athletes should be encouraged to be forthcoming about injuries so that appropriate management can be instituted and worsening or recurrent injury can be avoided [4–6].

Research

Concussion research is a very fertile area. There is a wealth of literature on concussion in adults and older adolescents. However, there is a paucity of research on children, particularly in the 5–12 year age group. Ongoing research looking at patterns of recovery, best management and RTL and RTP protocols, especially in the younger age groups, is very important to modify existing concussion guidelines based on solid evidence.

Summary

SRCs in children and adolescents are a significant concern. The majority of SRCs occur in the pediatric and adolescent population and the incidence of SRCs has been increasing in the past decade or so. Symptoms may persist for weeks to months which can negatively affect a student's scholastic achievement, sport participation and overall quality of life. Although pediatric and adolescent specific guidelines exist, they are based on little specific age group evidence. There is a paucity of concussion research in children aged 5–12 years and there is great need for more research in this age group to elucidate recovery patterns as well as best management principles. Prevention of concussion is vitally important and everyone involved in children's and youth sports should be educated about the signs and symptoms of concussion and the principles of management to ensure appropriate concussion management.

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12 Acute Catastrophic Injuries in High School Sports

Eric D. Zemper, Karen G. Roos, and Dennis Caine

Introduction

During the 2013–2014 academic year, a record total of almost 7.8 million students participated in US high school sports according to the annual High School Athletics Participation Survey [1]. This represents the 25th consecutive year in which the number of participants has increased. In addition to the well-known and documented health benefits of engaging in physical activity, participation in high school sports also is associated with higher grade-point averages, better attendance records, lower dropout rates, and fewer discipline problems than for students in the general student population [2]. However, participating in high school sports also carries risk of injury.

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The worst-case scenario in high school sports is catastrophic injury. While these types of injuries are rare, they can cause permanent neurological deficits or even death, which can be devastating to athletes and their families and may also result in major long-term medical costs [3]. Catastrophic sports injuries are categorized by the National Center for Catastrophic Sports Injury Research (NCCSIR) as fatalities, nonfatal injuries (permanent severe functional disability), and serious injuries (no permanent disability but significant initial injury, for example vertebral fracture without paralysis) [4]. Catastrophic sports injuries are further categorized as direct or indirect [4]. Direct injuries are those injures that result directly from participation in the sport, for example a spinal cord injury or skull fracture as a result of a collision while participating in a game or practice. Indirect injuries are those injuries that were caused by systemic failure as a result of exertion while participating in a sport activity or by a complication that was secondary to a nonfatal injury, such as a heat stroke injury or fatal complications from a surgery necessitated by a nonfatal sport injury.

The purpose of this chapter is to provide an epidemiological perspective on direct catastrophic injuries suffered by high school athletes. The most useful, comprehensive, and consistent data on catastrophic injuries in high school sports are found on the website of the National Center for Catastrophic Sports Injury Research

D. Caine, L. Purcell (eds.), *Injury in Pediatric and Adolescent Sports*, Contemporary Pediatric and Adolescent Sports Medicine, DOI 10.1007/978-3-319-18141-7_12

(NCCSIR) at the University of North Carolina, founded by Dr. Fred Mueller and Dr. Robert Cantu (http://nccsir.unc.edu/) and now directed by Dr. Kristen Kucera. The most recent report from the NCCSIR is the Thirty-First Annual Report (Fall 1982–Spring 2013) [4, 5] which, along with published articles based on the center's database, provides the data used for this chapter.

Van Mechelen et al. [6] established a four-stage approach to studying injury prevention in 1992 (provided in Fig. 14.1), which continues to be the model of choice in understanding the sequence of injury prevention in youth sport over the past two decades. The model establishes the need to first identify the extent of injury in a given population through surveillance (step 1) and second, the factors that play a part in the occurrence of the sports injuries can be identified (step 2). The next step is to introduce measures that are likely to reduce the incidence and/or severity of sports injuries (step 3). Finally, the effectiveness of preventive measures are evaluated through comparison of data from continued injury surveillance with data from step 1 (step 4). The discussion format in this chapter follows van Mechelen's sequence of injury prevention as it relates to catastrophic injuries [6].

Establishing the Extent of Injury

Participation Data

Table 12.1 provides a summary of the participation data for 18 US high school sports for the 31 year period during 1982–2013 [4]. Perusal of this table reveals a total of 191,854,483 participants during this period, including 122,757,746 males and 69,096,737 females. For males, the three sports with the highest number of participants are American football, basketball, and track and field. For females, the three sports with the greatest number of participants are track and field, basketball, and softball by the numbers presented in Table 12.1. However, an adjusted number of participants, based on the fact that the entry for volleyball represents only 20 years rather than 31 years, gives an estimate of 12.14 million participants for volleyball over 31 years, making it the sport with the third highest participation rate instead of softball.

Frequency and Injury Rates

While direct catastrophic injuries are relatively rare in high school sports, they do occur, and some sports appear to carry a greater risk than others. Data provided by the NCCSIR are provided as count data as well as in terms of injury rates per 100,000 participants. Count data provide a relative estimate of the frequency of catastrophic injuries across sports as well as an estimate of morbidity load on the health-care system. However, in order to investigate the distribution of injuries it is necessary to know the size of the population from which the injured individuals were derived, or the population-at-risk. The NCCSIR also provides data on the number of catastrophic injuries sustained in a particular sport relative to the total number of participants, or injury rates per 100,000 participant-seasons. While these data provide a basis for calculating injury rates, they may lack precision because of the varying exposure of participants to risk of injury. For example, a sidelined or second team player who sees little or no contact during a game is not at the same risk of sustaining a catastrophic sports injury as a healthy first team player. In addition, the number of practices and games may vary considerably from one sport or team to another.

Data on the total number of male direct catastrophic injuries sustained in US High School Sports during 1982–2013 are summarized in Table 12.2. High school male sports were associated with 174 fatalities, 469 nonfatal and 442 serious injuries for a total of 1,085 direct catastrophic injuries during that 31 year period [4, 5]. A review of Table 12.2 shows that fall sports were responsible for the greatest number of male direct catastrophic injuries, followed by spring and winter sports. The sports with the highest count of direct catastrophic injuries in each season were football (Fall), wrestling (Winter), and baseball (Spring). The sport showing the highest number of fatalities is football, followed by track

Table 12.1 US high school sports participation for the period 1982–1983 to 2012–2013

Season	Sport	Male	Female
Fall	American Football	41,583,382	24,768
	Cross Country	5,761,920	4,517,918
	Field Hockey	4,040	1,744,444
	Rowing (crew)[a]	30,081	36,908
	Soccer	9,172,094	6,989,588
	Water Polo	325,598	273,162
Winter	Basketball	16,502,134	13,233,336
	Gymnastics	110,044	733,459
	Ice Hockey	904,446	116,354
	Swimming	2,910,272	3,721,851
	Volleyball[b]	836,412	7,830,478
	Wrestling	7,591,328	83,833
Spring	Baseball	13,282,617	28,421
	Golf[c]	1,414,848	625,484
	Lacrosse	1,335,989	947,848
	Softball (fast and slow)	37,551	10,057,901
	Tennis	4,475,466	4,736,636
	Track and Field (indoor and outdoor)	16,479,524	13,395,348
Total	**191,854,483**	**122,757,746**	**69,096,737**

National Federation of State High School Associations (NFHS). High school participation increases for 25th consecutive year. NFHS News, October 30, 2014. http://www.nfhs.org/articles/high-school-participation-increases-for-25th-consecutive-year/ Accessed 12/22/2014 [1]

High School participation data started: [a]Rowing/crew in 2001; [b]Volleyball in 1994; [c]Golf in 2005

Table 12.2 1982–1983 to 2012–2013 US high school male direct catastrophic injuries

Seasons	Sport	Fatal	Nonfatal	Serious	Total
Fall	Cross Country	1	1	0	2
	Field Hockey	0	0	0	0
	Football	118	362	331	811
	Rowing (crew)	0	0	0	0
	Soccer	8	3	7	18
	Water Polo	0	0	0	0
	Total Fall	**127**	**366**	**338**	**831**
Winter	Basketball	2	4	11	17
	Gymnastics	1	2	1	4
	Ice Hockey	4	12	10	26
	Swimming	0	5	3	8
	Volleyball	0	0	0	0
	Wrestling	2	39	22	63
	Total Winter	**9**	**62**	**47**	**118**
Spring	Baseball	14	21	30	65
	Golf	0	0	0	0
	Lacrosse	2	4	7	13
	Softball	1	0	0	1
	Tennis	0	0	0	0
	Track and Field	21	16	20	57
	Total Spring	**38**	**41**	**57**	**136**

1982/1983–2012/2013 All Sport Report—Table Appendix. https://nccsir.unc.edu/files/2015/02/NCCSIR-31st-Annual-All-Sport-Report-1982_2013_Table-Appendix.pdf [5]

Table 12.3 1982–1983 to 2012–2013 US high school female direct catastrophic injuries

Seasons	Sport	Fatal	Nonfatal	Serious	Total
Fall	Football	0	0	0	0
	Cross Country	0	0	1	1
	Field Hockey	0	3	0	3
	Rowing (crew)	0	0	0	0
	Soccer	0	1	4	5
	Water Polo	0	0	0	0
	Total Fall	**0**	**4**	**5**	**9**
Winter	Basketball	0	2	3	5
	Gymnastics	0	6	3	9
	Ice Hockey	0	1	2	3
	Swimming	0	4	1	5
	Volleyball	0	1	0	1
	Wrestling	0	0	0	0
	Total Winter	**0**	**14**	**9**	**23**
Spring	Baseball	0	0	0	0
	Golf	0	0	0	0
	Lacrosse	0	0	2	2
	Softball	2	3	2	7
	Tennis	0	0	0	0
	Track and Field	1	2	6	9
	Total Spring	**3**	**5**	**10**	**18**

1982/1983–2012/2013 All Sport Report—Table Appendix. https://nccsir.unc.edu/files/2015/02/NCCSIR-31st-Annual-All-Sport-Report-1982_2013_Table-Appendix.pdf [5]

and field and baseball. It should be emphasized, however, that these are count data and do not necessarily reflect the risk of direct catastrophic injury in that number and exposure of participants are not taken into account.

High school females accounted for three deaths, 23 non-fatal and 24 serious injuries for a total of 50 direct catastrophic injuries over 31 years [4, 5]. A review of Table 12.3 shows that winter sports were responsible for the greatest number of female direct catastrophic injuries, followed by spring and fall sports. The sport with the highest count of direct catastrophic injuries in each season were soccer (Fall), gymnastics (Winter), and track and field (Spring). There were two female fatalities in softball and one in track and field. Again, it should be emphasized that these are count data and do not necessarily reflect the risk of direct catastrophic injury in that number and exposure of participants are not taken into account.

Using the participation data in Table 12.1 as the denominator data, and the numbers of injuries in Tables 12.2 and 12.3 as the numerator data, we can calculate direct catastrophic injury rates per 100,000 participant-seasons for each sport during 1982–2013 (Tables 12.4 and 12.5). As can be seen, looking at the rates rather than raw numbers changes the picture considerably. For example, as shown in Table 12.2, football had the highest number of fatalities. However, when the injury rate is calculated based on 31-year participation estimates (Table 12.4), the male sports with the highest rate of fatalities per 100,000 participant-seasons were softball (2.66), followed by gymnastics (0.91) and ice hockey (0.44). However, the rate for softball should be considered anomalous since there happened to be one direct male fatality in softball but only 37,551 participant-seasons over 31 years. In reality the highest risk male sports for direct fatalities are gymnastics, ice hockey, and football with 0.28 per 100,000 participant-seasons. The sports with the highest rates for male nonfatal direct catastrophic injuries were gymnastics (1.82 per 100,000 participant-seasons), ice hockey (1.33), and football (0.87). Among female participants, there were no fatalities

Table 12.4 US High School Sports. Direct Injuries per 100,000 Participant-Seasons: 1982–1982 to 2012–2013

		Male			Female		
Season	Sport	Fatalities	Nonfatal	Serious	Fatalities	Nonfatal	Serious
Fall	Cross Country	0.02	0.02	0.00	0.00	0.00	0.02
	Field Hockey	0.00	0.00	0.00	0.00	0.17	0.00
	Football	0.28	0.87	0.80	0.00	0.00	0.00
	Rowing (crew)	0.00	0.00	0.00	0.00	0.00	0.00
	Soccer	0.09	0.03	0.08	0.00	0.17	0.00
	Water Polo	0.00	0.00	0.00	0.00	0.00	0.00
Winter	Basketball	0.01	0.02	0.07	0.00	0.02	0.02
	Gymnastics	0.91	1.82	0.91	0.00	0.82	0.41
	Ice Hockey	0.44	1.33	1.11	0.00	0.86	1.72
	Swimming	0.00	0.17	0.10	0.00	0.11	0.03
	Volleyball	0.00	0.00	0.00	0.00	0.01	0.00
	Wrestling	0.03	0.51	0.30	0.00	0.00	0.00
Spring	Baseball	0.11	0.16	0.23	0.00	0.00	0.00
	Golf	0.00	0.00	0.00	0.00	0.00	0.00
	Lacrosse	0.15	0.30	0.52	0.00	0.00	0.21
	Softball	2.66	0.00	0.00	0.02	0.03	0.02
	Tennis	0.00	0.00	0.00	0.00	0.00	0.00
	Track and Field	0.13	0.10	0.12	0.01	0.01	0.04

1982/1983–2012/2013 All Sport Report—Table Appendix. https://nccsir.unc.edu/files/2015/02/NCCSIR-31st-Annual-All-Sport-Report-1982_2013_Table-Appendix.pdf [5]

reported except for track (0.01 per 100,000 participant-seasons) and softball (0.02). The female sports with the highest rates of nonfatal direct catastrophic injuries were ice hockey (0.86 per 100,000 participant-seasons) followed by gymnastics (0.82).

Table 12.4 also shows that males have considerably higher rates of direct catastrophic injuries (fatalities, nonfatal and serious) than females for most sports. Part of this may be explained by the fact that boys are taking part in more collision sports than girls, but even in sports like gymnastics or track and field, the boy's rates are much higher. Or perhaps these findings could relate to more aggressive or reckless behavior in boys, particularly in the earlier days of data collection. Notable exceptions to this generalization are field hockey and soccer, where girls have a slightly higher rate of nonfatal catastrophic injuries.

The presence of ice hockey and American football among sports with the highest direct catastrophic injury rates is not surprising given that these are contact and high-velocity sports. Gymnastics is not generally considered a contact sport, but in some respects it could be, given the risk of falls from various types of apparatus and contact with other objects in the environment [3].

The NCCSIR also has tracked catastrophic injuries that occurred during high school cheerleading activities. During 1982–2013 there were 86 direct catastrophic injuries involving high school female cheerleaders. These included 2 fatalities, 34 nonfatal and 50 serious injuries. High school cheerleading accounted for 64.2 % of all high school direct catastrophic injuries to female athletes (4). Figure 12.1 provides a comparison of high school direct catastrophic injuries among cheerleaders compared to all other female high school sports, 1982–1983 to 2012–2013. As shown in Fig. 12.1, the numbers of disability and serious injuries were twofold and threefold greater in cheerleading. During 1982–83 to 2007–2008, the direct rate for catastrophic injuries in high school female cheerleaders was 0.85 per 100,000 participant-seasons compared to 0.44 for male participants [7].

Cheerleading has changed dramatically in the past three decades from a simple leading of cheers on the sidelines to include a competitive aspect much closer to gymnastics in nature [3].

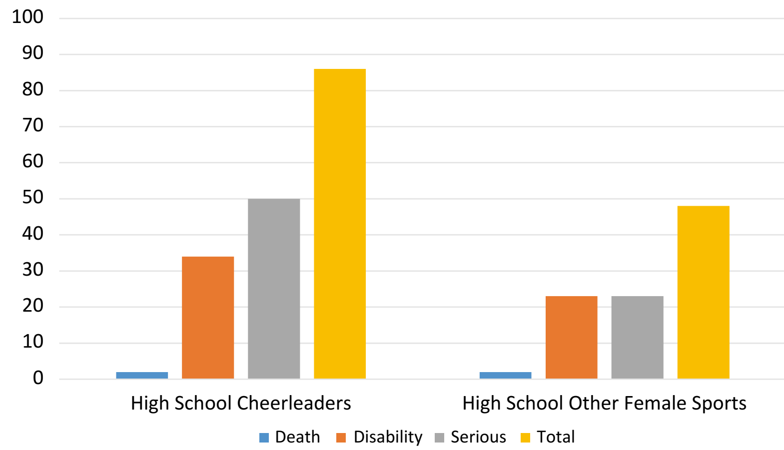

Fig. 12.1 High school direct catastrophic injuries among cheerleaders compared to all other female high school sports, 1982/1983 to 2012/2013 (Data from Mueller et al. [4])

In many respects, competitive cheerleading could be considered a contact sport, involving activities that require a high level of skill but, with the exception of possibly floor mats, utilizing no personal protective equipment as required in most team contact sports, a characteristic it shares with gymnastics and wrestling [3].

Establishing Risk Factors and Injury Mechanisms

The second stage of van Mechelen's sequence of injury prevention is to identify risk factors and injury mechanisms for injury. Injury risk factors are believed to render the athlete more susceptible to injury. Intrinsic factors are viewed as factors that predispose the athlete to react in a specific manner to an injury situation, whereas extrinsic or "enabling" factors may facilitate manifestation of the injury. While studies investigating risk factors for general sports injuries are becoming more common, there is a dearth of studies investigating risk factors for the rare catastrophic injuries. One injury that has been investigated extensively is concussion. Data from the NCCSIR [8, 9] and other sources indicate that a history of concussion is considered a risk factor for a new concussion. For example, a multi-year study of college football players showed those with a concussion in the previous 5 years had a six times greater risk of incurring a concussion during a given season [10]. This study was replicated 10 years later with high school and college players with the same result [11]. NCCSIR data also show that complications from subdural hematoma [9, 12, 13], as well as poorly fitting equipment [12] and aneurysm [8] are considered risk factors for new concussion.

Although risk factors may render the athlete more susceptible to injury, they are not sufficient for an injury to occur. The final element in the web of causation involves an inciting event or injury mechanism (i.e., the how). Injury mechanism is widely used in the medical literature to describe in biomechanical terms the inciting event, or event that directly precedes or occurs at injury onset [14]. Identifying injury mechanisms is a key component of preventing catastrophic injuries in youth sports. For example, high school swimming has been associated with 13 direct catastrophic injuries and the racing dive in the shallow end of the pool has been involved in all cases [4]. As a result, the National Federation of State High School Associations Swimming and Diving Rules Book 2011–2012 (Rule 2-7-2) established new water depth rules for the 2011–2012 season [15]. The new rule restricts the use of racing starts to pools with a depth of 4 ft

Table 12.5 Mechanism and risk factors for acute catastrophic injury by sport and body part

Type of injury	Mechanism of injury or risk factor	Nonspecific sport	Baseball	Cheer	Football	Ice Hockey	Lacrosse	Soccer	Swim and dive	Track and Field	Wrestling
Traumatic (nonspecific injury location)	Mechanism of injury		Collision between 2 players [19]				Initial contact with head [29]	Player-player contact [12, 21]		Being struck by a thrown apparatus (discus, javelin, shotput) [3]	
Head	Mechanism of injury	Contact with object or player [3]	Hit by thrown ball [12, 19–21]		Tackling/being tackled [3, 9, 20]					Landing in the pole vault plant box [12, 30, 31]	Takedown position [13]
			Pitcher hit by a batted ball [12, 19, 21]		Blocking/being blocked [9]					Missing the pole vault landing pads completely [12, 30, 31]	
			Non pitcher hit by batted ball [12, 19, 20]		Contact with object or player [3]					Landing with body on landing pad and head on hard ground [12, 30]	
			Player collision [20]								
	Risk factor		Aneurysm [19]		History of concussion [8, 9]						
			Cerebral hematoma [19]		Complications from subdural hematoma [8, 9, 12, 20]						
			Cerebral bleeding [19]		Poorly fitting equipment [9]						
					Aneurysm [8]						
					Ateriovenous malformation [8, 9]						
					Diffuse brain edema [8]						

(continued)

Table 12.5 (continued)

Type of injury	Mechanism of injury or risk factor	Nonspecific sport	Baseball	Cheer	Football	Ice Hockey	Lacrosse	Soccer	Swim and dive	Track and Field	Wrestling
Cervical Spine	Mechanism of injury	Over-extension/ hyper-extension [3]	Collision between players [19, 21–24]	Basket toss [22–24]	Tackle/being tackled (nonspecific) [3, 8, 25, 26]	Checking from behind and contacting the boards horizontally [3, 12, 22–24]		Player-player contact [12]	Racing dive into shallow end of pool [12, 22–24]		Head to head or head to knee collision [13]
		Over-flexion/ hyper-flexion [3]			Blocking/being blocked [3, 8, 27, 28]	Axial load to spine from hitting top of head [23, 24]					
		Axial loading in flexed position [3]			Spear tackling [3, 24, 28]						
					Axial compression [25, 28]						
					Hyperflexion [25, 28]						
					Hyper-extension [25, 28]						
					Collision with teammate [28]						
	Risk factor			Pyramid formation [22–24]	Defensive player [25, 26]						Takedown position [22–24]
					Smaller spinal canal diameter/ stenosis [22]						
Commotio cordis	Mechanism of injury	Projectile contact to chest wall [16–18]	Hit by a thrown or batted ball [19, 21]		Direct impact to chest during tackle/being tackled [8]		Hit by a lacrosse ball [4]				
		Collision with other athlete [16–18]									

(1.22 m) or more at the end of the pool where the start takes place. If the depth is less than 4 ft, the swimmer must start from within the pool.

Table 12.5 provides a summary of head and spinal catastrophic injuries, associated injury mechanisms, and related citations relative to a variety of high school sports [16–31]. The mechanisms and risk factors provided are sport-specific, as each sport has different rules, circumstances and equipment, which will lead to different sources of injury. There is more literature available regarding football and baseball, and these publications generally focus on head and neck injuries. Therefore, any empty cells in Table 12.5 likely represent absences in the literature and not the absence of mechanism or risk factors for specific sports or other types of injuries.

As shown in Table 12.5, the majority of mechanisms include an aspect of contact at the time of injury, specifically for head, neck, and commotio cordis injuries. A more detailed discussion of injury mechanisms relative to sport and playing season follows.

Fall Sports

For the 31 year period 1982–1983 to 2012–2013, high school fall sports (male and female combined) had 840 direct catastrophic injuries and 811, or 96.5 %, were related to football [4, 5]. Although permanent disability injuries in football have seen dramatic reductions when compared to the data from the late 1960s and early 1970s, a total of 51 catastrophic injuries (7 deaths, 21 disability, and 23 serious) in high school occurred during the 2008 season and was a substantial increase from previous years [4]. The nonspecific mechanism associated with major head injuries in football arise from contact with an object or a player. Most of these injuries occur while tackling, and most frequently as a result of helmet to helmet contact, but also as a result of helmet contact with another body part, such as an opponent's knee, or helmet to ground contact [9].

The nonspecific mechanisms associated with cervical spine injuries in high school football include overextension/hyperextension, overflexion/hyperflexion, and axial loading in a flexed position and are most often associated with tackling and blocking, frequently as a result of the illegal practice of using the helmet as an initial contact point ("spearing") [3, 24, 28].

Head injuries, including concussions are common injuries in soccer, mostly from collision between two players as in head-to-head contact [4, 21, 22]. A rare and sometimes fatal event is a blow caused by a falling soccer goalpost resulting from improper installation or use. Since 1998, there have been at least seven deaths and another 1,800 children treated in emergency rooms because of injuries from moveable soccer goals [4]. However, the NCCSIR reports only one fatality that involved a college athlete hanging on a soccer goal, and the goal falling and striking the victim's head [4], presumably causing internal structural injuries in the cranium. While heading continues to be a controversial issue in soccer, head injuries usually are the result of head-to-head or head-to-ground contact [4]. Although heading the ball does not appear to be an immediate cause of head injury, the cumulative long-term effects are still under investigation.

Winter Sports

The number of high school ice hockey injuries is relatively low, but the direct catastrophic injury rate per 100,000 participant-seasons is high when compared to other sports (see Table 12.4). Ice hockey catastrophic injuries usually occur when an athlete is struck from behind by an opponent and makes contact between the crown of his/her head and the boards surrounding the rink, resulting in fractured cervical vertebrae with paralysis [4, 9, 12, 22–24]. In general, contact of the head with the boards, whether as a result of a check from behind or not, and contact with another player were the most frequent injury mechanisms.

High school wrestling has been associated with 63 direct catastrophic injuries during the past 31 years [4]. These injuries usually occur in the takedown position and involve head to head or head to knee collision [13]. Gymnastics and wrestling share a common mechanism in contact of the head with the floor mat. Cheerleading also has a significant number of direct catastrophic injuries resulting from direct contact of the head with the floor (most often without protective mats) or ground, resulting from falls (or failure of other cheerleaders to properly catch) as the individual is dismounting from a pyramid or from a "basket toss", although other mechanisms occur, such as contact with another cheerleader's head or knee, or with a wall [32].

As previously mentioned, high school swimming has been associated with 13 direct catastrophic injuries due to the use of the racing dive in the shallow end of the pool [4, 12, 22, 24]. This is similar to catastrophic injuries in recreational swimming, where neck injuries occur while diving into water that is too shallow [3].

Spring Sports

High school baseball has been associated with 65 direct catastrophic injuries during the past 31 years; however, there were no direct high school catastrophic injuries during 2013. A majority of the baseball injuries have been caused by the head first slide or by being struck with a thrown or batted ball [4, 12, 19, 21]. There also are injuries caused by collision between two players [17, 19, 21–24].

High school lacrosse has been associated with 15 catastrophic injuries during 1982–1983 to 2012–2013 (13 males and 2 females) [4, 5]. An injury mechanism of growing concern is blunt impact to the chest by the lacrosse ball causing death (commotio cordis). There have been six deaths related to this mechanism during the past 13 years [4]. There also have been questions regarding the particular helmet used by players. There was one direct serious injury with recovery to a female high school lacrosse player in 2010 [4].

There were 66 high school track and field catastrophic injuries during the past 31 years and 43 of these involved pole vaulting [4]. Based on these estimates, the catastrophic injury rate for high school pole vaulters would be approximately 1.59–1.79 catastrophic injuries per 100,000 participant-seasons, similar to gymnastics (1.54) and football (1.95) during the same 31-year period. Most pole vaulting accidents involve the vaulter bouncing out of or landing outside of the pit area and sustaining head and neck injuries [22, 30, 31]. There have also been 23 catastrophic injuries (including five fatalities) in high school track and field involving participants being struck by a thrown discus, shot put or javelin; however, there were no such incidents during the last 3 years [4].

Preventive Measures

Once the analytical evidence points to an association between certain risk factors and injury mechanisms and injury, thereby establishing a degree of predictability for those participants who are likely to sustain injury, the next step in epidemiologic research is to seek ways to prevent or reduce the risk of occurrence of such injury [6]. The effectiveness of a preventive measure ideally should be determined by employing an intervention study in which subjects are randomly assigned to treatment and control groups. In practice, however, there has been very little research, whether randomized controlled trials or not, designed to determine the effectiveness of catastrophic injury prevention measures. Ethical, cost, and feasibility issues no doubt combine to preclude experimental research of this nature.

Most injury prevention strategies related to catastrophic injuries, rather, have emerged from clinical and descriptive epidemiological research and have not been tested to determine their effectiveness. In some cases determination of their effectiveness has been based on a comparison of incidence and severity of catastrophic injury prior to and following the intervention (i.e., Step 4, Sequence of Injury Prevention). For instance, the institution of helmet standards and rule changes eliminating spearing and use of the helmet as an initial contact point in American football in the mid-1970s appear to have significantly reduced the number of catastrophic injuries in that sport [7].

National surveillance of catastrophic sports-related injuries conducted by the NCCSIR over

Table 12.6 Prevention guidelines for traumatic injury by injury and sport

Type of prevention intervention	Nonspecific	Baseball	Cheer	Football	Ice Hockey	Lacrosse	Soccer	Swim and Dive	Track and Field	Wrestling
Rules/policy prevention	Enforcement of rules by coaches and officials that reduce risk of injury [3, 20, 21]		Adhere to safety guidelines for aerial and toss maneuvers. [3, 12]	Enforce penalties for illegal contact with helmet/ facemask [21, 33–35]		Enforce current rules which prohibit contact with the head [21]		Dive only in deep end of pool [12, 21]	Recommend that all landing sectors for throwing events be roped off at 3 m outside of sector lines and rope off runways [3]	Referees should enforce penalties for slams [12, 13, 21]
	Have emergency plans in place. [21]			Emergency plans in place. [33, 34]					Enact policy among athletes, coaches and officials to never turn back on throwing circle or runway when in landing area [3]	
	Education of players, coaches and parents about risks of catastrophic injury. [3]		Stunts restricted in rainy /inclement weather. [12]		Officials and coaches enforce rules about illegal checking. [3, 21]					

(continued)

Table 12.6 (continued)

Type of prevention intervention	Nonspecific	Baseball	Cheer	Football	Ice Hockey	Lacrosse	Soccer	Swim and Dive	Track and Field	Wrestling
Coaching prevention	Coaches should not be involved with medical decisions [21]	Teach appropriate fielding techniques [3, 19, 21]	Coaches complete safety certification [12]	Coaches should not make return to play decisions [35]		Coaches should be certified to coach [21]	Teach appropriate heading technique [12]		All coaches be properly trained to coach pole vault. [3, 12, 30]	Coaches emphasize proper techniques. [12, 21, 13]
	Coaches should be well trained in the skills of the sport [21]	Teach appropriate base running techniques [3, 19]	Limit height of pyramid formation.	Coaches should teach fundamentals of tackling and blocking with head up [21, 33–35]					All competitions or practice activities should be supervised by coaches or officials [3]	
Athlete prevention	Proper conditioning [19, 21]	Avoid head first slide [1, 3]	Use spotters [12]	Neck strengthening to assist with tackling/ blocking [33, 34]	Educate players about risk of rule violations [21]				Don't release the pole prematurely [30]	
									Learn proper procedures for bailing out of a bad vault [3]	
									Athletes should not be allowed to retrieve their own implements in the landing sector [3]	

Equipment Prevention	Protective equipment is adequate and well-fitting and well-maintained. [3]	Protective helmets with faceguards for pitchers [1, 2, 4]	Use mats for tumbling/tosses [12]	Equipment is well fitting and properly maintained [21, 33, 34]		Develop better headgear, shoulder pads, and possibly chest protector [36]	Goal posts should be secured and only moved by trained personnel [3, 12, 21]		All hard surfaces be covered [3, 12, 21, 30]	Mats are good quality and well-maintained [21]
	Sport venues are well-maintained and free of hazards [3]	Screens for pitchers during practice [1–4]							Vaulters weight be below the manufacturer's pole rating [30]	
		Wear batting helmets in practices and games [1]							Use compliant and appropriate landing pads [3, 12, 21, 30, 31]	
		Eliminate aluminum bats.[1]							Wear helmets specifically designed for pole vault [3]	
Medical prevention	Pre-partici-pation physical exam [20, 21]			Pre-participation physicals [35]						
	Have adequate medical coverage, including ATCs [3, 20, 21]			ATC or other medical care present [33, 35]						

the last 31 years has facilitated the introduction of numerous data-driven sports safety interventions. These include rule changes, changes to safety and playing equipment, and improved emergency procedures and medical care for catastrophic injury and illness events. In the literature, prevention interventions have been addressed at many levels. For the purposes of this chapter, they have been categorized generally as rules and/or policy, coaching, athlete, equipment and medical interventions and are indicated both in general (nonspecific) terms as well as specific to various sports (Table 12.6) [1–4, 12, 13, 19–21, 30, 31, 33–36]. As with mechanism of injury and injury risk factors, the literature regarding injury prevention is inconsistent; therefore, any empty cells in Table 12.6 represent areas requiring further research rather than areas without means of intervention.

Rules/policy generally address the enforcement of the present rules associated with each sport, and effective emergency plans that are not only in place, but well-rehearsed and readily enacted. The 30–30 rule is a specific prevention measure for lightening injuries, which states that if thunder is heard less than 30 s after seeing lightening, then outdoor activity should be postponed until at least 30 min after the last thunder or lightening is present [37].

Coaching prevention focuses on coaches teaching safe and appropriate techniques, being educated on the signs of injury, and when athletes should be removed from play. Athlete-centered interventions address the individual athletes' role in injury prevention and include removal from the sport when injured, and behaviors such as avoiding inappropriately aggressive play and attentiveness to the play scenario.

The proper and constant use of well-maintained, frequently inspected and well-fitting (when appropriate) equipment is an easily implementable form of injury prevention. Medical interventions often require the presence of qualified medical personnel (including, but not exclusively certified athletic trainers) for both pre-participation physicals and during sport participation. Medical professionals present at sporting events should not only identify and address all potential catastrophic injuries, but also have the power to withhold injured athletes from participation until their injuries have resolved. Athletic trainers are trained to be first responders for catastrophic sports injuries and thus, the "first line of defense" to provide immediate care and help reduce the risk of exacerbating major injuries, increasing the odds of a better outcome [3].

Summary

More extensive injury surveillance systems are needed for coverage of direct catastrophic sports injuries. The National Center for Catastrophic Sports Injury Research at the University of North Carolina has been doing admirable work for many years now covering high school and collegiate sports, and the information produced there is invaluable. But there are many sports and recreational activities that the NCCSIR does not cover, and some sports like gymnastics are school sports but the majority of participants are involved in non-school club programs. This should be the responsibility of the national organizations overseeing or promoting these activities. Indeed, it is an ethical responsibility of these organizations. If they do not maintain the surveillance systems themselves, they should be providing financial and logistical support for those doing the work. Solid data on numbers, rates, etiologies and circumstances of these injuries is needed before effective preventive measures to reduce the occurrence and severity of these injuries can be developed and tested. Because these injuries are relatively rare, large-scale on-going surveillance systems will be necessary.

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13 Psychological Injury in Pediatric and Adolescent Sports

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Introduction

Sport participation for young people has been associated with numerous potential physical, psychological, and social benefits, including for example, enhanced self-esteem, perseverance, physical strength and agility, and the establishment of friendships [1, 2]. Despite these well-documented benefits, sport participation for children and adolescents has also been associated with detrimental outcomes such as the occurrence of injuries—the focus of this book. To-date, the attention on injuries in children's and adolescent sport has been directed primarily at the occurrence of physical injuries ranging from growth-plate damage, concussions, and overuse injuries as examples [3].

Far less attention, however, has been devoted to the occurrences and prevention of psychological injuries in children's and adolescent sport. Despite long-standing concerns expressed by scholars about the competitive nature of organized youth sport and its negative effects on the psychological well-being of young athletes, many of these concerns still characterize sport experiences for young people, including as examples: an over-emphasis on winning at the expense of holistic development, the instrumentalization of child athletes, and overzealous coaches and parents [4–6]. Previous researchers have highlighted psychological implications of these experiences for young athletes, including stress and anxiety, burnout, disordered eating, and identity challenges upon retirement from sport [7–9].

Augmenting these long-standings concerns about the competitive culture of children's and adolescent sport is an increase in academic and public awareness of the potential for psychological harm to be experienced by youth athletes within their important relationships in sport—namely with their parent(s), coach(es), and teammates. This enhanced awareness may, in part, be attributed to the child-centered approach that pervades society more broadly, as reflected by child-rearing and educational practices that prioritize the holistic development of the child including physical, psychological, social, and spiritual considerations [10]. Additionally, the growth of social media has inevitably raised public awareness of sport-related practices that are psychologically harmful to young people. For example, U.S. Olympic gymnast Dominique Moceanu's accounts of struggling with long-term psychological harm as a result of being continually belittled and degraded by her coaches were

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D. Caine, L. Purcell (eds.), *Injury in Pediatric and Adolescent Sports*, Contemporary Pediatric and Adolescent Sports Medicine, DOI 10.1007/978-3-319-18141-7_13

widely publicized [11]. Further, the media is rife with shocking stories of hazing and bullying. For example, Carson Shields, a Canadian junior hockey player, became addicted to illicit drugs and was diagnosed with posttraumatic stress disorder after a hazing incident that included being forced to drink excessive amounts of alcohol and having pictures taken of him while teammates performed degrading acts on him [12].

The purpose of this chapter is to review the research on harm experienced by young athletes in the important relationships within the sport context—namely, those with the coach(es), parent(s), and teammates. Using an athlete-centered perspective, research on harmful parental behaviors, emotionally abusive coaching behaviors, as well as hazing and bullying, will be reviewed with a focus on the psychological injuries caused for the young athlete. Recommendations are made for further research and applied interventions that focus on the cognitive and affective elements of empathy-building.

Athlete-Centered Perspective

In this chapter, the issue of athlete psychological harm will be reviewed from an athlete-centered perspective using a modified framework based on Hellstedt's work [13]. Hellstedt referred to the "athletic triangle" which includes the parent, coach, and athlete, and uses family systems theory to understand the influence of parents and coaches on the development of the athlete. In children's and adolescent sport in particular, the adults in positions of authority, namely the parents and coaches, have particular influence on the nature and quality of the sport experience. We are suggesting a modification to Hellstedt's framework which includes the addition of teammates to the athletic triangle. This modification is proposed because peers in sport play an important role in affecting the nature of the sport experience. While this is easily understood in sports that are traditionally viewed as team sports such as basketball, hockey, or soccer, we argue that even in sports that are typically characterized as individual sports such as swimming, track and field, or gymnastics, these athletes train and travel to competitions together as a group and often share important friendships. Further, it is important to consider the influence of teammates in children's and adolescent sport because developmentally, children and adolescents rely on peer relationships to learn about themselves and their competencies, to help construct their identities, and to meet needs for social connectedness and a sense of belonging [14].

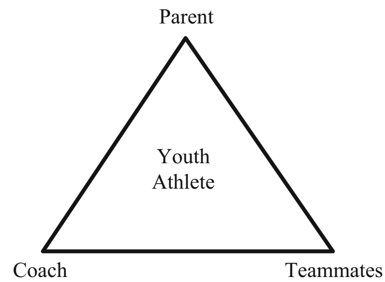

Fig. 13.1 Modified Hellstedt's athletic triangle

Using an athlete-centered perspective, we propose that Hellstedt's model be revised to reflect a focus on the athlete and his or her overall development and athletic success in the center of the athletic triangle, with various influences from the coach(es), parent(s), and teammates on each point of the triangle. This revised framework is seen in Fig. 13.1.

The existing research on psychological harm within the relationships an athlete has with the parent, coach, and teammates will be addressed in turn.

Psychological Harm Within the Athlete–Parent Relationship

> "Mary, kill the bitch!" These are the words of Jim Pierce, father of the former French and Australian Open champion Mary Pierce, when his daughter was 12 and playing a junior match. He also punched two fans at the French Open in 1992 … Mary later acquired a restraining order against her father and hired a bodyguard to protect her; the Women's Tennis Association banned her father from all tournament sites. [15]
>
> "My dad could be pretty intense, too. He'd needle me anytime I decided to come home after school instead of going to the recreation center to

> work on my basketball game and play pickup with older kids. At high school basketball games, students who wanted a little bit of a sideshow with the main event would sit near my father, who could be counted on to yell things like, "Don't sub in Jeff! He's fucking terrible!" … It got a little intense, and there were times when my father's exhortations made me cry, and when I said things to him that I regret ever saying." [16]

Clearly, one of, if not the most, critical relationships a young athlete has is with her or his parent(s). A plethora of literature highlights the important role parents can play by introducing young people to sport, and providing financial, instrumental, and psychological support for athletes to train and compete [17, 18]. On the other hand, researchers have also identified parental behaviors that have detrimental effects on young athletes' psychological health.

Child and adolescent athletes' perceptions of parental overinvolvement for example, have been positively associated with anxiety and burnout [19]. Similarly, perceived parental pressure and excessively high expectations for performance have been linked with increased anxiety amongst youth athletes [20, 21]. Sometimes the excessive pressure to perform well is manifested in harsh criticisms from parents; in fact, Shields, Bredemeier, LaVoi, et al. [22] reported that amongst 189 U.S. youth sport parents, 13 % admitted to angrily criticizing their child's performance. Similarly, in Kidman and colleagues' observations of youth sport competitions, 34 % of the verbal comments from parents were negative in nature, and included scolding the child and criticizing their child's performance [23].

In addition to having direct influences on a child's psychological health, parents play important roles in helping the child navigate important relationships with others in sport including the coach and teammates. One may intuitively assume that parents play a protective role for their children; in fact, Brackenridge [24] suggests that parents play a key role in preventing the sexual abuse of their children by coaches. Interestingly however, research on athletes' experiences of emotionally abusive coaching behaviors suggests that parents are socialized into the sport culture in such a way as to become bystanders in their children's experiences of abuse. More specifically, Kerr and Stirling [25] reported that parents are socialized to accept the coach's authority and expertise and to relinquish control of the nature of their children's sport experiences to the coach. Further, parents learn that what they may initially deem to be inappropriate coaching methods are normalized by other parents as just "part of the game" and thus come to accept them as well.

Further research is needed to examine ways in which parents can enhance their child's psychological health in the sport environment, including the protection of their child from potentially harmful interactions with other stakeholders. Consistent with this view, Fredricks and Eccles ([26], p.145) write, "considering the potential of parents to have either a positive or negative role in children's sport experiences, it is unfortunate that research on this topic is limited."

Precipitating Influences

Although research has not directly examined the precipitating influences of harm within the parent–athlete relationship, several possibilities have been proposed. Excessively high expectations and inappropriate criticisms may be attributed to a lack of education about sport and talent identification and/or child and adolescent development. As Tofler and DiGeronimo [27] have suggested, parents may live their own unmet aspirations through their children, and in the process, lose perspective of their child's abilities and interests. Numerous researchers have discussed the powerful influence of the "win-at-all-costs" attitude or narrowly focused pursuit of excellence that so often characterizes the culture of sport, including children's and adolescent sport [6, 28]. Without appropriate attention to developmentally appropriate experiences for young people, the potential for physical and psychological harm as well as drop-out from sport increases. An overemphasis on wining also encourages parents to relinquish control of decision-making to the coach [25]. Future research is needed to better understand the influences on harm within the parent–athlete relationship.

Psychological Harm Within the Athlete–Coach Relationship

A 13-year-old male hockey player described his coach's behavior as follows:

> My coach would scream and freak out over things in practices, breaking sticks and singling me out in the dressing room saying, 'You don't care about this game, you have no commitment to the team and shouldn't be playing,' He'd say, 'I told you to take that kid's head off and you didn't.' It made me not want to go to my games and practices because I was going to get yelled at. It demoralizes you. [29]
>
> A parent told the Daily Press that Mercedes Winchester, the high school volleyball coach, forced the team to do bear crawls and push-ups on the blacktop at practice, causing the girls' hands to blister and bleed. The reported temperature on that day reached a high of 101 degrees. "The coach had them doing drills and I guess they weren't doing them fast enough or correctly, so she took them outside as punishment," Irene Castro, the mother of a 14-year-old volleyball player, told the Daily Press. "She told them their hands couldn't leave the ground and then she took them back inside and they had regular practice, so they were sliding across the gym floor and the blisters ripped open." [30]

The research on the occurrence of psychological harm within the athlete–coach relationship is characterized predominantly through the study of emotional abuse which is defined as "patterns of nonphysical harmful interactions" between a child and a caregiver [31]. Although the study of emotional abuse of young people has long-existed in the fields of child development, psychology, sociology and social work, empirical research on emotional abuse in sport has emerged only recently.

Of this work in sport, studies have focused on emotionally abusive coaching practices experienced by athletes, and usually student-athletes, aged 18 years and older. In some cases, these young adults were asked to recall and report on their experiences when they were child athletes [32, 33]. For example, a recent online survey of more than 6,000 students reported childhood experiences of harm in sport including emotional, sexual, physical, and self-harm, and body image issues [32]. Emotional harm was the most commonly reported type of harm experienced, with 34 % of the athletes indicating that their coach or trainer was involved in treating them in an emotionally harmful manner. More specifically, both male (29 %, $n = 328$) and female (36 %, $n = 1{,}056$) athletes reportedly experienced emotional harm from their coach. A greater percentage of athletes from individual sports (e.g. dance, swimming, athletics) compared to athletes from team sports (e.g. netball, football, hockey, rugby) reported emotionally harmful coaching experiences.

In all of the existing studies of young adult athletes across a number of countries and sports [32–34] emotional abuse is the most commonly reported form of maltreatment within the athlete–coach relationship. The behaviors that characterize emotionally abusive coaching practices include verbal comments (e.g. yelling, belittlement, degrading comments), physical behaviors (e.g. throwing objects with the purpose of intimidating the athlete), and the denial of attention [34].

To date, the research on emotionally abusive coaching practices is limited by its focus on young adult athletes and intercollegiate student-athletes. There is a paucity of work on child and adolescent athletes' experiences of emotional abuse, and one may speculate that this dearth of research is due, in part, to ethical challenges associated with probing vulnerable populations about such sensitive topics.

Preliminary evidence of the psychological harm experienced by athletes as a result of emotionally abusive coaching behaviors has been provided by Stirling and Kerr [35] who interviewed retired elite athletes from a variety of sports. When asked to reflect on their responses to emotionally abusive coaching practices, these retired athletes reported low mood, anger, low self-efficacy and esteem, anxiety, and reduced enjoyment.

In summary, emotionally abusive coaching behaviors are frequently reported as being experienced by athletes. Preliminary research suggests that psychological harm results from such experiences although further study is needed to better understand the psychological sequelae of emotionally abusive coach–athlete relationships. In addition, future research is needed on current rather than retrospective examinations of child and adolescent experiences of emotionally abusive coaching practices.

Precipitating Influences

A significant body of literature exists on the sources of power held by the coach; this power may be used appropriately or misused in such ways as to harm young athletes. Simply by virtue of their age, size, expertise, access to resources, and ascribed authority as a coach, young athletes are in an unbalanced power relationship with the coach [36]. The abuse of positions of power is at the core of all forms of maltreatment—sexual, physical, and emotional abuse as well as neglect.

Further, some authors have proposed that coaches are ill-prepared for the role and responsibilities of the position and the power that comes with it [37, 38]. While coaches may understand the technical and tactical aspects of a particular sport, there is no guarantee they have a foundational knowledge of child and adolescent development. The latter cannot be assured because no formal educational requirements exist for coaches. In addition, it is not unusual for youth sport settings to rely on volunteer coaches, many of whom are parents from the team. Again, there are no assurances that these volunteer coaches have the requisite competencies for working with young people.

Psychological Harm Within the Athlete–Teammate Relationship

> Hayleigh Abbott, a 12-year-old Quebec Junior Champion had a promising future as a figure skater until her coach allegedly kicked her out of the program after she reported repeated bullying by an older male student. "He would pass her on the ice and he would just swear at her and just call her names," said Cynthia Ruffino, Hayleigh's mother. According to Hayleigh, the verbal insults quickly escalated to physical intimidation. "He would cut me off right before I would jump and he would speed at me really quickly and almost hit me. When I would fall he would just charge at me." said Hayleigh. Her parents began to fear for her safety but despite several complaints to the coach, Hayleigh's family insists nothing was done. [39]
>
> Some Juneau students came back from a high school wrestling meet in Petersburg a few weeks ago with injuries not common to their sport. The frostbitten hands and welts on backsides were the result of hazing from older teammates, according to accounts from parents. The frostbite came after being ordered to hold onto ice until the skin burned. The welts came from being held down and paddled by a group of students. [40]

Peer relationships have been well-recognized in the sport psychology literature as having a significant influence on the psychological development of young athletes. According to some researchers, peers enhance perceived physical competence, motivation for engagement in physical activity, feelings of companionship, and self-esteem [41, 42]. Conversely, recent research on hazing and bullying indicates that peers can also affect a young athlete's psychological health in profoundly negative ways; each of these will be addressed in turn.

Hazing

In 2008, a community in New Mexico was rocked with a scandal that involved a group of male junior high school football players being sodomized by senior teammates as part of a hazing incident [43]. In Saskatchewan, Canada, eleven senior high school athletes were charged in a hazing event that involved hitting younger Grade 9 and 10 team members with hickey sticks [44]. Hazing is defined as: Any potentially humiliating, degrading, abusive, or dangerous activity expected of a junior ranking athlete by a more senior teammate, which does not contribute to either athlete's positive development, but is required to be *accepted* as part of the team ([45], p.449).

Studies examining the prevalence rates of hazing in sport have demonstrated that 17 % of adolescent athletes and approximately 80 % of intercollegiate athletes experience hazing from fellow members of their sport team [46, 47]. Examples of hazing behaviors within sport teams include, being shouted or cursed at, forced sleep deprivation, being contained in a small area, degrading comments based on race, ethnicity, or sex, serving as a personal attendant to someone, or being pressured to consume excessive alcohol or engage in sexual acts [48, 49]. Potential psychological injuries identified as a result of hazing experiences outside of sport environments include loneliness, depression, posttraumatic stress disorder, suicide ideation, and loss of self-esteem [50] although to the best of our knowledge, psychological harm caused by hazing practices in sport has not been explored.

Bullying

Milena Clarke, a 14-year-old basketball player, describes the following experiences of bullying amongst teammates:

> How it [the bullying] started was during one practice, some girls restrained my arms during a drill, then it started going into verbal [taunts]. I tried to go to the coaches and [in front of the team] they told me to 'Toughen up, act as a leader.'" Clarke said the girls teased her with ethnic slurs, which she said she had to look up because she did not even know what the words meant. She lost weight, had trouble sleeping, her grades suffered and she contemplated quitting basketball. "I was just thinking since I wasn't given any chance [to play without being bullied] and they weren't going to do anything to help me, I'll just quit and it will all be over." [51]

According to Mishna ([52], p. 9), bullying is identified as a detrimental relationship problem, which is pervasive throughout society, and tends to result in harmful consequences for those who experience it. Bullying is broadly conceptualized as a repeated behavior characterized by aggression, in a relationship where a power differential exists [52, 53]. An individual can attain power within a peer relationship as a result of personal characteristics (e.g., size, strength, age) or position within a social network (e.g., high social status) [54]. These behaviors are often employed with the intention to cause social, psychological, or physical harm on a target who is perceived as vulnerable or unable to defend oneself with repeated exposure to these behaviors over time [53, 54]. Due to the subjective nature of bullying, experiences may not require repetition over time to be considered harmful; instead, Collot-D'Escury and Dudink [55] propose that a single incident of bullying has the potential to have a strong or chronic impact.

Bullying tends to be categorized into two broad types—direct and indirect bullying—with four separate sub-types, including direct physical aggression, direct verbal aggression, indirect aggression, and cyber bullying [52, 54]. According to Olweus ([54], p.65), direct bullying involves open attacks explicitly demonstrated by an aggressor. These attacks may include physical contact (e.g., hitting, kicking, punching, or stealing) or verbal attacks (e.g., insults, taunting, or teasing) by the aggressor [52, 54, 56]. Conversely, indirect aggression is typically executed through a third party and is intended to cause damage to an individual's peer relationships, self-esteem, or social status [57]. Examples of indirect aggression include gossiping, spreading rumors, or imitating an individual behind his or her back [57]. The final sub-type—cyberbullying—was recently acknowledged as a sub-type of bullying due to an increase in communication through technological devices [58]. Cyberbullying is particularly concerning as it allows the victimization to spread to a larger audience and can be perpetuated over a longer period of time than other forms of bullying [58–61].

To-date, experiences of bullying in the sport context have received limited empirical attention which is perplexing given the vast body of research on bullying in the school environment. One study in sport revealed that 26 % of youth athletes experienced bullying behaviors and of those, 65 % reportedly experienced bullying behaviors in other domains, such as the school environment [55]. Specific to relational aggression, Volk and Lagzdins [62] suggested that female youth athletes experience two-to-three times more relational aggression than nonathletes.

Despite the paucity of research on bullying in sport, the school-based literature clearly highlights the detrimental and often severe effects of bulling, including increased feelings of loneliness, depression, anxiety, suicidal ideations, incidences of self-harm and suicide, and acts of violence [63, 64]. Given these well-documented outcomes of harm and early indicators that the sport context is not immune from incidences of bullying, exploring these behaviors in youth sport context is a critical area for future research.

Precipitating Influences

The influences that may precipitate peer-related violence include power differentials between perpetrators and victims. Those athletes of greater age, physical size, athletic ability, seniority on the team, and social status often have power over athletes with less of these qualities. Further, sexual orientation, ethnicity, and social awkwardness often lead to victimization [47]. Contextual aspects of the sport culture cannot be overlooked when considering peer-related violence in sport. Hazing in particular has long-existed and until fairly recently has been widely accepted as a rite of passage to becoming a member of a sport team. Undoubtedly, sport's roots in the military account in part for the tradition of hazing.

Recommendations for Prevention of Psychological Harm

Numerous initiatives have been established in efforts to prevent psychological harm to young athletes and can be broadly conceptualized into the categories of research, education, policy, and advocacy. Calls for further research on healthy parent, coach, and teammate relationships with young athletes have been addressed throughout the chapter. In addition, various educational programs have been developed and implemented internationally with a focus on raising awareness of harmful coaching behaviors in particular. For example, the Safe4Athletes program in the U.S. aims to educate and prevent experiences of abuse and bullying of athletes [65]. Similarly, the Respect in Sport and the Play by the Rules programs in Canada and Australia respectively seek to educate stakeholders about the maltreatment of athletes [66, 67]; interestingly however, these programs emphasize behaviors to be avoided rather than the education of health-enhancing behaviors. Empirical evaluation of the efficacy of these programs remains an important area for future research. With respect to policy, it has become increasingly popular to have Codes of Conduct for parents, coaches, and athletes that focus on articulating prohibited and expected behaviors (for examples see [68, 69]). With respect to hazing, most sport organizations and educational institutions have implemented policies prohibiting these acts and delineating strict penalties should these policies be violated [70]. Further, advocacy initiatives have been developed to raise awareness amongst stakeholders in sport regarding methods to contribute positively to the healthy development of young athletes. The Positive Sport Coaching initiative in the U.S. [71] and True Sport in Canada [72] are examples of such advocacy initiatives. Empirical evaluations of the extent to which these initiatives achieve their intended outcomes are needed.

Although the effectiveness of these preventative measures is unknown, anecdotal information suggests that the maltreatment of young athletes persists as incidences of emotionally abusive coaches, parents who behave badly, and incidents of hazing continue to emerge in youth sport. We suggest that findings from the research on bullying and offending may contribute to the advancement of our thinking about effective preventative measures. A frequently recommended intervention to address bullying and other offending behaviors pertains to empathy-building. Empathy, defined as "the ability to understand and share in another's emotional state or context" ([73], p. 988) involves both cognitive and affective elements. Previous research indicates that a lack of affective empathy more so than a lack of cognitive empathy characterizes behaviors such as bullying. As Jolliffe and Farrington [74] suggest, it is the ability to experience the emotions of others and not necessarily the ability to understand the emotions of others that is important for the prevention of bullying. It is our supposition that existing measures to prevent the maltreatment of young athletes may not be optimally effective because they focus exclusively on the dissemination of information and thereby address the cognitive dimension of empathy only. It follows therefore that future measures targeted at preventing harm within key relationships in sport should address the affective or emotional dimension of empathy in addition to the cognitive element.

Although simply conjecture at this point, it is intuitively appealing to think that the ability to both understand and experience the emotions of others within a relationship would enhance the psychological health of all parties involved. Moreover, as the use or misuse of power is at the root of psychological harm of the young athlete within his or her relationship with parents, coaches, and teammates, empathy-building may help to promote an understanding of the experiences of those in vulnerable positions of lesser power, including young athletes.

Summary

For the well-documented health and developmental benefits of sport participation to be reaped by child and adolescent athletes, the prevention of injuries—both physical and psychological—must be addressed. In this chapter, we argue that there is sufficient evidence to indicate that psychological injury can occur for youth athletes as a function of harmful relationships with their parent(s), coach(es), and teammates. More specifically, child and adolescent athletes may experience psychological injury as a consequence of parents who exercise excessive pressures to perform or do not protect their children from other harmful relationships; from emotionally abusive coaching behaviors; or from bullying and hazing behaviors from teammates. Although a plethora of preventative measures have been suggested and implemented previously in sport including educational programs, policies, and advocacy, there is an absence of empirical research on their effectiveness. Further, we argue that an enhanced focus on building empathy would go a long way to prevent psychological harm of young athletes. While a lack of empathy doesn't account for all harm within interpersonal relationships, it is foundational to all healthy relationships. Empathy has both cognitive and affective components with the latter found to be more important for preventing such aggressions as bullying behaviors. We propose that the preventative measures implemented in sport currently have been minimally effective because they are focused on the dissemination of information and therefore address the cognitive dimension of empathy exclusively. To promote healthy relationships for young athletes, the affective component of empathy or the ability to experience the emotions of others will also need to be addressed. Future theoretical and applied work should examine this proposition.

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Part V

Injury Causation and Prevention

Risk Factors for Injury in Pediatric and Adolescent Sports

14

Dennis Caine and Brett J. Goodwin

Introduction

Increased participation of children and adolescents in organized sports worldwide is a welcome trend given evidence of declining physical fitness and increasing adiposity [1]. Along with increased participation are increased duration and intensity of training, earlier specialization, year-round training, and increased difficulty of skills practiced and performed [2]. Increased sports involvement of children from an early age and continued through the years of growth gives rise to concern about the risk and severity of injury. Recent data suggest that high sport-, recreation-, and exercise-related (SRE) injury risk constitutes a significant public health burden. For example, more than 7,100 children aged 0–19 years were treated in US hospital emergency departments (ED) for SRE injuries in 2009 [3]. Although it is impossible to eliminate all injuries, attempts to reduce them are obviously warranted.

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An epidemiologic model of sports injury prevention was first proposed by Willem van Mechelen and his colleagues [4] (Fig. 14.1). First, describe the incidence and severity of the sports injury problem. Second, identify factors and mechanisms responsible for sports injury occurrence. Third, introduce preventative measures likely to reduce the future risk and/or severity of sports injuries. Finally, evaluate effectiveness of the preventative measures by reproducing the first step.

Two comprehensive reviews examined risk factors for pediatric sports injuries [5, 6]. The present chapter serves to expand upon this research with more recently published work given the proliferation of risk factor research in the last 5 years. The focus of the chapter is injury risk factors related to sport-related injuries sustained by children and adolescents that have been subjected to statistical tests for correlation and predictive value.

Injury Risk Factors

Risk factors in sport are any factors that may increase the risk of injury. These factors may be classified as either intrinsic or extrinsic [7]. Intrinsic factors are individual biological and psychosocial characteristics predisposing an athlete to injury, such as previous injury or life stress. Extrinsic factors impact the athlete while participating in sport, such as training methods or

D. Caine, L. Purcell (eds.), *Injury in Pediatric and Adolescent Sports*, Contemporary Pediatric and Adolescent Sports Medicine, DOI 10.1007/978-3-319-18141-7_14

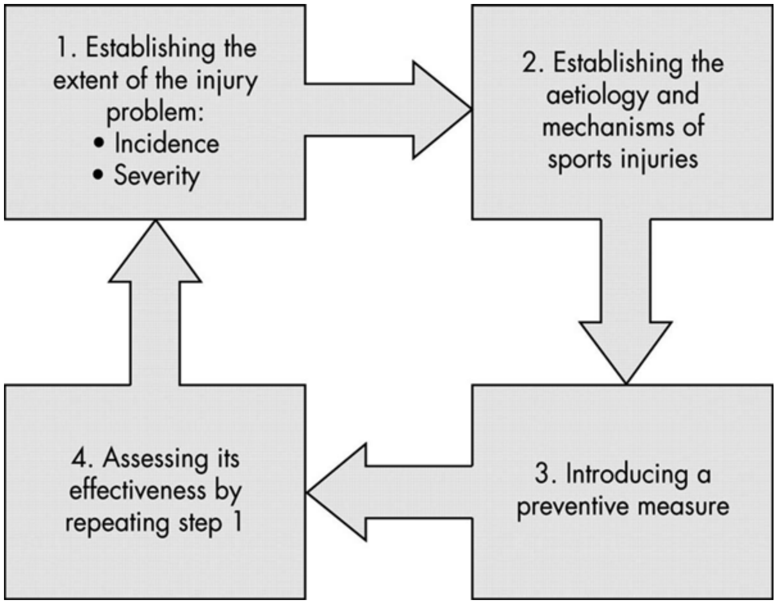

Fig. 14.1 Four-step sequence of injury prevention research. Reproduced with permission from [4]

equipment. Intrinsic factors are viewed as factors that predispose the athlete to react in a specific manner to an injury situation. Once the athlete is predisposed, extrinsic or "enabling" factors may facilitate manifestation of injury [8].

Risk factors can also be divided into modifiable and nonmodifiable factors. Modifiable risk factors can be altered by injury prevention strategies to reduce injury rates while nonmodifiable factors cannot. Although nonmodifiable risk factors may be important considerations in injury prediction, it is clearly important to study factors that are potentially modifiable through physical training and behavioral approaches. The interrelationships between risk factors and their contribution to injury occurrence can be explored using a model by Bahr & Holme [9] (Fig. 14.2). The contribution of an intrinsic or extrinsic factor to injury risk is extremely variable depending on the individual athlete, the sport environment, and the interaction that occurs during participation [10].

Intrinsic Risk Factors

Adolescent Growth Spurt

The adolescent growth spurt is believed to be associated with increased risk of acute sport-related injury [11]. Some studies of SRE injuries indicate increased occurrence of injury during pubescence [12–14]. However, prospective studies linking individual injury rates with longitudinal growth records are required to confirm these findings. The risk of sport-related overuse injury also increases during the adolescent growth spurt [10, 13, 15]. Overuse or repetitive microtrauma can strain the musculotendinous units which may occur more frequently during growth spurts [16]. For example, 10–14-year-old (expected age of peak growth) non-elite gymnasts are more likely to experience chronic wrist pain than either before or after this period [17]. Similarly, stress fractures and low back pain occur with greater

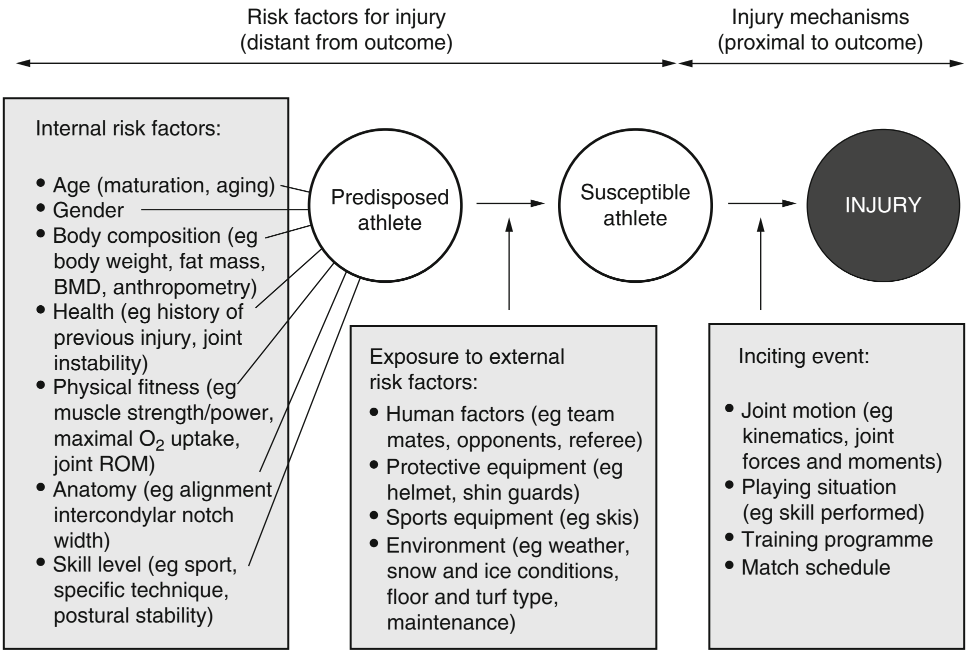

Fig. 14.2 A dynamic, multifactorial model of sports injury epidemiology. Reproduced with permission from [9]

prevalence during the adolescent growth spurt [18, 19]. However, prospective studies are needed to further evaluate this relationship [10]. The adolescent growth spurt also increases the risk of epiphyseal growth plate injury due to decreased physeal strength [20, 21]. Structural changes in growth plate cartilage during pubescence result in a thicker and more fragile epiphyseal plate [22]. In addition, bone mineralization may lag behind bone linear growth during the pubescent growth spurt, rendering the bone temporarily more porous and more subject to injury [11]. This is supported by the finding that peak gains in bone area preceded peak gains in BMD in a longitudinal sample of boys and girls [23]. Studies of the incidence of acute physeal injuries indicate an increased occurrence of fractures during pubescence [11, 24, 25] and a noteworthy association between peak growth and peak fracture rate [11]. In adolescents, peak incidence of distal radius fracture coincides with a decline in size-corrected bone mineral density (BMD) in both boys and girls.

Age/Level of Play

In boys' sports, it is believed that risk of injury is greater among older boys since they are faster, heavier, and stronger, and they generate more force on contact. Years of playing experience and older age were significant predictors of high school gridiron football injury [26]. Practice and overall injury rates increased with grade level in boys' gridiron football [27]. In minor hockey, compared to the youngest age group, Atom, the risk of injury increased significantly through Pee Wee [Rate Ratio (RR) = 2.97; 95 % CI:1.63–5.8], Bantam (RR = 3.72; 95 % CI, 2.08–7.14), and Midget (RR = 5.43, 95 % CI, 3.14–10.17) [28]. In contrast, McKay et al. [29] reported that injury rates were significantly higher among bantam vs. midget hockey players [Injury rate ratio (IRR) 1.51; 95 % CI, 1.03–2.22].

In girls' sports, the findings between age/level of play are also mixed. Emery and colleagues [30] report a significantly higher injury rate among U14 relative to U18 female soccer players

[RR = 3.13, CI: 1.14–10.67 ($p = 0.01$)]. In contrast, the relative risk for injury among USA Gymnastics level 7–9 girls was 1.47 times greater than level 4–6 gymnasts [31]. This difference was even greater (RR = 4.22) for competition, but not for practice (RR = 0.97).

In some sports, there is evidence of an increased risk of certain types of injury with increasing age. Among baseball players aged 9–12 years, there was a significant increase of elbow injuries in the 11–12-year-old age group (OR = 2.82; CI: 1.30–6.10) [32]. Similarly, gridiron football players aged 11–12 years were 2.9 (95 % CI: 1.01–8.12) times more likely to have a concussion than those aged 8–10 years [33]. Head-injured youth soccer players, aged 15–19 years, were almost two times more likely to be admitted to hospital than their younger counterparts (RR = 2.2; 95 % CI: 1.3–3.6) [34].

Injury characteristics may change across age groups. A retrospective chart review on a 5 % random sample of 5- to 17-year-old patients revealed that the 13–17-year age group sustained more anterior cruciate ligament (ACL) injuries, meniscal tears, and spondylolysis, while young children were diagnosed with fractures, including physeal fractures, apophysitis, and osteochondritis dissecans [35]. The proportion of injuries that were fractures was significantly lower for varsity level of competition than for junior varsity, freshman, combined, or other levels [Injury Proportion Ratio (IPR) 0.71;95 % CI, 0.66–0.77] [36].

Balance

Deficiencies in balance are believed to be a risk factor for sport injury, especially to the lower extremity (LE) [5, 37]. Components of the Star Excursion Balance Test (SEBT) were significantly predictive of LE injury in male and female high school basketball players ($p < 0.05$) [38]. High variations of postural sway in high school basketball players corresponded to occurrence of ankle injuries [Odds Ratio (OR) = 1.22, $p = 0.01$] [39]. The association between a positive single leg balance (SLB) test and future ankle sprains was significant among high school and college athletes involved in football, men's and women's soccer, and women's volleyball [40]. The relative risk for an ankle sprain with a positive SLB was 2.54 (95 % CI, 1.02–6.03) in this study. Male and female high school basketball players who demonstrated poor balance had nearly seven times as many ankle sprains as subjects who had good balance [41].

In contrast, balance, as measured on a balance board, was not a significant indicator for noncontact ankle sprains in a sample ($n = 169$) of high school athletes [42]. Similarly, Frisch et al. [43] applied an extensive pre-season test battery, including static and dynamic balance, on a group of U15–U19 football players to determine their relation with risk for injury in general, and for noncontact acute and progressive injuries in particular. Of the variables tested, only physical fatigue was significantly associated with injury ($p < 0.05$).

Biological Maturity

Children of the same chronological age may vary considerably in biological maturity, including growth and athletic performance [44]. Unbalanced competition between early- and late-maturing boys in contact sports such as gridiron football, soccer, and ice hockey may contribute to some of the serious injuries in these sports. Unfortunately, data regarding the relationship between maturity and injury in team sports are limited. The nature of this relationship may vary across gender and sport given the specific somatic and maturational demands of sports.

Injured junior high school football players were lighter and slightly less mature (composite of testicular volume, pubic hair, and axillary hair) than noninjured teammates [45]. A study of the relation between biological maturity, as estimated from grip strength and height, and injury among male soccer players aged 6–17 years found a significantly higher proportion of injuries among the tall/weak boys compared with the immature (short/weak), and mature (tall/strong) boys ($p < .05$) [46].

More physically mature (Tanner stages 3–5) junior high gridiron football players had significantly more injuries than less physically mature (Tanner stages 1, 2) players ($p = 0.03$) [47]. Similarly, Tanner stage 4/5 was a significant predictor of sport injury among adolescents, ages 10–19 years (OR = 1.3; 95 % CI, 1.2–1.4, $p = 0.05$) [48]. Unfortunately, individual variation in exposure to risk of injury was not accounted for in this research. Malina et al. [27] estimated injury rates and relative risks of injury during practice and games by grade over two seasons among youth gridiron football players, aged 9–14 years. Age, height, and estimated maturity status (current height as a percentage of predicted mature height) were not related to injury risk.

A nonsignificant higher injury incidence was found in early and normal maturing soccer players compared with later maturing players (as determined by skeletal age) [49]. In contrast, the late maturing players incurred a significantly higher incidence of major injuries compared with early maturing players ($p = 0.039$). However, early maturing players sustained the highest incidence of groin strains and re-injuries. In contrast, older, taller, and more mature adolescent soccer players had a significantly lower incidence of chronic pain playing on artificial turf [50].

Body Size

There is conflicting evidence regarding body size and injury risk. A concern, particularly in sports where grouping for competition is by age or grade level, is mismatch between smaller and larger boys. In ice hockey, for example, the average weight and height differences between small and large Pee Wee hockey players were 37.2 kg and 31.5 cm, respectively [51]. Injured fourth and fifth grade gridiron football players were significantly lighter in weight and had lower BMI than their noninjured peers ($p = <0.05$) [27].

Several studies report an increased rate of injury among heavier gridiron football players [52–54] or football players with a high BMI [54]. Heavier weight produces greater forces which are absorbed through soft-tissue and joints, perhaps increasing injury risk. Increased risk of injury would seem especially true for overweight football players, or among "oversized" athletes in sports like gymnastics [55, 56] and cheerleading [57] where a small body size is related to success in the sport.

Richmond et al. [58] reported a 34 % increased risk for all sports injuries in obese adolescents over 1 year, as determined by BMI, compared to healthy adolescents [OR = 1.34; 95 % CI: 1.02–1.80)]. In contrast, a curvilinear relationship between BMI and sport injury was reported among a random sample of high school students [59]. The lowest risk of injury was observed in adolescents with a BMI >90th percentile, after controlling for other factors. Students with BMI in the 50th–90th percentiles had the greatest risk of sport injury. A relation between body size and specific injury types has also been reported. Nine-12 year-old baseball players taller than 150 cm had a significantly higher risk of elbow injuries (OR = 2.02; CI: 1.07–3.82) [32]. Similarly, among male and female soccer players 13 years and older, taller players (180–189 cm: IRR = 1.32; 95 % CI: 1.06–1.63) had an increased risk of match injury [60]. Being overweight, as indicated by BMI, and an increased risk of ankle sprains was reported in high school athletes [42] and gridiron football players ($p < 0.05$) [61]. Higher BMI significantly increased the risk of medial tibial stress syndrome in high school female runners (OR = 0.51; 95 % CI: 0.31–0.86) [62]. In contrast, low BMI (<19) was an independent risk factor for stress fractures in a study of female competitive high school runners ($p < 0.05$) [63].

Flexibility

Most studies examining flexibility did not find an association between flexibility and injury in child and adolescent sport [6]. However, less-flexible female gymnasts were more likely to be injured, although this was not significant at all age and competitive levels [64]. In high school wrestlers, increased shoulder ligament laxity was related to increased risk of shoulder injury ($p < 0.05$) [65]. However, this finding did not account for differential exposure to risk of injury.

An explanation for the increased risk of overuse injury during the growth spurt was increased muscle-tendon tightness and accompanying loss of flexibility during the growth spurt [15]. However, the results of several studies have not supported this concept [66–68].

Gender

Studies of injury in gender-comparable sports indicate a variable risk of overall and specific injury types among males and females. For example, in a study of community-level soccer players aged ≥13 years, injury incidence rates were significantly higher for females (95 % CI: 54.9–74.3) than males (95 % CI: 43.0–51.1) [69]. In contrast, boys had a higher injury rate than did girls (RR = 1.33; 95 % CI: 0.99–1.79) in a 3-year study of high school athletes [70].

Among U.S. high school athletes rare injuries and conditions occurred at a higher rate in boys (12.4 injuries per 100,000 AEs) than in girls (2.51) (RR = 4.93; 95 % CI: 3.39–7.18) [71]. Boys also incurred a greater proportion of shoulder injuries (11.1 %) than girls (1.6 %) (IPR, 6.86;95 % CI3.31–14.43; $p < 0.001$) in high school sports during 2005–2010 [72]. Among high school cross-country runners, girls had significantly higher injury rates than boys for overall injuries, initial injuries, subsequent injuries for shin, hip, and foot injuries, and for re-injury rates for knee, calf, and foot injuries [73].

During 2008–2010 high school girls had a higher concussion rate (1.7 per 10,000 AEs) than boys (1.0 per 10,000 AEs) (RR = 1.7; CI, 1.4–2.0) in gender-comparable U.S. high school sports [74]. The incidence of concussion was higher for girls than for boys for basketball and track but not for soccer and baseball/softball in the North Carolina High School Athletic Injury Study (NCHSAIS) [57].

In the NCHSAIS [75], the overall rate of knee injuries for boys was 39.2 injuries per 100,000 AEs compared to 24.9 for girls. Although boys had a higher overall rate of knee injuries in US high schools during the 2005–2007 seasons, girls were twice as likely to sustain knee injuries requiring surgery than boys (IPR = 1.98; CI, 1.45–2.70) and twice as likely to incur noncontact surgical injuries (IPR 1.98, CI: 1.23–3.19) [76]. ACL injuries have also been extensively studied in female athletes and there is consensus that they have a higher risk than male athletes [77].

Possible explanations for the difference between genders include hormonal differences, increased joint laxity in female athletes, anatomical differences, and differences in motor control of knee function which may predispose adolescent females to knee injuries in cutting and jumping sports [78]. Furthermore, adolescent growth in females is associated with increases in knee extension strength and decreases in hip abduction and hamstrings-quadriceps ratio strength which have been linked to increased risk for ACL injury and patella-femoral syndrome [79]. Pubertal females had an increased change in abnormal landing mechanics over time, thus predisposing to knee injury [80].

Menstrual Regularity and Low Energy Availability

A history of amenorrhea, especially in sports that emphasize leanness, is a risk factor for bone stress injury in physically mature females [10]. However, data regarding menstrual irregularity, low-energy availability, and injury in younger adolescents are rare. Late menarche (age menarche ≥ 15 years) was an independent risk factor for stress fracture among high school female runners [63]. A survey of high school female athletes on disordered eating (DE) and musculoskeletal injury found that athletes reporting DE were twice as likely to report injury compared to those reporting normal eating behaviors [OR =2.3; 95 % CI: 1.4, 4.0; $p < 0.05$) [81]. In a study of female athletes competing in eight interscholastic sports, athletes who scored ≥4.0 on the Eating Disorder Examination Questionnaire had a history of oligo/amenorrhea during the past year, and those who had a low BMD (BMD *Z*-score of -2SD or less) had a significantly greater occurrence of musculoskeletal injury ($p < 0.05$) [82].

Previous Injury

Previous injury is a well-known risk factor for new injury at the same location [26, 30, 63, 73, 83]. Previous musculoskeletal injuries can lead to fibrosis, with adhesions and limited joint motion and function, thus predisposing to further injury at the same site [73]. Restricted joint motion will lead to muscle atrophy and increased compensatory stress on other areas, thus predisposing to injury at other sites. Injury at other sites has also surfaced as a risk factor for new injury [83].

Psychosocial Characteristics

Life stress has been shown to predict injury [84, 85]. In youth sports, this link has been demonstrated in gymnastics [86, 87], soccer [88], and ice hockey [89]. The retrospective nature of injury data collection in some studies and the relatively short periods of monitoring injury and psychosocial variables may influence these findings. However, Steffen et al. [88] reported that high life stress ($p = 0.003$) and perception of a mastery climate ($p = 0.03$) (personal accomplishment is emphasized) were significant risk factors for new injuries in female youth soccer players. McKay et al. [29] reported that athletic identity scores below the 25th percentile (as measured by the AIMS) were associated with subsequent injury [IRR = 2.28; 95 % CI, 1.01–1.64)]. However, state anxiety was not a significant predictor of injury in this study of elite youth ice hockey players.

Extrinsic Risk Factors

Coaching

Although multiple coaching education programs are available there are no mandated national coaching education programs in the United States [90]. Additionally, requirements for high school coaches vary from state to state, with some requiring first aid and cardiopulmonary resuscitation (CPR) certification. Numerous coaching education programs provide information related to proper biomechanics of sporting skills, nutrition, physical conditioning, development of athletes, and prevention, recognition, and management of injuries. Unfortunately, many youth sports coaches, although well-meaning parents or teachers, have little professional training or certification related to the sport(s) they coach. This situation has raised concern regarding increased risk of injury in the absence of well-trained coaches.

The National Center for Catastrophic Sport Injury (NCCSI) reports that more than one-half (63.3 %) of direct catastrophic injuries to female athletes arise from high school and college cheerleading [91]. The NCCSI suggests that inexperienced and untrained coaches who try to teach stunts that they neither have the knowledge nor ability to teach, or that are above the skill and capabilities of the team, may increase the risk of catastrophic injury.

Among high school football players, injury rate was not associated with coach skill level [70]. However, if injured, having a coach with more experience, qualifications, and training was associated with reduced odds of severe injury [OR = 0.49; 95 % CI, 0.27–0.92].

In a 3-year study of cheerleading injuries testing a coaching experience/qualification/training (EQT) variable, supervision by coaches with higher EQT reduced injury risk by 50 % (RR = 0.5; CI, 0.3–0.9) and supervision by coaches with medium coach EQT reduced injury risk by nearly 40 % (RR = 0.61;95 % CI, 0.32–1.160 [57]. In contrast, Knowles et al. [70] tested a similar coach EQT across 12 sports and found it not to be a predictor of injury rates when subjected to multivariate analysis.

Fatigue

There is growing concern regarding the contribution of overscheduling (e.g., practices, games, and matches) in youth sports to fatigue overuse injuries [16]. An overscheduling injury may be defined as an injury related to excessive planned physical activity without adequate time for rest or recovery [10]. Studies in a variety of sports such as baseball, tennis, cricket, running, and soccer have demonstrated that high workloads between hours and bouts of activity are consistently associated with increased injury risk [10]. For example, athlete or parent perception of excessive playing/training time without adequate rest in the days before an injury was related to frequency of overuse ($p = 0.16$) and fatigue-related ($p = 0.01$) injuries [92]. Only physical fatigue was significantly associated with injury in youth football (U15–U19) [43].

In a case-control study comparing adolescent pitchers who had shoulder or elbow surgery ($n = 95$) with pitchers with no significant pitching-related injury ($n = 45$), the factors with the strongest associations with injury were overuse and fatigue [93]. Arm fatigue during the game pitched was a predictor ($p < 0.01$) of elbow pain in a longitudinal study of elbow and shoulder pain in youth baseball pitchers [94]. Fatigue also appears to play a role in Junior ice hockey, where most injuries occurred during the middle and later portions of the period. Also, most injuries were sustained during the third period of the game [95].

Rules Regarding Body-Checking in Ice Hockey

Body-checking has been identified as a significant injury risk factor in youth ice hockey [96]. A 10-year study showed that the likelihood of an ED visit increased because of body-checking-related injury (OR = 1.26; 95 % CI: 1.16–1.38) after a rule change allowing body checking for players as young as 9 years in the 1998–1999 season [97]. Similarly, there was more than a threefold increased risk of all game-related injuries (RR = 3.26; 95 % CI: 2.31–4.60) among 11–12-year old ice hockey players in a league which allowed body checking compared with players in a league which prohibited body checking [98]. Notably, the RR for concussion was also greater (RR = 3.88; 95 % CI:1.91–7.89) in the league in which body checking was permitted.

Volume and Intensity of Training

Sport specialization and increased complexity of skills practiced and performed at an early age raises concern regarding how much training is too much and at what age intensive training should begin. Participation in only one sport, beginning at an early age, can result in increased risk for repetitive microtrauma [99]. Notably, in a study of 2,721 high school athletes, the risk of injury increased with weekly hours of participation [59].

In youth baseball pitchers, pitch volume has the greatest association with injury rate [100, 101]. Participants who pitched more than 100 innings in a year were 3.5 times more likely to be injured (95 % CI, 1.16–10.44) [102]. Similarly adolescent pitchers who had shoulder or elbow surgery pitched significantly more months and games per year, and more innings per game than their uninjured counterparts [93].

Australian Junior Cricket bowlers with an average of <3 rest days between bowling were at a significantly increased risk of injury [RR = 3.1, 95 % CI, 1.1–8.9) compared to bowlers with ≥3.5 rest days [103]. In junior tennis, injured players performed significantly more singles matches per week ($p < 0.0001$) and played more tennis hours than uninjured players [104]. Finally, young gymnasts with wrist pain trained significantly more hours per week (13.5 vs. 7.7) than gymnasts without wrist pain ($p = 0.016$) [105].

How much training per week is too much and after what point does the risk of injury begin to rise markedly? Several authors report that training in excess of 16 h/week is associated with a significant increase in injury risk requiring medical care [59, 106, 107]. For example, girls who participated in ≥16 h/week of activity had 1.88 greater odds of a history of stress fracture than girls who participated in <4 h per week (95 % CI, 1.18–1.30) [106]. However, the recommended volume of training varies depending on a variety of factors including sport and response to training, making it a challenge to define sport-specific workload thresholds that correlate with increased injury rates [10].

Study Limitations

Analysis of injury risk factors in children's and youth sport has produced a number of significant injury predictors. However, the following study limitations are common: (a) variable definitions of injury, (b) use of clinical incidence rather than incidence rates (rates based on hours or sessions of exposure) to distinguish high-risk athletes, (c) failure to account for different categories of injury onset, (d) inappropriate analyses for detecting multifactorial risks, (e) small sample sizes, and (f) relatively short periods of data collection. Research limited to one event, one season, or 1 year is unlikely to provide trustworthy estimates of injury rates or strong evidence for predominant injury risk factors due to the relatively strong effect of unusual events [108].

What complicates the identification and quantification of risks is that causes of injury are both extremely complex and dynamic. Meeuwisse et al. [109] proposed a dynamic recursive model that accommodates a multifactorial assessment of causation in athletic injuries and emphasizes that adaptations occur within the context of repeated participation in sport (both in the presence and absence of injury) that alter risk and affect etiology in a dynamic, recursive fashion (Fig. 14.3). In this model, intrinsic factors predispose the athlete to react in a specific manner to an injury situation. However, intrinsic factors are not constant and may change in response to injury or to absence of injury (i.e., adaptive changes such as increased intrinsic strength). Once the athlete is predisposed, extrinsic or "enabling" factors such as faulty equipment or coaching behavior may facilitate manifestation of injury. According to the dynamic recursive model, extrinsic risk factors are also subject to change in the context of repeated participation in sport. For example, adaptations in the athlete may occur due to participation itself, for example injured or not injured, thus altering risk of injury.

It is noteworthy that study designs related to the risk factor research reviewed in this chapter typically did not account for the dynamic recursive nature of sport injury. We have to ask whether it is appropriate to measure variables (e.g., height, weight, flexibility, maturity) once or whether they should be measured multiple times to incorporate changes during the study [110]. Placing this in the context of nonexperimental designs, cohort stud-

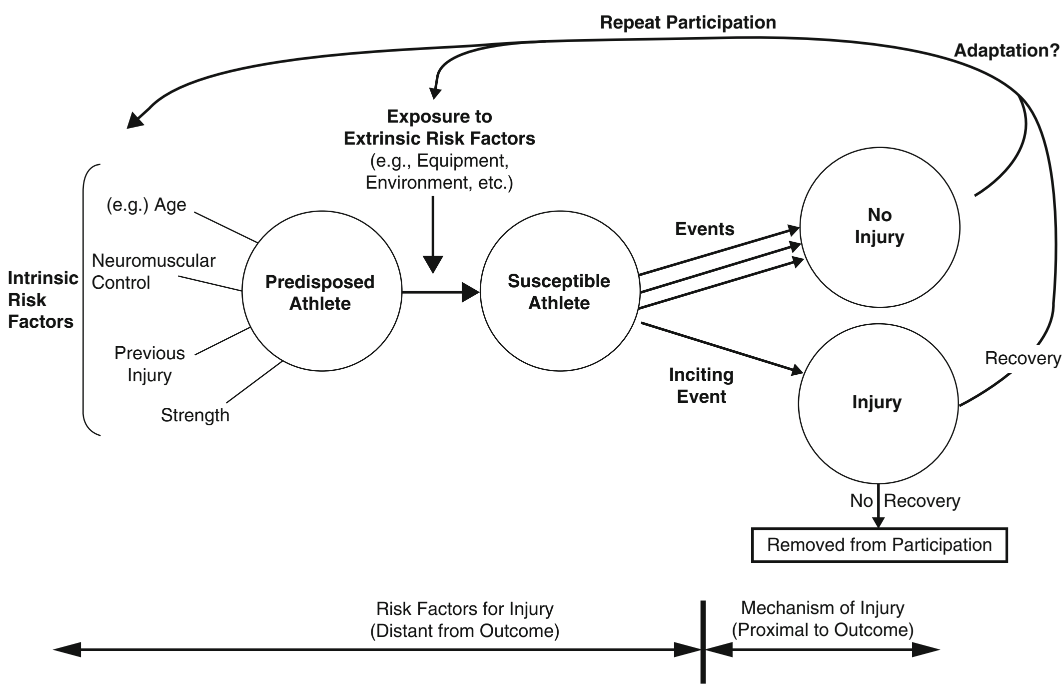

Fig. 14.3 Recursive model of etiology in sport injury. Reproduced with permission from [109]

ies would better be accomplished with repeated measures to account for changes over time, allowing for an accounting of exposure implications, specifically, with time-dependent variables [110].

Summary

Analysis of sports injury risk factors in child and adolescent sport has produced a number of significant injury predictors including age, balance, body size, maturity status, gender (specific to sport and type of injury), previous injury, stressful life events, rules regarding body-checking in ice hockey, volume of training, and fatigue. There is also preliminary evidence that the growth spurt is associated with an increased risk of injury and that menstrual irregularity and low-energy availability may relate to increased risk of injury in younger adolescents. However, results of the analyses of risk factors in child and adolescent sports are not consistent from sport to sport and may suffer from one or more methodological limitations and therefore should be interpreted cautiously. 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.

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15 Injury Prevention in Youth Sport

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Introduction

Youth have very high participation and injury rates in sport; in fact sport is the leading cause of injury in adolescents, accounting for >30 % of injuries in this population across many countries [1–4]. Participation in sport has important implications for public health benefit in our young population. In addition, the benefits of ongoing sport participation in youth will also include the psychosocial benefits of greater self-esteem, motor skill development, socialization, teamwork, competition, and stress reduction. However, the proportion of overweight and obese children has increased over the past 25 years in Canada with more than 30 % of children and adolescents classified as overweight or obese and similar trends are found worldwide [5, 6]. Sport participation rates decrease significantly in adult years [7]. Sport injury may contribute to this burden with reportedly 8 % of youth dropping out of sport annually because of injury [8]. In Canada, the estimated injury incidence proportion in youth sport is 40 injuries/100 students/year requiring medical attention (ages 15–18) and 30 injuries/100 students/year requiring medical attention (ages 11–14) [9, 10]. This burden of injury highlights the need for interventions to reduce risk of injury in youth. Lower extremity injury and concussion are among the most common, accounting for over 60 % and 15 % of the overall injury burden in youth sport respectively [9, 10]. Sport injury not only reduces future participation in physical activity which adversely affects future health but also leads to overweight/obesity, post-traumatic osteoarthritis, or post-concussion syndrome [11–15]. Joint injury is a leading cause of osteoarthritis, with a recent meta-analysis indicating a fourfold increased risk of developing OA after knee joint injury [14]. In addition, 14 % of school-aged children sustaining a concussion will still be symptomatic after 3 months [15]. As such, reducing the public health burden associated with injury in youth sport is critical.

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D. Caine, L. Purcell (eds.), *Injury in Pediatric and Adolescent Sports*, Contemporary Pediatric and Adolescent Sports Medicine, DOI 10.1007/978-3-319-18141-7_15

Reduction of sport injury would have a major impact on quality of life through the promotion of physical activity. There is long-standing epidemiological evidence that level of physical activity participation is a significant predictor of multiple-cause morbidity and mortality (e.g., cancer, cardiovascular disease, diabetes, mental illness) [11–13]. Thus, reducing the public health burden associated with injury in youth sport is critical.

Van Mechelen developed a four-stage approach to studying injury prevention in 1997, which continues to be the model of choice in the evaluation of injury prevention strategies in youth sport over the past two decades [16]. The model establishes the need to first identify the extent of injury in a given population through surveillance and second to identify risk factors for injury in that population. Third, injury prevention strategies require development and validation prior to evaluation studies to measure the impact of the prevention strategy using appropriate surveillance. Randomized controlled trials (RCT) are the ideal research design to evaluate the efficacy of a prevention strategy; however when an RCT is not plausible, a quasi-experimental, cohort, case-control or other non-experimental analytic study is often used [17].

The implementation of injury prevention research into practice has had a great deal of attention in recent years [18–20]. Wide-scale implementation of cost-effective intervention measures under real life conditions has proven to be an ongoing challenge that cannot only be examined in the context of an RCT [21]. Various implementation sport injury prevention research frameworks have been proposed including the Translating Research into Injury Prevention Practice (TRIPP) Framework which is the most widely adopted and should be considered [20]. The TRIPP framework is in essence an addendum to the original van Mechelen model [16], describing two additional stages that are required to translate effective prevention strategies into practice [20]. In TRIPP stage 5, implementation starts with the description of the context for which the original intervention was developed in order to inform implementation strategies [20]. This description is necessary to understand how the outcomes of the controlled studies can be successfully transferred to a real-world context of elite and community sports. In order to inform implementation strategies, effectiveness studies should aim to describe the type of sport or activity, age groups, level of play, and organizational structure in which the original intervention was evaluated. The TRIPP stage 6 involves implementing the intervention in a real-world context and evaluating its effectiveness. In other words, determining how effective the scientifically proven interventions are when applied to the real-world context of player behaviors and sporting culture [20].

The RE-AIM framework (Reach Efficacy Adoption Implementation Maintenance Framework) was originally developed to evaluate the public health impact of health promotion interventions [22]. This framework describes five cross-cutting dimensions that identify the translatability and feasibility of a program [22]. There has been minimal focus on such a framework in the context of sport injury prevention strategy evaluation to date, but it is expected that this will continue to be an area of further development in the field [23–25]. In addition, the value of economic evaluation of injury prevention research has more recently been identified, adding relevant insights into the financial input and outcomes of preventive approaches. This information will inform practice and policy related to injury prevention strategies. An efficient use of limited financial resources is imperative, yet only a handful of full economic evaluations in the field of injury prevention in sport have been published [26–29].

In developing the optimal implementation strategy that will maximize the effectiveness of a specific sport injury prevention program, it is critical to consider the multiple factors that may influence adherence to such a program across levels of influence (Table 15.1) [30].

An extension of this model developed by Emery et al. [30] emphasizes the diversity of factors across the multi-leveled influences on youth safety behaviors (Fig. 15.1) [31].

Table 15.1 Goals and strategies recommended at each level of responsibility based on the "Levels of Responsibility in Injury Prevention Model" (Emery et al. [30], reproduced with permission)

Level of responsibility	Goals	Sample strategies
Child	Enhance behavior adoption, adherence, and short- and long-term maintenance	Identify: • Reasons for participating in sport (i.e., skill development, enjoyment, social interaction, competition) • Role of significant others/role models (i.e., parents, coaches, peers, teammates) • Knowledge of injury risk and long-term health implications • Attainable and meaningful goal • Barriers and facilitators to adoption and adherence of sport safety measures (i.e., skill, availability of resources)
Parent	Support child's interests, motivation for participation, and facilitate adoption and adherence to sport safety measures	• Reinforce importance of injury prevention messages and strategies • Model appropriate behavior • Acknowledge feelings and be supportive
Coach/Teacher/ Trainer	Support effective knowledge transfer and facilitate intrinsic motivation toward the adoption and adherence of sport safety and injury prevention measures	Provide: • Meaningful rationale for engaging in the task • Opportunities for skill development • Skill contingent activities • Acknowledge participation • Appropriate and meaningful feedback • Involve youth in decision making and goal-setting (individual and team); incorporate their ideas, interests, and needs • Identify how injury prevention goals align with individual and team goals; monitor progress • Adopt a supportive and communicative style; listen, clarify expectations, and offer choice • Acknowledge that the needs of the youth participant go beyond the realm of sport (care about the whole individual)
Sport organization	Awareness, engagement, training and educational opportunities for coaches, parents, and children	• Reinforcement through policy and supportive environments (social, physical, cultural)
Government	Prioritization of injury prevention and health promotion within the context of youth sport	• Policy generation and community level translation (education, sport) • Establish risk management procedures • Provide targeted funding and infrastructure support

It is impossible to eliminate all injury in youth sport; however, injury prevention strategies can reduce the number and severity of injuries in many sports. The purpose of this chapter is to provide an evidence-based review on what is known about intrinsic and extrinsic injury prevention strategies which have been evaluated in child and adolescent sports. Injury prevention strategies are highlighted and gaps in the literature in injury prevention in youth sport are summarized.

Injury Prevention

Based on relative burden, the focus of much of the evidence surrounding injury prevention in youth sport has been on reducing the risk of lower extremity injuries and concussions. Until the past decade, there has been a relative paucity of scientifically rigorous evaluation studies examining the efficacy of injury prevention strategies in youth sport [32, 33]. Historically, epidemiological

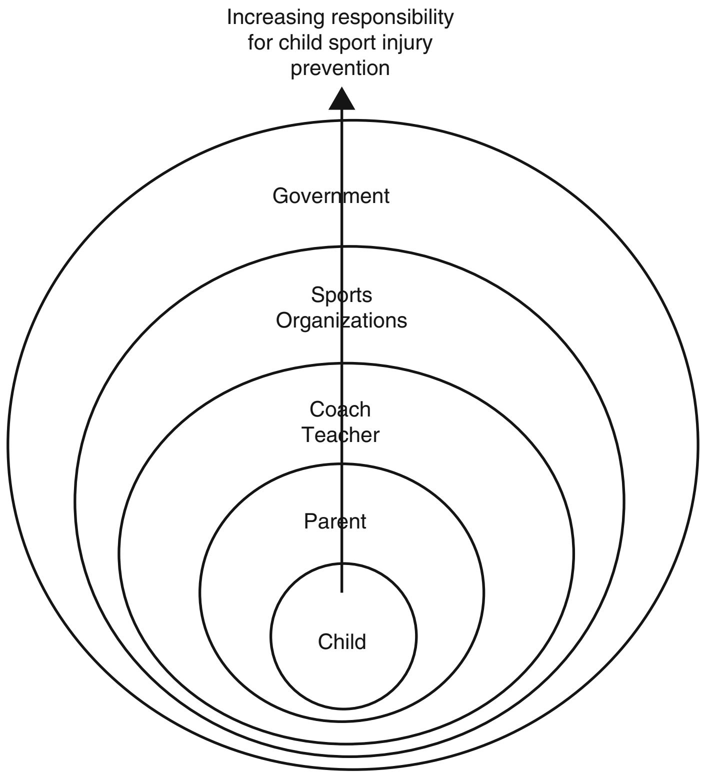

Fig. 15.1 Responsibility for sport injury prevention (Emery et al. [30] reproduced with permission)

research focused on the evaluation of prevention strategies in elite adult amateur and professional athlete populations where injury surveillance practice was established more commonly with the presence of medical staff within the sport structure [32, 33]. As a result, previous recommendations for injury prevention practice in youth sport have relied heavily on studies in adult elite sport populations [32, 33].

Injury prevention strategies may be developed to target intrinsic risk factors including previous injury, decreased strength, endurance, flexibility, and neuromuscular control including balance. Alternatively, prevention strategies may be developed to address extrinsic risk factors including changes in the rules of the sport and protective equipment. To inform this book chapter, the literature evaluating injury prevention strategies in youth sport has been systematically reviewed and has demonstrated an increasing body of literature in the youth athlete population. Studies selected and summarized in Table 15.2 included only studies which (1) were based on original data with full-text paper published; (2) included only youth sport participants under age 19; (3) evaluated an injury prevention intervention with a primary outcome of sport injury; (4) study design was prospective and included randomized controlled trials (RCT), quasi-experimental, or cohort designs. In addition, review articles are also considered. In total, 31 studies have been identified and categorized by sport (Table 15.2) [34–64]. Seventeen studies are RCTs with the remainder being primarily quasi-experimental (non-randomized experimental design) and cohort studies [34–64]. The studies included are in youth soccer (11), ice hockey (2), European handball (3), American Football (3), basketball (2), rugby (1), Australian football (1), baseball (1), multi-sport (5), and school physical education (2). A diversity of at risk sport-specific and school-based youth sport populations have been targeted for injury prevention strategy evaluations. The greatest proportion of these strategies have targeted modifiable intrinsic risk factors (e.g., strength, endurance, balance) through exercise interventions, primarily neuromuscular training interventions [34–44, 47–51, 53, 54, 56, 58–61,

Table 15.2 Injury prevention research in youth sport

Sport title Author Publication Year	Study, design, duration, country	Participants (sport, level, sex, age, sample size) (IG = Intervention group; CG = Control group) (*n* = # players, *N* = # teams)	Outcome (injury definition)	Intervention description	Control condition description	Reported incidence rate (IR/1,000 h) or incidence proportion (IP/100 players) (IG = Intervention group; CG = Control group)	Effect estimates [incidence rate ratios (IRR), risk ratio (RR), odds ratio (OR) (95 % CI)] Reported or calculated based on data provided
Soccer							
Emery et al. 2010 [34]	Cluster RCT 1 indoor season (20 weeks) Canada	Soccer Male and female (12–17) IG: (*n* = 380, *N* = 32) CG: (*n* = 364, *N* = 28)	Soccer injury requiring medical attention and/or time loss (assessed by physiotherapist)	NMT program (15 min coach delivered, physiotherapist taught warm-up) (aerobic, dynamic stretching, strength, balance, agility) and a 15-min home-based balance training (wobble board)	Home stretching program + standard of practice warm-up	All injury IG: IR = 2.08 CG: IR = 3.35 Acute injury IG: IR = 1.75 CG: IR = 3.05 LE injury IG: IR = 1.75 CG: IR = 2.54 Ankle sprain IG: IR = 0.58 CG: IR = 1.14 Knee sprain IG: IR = 0.12 CG: IR = 0.34	All injury IRR = 0.62 (0.39–0.99) Acute injury IRR = 0.57 (0.35–0.91) LE injury IRR = 0.68 (0.42–1.11) Ankle sprain IRR = 0.5 (0.24–1.04) Knee sprain IRR = 0.38 (0.08–1.75)
Hägglund et al. 2013 [35]	Cohort study 1 season (7 months) Sweden (secondary analysis of an RCT)	Soccer Eight Swedish districts Female (12–17 years) IG (*n* = 2,471, *N* = 181) CG (*n* = 2,085, *N* = 157)	Soccer injury (a) Acute knee injury—sudden onset and time loss (b) ACL injury—partial or total tear isolated, concomitant, new or recurrent	NMT program (Knakontroll)—taught by therapist, coach, and player delivered 2×/week training session (DVD and pamphlet)	Standard of practice	IG: IR low compliance = 0.72 IR intermediate compliance = 0.19 IR High compliance = 0.2 (7 ACL) CG: IR = 0.34 (14 ACL)	IG: Low compliance: 1 (reference) Intermediate compliance: IRR = 0.26 (0.12–0.57) High compliance: IRR = 0.28 (0.13–0.55) CG: Control IRR = 0.48 (0.29–0.82)

(continued)

Table 15.2 (continued)

Sport title Author Publication Year	Study, design, duration, country	Participants (sport, level, sex, age, sample size) (IG = Intervention group; CG = Control group) (n = # players, N = # teams)	Outcome (injury definition)	Intervention description	Control condition description	Reported incidence rate (IR/1,000 h) or incidence proportion (IP/100 players) (IG = Intervention group; CG = Control group)	Effect estimates [incidence rate ratios (IRR), risk ratio (RR), odds ratio (OR) (95 % CI)] Reported or calculated based on data provided
Heidt et al. 2000 [36]	RCT 1 year (4 month + 6 month season) USA	Soccer Female (14–18 years) IG (n = 42) CG (n = 258)	Soccer injury Time loss	Preseason NMT (7 week—20 session) (sport-specific cardiovascular conditioning, plyometrics, sport cord drills, strength, and flexibility)	Standard of practice	IG: 7 injuries IP = 16.67 Knee: 3 ACL: 1 Ankle: 2 CG: 91 injuries IP = 35.27 Knee: 29 ACL: 8 Ankle: 26	All injury RR = 0.47 (p = 0.0085) ACL injury RR = 0.77 (p > 0.05)
Junge et al. 2002 [37]	Quasi-experimental design 2 seasons Switzerland	Soccer Male (14–19 years) IG (n = 101, N = 7) CG (n = 93, N = 7)	Soccer injury Any physical complaint >2 weeks or time loss injury Overuse injury	F-MARC Bricks—NMT program Warm-up (flexibility, strength, coordination, reaction time, endurance), cool down, ankle taping, rehabilitation, fair play Coach education, coach delivered + physiotherapist weekly	Standard of practice	IG: 77 injuries in 53 players IR = 6.71 CG: 111 injuries in 67 players IR = 8.48 Overuse IR IG IR = 3.96 CG IR = 5.69 High-skill group IG: 6.35 CG: 6.78 Low-skill group IG: 6.95 CG: 11.1	All injury IRR = 0.79 (p > 0.05) Overuse injury IRR = 0.7 (p > 0.05) High-skill group IRR = 0.94 (p > 0.05) Low-skill group IRR = 0.63 (p < 0.5)

Kiani et al. 2007 [38]	Quasi-experimental design 1 season 12 weeks preseason training + 6 month season Sweden	Soccer Female (13–19 years) IG (n = 777, N = 48) CG (n = 729, N = 49)	Knee injuries requiring medical attention	Harmo Knee (warm-up, muscle activation, balance, strength, core stability) (2×/week preseason, 1×/week season)	Standard of practice	Knee injury IG: IR = 0.04 CG: IR = 0.2 Noncontact knee injury IG: IR = 0.01 CG: IR = 0.15	Knee injury IRR = 0.17 (0.04–0.64) Noncontact knee injury: IRR = 0.06 (0.01–0.46) Adjusted for cluster, age, match:training ratio, # players on team, intensity
Malliou et al. 2004 [39]	Quasi-experimental design 12 months Greece	Soccer elite youth (mean age 16.7 IG and 16.9 CG) IG (n = 50, N = 2) CG (n = 50, N = 2)	Lower extremity injury requiring time loss (assessed by orthopedic surgeon, physiotherapist, and/or trainer)	Balance training (Biodex Stability System, mini trampoline, balance boards) (2×/week, 20 min)	Standard of practice soccer training	LE injury IG: 60 (IP 1.2) CG: 88 (IP 1.76)	RR = 0.68 (0.48–0.96)
Mandelbaum et al. 2005 [40]	Quasi-experimental design 2 season USA	Soccer Female (14–18 years) Season 1 IG (n = 1,041, N = 52) CG (n = 1,905, N = 95) Season 2 IG (n = 844, N = 45) CG (n = 1,913, N = 112)	Knee injury—self-report Noncontact ACL tear—physician assessed and MRI and/or arthroscopic procedure	The Prevent Injury and Enhance Performance (PEP) Program (videotape including warm-up activities, stretching, strengthening, plyometric, agility)	Standard of practice	Year 1: IG: 2 ACL IR = 0.05 CG: 32 ACL IR = 0.47 Year 2 IG: 4 ACL IR = 0.13 CG: 35 ACL IR = 0.51	Year 1 ACL IRR = 0.11 (0.03–0.48) Year 2 IRR = 0.26 (0.09–0.73)

(continued)

Table 15.2 (continued)

Sport title Author Publication Year	Study, design, duration, country	Participants (sport, level, sex, age, sample size) (IG = Intervention group; CG = Control group) (n = # players, N = # teams)	Outcome (injury definition)	Intervention description	Control condition description	Reported incidence rate (IR/1,000 h) or incidence proportion (IP/100 players) (IG = Intervention group; CG = Control group)	Effect estimates [incidence rate ratios (IRR), risk ratio (RR), odds ratio (OR) (95 % CI)] Reported or calculated based on data provided
Soligard et al. 2008 [41]	Cluster RCT 1 season (8 months) Norway	Soccer Female 125 clubs (13–17 years) IG (*n* = 1,055, *N* = 65) CG (*n* = 837, *N* = 60)	Soccer injury (a) All—time loss injuries only (b) Lower extremity (LE) (c) Knee (d) Ankle (e) Acute—sudden onset (f) Overuse: gradual onset (g) Severe—time loss >28 days	NMT program (11+) Running, strength, plyometrics, balance, and running exercises—instructional workshop, coach, and player delivered every training session (DVD, poster, pamphlet, and exercise cards)	Standard of practice	IG: 161 injuries in 1,055 players CG: 215 injuries in 837 players IRs reported: Knee injury: IG = 0.7 CG = 1.3 Ankle injury: IG-1.0 CG = 1.1	(a) All IRR = 0.71 (0.49–1.03) (b) LE RR = 0.71 (0.49–1.03) (c) Knee IRR = 0.55 (0.36–0.84) (d) Ankle IRR = 0.89 (0.61–1.31) (e) Acute RR = 0.74 (0.51–1.08) (f) Overuse RR = 0.47 (0.26–0.85) (g) Severe 0.55(0.36–0.83)
Steffen et al. 2008 [42]	Cluster RCT 1 season (8 months) Norway	Soccer Female (13–17 years) IG (*n* = 1,091, *N* = 59) CG (*n* = 1,001, *N* = 54)	Time loss injury Acute—sudden onset	NMT program (F-MARC 11) (core stability, strength, NM control, agility) Instructor taught (4 sessions) and coach delivered	Standard of practice	IG 204 injuries (IP = 19) IR = 3.6 (3.2–4.1) CG 192 injuries (IP = 20) IR = 3.7 (3.2–4.1)	All injury RR = 1.0 (0.8–1.2) for Acute match injury RR = 1.1 (0.9–1.3) Acute training injuries 0.7 (0.5–1.1) ACL injury RR 0.8 (0.2–2.9)

Steffen et al. 2012 [43]	Cluster RCT 1 season (4 months) Canada	Soccer Female (13–18 years) IG(comp = comprehensive delivery) (n = 129, N = 10) IG(reg = regular delivery) (n = 121, N = 8) CG (n = 135, N = 11)	Soccer injury (a) All injury requiring medical attention and/or time loss (b) Lower extremity injury (LE)	NMT program (11+) Running, strength, plyometrics, balance—instructional workshop, coach delivered every training and game session Regular IG: 11+ coach workshop (DVD, poster, 11+ web site) Comprehensive IG: 11+ coach workshop (DVD, poster, 11+ web site) and regular follow-up to team by physiotherapist	11+ web site information only	All injuries CG: 21 injuries (IP = 15.6) RIG: 25 (IP = 20.7) CIG: 22 (IP = 17.2)	All injury: IRR(comp) = 0.44(0.18–1.06) IRR(reg) = 0.97(0.47–2.0) LE injury: IRR(comp) = 0.52(0.21–1.31) IRR(reg) = 0.97(0.46–2.01) Across all study groups All injury Low adherence tertile: 1 (reference) Medium: IRR = 0.97 (0.47–2.0) High: IRR = 0.44 (0.18–1.06) *Adjusted for cluster, age groups, level of play, and previous injury
Waldén et al. 2012 [44]	Cluster RCT 1 season (8 months) Sweden	Soccer Female (12–17 years) 4,564 players IG: (n = 2,479, N = 121) CG: (n = 2,085, N = 109)	Soccer Time loss knee injuries: Acute onset Severe (>4 weeks time loss) ACL (physician + MRI)	NMT warm-up program (knee control and core stability) (2×/week)	Standard of practice	Acute IG (IR = 1.94) CG (IR = 0.67) Severe IG (IR = 1.05) CG (IR = 1.49) ACL IG (IR = 0.28) CG (IR = 0.67)	Acute IRR = 0.92 (0.61–1.4) Severe IRR = 0.7 (0.42–1.18) ACL IRR = 0.36 (0.15–0.85)

(continued)

Table 15.2 (continued)

Sport title Author Publication Year	Study, design, duration, country	Participants (sport, level, sex, age, sample size) (IG = Intervention group; CG = Control group) (n = # players, N = # teams)	Outcome (injury definition)	Intervention description	Control condition description	Reported incidence rate (IR/1,000 h) or incidence proportion (IP/100 players) (IG = Intervention group; CG = Control group)	Effect estimates [incidence rate ratios (IRR), risk ratio (RR), odds ratio (OR) (95 % CI)] Reported or calculated based on data provided
Ice hockey							
Brunelle et al. 2005 [45]	Cohort study/ season Canada	Minor hockey Bantam (ages 14–15) 2001/02 hockey season n = 52 teams	Any injuries that led players to seek medical advice or miss one game or one practice session on ice	League with Fair Play Program	No Fair Play Program	Number of injuries: n = 178 (57.4 %) IP Assumption ~18 players per team: IP = 178/936 *100 = 19.0	Fair Play Program (FP) OR = 0.43 (0.11–1.47)
Emery et al. 2008 [46]	Cohort study/ season Canada	Youth ice hockey (11–12 years) IG: (n = 1,057, N = 78) CG: (n = 1,106 on 74 t)	Any ice hockey injury that requires medical attention and/or results in time loss from hockey Concussion based on international consensus management (2005)	Policy disallowing body checking in game play	Body checking allowed	No body checking All injury IR = 1.37(1.04–1.8) Concussion IR = 0.39(0.23–0.67) Body checking All injury IR = 4.2(3.49–5.07) Concussion IR = 1.47(1.08–1.99)	All injury IRR = 0.31 (0.22–0.43) Concussion IRR = 0.26 (0.13–0.52)

Handball							
Olsen et al. 2005 [47]	Cluster RCT (8 months) Norway	Handball Male and female (15–17 years) IG (n=959) CG (n=79)	Handball injury requiring medical attention or time loss Acute—sudden onset Overuse—gradual onset	NMT program Wobble boards/balance mats (coach delivered 15 sessions then 1×/week) (running, landing technique, balance, strength, power)	Standard of practice	All injuries IG: 95 (9.9 %) CG: 167 (19 %) Acute knee injuries IG: 19 (2 %) CG: 38 (4.3 %) Acute ankle injuries IG: 28 (2.9 %) CG: 40 (4.6 %)	All injuries IRR = 0.49 (0.39—0.63) Acute knee/ankle injury IRR = 0.55 (0.39–0.79) Overuse injuries IRR = 0.43 (0.25–0.75)
Wedderkopp et al. 1999 [48]	Cluster RCT (10 months) 3 tournaments Denmark	Handball Female (16–18 years) Players from 22 teams IG (n=111) CG (n=126)	Handball injury time loss or unable to participate without considerable discomfort	NMT program Ankle disk + warm-up including 2 or more functional activities for all major LE muscle groups	Standard of practice warm-up	IG: Game IR = 4.68 Practice IR = 0.34 CG: Game IR = 23.38 Practice IR = 1.17	OR = 0.17(0.089–0.324)
Wedderkopp et al. 2003 [49]	Cluster RCT 1 season (9 months) Europe	Handball Female (14–16 years) IG (n=77, N=8) CG (n=86, N=8)	Handball injury time loss or unable to participate without considerable discomfort	NMT program Ankle disk + warm-up including 2 or more functional activities for all major LE muscle groups	NMT program Warm-up including ≥2 functional activities LE muscle groups (No ankle disk)	IG Match IR = 2.4 Practice IR = 0.2 CG Match IR = 6.9 Practice IR = 0.6	OR = 0.21(0.09–0.53)
US Football							
Cahill et al. 1978 [50]	Cohort study 8 seasons USA	High School Football Male No conditioning n=1,254 Conditioning n=1,227	Knee injury time loss ≥2 sessions	Total body conditioning (C) through cardiovascular stressing, acclimatization to heat, weight training, flexibility drills, and agility exercises	Standard of practice 4 years without conditioning (NC)	No of knee injuries: NCg: 85 Cg: 50 No of knee operations: NCg: 19 Cg: 7	↓ reported knee injuries: NCg: 85 Cg: 50 $X2$=0.01 ↓ reported knee injuries requiring surgery: NCg: 19 Cg: 7 $X2$=0.01

(continued)

Table 15.2 (continued)

Sport title Author Publication Year	Study, design, duration, country	Participants (sport, level, sex, age, sample size) (IG = Intervention group; CG = Control group) (n = # players, N = # teams)	Outcome (injury definition)	Intervention description	Control condition description	Reported incidence rate (IR/1,000 h) or incidence proportion (IP/100 players) (IG = Intervention group; CG = Control group)	Effect estimates [incidence rate ratios (IRR), risk ratio (RR), odds ratio (OR) (95 % CI)] Reported or calculated based on data provided
McHugh et al. 2007 [51]	Cohort study 3 seasons	US Football Male (15–18 years) 175 player-seasons N = 2	Inversion ankle sprain	Balance training on a foam pad (5 min each leg, 5×/week for 4 weeks preseason and 2×/week for 9 weeks in the season) for low, moderate, and high risk players, no program for minimal risk players	Pre-intervention 107 player-seasons	Pre-intervention Minimal risk IR = 0.4 Low risk IR = 1.2 Moderate risk IR = 1.9 High risk IR = 5.7 Post-intervention Minimal risk IR = 0.8 Low risk IR = 0.4 Moderate risk IR = 0.6 High risk IR = 1.4	Combined low, moderate, and high risk IRR = 0.23 (0.08–0.69)
Mickel et al. 2002 [52]	RCT 1 season USA	High School Football Bracing group (n = 42) Taping group (n = 41)	Ankle sprain time loss injury	Ankles braced for every practice or game	Ankles taped for every practice or game	Ankle sprains : BG IR = 0.83 TG IR = 0.77	No difference between groups Only three sprains per study group all Grade 1

Basketball							
Emery et al. 2007 [53]	Cluster RCT 1 season (18 weeks) Canada	Basketball Male and female (12–18 years) IG (n=494, N=47) CG (n=426, N=41)	Basketball injury requiring medical attention and/or time loss	NMT warm-up 10 min (aerobic, static, and dynamic stretch)+5 min balance training with wobble board+20 min home balance training program using a wobble board	The 10 min warm-up routine (aerobic, static, and dynamic stretch only)	All injury IG IR=3.3 CG IR=4.03 Acute injury: IG IR=2.77 CG IR=3.83 LE injury IG IR=2.69 CG IR=3.18 Ankle injury IG IR=1.57 CG IR=2.46	All injury IRR=0.8 (0.57–1.11) Acute injury IRR=0.71 (0.5–0.99) LE injury IRR=0.83 (0.57–1.19)
Longo et al. 2012 [54]	Cluster RCT 1 season (9 months) Italy	Basketball Male (mean age 13.5 IG 15.2 CG) IG (n=80, N=7) CG (n=41, N=4)	Basketball injury requiring time loss (reported by coach, assessed by blinded orthopedic specialist)	11+ NMT warm-up (running, strength, plyometrics, balance) with progressions	Standard of practice	All injury IG 14 injuries IR=0.95 CG 17 injuries IR=2.16	All injury IRR=0.44 (0.2–0.95)
Rugby							
McIntosh et al. 2001 [55]	Pilot RCT 1 season Australia	Rugby Male 16 teams (U-15) 294 players with headgear (1,179 player exposures with and 357 without headgear) IG (N=9) CG: (N=7)	Tim loss Rugby injuries	Wearing headgear during matches	Not wearing headgear during matches	# concussion: CG: 2 IG: 7	No significant difference (p=0.48) between the crude injury rates The standardized normal deviate, z=0.06(0.0092–0.0086)
Australian football							
Scase et al. 2006 [56]	Quasi-experimental design 2 seasons Australia	Australian football U-18 Elite competition Male 723 players IG (n=114) CG (n=609)	Rugby time loss injury	30 min sessions (training, landing, falling, and recovery skills)	Standard of practice	Incidence rate: CG: 38.51 (34.04–42.98) IG: 26.33 (18.28–34.38)	IRR=0.72 (95 % CI 0.52–0.98) Risk ratio/landing injury: RR=0.40 (0.17–0.08)

(continued)

Table 15.2 (continued)

Sport title Author Publication Year	Study, design, duration, country	Participants (sport, level, sex, age, sample size) (IG = Intervention group; CG = Control group) (n = # players, N = # teams)	Outcome (injury definition)	Intervention description	Control condition description	Reported incidence rate (IR/1,000 h) or incidence proportion (IP/100 players) (IG = Intervention group; CG = Control group)	Effect estimates [incidence rate ratios (IRR), risk ratio (RR), odds ratio (OR) (95 % CI)] Reported or calculated based on data provided
Baseball							
Marshall et al. 2003 [57]	Cohort 3 years USA	Baseball Little League Age (5–18 years) Safety balls IG: Use of faceguards CG: Not using faceguards	Baseball injury—insurance policy reported	The use of safety balls The use of faceguards	The use of regular ball Players not using faceguards	IR = 28.02 (26.76–29.29)	IRR: faceguards vs. no faceguard: 0.65(0.43–0.98) Safety balls: 0.72(0.57–0.91)
Multisport							
Hewett et al. 1999 [58]	Quasi-experimental design (1 season)	Soccer volleyball basketball IG (n = 366 girls, N = 15) CG1 (n = 463 girls, N = 15) CG2 (n = 434 boys, N = 13)	Serious knee injury—knee ligament sprain with ≥5 days time loss ACL ruptures confirmed by arthroscopy. MCL ruptures clinically diagnosed	Jump training program (60–90 min a day, 3 days a week for 6 weeks preseason) Phase 1: technique Phase 2: fundamentals Phase 3: performance	No training program	Serious knee injuries IG IR = 0.12 CG1 IR = 0.43 CG2 IR = 0.09 Noncontact injuries IG IR = 0 CG1 IR = 0.35 CG2 IR = 0.05	IRR = 0.28 (compared to CG1) IRR = 0.21 (compared to CG2) Significant difference between groups in noncontact knee injuries (P = 0.005)

LaBella et al. 2011 [59]	Cluster RCT USA	Soccer and basketball Female Mean age: 16 IG: 45 coaches, 53 teams, 737 athletes CG: 45 coaches, 53 teams, 755 athletes	All sport injuries ACL injuries verified by MRI or operative reports	NMT warm-up (20 min) (progressive strength, plyometrics, balance, and agility)	Standard of practice warm-up	Gradual onset: 1.22 Acute onset: 1.61 Ankle sprains: 0.74 Knee sprains: 0.48 ACL sprains: 0.26 LE injuries treated surgically: 0.17 IG Gradual onset: 0.43 Acute onset: 0.71 Ankle sprains: 0.25 Knee sprains: 0.21 ACL sprains: 0.07 LE surgical: 0	Gradual onset: IRR = 0.35 (0.18–0.69), Acute onset: IRR = 0.44 (0.26–0.76) Ankle sprains: IRR = 0.34 (0.14–0.81), Knee sprains: IRR = 0.45 (0.17–1.21), ACL sprains: 0.27 (0.06–1.35)
McGuine et al. 2006 [60]	RCT USA	Soccer and basketball 523 girls 242 boys Mean age 16.5 IG (n = 373, N = 27) CG: (n = 392, N = 28)	Time loss ankle sprain	Balance training program (5 phases using balance board)	Standard of practice training	Ankle sprains: IG IR = 6.1 CG IR = 9.9	IRR = 0.56 (0.28–1.08)
Pfeiffer et al. 2006 [61]	Cohort 2 seasons USA	Female Soccer Basketball Volleyball IG: (n = 577, N = 43) CG: (n = 862, N = 69)	Noncontact ACL injury	The Knee Ligament Injury Prevention (20 min pre- or post-session) NMT 4 phases (jumping, bounding, leaps, hops)	Standard of practice	IG: Soccer IR = 0.167 Basketball IR = 0.476 Volleyball: IR = 0 CG: Soccer IR = 0.078 Basketball IR = 0.111 Volleyball: IR = 0.107	OR = 2.05 (0.21–21.7) (p > 0.05)

(continued)

Table 15.2 (continued)

Sport title Author Publication Year	**Study, design, duration, country**	**Participants (sport, level, sex, age, sample size) (IG = Intervention group; CG = Control group) (*n* = # players, *N* = # teams)**	**Outcome (injury definition)**	**Intervention description**	**Control condition description**	**Reported incidence rate (IR/1,000 h) or incidence proportion (IP/100 players) (IG = Intervention group; CG = Control group)**	**Effect estimates [incidence rate ratios (IRR), risk ratio (RR), odds ratio (OR) (95 % CI)] Reported or calculated based on data provided**
Yang et al. 2005 [62]	Cohort 3 years USA	Male and female *N* = 19,728 athlete-seasons 9 sports Soccer, track, basketball, baseball, wrestling, football, softball, volleyball, cheerleading	Lower extremity injury in organized sport requiring medical attention or time loss	Discretionary lower extremity protective equipment (e.g., hip pads, knee pads, shin guards, knee brace, ankle brace, hip pads, knee pads, other)	No discretionary lower extremity protective equipment	Overall IR = 1.17 (1.0–1.36)	LE injury IRR = 0.91 (0.72–1.15) Knee injury Knee pad IRR = 0.44 (0.27–0.74) Knee brace IRR = 1.61 (1.08–2.41) Ankle injury Ankle brace IRR = 1.74 (1.11–2.72)
School Physical Education							
Collard et al. 2012 [63]	Cluster RCT (7 months) Netherlands	School Male and female (10–12 years) IG *n* = 1,015 CG *n* = 996	All sport injuries requiring medical attention or time loss	PE warm-up (strength, speed, flexibility, overall coordination.) 5 different speed, strength, coordination, and flexibility exercises	Standard of practice	Total PA injuries: IG IR = 0.38 CG IR = 0.48	Hazard ratio (95 % CI) (adjusted for clustering): 0.81 (0.41–1.59)
Emery et al. 2005 [64]	Cluster RCT (8 months) Canada	High School Physical Education Classes Male and female (14–19 years) CG (*n* = 61, *N* = 5 schools) IG (*n* = 66, *N* = 5 schools)	Sport injury requiring medical attention or time loss	Physiotherapist taught home-based, balance training program using wobble board (daily for 6 weeks then 1×/week for 6 months)	Standard of practice	IG IP = 3 (0–12) CG IP = 17 (8–29)	All injury IRR = 0.20 (0.05–0.88) Ankle sprain IRR = 0.14 (0.18–1.13)

63, 64]. In addition, extrinsic risk factors have been addressed through rule modification [45, 46] and equipment strategies [52, 55, 57, 62] in some youth sports. Additionally, 17 review articles (including systematic reviews and meta-analyses) and relevant studies in adult populations and studies using retrospective (case-control or historical cohort) or cross-sectional designs are discussed [32, 33, 65–91].

Intrinsic Injury Prevention Strategies

In youth athlete populations, multifaceted neuromuscular training programs (e.g., balance, strength, agility) implemented as preseason and/or warm-up training strategies have been shown to reduce the incidence of injury in sports such as soccer, European handball, American football, basketball, and multisport between 28 % and 80 % [34–41, 43, 44, 47–51, 53, 54, 56, 58–60, 64] with few exceptions that demonstrate no preventative effect in youth sport [42, 61, 63]. In addition, the evidence supports the efficacy of such neuromuscular training programs in the reduction of knee injuries 45–83 % [35, 38, 40, 41, 44, 47] and a significant trend supporting efficacy in the reduction of ankle injuries 44–86 % [52, 60, 64].

Meta-analyses were conducted based on available outcomes of RCTs only to produce combined estimates of measure of effect using incidence rate ratios (IRR) based on a random effects model for seven studies examining overall lower extrem-

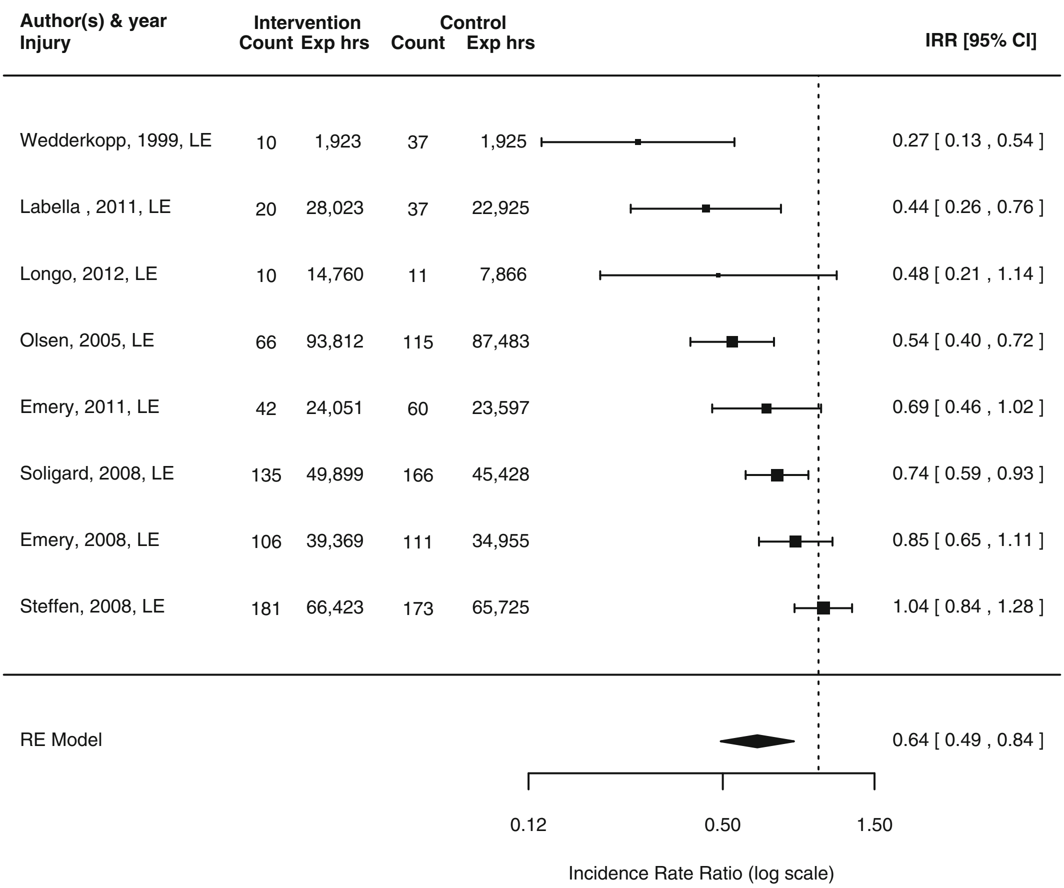

Fig. 15.2 Meta-analysis examining the protective effect of neuromuscular training strategies in reducing the risk of lower extremity injury in youth sport

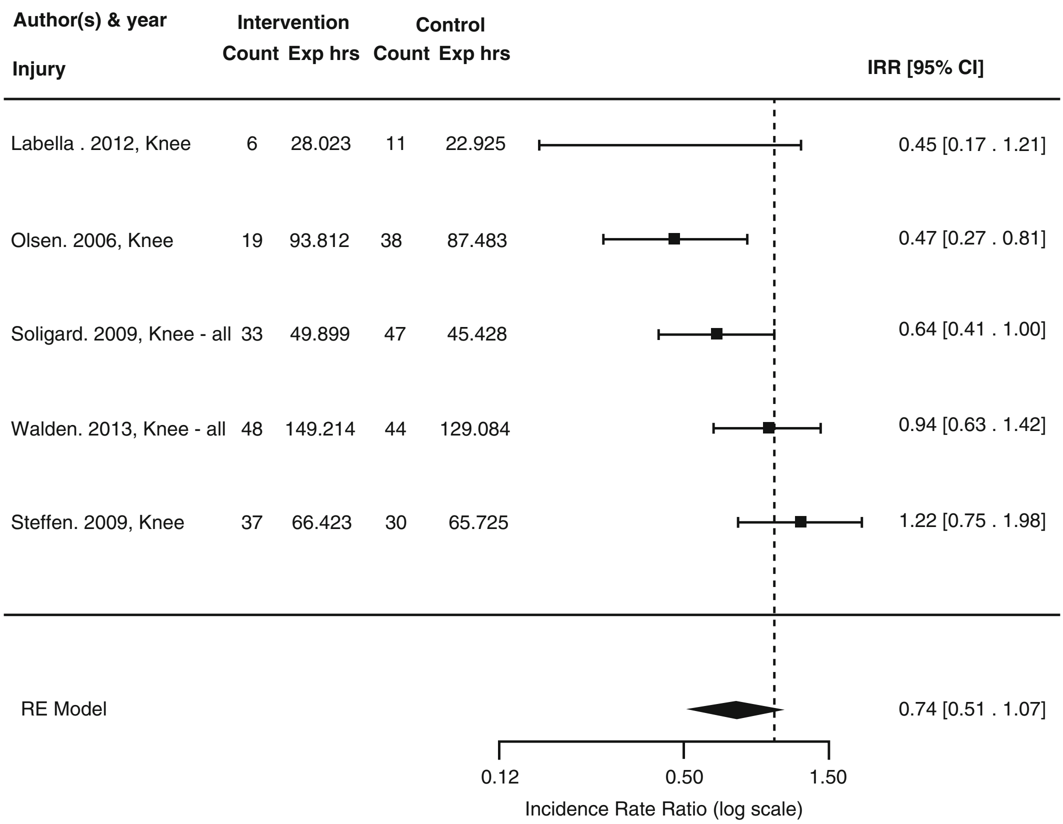

Fig. 15.3 Meta-analysis examining the protective effect of neuromuscular training strategies in reducing the risk of lower extremity injury in youth sport

ity injury outcome (Fig. 15.2) and five studies examining knee injury outcomes specifically (Fig. 15.3) in youth sport [24]. The size of the box in these figures represents the relative weights given to each study in calculating the overall summary measure. The weights depend on the standard errors of the incidence rate ratio. The combined estimate for RCT studies examining a preventative effect of neuromuscular training in the reduction of lower extremity injuries in youth team sport (soccer, European handball, basketball) demonstrates a significant overall protective effect [IRR = 0.64 (95 % CI; 0.49–0.84) or a 36 % reduction in lower extremity injury risk] (Fig. 15.2). The combined estimate for RCT studies examining the preventative effect of neuromuscular training in the reduction of knee injuries in youth team sport (soccer, European handball, basketball) suggests a protective effect of knee injuries specifically, but this finding is not statistically significant [IRR = 0.74 (95 % CI; 0.51–1.07) or a 26 % reduction in knee injury risk].

While this evidence is consistent with previous reviews in youth sport [32, 33, 65–67], it is strengthened by the addition of 12 prospective evaluation studies, primarily RCTs, published in the past decade which focus on youth sport populations. In addition, the meta-analyses are the first to contribute specifically to the adolescent injury prevention evaluation literature. As the majority of studies in youth examining neuromuscular training strategies include multiple components (e.g., strength, balance, agility), it is difficult to assess the contribution of each component. In addition, the injury-specific effect of these programs is more difficult to assess given the need for large sample sizes to do so. Two systematic reviews recently published include adult and youth athlete studies combined [68, 69]. Based on meta-analysis, Lauersen et al. [68] demonstrate a significant preventive effect of neuromuscular training intervention programs focused on components including strength and proprioception/balance, but no preventive effect associated with programs focused on stretching across numerous sports. In addition, multifaceted programs demonstrated the greatest overall protective effect, consistent with the youth studies included in this review [68]. Consistent with these findings, Herman et al. [69] found a protective effect across multifaceted neuromuscular training strategies in multiple sports with meta-analyses supporting the efficacy of such programs in reducing the risk of lower extremity injury (acute and chronic) and knee injuries and demonstrate a trend toward a protective effect in reducing the risk of hip and thigh and ankle sprain injuries. Educational interventions hold promise for the prevention of skiing and snowboarding injuries, though the evidence of their effectiveness is mixed [70–73].

There is evidence from adult and elite and recreational youth athletes to support the further development and evaluation of sport-specific and more global multifaceted injury prevention training strategies to reduce sport injuries in youth through appropriate RCT design in populations that have not been previously examined. Currently, there is arguably adequate evidence to inform policy and practice recommendations to prevent injuries in many youth sporting venues including soccer, European handball, Australian rules football, and basketball. With valid injury surveillance in place, development of optimal sport-specific multifaceted neuromuscular prevention strategies and implementation of an RCT design, the effectiveness of such prevention strategies should be further evaluated in other youth sports where lower extremity injury risk is high.

Extrinsic Injury Prevention Strategies

Using protective equipment may help prevent injury in many sports. Such equipment may include bracing/taping, face shields and eyewear, mouth guards, helmets, and wrist guards. In a systematic review in adult and youth athletes, Dizon et al. [74] demonstrate a protective effect of ankle bracing and taping among previously injured adult and youth athletes only in reducing the risk of ankle sprain re-injury 69 % and 71 % respectively. The evidence in youth sport does not support the preventative effect of ankle bracing/taping or knee bracing as a primary strategy to prevent ankle and knee injuries in youth sport [52, 62]. While there are no RCTs examining face shields in youth or adult sport, there is evidence to support the efficacy of face shields and the use of safety balls in reducing the risk of injury in youth baseball [57]. Additionally, in adult elite ice hockey there is cohort evidence that partial or full face shields are effective in reducing the risk of facial and eye injuries and that full face shields reduce the risk of sustaining facial and dental injuries compared with half face shields and that playing time loss is reduced if players wear full face shields [75–77]. Mouth guards have consistently demonstrated a protective effect in decreasing the risk of orofacial injuries (i.e., dental, mouth, jaw) across numerous adults sports (e.g., ice hockey, rugby, basketball, football) demonstrating a pooled 86 % increased risk in non-users through meta-analysis [78]. Benson et al. [76] further demonstrate that time loss associated with concussion is lower in National Hockey League players wearing mouth guards and full face shields, compared with those players with full face shields and no mouth guard. Despite this, mouth guards are not mandatory in all youth ice hockey associations.

The use of helmets in youth sport is pertinent in ice hockey, skiing, snowboarding, baseball, bicycling, equestrian, bobsleigh, luge, and skeleton. Three systematic reviews [79–81] including a meta-analysis [79] support the effectiveness of helmets in skiing and snowboarding in reducing the risk of head injuries based on observational study designs (i.e., case-control and cohort) in a combination of adult and youth populations. In the studies including children, the associated odds ratio (OR) was 0.41 (95 % CI; 0.27–0.59) [79]. In addition, there was no evidence of helmet use being a risk factor for neck injuries across studies examining this relationship [79]. A Cochrane systematic review synthesized the evidence around bicycle helmet laws and head injuries [82]. The authors found that helmet laws were associated with an increase in helmet use and a decrease in head injuries in all of the studies included [82]. Other systematic reviews of the association between helmet laws and helmet use report increased use of helmets subsequent to the introduction of a law [83, 84]. In Canada, Dennis et al. [85] reported that youth in provinces with all-ages legislation were more likely to report wearing helmets than youth in either a province with child-only legislation, or a province with no legislation. One challenge faced is to get youth using the equipment [9, 10]. Combining educational approaches (e.g., social media, legislation, and facility/sport association requirements) may be the best way to encourage use of protective equipment. Other equipment strategies examined include wrist guard use in snowboarding [86]. A systematic review examining wrist guards in snowboarding reveals a significant protective effect in reducing the risk of wrist injury (OR = 0.23), wrist fracture [Risk Ratio (RR) = 0.29], and wrist sprains (RR = 0.17) [86]. As with helmets, the challenge is to get youth to use wrist guards [9, 10]. Finally, break away bases have been examined in baseball and softball and have consistently demonstrated a protective effect on sliding injuries in adult and youth population [87–89]. There is significant evidence to endorse the use of protective equipment in youth sport, yet despite this evidence there is evidence to support less than optimal uptake of equipment strategies (e.g., bicycle and ski/snowboarding helmet use, wrist guard use in snowboarding) [10, 82–86].

Sporting rules and policy are critical for regulation of the sport but some have been implemented specifically to reduce the risk of injury. An example is in football where spearing tackles were banned at all levels of play in 1976. This and many other rule changes have not been rigorously evaluated. An exception to this is the evaluation of policy related to the age of introduction of body checking in youth ice hockey. In a meta-analysis, policy allowing body checking in youth age groups was identified as a significant risk factor for all injuries (Summary RR = 2.45; 95 % CI 1.7–3.6) and concussion (Summary OR = 1.71; 95 % CI 1.2–2.44) [90]. Further to this, policy delaying body checking from age 11 to age 13 had been evaluated in a further cohort study which demonstrated a three- to fourfold greater risk of injury and concussion in 11- and 12-year-old players in regions where body checking was still allowed in this young age group [46]. This work has led to a national policy change in Canada and the USA.

Addressing the Gaps in Injury Prevention in Youth Sport

While there is an increasing body of rigorous scientific evidence (including RCT evidence) to inform best practice in injury prevention in youth sport, there is evidence to support the lack of program uptake and ongoing maintenance following an evaluation study [91]. This highlights the need to focus on the implementation context and real-world effectiveness in evaluating prevention strategies in youth sport [20, 21, 25]. In team sports such as European handball, it is evident that the program needs to be sport-specific with a focus on coach training to ensure program effectiveness [91]. This is supported by research evaluating the implementation strategy for delivery of a team-based neuromuscular training warm-up program, which highlights the greater adherence when a comprehensive coach workshop precedes the coach-delivered intervention in a team-based setting in youth soccer [43]. It may also be important to focus on player performance improvement as a side effect to injury prevention strategies in youth sport to facilitate uptake by coaches and players [92]. Internationally, there is a deficiency in coach, player, and parent knowledge and behaviors regarding injury prevention programs in youth sport populations despite the evidence to support their implementation in soccer, European handball, and football [93–95]. There is a need to focus on the ongoing and sustainable implementation of effective injury prevention strategies in youth sport (e.g., soccer, European handball, basketball, Australian football), in addition to further evaluation in sports where there is a paucity of research evaluating such programs (e.g., rugby, field hockey, volleyball, lacrosse, track, cross-country running, gymnastics, martial arts, tennis, and wrestling). This is also true for more general school populations.

There is significant evidence to support the use of protective equipment in youth sport, yet despite this evidence there is less than optimal uptake of equipment strategies (e.g., bicycle and ski/snowboarding helmet use, wrist guard use in snowboarding) [10, 82–86]. It is expected that this research will continue to inform policy change in a variety of sport contexts (e.g., legislation of helmets in terrain parks and ski resorts, mandate of mouth guards in contact sports). An example of rigorous evaluation informing effective policy change (e.g., age of introduction of body checking in youth ice hockey) may inform policy and/or rule changes in other sport contexts (e.g., age to allow tacking in rugby and football) that will also have significant public health impact.

A focus on implementation is critical if there is going to be a shift in knowledge, behavior change, and sustainability of evidence-informed injury prevention practice. An argument has been made for a hierarchy of responsibility with the lowest level of responsibility assigned to the child and the highest level to those organizations or groups with the potential to effect the most change [31]. The justification for this approach has been discussed in the context of the desirability of passive prevention strategies, the limited evidence for the effectiveness of strategies relying solely on behavior change in children and parents, and the level of perceptual and cognitive development in children that inadequately prepares them to take primary responsibility for their own safety in sport [31]. In addition, a greater focus on implementation research is key, including behavior change in the youth sport population and the critical role of coach behavior related to injury prevention [30].

Summary and Recommendations

There is an increasing body of rigorous scientific evidence to inform best practice and policy in injury prevention in youth sport. However, there is a paucity of injury prevention research involving children under age 12. While there is evidence for the effectiveness of neuromuscular training strategies in the reduction of injury in numerous team sports, there is also evidence to support the lack of program uptake and ongoing maintenance of such programs. There is evidence to support the use of protective equipment (e.g., helmets, wrist guards) in youth sport, yet despite this, there is less than optimal uptake of effective equipment strategies. A focus on implementation is critical if there is going to be a shift in knowledge, behavior change, and sustainability of evidence-informed injury prevention practice and policy. Recommendations to contribute to effective and sustainable injury prevention in youth sport are summarized below.

1. Development of sustainable knowledge translation strategies based on community stakeholder engagement that will inform a shift in injury prevention knowledge and behavior. This will lead to a sport culture where injury prevention is a primary focus in the development of healthy and capable youth athletes across all sport.
2. Development and evaluation of implementation strategies for injury prevention programs that are context specific, adaptable to specific settings, coach championed, sustainable, and consistent with performance and participation goals.
3. Identification of opportunities to inform rules, policy, protective equipment legislation, and appropriate training of referees to identify illegal play and lack of adherence to equipment use policies to reduce the burden of injury in youth sport based on the available evidence.
4. A combined approach to injury prevention including an emphasis on public education through social media, coach and clinician education, sport-specific policy changes, and development and availability of accessible web-based sport-specific and more globally targeted injury prevention applications.
5. Attention to secondary prevention strategies including early diagnosis and adequate

rehabilitation following a sport injury and appropriate clearance from an appropriate clinician before returning to sporting activity.
6. Further evaluation of preseason examination to identify high-risk sport participants and individually targeted secondary prevention strategies based on evidence-informed primary prevention strategies.
7. Enhance communication strategies between youth athletes, parents, coaches, sport administrators, and clinicians to support a greater capacity for effective and sustainable injury prevention efforts.

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Part VI

Future Research in Pediatric and Adolescent Sports

16 Injury Research in Pediatric and Adolescent Sports

Peter A. Harmer

Introduction

The era of organized sport for children and adolescents may be argued to have begun toward the end of the Industrial Revolution, when economic and population growth interaction reached critical mass that resulted in the rise of public education in the industrialized world. For example, two of the most popular team sports in the world, association football (soccer) and rugby, were created in English schools in the mid-1800s and interscholastic competition in baseball was recorded as early as 1868 in the USA [1]. Organized sports opportunities grew rapidly in Europe and the USA; for example, in the USA, by 1889 Chicago, Illinois, had established an interscholastic athletic league, with championships in athletics and baseball. By 1910, the league had added championships for tennis, girls and boys basketball, swimming, cross-country, and soccer [1] and the first national championship in football was won by a Chicago school. The trend of increasing organizational effort devoted to interscholastic sport was reflected across the country resulting in the establishment of the National Federation of High School Athletic Associations. A study of high school sports in 1930 [2] found that 47 of the 48 states had a state high school athletic association, with state championships sponsored in at least eight sports (ranging from basketball (80.8 % of states) and football (31.9 %) to golf (10.6 %) and skating (4.2 %)). More importantly, there are indications of the emerging professionalization of children and adolescent sports in that in this study coaches were employed as full time members of the faculty in 29 states. The situation was more complicated for girls, with active opposition to interscholastic athletic competition for them evident as early as 1925. However by 1930 at least 45 % of states had a state-level organization responsible for girls sporting competition [3]. In parallel with the rise of interscholastic sport in Europe and the USA, other nations developed infrastructure to support competition. The first Japanese national high school baseball championship was held in 1915, with teams from other countries competing by 1921. In contrast to organized sport opportunities through schools, sports clubs supported by community organizations have offered more options for participation (range of sports; levels of expertise). This model is the most typical internationally.

Regardless of the administrative structure, child and adolescent participation in organized sports has continued to rise, driven by the intrinsic attractiveness of activity and supported by its

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D. Caine, L. Purcell (eds.), *Injury in Pediatric and Adolescent Sports*, Contemporary Pediatric and Adolescent Sports Medicine, DOI 10.1007/978-3-319-18141-7_16

recognized physical, social, psychological, and emotional benefits [4]. As an indication, estimates of current participation numbers range from 38 to 60 million per year in the USA alone [5, 6]. However, it is clear that the very nature of competitive sport entails potential harm that threatens to undermine the value of participation. While physical injury is the most obvious concern, the nature of modern organized sport for children and adolescents can also threaten their psychological and emotional health. Therefore, it is important from moral, pedagogical, and public health perspectives that the various harms be accurately identified and the possibility of them occurring be minimized or eliminated.

To achieve the goal of maximizing safety in pediatric and adolescent sports participation six stages of research are required: (a) conception (awareness of a problem), (b) description (identifying the extent of the problem), (c) explanation (determining the cause(s) of the problem), (d) prediction (devising methods of alleviating the problem), (e) control (testing the efficacy of the proposed solutions, ideally with randomized controlled trials (RCT)), and (f) research-to-practice translation (dissemination, implementation, and cost-effectiveness—comparing various solutions to determine the most utilitarian in terms of efficacy and economics). In general, the conventions of descriptive and analytical epidemiology are appropriate to address items b–e (refer to Chap. 5 [7] for details of important characteristics of this type of research, including common problem areas such as poor operational definitions, lack of exposure data, small sample sizes, and short data collection periods). However, to appropriately complete a "womb to tomb" study on some aspect of youth sports injury risk and prevention requires several other considerations. The two most overlooked are: (1) an appropriate data collection system (as a necessary element for meaningful information for (b), which is the critical foundation for (c), etc.), and (2) a research-to-practice framework, such as RE-AIM [8] (to rigorously evaluate proposed solutions under items d–e).

As detailed later in this chapter, although general awareness of the need for injury research in children's and youth sports has burgeoned in the past 10 years, as evidenced by the increase in the number of research papers published on the topic, the scientific exploration has not been directed logically or systematically, or even conducted particularly well. The result is a glut of descriptive studies of widely varying quality and utility [9] and a failure to advance research from identifying/quantifying risk to developing solutions. For example, in 2014, both Leppänen et al. [10] and Lauersen et al. [11] conducted systematic reviews and meta-analyses on RCT of injury prevention protocols. From more than 5,500 articles retrieved by Leppänen et al. [10] and almost 3,500 by Lauersen et al. [11], the authors found only 68 and 25 studies, respectively, that met their inclusion criteria for analyses. On this rough approximation, less than 1 % of sports injury research progresses to the stage of even being theoretically implementable to decrease injury risk. In essence, there is a lot of research activity but very little pay-off.

This phenomenon is not new. In 1963, concerned about what he perceived as a growing trend of non-theory-driven research, Forscher [12] had a tongue-in-cheek allegorical letter published in *Science* titled "Chaos in the brickyard" in which he compared research findings to bricks. The take-home message was the bricks per se were not the point; an edifice that could be constructed from the bricks was the goal. Simply producing bricks without a clear plan for using them just results in a potentially impenetrable jumble of bricks. Currently, it may be argued that pediatric and adolescent sports injury research has too many brick-makers (most of whom are "one-and-done" producers) and too few builders. Without an overarching, carefully prioritized program of research goals that directs the production of bricks of specific dimensions to ensure a robust finished product, the field becomes littered with bricks of varying dimensions and quality, depending on the predilections of individual brick-makers, that undermine their utility in contributing to a useful edifice. This general lack of cohesive research goals in pediatric sports injury research may be seen in the fact that of the approximately 1,000 data-based articles from 1957 to 2014 (inclusive) in the analysis below, only 14 authors are associated with five or more studies. As many of these researchers are collaborators, it appears that the majority of research is produced by researchers who do not have an extended research program in this area. Furthermore, even for researchers who have a sustained interest in the field there seems to be a lack of a progressive research agenda that systematically builds toward testing and implementing injury prevention protocols. For example, of the approximately 550 data-based studies in the sample in the past decade, the maximum number of citations attributed to one author is 11. While this author has maintained a focus in studying in a particular sport, the work does not seem to have progressed beyond quantifying risk and identifying risk factors.

In one sense, the clustering of studies at the descriptive stage is understandable as accurately identifying important risk factors is complicated and there seems to be little point in developing prevention protocols unless clear causal relationships can be confirmed. Because injury is the result of a complex interaction of factors [7, 13], the contribution that any specific factor plays in injury risk (either singularly or in combination with other factors) may change in response to variations in both intrinsic (age, sex, skill level, history of previous injury, etc.) and extrinsic (weather, field conditions, characteristics of opponents, etc.) characteristics that are at play in any given sporting environment [6]. Additionally, whether intrinsic or extrinsic, risk factors can also be classified as modifiable (e.g., fitness level) or nonmodifiable (e.g., sex), with the key distinction in terms of injury prevention being a clear assessment of which category a particular risk factor falls into. Understanding whether an identified risk factor is modifiable or not provides insight into options for developing the most effective prevention strategies while minimizing unintended consequences. However, even the impact of a nonmodifiable risk factor may not be static as its influence may be altered through manipulating a modifiable characteristic. For example, although being female is a nonmodifiable factor (sex) that might be associated with increased injury risk, manipulating modifiable factors, such the equipment or some aspect of rules may diminish the impact of the nonmodifiable factor on injury risk although the specific nonmodifiable factor itself does not change. Thus, trying to identify what "causes" an injury is somewhat quixotic.

Given the multitude of possible permutations of risk factors in "predicting" injury, it seems reasonable for researchers to investigate as many variations as possible before attempting to devise a prevention program. Unfortunately, this viewpoint results in numerous researchers earnestly harvesting the low-hanging fruit of small scale (one team; one league, etc.), short-term (one season; one year) studies supposedly designed to identify the "injury risk" in a sub-population of a particular sport. Despite the well-known methodological deficiencies in such work, these studies often find publication outlets, especially if they are focused on popular or obscure sports, and the process of propagating epidemiological research of limited utility is reinforced.

History of Existing Research

To gain some perspective on the status of research into sports injury in children and adolescents, a search was conducted on Scopus, the world's largest database of peer-reviewed research, which incorporates complete coverage of Medline, the bibliographic database of the USA National Library of Medicine. Due to the diverse and chaotic nature of research in this area, this task is both Herculean and Sisyphean and precise analysis of the available literature is not possible. For example, although high-quality research is published in the native language of many researchers, English has become the standard language of international scientific exchange, thus analyzing peer-reviewed studies published in English provides the most comprehensive, but not necessarily the most precise, approach to capturing research of interest. Moreover, by restricting search parameters a utilitarian overview of the past and current status of the work can be derived. Using the search term "children sports injuries" in the subject areas of "Medicine; Health Professions" for documents "article; review" from "journals" for the timeframe "first record-2014, inclusive", a total of 1913

Table 16.1 Overview of peer-reviewed research 1957–2014

	1957–1989	1990–2004	2005–2014	Totals
Overall (total)	349	603	961	1,913
Mean/year	10.5	40	96	
Median	11	34	92	
Range	1–29	20–66	59–127	
Articles (total)	327	395	714	1,436
Mean/year	10	26	71	
Median	12	25	70	
Range	1–26	16–38	40–98	
Reviews (total)	22	208	247	477
Mean/year[a]	1.3	14	25	
Median	1	10	20	
Range	1–7	3–28	14–45	
Systematic reviews	(0)	(21)	(97)	(118)

[a]The first review in this analysis was 1973. Thus, the mean number of publications per year in this category is based on 17 years

citations were returned in December 2014. Table 16.1 details the breakdown by document type and era (systematic reviews are listed as a sub-set of Reviews).

As can been seen in Table 16.1, scientific investigation of injuries in children's sport has an uneven history. For the first half of the twentieth century there was virtually no interest from researchers or administrative organizations supervising youth sport (whether school or clubs) in investigating the scope, mechanisms, or implications of sports-related injury. However, from the late 1950s there was a slow but steady increase in publications related to injuries in children's and youth sport leading to a sharp increase in the number of peer-reviewed publications from the early 1990s to the mid-2000s. A similar exponential increase in the literature has occurred in the past 10 years (January 1, 2005–December 31, 2014). Of particular interest, in addition to the geometric increase in publications in general, is the concomitant increase in the number of review articles and the subsequent emergence of systematic reviews to provide more stringent filters through which to evaluate the myriad of descriptive, and to a lesser degree, analytical, studies. Overall, the annual rate of publications for both articles and reviews increased by at least 250 % in each subsequent era.

The rising interest in pediatric and adolescent sports injuries can also be judged by the origins of the published research. Overall, the vast majority of the literature arises from the USA, which accounted for 38.5 % of the total in this analysis; in the past decade its contribution has risen to 41 %. The next four major contributors combined (Canada, United Kingdom, Germany, Australia) account for 19.5 % overall and 24 % over the past 10 years. However, the internationalization of the field may be illustrated by the fact that in the 48 years from 1957 to 2004, only four countries outside the top five produced at least ten papers each, with an additional 28 countries being attributed with at least one publication. In the past 10 years, 14 different countries outside of the top five have at least ten papers with an additional 33 countries providing at least one peer-reviewed manuscript (Europe: 10; Asia: 8; Middle East: 7; Central/South American: 4; Africa: 3; Oceania: 1).

It is not clear what prompted these radical shifts in research interest but it may be argued that factors such as the growing professionalization of children and adolescent sport, litigation, media coverage of the increasing number of youth athletes who were qualifying for national teams for World Championships and Olympic Games, and a "trickle down effect" from the interest in injury prevention in elite/professional adult sport have all played a role. This last point is an important one to consider as injury research in children's and youth sport is still overshadowed by work on college, adult, and professional sports even though the total number of participants under the age of 18 in organized competitive sport is significantly greater than the number aged 19 and older. Despite the participation disparity, there is 8–10 times more peer-reviewed sports injury research on adults than on children and adolescents. However, the growing "acknowledgement" that children are not little adults and have physical, psychological, and emotional characteristics that have been shown to place them at increased risk of harm in both daily life and sociocultural activities such as participation in organized sport [5] may also be helping move the research momentum to specialized study of risk in pediatric sports.

Despite differences such as the magnitude of research interest, sports injury research with children and adults shares a common quality, that is, as discussed previously, the generally ad hoc nature of the work. The vast majority of injury research in both children's and adult's sport consists of "one-off" studies, of varying quality, that investigate the idiosyncratic interests of individual researchers utilizing widely divergent research designs, operational definitions, sample sizes, study lengths, and outcomes.

The lack of an over-arching research philosophy in children and adolescent sport can be indirectly gaged from an analysis of the 97 systematic reviews published in the past 10 years. Systematic reviews stand as a useful proxy for the state of research in a field as they are evidence of both the maturity of the field (i.e., there are a sufficient number of papers on a topic to warrant a summary) and its disorder (i.e., the available studies are so disparate that there is a critical need for synthesis to bring some coherence to the available information). Additionally, the focus of systematic reviews reflects the research priorities across an area of interest. For example, the 97 papers retrieved in this analysis can be grouped into six topic categories: Central Nervous System (25 systematic reviews; 26 % of the total), epidemiology (8; 8 %), injury prevention (13; 13 %), growth-related (12; 12 %), specific sports (18; 18.5 %), and miscellaneous (21; 21.5 %). The topic with the greatest number of systemic reviews relates to central nervous system injuries, primarily concussion. Although brain injuries are cause for concern and may have significant ramifications, given the vast range of unexplored or underexplored issues in pediatric and adolescent sport, especially the development of prevention protocols, from a scientific standpoint it's not clear why so much emphasis should be placed on concussion. It may be argued that the number of sports in which this is important, or even relevant, is a very small proportion of all of the youth sports available. Caine at al. [14] perhaps inadvertently touch on the answer when they note that it is "probably the hottest topic in sports injury". Such an observation points to an undue influence of media playing into an opportunistic mindset of many researchers seeking funding. While this pragmatic approach to research is understandable, it is not conducive to ensuring cohesive research programs that ultimately aim to produce cost-effective prevention program and ensure the well-being of youth in sport.

The topic area with the second highest number of systematic reviews in this analysis related to specific sports. However, these 18 reviews covered 13 different sports, only five of which rated two reviews (American football, ice hockey, Australian Rules football, soccer, weight training). Other sports represented by one review each, such as snowboarding, cheerleading, and judo, have been shown to be high-risk activities but the amount of research attention shown in this sampling seems to indicate a problematic hierarchy of importance. Finally, it is interesting to note that the purported "end-game" of sports injury research, that is, prevention, was the focus of only 13 % of these systematic reviews. Within this pool, only four reviews used meta-analytical approaches to provide a rigorous evaluation of the disparate findings of individual studies [11, 15–17], emphasizing considerable variation in the quality of the work even within what is supposed to be the highest level of evidence. Two interesting facts emerge from these analyses: (a) that exercise-based injury prevention programs appear to demonstrate beneficial effects in youth sports, and (b) there is little data on injury prevention available for children younger than 14 years of age.

Suggestions for Further Research

Despite the advances made in understanding and addressing injury risk in children's and youth sports, overall the process has been very inefficient. While there will always be a need for independent researchers to open new avenues of inquiry, real advances will only be made when administrative units responsible for youth sports organization, such as national school systems, national governing bodies for particular sports, and international sports federations, take the lead in developing, directing, and supporting injury prevention research. They are the only entities capable of creating and maintaining well-constructed, large-scale, long-term surveillance systems that are the key to any meaningful investigation into the scope, nature, or prevention of child and adolescent sports injury. Additionally, they are best positioned to prescribe authoritative guidelines defining critical elements for epidemiological work in and across various sports, including a clear definition of a reportable incident, well-delineated study samples, appropriate sample sizes and study duration, and consistent standards for determining exposure, into data collection systems without which the current patchwork of research will only grow more confusing. Finally, these organizational entities have the authority to instigate prevention programs on a scale necessary for meaningful impact and sufficient to allow evaluation of the efficacy and cost-effectiveness of such programs. Individual researchers are rarely in a position to do so.

To date, the literature has various studies derived from examples of surveillance systems supported by large organizational entities that can be specifically mined for children's and youth sports data and which may serve as models for future data-collection efforts, including:

(a) existing public systems (e.g., National Health Insurance System in Japan [18]; National Electronic Injury Surveillance System (NEISS) in USA [19]),
(b) specifically developed databases (US Registry of Sudden Death in Young Athletes [20]; High School Sports-Related Injury Surveillance Study [21]; National Center for Catastrophic Sport Injury Research [22]),
(c) national governing bodies (United States Fencing Association [23]; French Judo Federation [24]), and
(d) education-based/associated sports organizations (NCAA Injury Surveillance System [25]; National High School Sports-related Injury Surveillance Study [26]).

Although the utility of some of these sources, such as NEISS (or similar including hospital admissions databases), is constrained by their specific structure (that is, they are incident-based and cannot provide exposure data), their magnitude is a key characteristic that needs to be emulated.

Perhaps appropriately, given soccer's status as the world's most popular sport (and one in which the risk of injury is well recognized), in 2006 the Fédération Internationale de Football Association (FIFA) was the first (and is currently the only international federation) to publish a consensus statement on injury definitions and data collection procedures to guide injury research for its sport [27] with the intention of bringing some consistency to soccer injury research and improving the ability to compare findings across studies. This approach should provide the foundation for building a cohesive understanding of injury risk and prevention in soccer. However, while this is an important step that other youth sports organizations should emulate, it still falls short of what is required to ensure systematic exploration of all of the elements involved in producing as safe a soccer environment as possible. For example, what questions researchers will explore is still up to the discretion of the individual researchers, which inevitably leads to continuing gaps in knowledge, and there is no central injury surveillance system to provide high-quality raw data for research.

These problems are clearly illustrated in a systematic review of the FIFA 11+, an injury prevention program for soccer players 14 years old and above consisting of 10 warm-up conditioning exercises developed by the FIFA Medical and Research Center (F-MARC) [28]. The program is well documented and extensively supported by ancillary educational materials for coaches, etc. (print and on-line), and is an interesting model as an injury prevention intervention. Despite the inconsistencies and confusion in the research data related to injury characteristics and risk factors in soccer for reasons noted previously, the F-MARC identified features believed to be most important in contributing to injury risk and developed their initial prevention program (The 11) in 2003. The validity of this program was demonstrated in a national study in Switzerland which found significantly decreased injury rates for players using the program and indirect evidence of its cost-effectiveness as measured by population-based insurance data [29]. In 2006, the F-MARC introduced a refined version of the program (The 11+), which was tested in a national sample of adolescent female players in Norway [30] and shown to be associated with a decrease in overall injury rate as well as decreased risk of severe and overuse injury.

As The 11+ was introduced in 2006, the same year as F-MARC released its Consensus Statement on injury research it would be reasonable to assume that researchers investigating the efficacy of the FIFA 11+ program would be utilizing the appropriate guidelines from the Consensus Statement. However, of the 911 studies initially identified by Barengo et al. [28] for their systematic review only 12 met their inclusion criteria, and these 12 varied considerably in both sample sizes and participants population characteristics (although 12 papers were selected they represented only ten studies as data from two studies formed the basis for two different analyses each). Although two of the implementation studies involved sample sizes of 1,055 and 2,729, respectively, half of them had sample populations of less than 50 participants. Additionally, only four of these studies used a sample that was younger than 18 years of age and these were exclusively female players and although they all used The 11+ for the designated 20 min per session, the frequency varied widely (once/week for 8 months; 2–3 times/week for 4.5 months; 3 times/week for 4 months; 3 times/week for 8 months). Perhaps not surprisingly, the efficacy findings in these follow-up studies have been mixed. Moreover, demographic "holes" can be seen even at this juncture in the literature. For example, the program is designed for ages 14 and older. Given the dearth of injury data for those younger than 14 [11, 31], not including children in the mandate of The 11+ reflects reasonable limits on the interpretation and application of the epidemiological research that was the foundation for the development of the program. As mentioned previously, research with adults cannot be simply transposed onto children because of meaningful anatomical, physiological, and psychological differences. Similarly, children and adolescents are not the same. For example, Stracciolini and colleagues [32] noted significantly different injury risks and profiles for children aged 5–12 years compared to adolescents aged 13–17 years. However, as the participation rates in soccer for those under 14 years of age have been high for several decades and are continuing to increase, the knowledge gap for the younger age group again points to the lack of a coordinated approach and/or a priority conflict, even as FIFA is attempting to systematically introduce this standardized program throughout the world. Gender and geographic imbalances are also evident. In a recent study not included in the Barengo et al. [28] review, Owoeye et al. [33] noted they were the first to study The 11+ in male youth players and also the first to involve players from Africa. Finally, building on dissemination and implementation strategies in part derived from the experiences of other sports organizations and tested on a national level, FIFA developed an 11 step protocol to maximize the potential for up-take and maintenance of The 11+ by member nations [34].

Unfortunately, as yet, there has been no directed research to rigorously evaluate the success of this approach. To date, FIFA has measured the success of its dissemination and implementation plan by the number of member associations that have signed licensing agreements for The 11+ and the number of coaches exposed to the program but these metrics do not provide objective evidence of the real impact of the intervention. For example, as noted above, the fidelity with which the program is implemented can vary considerably, which, in turn, will affect its efficacy and potential cost-effectiveness. To strengthen the impact of its outreach efforts, FIFA must build a mechanism for quantifying important aspects of dissemination and implementation into its research agenda. For example, RE-AIM [8] captures Reach (the proportion and representativeness of clubs which participate in the program), Effectiveness (the degree to which injury rates decline as a result of the program), Adoption (the proportion of member associations that agree to adopt the program), Implementation (the degree to which The 11+ is delivered as it is intended), and Maintenance (the level at which member nations and individual clubs continue to use The 11+). Currently, FIFA only has data that may apply to Adoption (approximately 25 % of member nations have signed licensing agreements). Other measures of the success of its efforts are subjective or inconsistent (e.g., number of coaches exposed to the program; the impact on injury rates) and provide little guidance for strengthening the potential of the program to influence injury risk.

In sum, the approach that FIFA has taken to address injuries and injury prevention in its young players can be measured against the six-step research progression framework needed to ensure a best-practices outcome to highlight its strengths and shortcomings as a model for other organizational entities overseeing youth sport:

(a) Conception—it is clear that FIFA is well aware of the risk of injury in soccer and has made it a priority to address the problem. However, the lack of research on pre-adolescents, especially in light of the number of participants in this demographic, indicates a deficiency in its current list of priorities.

(b) Description—the development of the Consensus Statement for Injury Research is an excellent model for other federations, etc., to emulate or utilize as a measure to impose order on injury research efforts. However, FIFA's failure to institute and support its own surveillance system at any level (regional, national, international) or to develop a list of research questions means that the scope of injury research and the quality of data will still rest with the interests, experience, and resources of individual researchers, continuing the current piece-meal approach.

(c and d) Explanation and Prediction—although the sheer volume of soccer injury research data might indicate a useful resource for identifying meaningful risk factors across its participant demographics, the widely varying quality of the work undermines it utility. Nonetheless, F-MARC has done an excellent job of sifting through the evidence and devising a prevention program that is, to the extent possible, based on empirical evidence. Better quality descriptive and analytical epidemiological studies would enhance the potential for refining future prevention programs.

(e) Control—while not instigated by FIFA, the easy availability of The 11+ has allowed independent researchers to run randomized controlled trials to evaluate the efficacy of the program. Unfortunately, as noted previously, this has resulted in RCT of varying value. To ensure studies that are rigorous, FIFA should take the lead in devising and running appropriate RCT.

(f) Research-to-practice translation—FIFA has developed an implementation protocol that has been shown to have good utility. However, the organization has not undertaken any methodical or rigorous analysis of its dissemination and implementation approach nor has it produced any cost-effectiveness data. This last becomes increasingly important as both the cost of participation and healthcare continue to rise across the world.

Summary

The inevitable increase in the number of injuries tied to growing participation in organized sport for children and adolescents, including new sports with significant intrinsic injury risk, has prompted researchers to investigate the characteristics and risk factors of various sports and develop prevention approaches to minimize the negative influence of injury on this population. While valuable insights have been gained from these efforts to date, overall the research has been hampered by lack of guidance and support from sports organizations, reliance on the interests of individual researchers, limited resources, and the lack of overarching, long-term, coherent systematic research programs, even in the most popular sports. Until these issues are addressed, progress toward maximizing safety in organized sport for children and adolescents will remain a piece-meal, hit-and-miss endeavor.

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D. Caine, L. Purcell (eds.), *Injury in Pediatric and Adolescent Sports*, Contemporary Pediatric and Adolescent Sports Medicine, DOI 10.1007/978-3-319-18141-7