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Section One

FUNDAMENTALS OF PEDIATRIC FRACTURE CARE

1

Epidemiology of Fractures in Children

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INTRODUCTION

Epidemiology is defined as the study of the distribution and determinants of health and disease and the application of this science to the control of diseases and other health problems. As such, epidemiology is the cornerstone of an evidence-based approach to preventing disease and to optimizing treatment strategies. Various epidemiologic methods including surveillance and descriptive studies can be used to investigate the distribution of frequency, pattern, and burden of disease whereas analytical methods can be used to study the determinants of disease. An understanding of the epidemiology of pediatric trauma is a prerequisite for the timely evolution of optimal care strategies, and for the development of effective prevention strategies.

Injuries in children and adolescents represent a major public health challenge facing pediatric patients, families, and health care providers worldwide. Given the wide-reaching impact that pediatric musculoskeletal injury has on public health, an understanding of the epidemiology of pediatric fractures provides an opportunity to maximize efforts aimed at prevention and optimal treatment. Unintentional injuries are the leading cause of death for children in the United States. In 2015, the Centers for Disease Control and Prevention (CDC) reported over 10,000 deaths of children between the ages of 0 and 18 years caused by unintentional injuries (http://webappa.cdc.gov/sasweb/ncipc/mortrate.html). However, fatalities only represent a small portion

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of the impact unintentional injuries have on children. There were over 7.5 million nonfatal unintentional injuries to children of the same age group in 2015 (http://webappa.cdc.gov/sasweb/ncipc/nfirates.html). Pediatric trauma often results in temporary activity limitation, hospitalization, and sometimes in permanent disability.[1,92] The Center of Disease Control's Web-based Injury Statistics Query and Reporting System (CDC WISQARS™) estimates that nonfatal injuries requiring medical attention affected more than 8.5 million children and adolescents and resulted in $24 billion in medical care and work loss costs (https://wisqars.cdc.gov:8443/costT/). As the leading cause of death and disability in children, pediatric trauma presents one of the largest challenges to the health of children, as well as an important opportunity for positive impact.

INCIDENCE OF FRACTURES IN CHILDREN

"CLASSIFICATION BIAS": DIFFICULTIES DEFINING DISEASE

Descriptive epidemiologic studies demand consistent information about how we define and classify a given disease state. This is a challenge in pediatric trauma, making it difficult to compare studies. An international study group has developed and performed early validation of a standardized classification system of pediatric fractures.[95–99] The authors of an agreement study found that with appropriate training, the AO Pediatric Comprehensive Classification of Long Bone Fractures (PCCF) system could be used by experienced surgeons as a reliable classification system for pediatric fractures for future prospective studies (Fig. 1-1).[96,99] In addition, follow-up studies have provided useful epidemiologic reporting of pediatric long-bone fractures using the AO PCCF.[3,33–35]

The incidence of pediatric fractures differs among published series because of geographical, environmental, gender, and age differences. Early studies on the incidence of fractures in children formed a knowledge base about fracture healing in children. Landin's 1983 report on 8,682 fractures remains a landmark study on the incidence of fractures in children.[45] He reviewed the data on all fractures in children that occurred in Malmö, Sweden, over 30 years and examined the factors affecting the incidence of children's fractures. By studying two populations, 30 years apart, he determined that fracture patterns were changing and suggested reasons for such changes. His initial goal was to establish data for preventive programs, so he focused on fractures that produced clean, concise, concrete data. Lempesis provided the most recent update from Malmö, Sweden over the years 2005 to 2006 and noted the previously reported declines in overall fracture rate remained unchanged and may have been related to a change in the region's demographics. There was however a decrease in incidence among girls. The pediatric fracture incidence during the period 2005 to 2006 was 1,832 per 10,000 person-years (2,359 in boys and 1,276 in girls), with an age-adjusted boy-to-girl ratio of 1.8 (1.6% to 2.1%).[59]

Figure 1-1. The AO PCCF for fracture classification with bone, segment, and subsegment nomenclature. (From Slongo TF, Audige L. Fracture and dislocation classification compendium for children: the AO Pediatric Comprehensive Classification of Long Bone Fractures (PCCF). *J Orthop Trauma*. 2007;21(10 Suppl):S135–S160.)

More recently, studies on the incidence of fractures in Edinburgh, Scotland in 2000, as reviewed by Rennie et al.,[64] was 20.2 per 1,000 children annually. A similar fracture incidence of 201/10,000 among children and adolescents was reported in northern Sweden between 1993 and 2007 with a 13% increase during the years between 1998 and 2007. The authors also reported the accumulated risk of sustaining a fracture before the age of 17 being 34%.[29] In Landin's series from Malmö, Sweden, the chance of a child sustaining a fracture during childhood (birth to age 16) was 42% for boys and 27% for girls.[45] When considered on an annual basis, 2.1% of all the children (2.6% for boys; 1.7% for girls) sustained at least one fracture each year. These figures were for all fracture types and included those treated on an inpatient basis and an outpatient basis. The overall chance of fracture per year was 1.6% for both girls and boys in a study from England of both outpatients and inpatients by Worlock and Stower.[114] The chance of a child sustaining a fracture severe enough to require inpatient treatment during the first 16 years of life is 6.8%.[10] Thus, on an annual basis, 0.43% of the children in an average community will be admitted for a fracture-related problem during the year. The overall incidence and lifetime risk of children's fractures are summarized in Table 1-1.

Early reports of children's fractures grouped the areas fractured together, and fractures were reported only as to the long bone involved (e.g., radius, humerus, femur). More recent reports have split fractures into the more specific areas of the long bone involved (e.g., the distal radius or the distal humerus). In children, fractures in the upper extremity are much more

TABLE 1-1. Overall Frequency of Fractures[16,30,36,46,57,68]

Percentage of children sustaining at least one fracture from 0–16 yrs of age: Boys, 42–60% Girls, 27–40%
Percentage of children sustaining a fracture in 1 yr: 1.6–2.1%
Annual rate of fracture in childhood: 12–36/1,000 persons

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TABLE 1-2. Incidence of Fractures in Long Bones

Bone	%
Radius/ulna	59
Humerus	21
Tibia/fibula	15
Femur	5

From Joeris A, Lutz N, Wicki B, et al. An epidemiological evaluation of pediatric long bone fractures: a retrospective cohort study of 2716 patients from two Swiss tertiary pediatric hospitals. *BMC Pediatr.* 2014;14:314 © Joeris et al; licensee BioMed Central. 2014.

common than those in the lower extremity.[115] Overall, the radius is the most commonly fractured long bone, followed by the humerus. In the lower extremity, the tibia is more commonly fractured than the femur (Table 1-2).[35]

The individual reports agree that the most common area fractured in children is the distal radius. The next most common area involves the hand (phalanges and metacarpals), clavicle and distal humerus.[46,71,83,84]

Physeal Fractures

The incidence of physeal injuries overall varied from 14.8% to as high as 30% in the literature across various series.[37,60,63,77,84,106]

Open Fractures

The overall reported incidence of open fractures in children has changed over time ranging 1.5% to 2.6% in older series[10,60,114] to 0.7% to 1% in recent reports.[35,84] Regional trauma centers often see patients exposed to more severe trauma, so there may be a higher incidence of open fractures in these patients. The incidence of open fractures was 9% in a report of patients admitted to an urban trauma center.[7]

Despite the importance of understanding the epidemiology of pediatric fractures, there are still significant gaps in our knowledge base, and there is much work to be done. There are several challenges to gathering appropriate data in this area: risk factors for pediatric injury are diverse and heterogeneous, practice patterns vary across countries and even within countries, and the available infrastructure to support data collection for pediatric trauma is far from ideal.

PATIENT FACTORS THAT INFLUENCE FRACTURE INCIDENCE AND FRACTURE PATTERNS

Age

Fracture incidence in children increases with age. Age-specific fracture patterns and locations are influenced by many factors including age-dependent activities and changing intrinsic bone properties. Starting with birth and extending to age 12, all the major series that segregated patients by age have demonstrated a linear increase in the annual incidence of fractures with age (Fig. 1-2). The peak age for fracture occurrence in girls is age 11 to 12 and for boys it is age 13 to 14.[10,28,36,83,84]

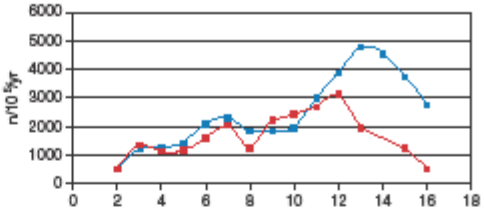

Figure 1-2. Incidence of fractures by age. Boys (*blue*) peak at 13 years whereas girls (*red*) peak earlier, at 12 years, and then decline. (Reprinted from Rennie L, Court-Brown CM, Mok JY, et al. The epidemiology of fractures in children. *Injury.* 2007;38(8):913–922. Copyright © 2007 Elsevier Ltd. With permission.)

Although there is a high incidence of injuries in children of ages 1 to 2, the incidence of fractures is low with most fractures being related to accidental or nonaccidental trauma from others.[14,42] The anatomic areas most often fractured seem to be the same in the major series, but these rates change with age. Rennie et al.[84] demonstrated in their 2000 study from Edinburgh that the incidence of fractures increased and fracture patterns changed as children aged. Fracture incidence curves for each of the most common fractures separated by gender were shown on six basic incidence curves similar to Landin's initial work (Fig. 1-3).[45] When Landin compared these variability patterns with the common etiologies, he found some correlation. For example, late-peak fractures (distal forearm, phalanges, proximal humerus) were closely correlated with sports and equipment etiologies. Bimodal pattern fractures (clavicle, femur, radioulnar, diaphyses) showed an early increase from lower-energy trauma, then a late peak in incidence caused by injury from high- or moderate-energy trauma likely caused by motor vehicle accidents (MVAs), recreational activities, and contact sports in the adolescent population. Early-peak fractures (supracondylar humeral fractures are a classic example) were mainly caused by falls from high levels.

Gender

Gender differences can be seen across the incidence of injures, location of injuries, and etiology of injuries across all age groups. For all age groups, the overall ratio across a number of series of boys to girls which sustains a single fracture is about 1.5:1.[10,29,30,36,46,84]

In some areas, there is little difference in the incidence of fractures between boys and girls. For example, during the first 2 years of life, the overall incidence of injuries and fractures in both genders is nearly equal. During these first 2 years, the injury rates for foreign-body ingestion, poisons, and burns have no significant gender differences. With activities in which there is a male difference in participation, such as with sports equipment and bicycles, there is a marked increase in the incidence of injuries in boys.[9,85] The injury incidence may not be caused by the rate of exposure alone; behavior may be a major factor.[107] For example, one study found that the incidence of auto/pedestrian childhood injuries peaks in both sexes at ages 5 to 8.[86] When the total number of street crossings per day was studied, both sexes did so equally. Despite this equal exposure, boys had a higher number of

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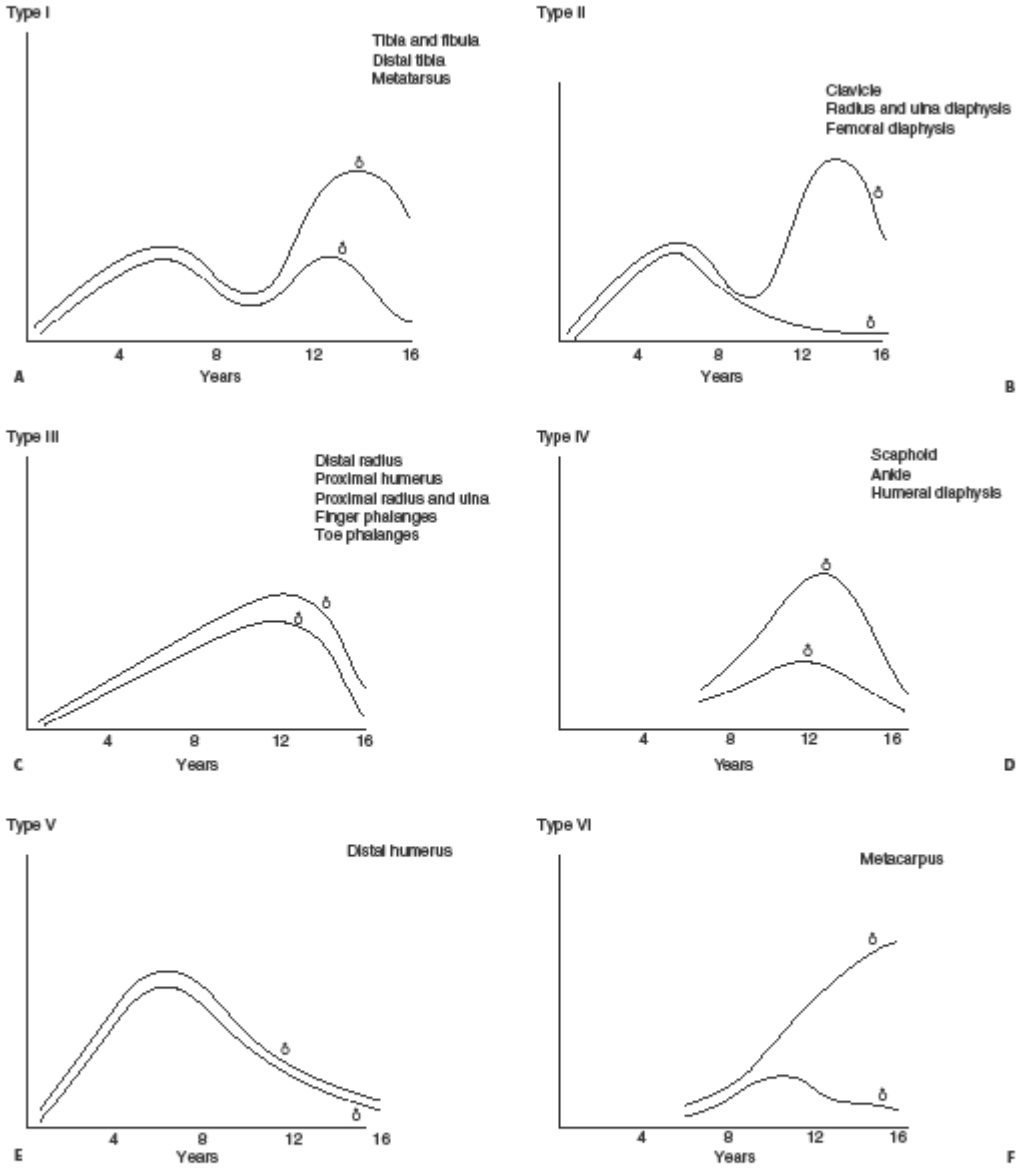

Figure 1-3. Variations of fracture patterns with age. The peak ages for the various fracture types occur in one of six patterns. (Reprinted from Rennie L, Court-Brown CM, Mok JY, et al. The epidemiology of fractures in children. *Injury*. 2007;38(8):913–922. Copyright © 2007 Elsevier Ltd. With permission.)

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injuries. Thus, the difference in the rate between the sexes begins to develop a male predominance when behaviors change.

Socioeconomic and Cultural Differences

The incidence of pediatric fracture varies in different geographic settings, socioeconomic climates, and differing ethnicities. Two studies from the United Kingdom looked at the relationship of affluence to the incidence of fractures in children and had differing conclusions. Lyons et al.[58] found no difference in the fracture rates of children in affluent population groups compared to those of children in nonaffluent families. On the other hand, Stark et al.[103] in Scotland found that the fracture rates in children from nonaffluent social groups were significantly higher than those in affluent families. There are also contradictory results in the literature with regard to fracture risk associated with living urban versus rural settings.[21,30] In the United States, the increased rate of pediatric femur fractures was influenced by adverse socioeconomic and sociodemographic fractures.[32] Wren et al.[115] in a large prospective cohort studied the association of race and ethnicity as a risk factor for fracture in children and adolescents. They found that fracture rates were higher, regardless of sex, for white children compared with all other racial and ethnic groups.

Clinical Factors

In recent years there has been an attention to a number of clinically related factors in determining children's fractures, such as obesity, low bone mineral density (BMD), and low calcium and vitamin D intake. Obesity is an increasing health problem in children and adolescents representing a complex interaction of host factors, and is the most prevalent nutritional problem for children in the United States. In a retrospective chart review, Taylor et al.[105] noted that overweight children had a higher-reported incidence of fractures and musculoskeletal complaints. Although Leonard et al.[50] found increased BMD in obese adolescents, the lack of physical activity often seen in obesity may in fact lead to reduced muscle mass, strength, and coordination resulted in impaired proprioception, balance and increased risk of falling and fracture. In a recent study, Valerio et al.[108] confirmed a greater prevalence of overweight/obesity in children and adolescents with a recent fracture when compared to age- and gender-matched fracture-free children, and found obesity rate was increased in girls with upper limb fractures and girls and boys with lower limb fractures.

Low BMD and decreased bone mass are linked to increased fracture risk in the adult population; however, in children, the relationship is less clear with a meta-analysis showing some association between fracture risk and low BMD.[13] In 2006, Clark examined in a prospective fashion the association between bone mass and fracture risk in childhood. Over 6,000 children at 9.9 years of age were followed-up for 2 years and the study showed an 89% increased risk of fracture per standard deviation (SD) decrease in size-adjusted BMD.[11] In a follow-up study of this same cohort, the risk of fracture following slight or moderate to severe trauma was inversely related to bone size relative to body size perhaps reflecting the determinants of volumetric BMD such as cortical thickness on skeletal fragility.[12]

Nutritional factors may also play a role in the incidence of fractures in children.

THE IMPACT OF ENVIRONMENTAL FACTORS ON FRACTURES IN CHILDREN

Seasonal and Climatic Differences

Fractures are more common during the summer, when children are out of school and exposed to more vigorous physical activities. An analysis of seasonal variation in many studies shows an increase in fractures in the warmer months of the year.[9,10,28,45,83,84,95,111,114]

Children in colder climates, with ice and snow, are exposed to risks different from those of children living in warmer climates. The exposure time to outdoor activities may be greater for children who live in dry and warm weather climates.[84] The most consistent climatic factor appears to be the number of hours of sunshine. Masterson et al.,[61] in a study from Ireland, found a strong positive correlation between monthly sunshine hours and monthly fracture admissions. There was also a weak negative correlation with monthly rainfall. Overall, the average number of fractures in the summer was 2.5 times than that in the winter. In days with more sunshine hours than average, the average fracture admission rate was 2.31/day; on days with fewer sunshine hours than average, the admission rate was 1.07/day. Pediatric trauma should be viewed as a disease where there are direct and predictable relationships between exposure and incidence.

Time of Day

The time of day in which children are most active seems to correlate with the peak time for fracture occurrence. Seasonal variation and geographic location seem to play a role as to which time during the day injury occurs (Fig. 1-4).[63] In a Swedish study, the incidence peaked between 2 PM and 3 PM,[83] whereas in a study out of Texas by Shank et al.,[73] the hourly incidence of fractures formed a well-defined bell curve peaking at about 6 PM.

Home Environment

Fractures sustained in the home environment are defined as those that occur in the house and surrounding vicinity. These generally occur in a fairly supervised environment and are mainly caused by falls from furniture, stairs, fences, and trees as well as from injuries sustained from recreational equipment (trampolines and home jungle gyms). Falls can vary in severity from a simple fall while running, to a fall of great magnitude, such as from a third story window. In falling from heights, adults often land on their lower extremities, accounting for the high number of lower-extremity fractures, especially the calcaneus. Children tend to fall head first, using the upper extremities to break the fall. This accounts for the larger number of skull and radial fractures in children. Femoral fractures also are common in children falling from great heights. In contrast to adults, spinal fractures are rare in children who fall from great heights.[90] In one study, children falling three stories or less all survived. Falls from the fifth or sixth floor resulted in a 50% mortality rate.[6,62,93,101]

Interestingly, a Swedish study showed that an increased incidence of fractures in a home environment did not necessarily correlate with the physical attributes or poor safety precautions of the house.[6] Rather, it appears that a disruption of the family

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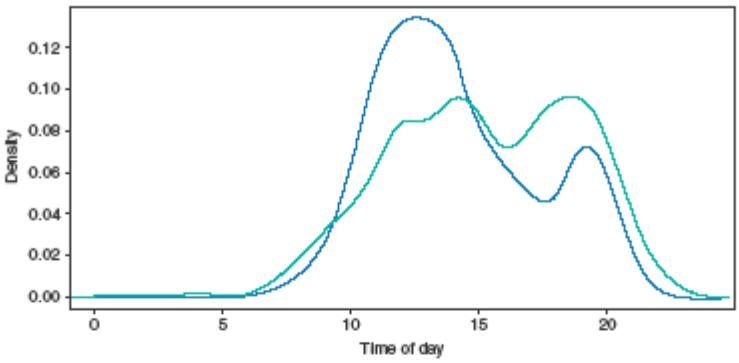

Figure 1-4. Distribution of fractures during time of day by summertime (*green*) and wintertime (*blue*). Density estimates are computed using kernel-smoothing method with normal kernel function and suitable bandwidth. The *x* axis represents the hours in 5-hour intervals throughout the day (i.e., *0*, midnight; *5*, 5 AM; *10*, 10 AM; *15*, 3 PM; and *20*, 8 PM), and the *y* axis represents the probability density that a fracture would occur at any given time of day. (Redrawn from Randsborg PH, Gulbrandsen P, Saltyte Benth J, et al. Fractures in children: epidemiology and activity-specific fracture rates. *J Bone Joint Surg Am*. 2013;95A:e42.)

structure and presence of social handicaps (alcoholism, welfare recipients, etc.) are important risk factors for pediatric fracture.

School Environment

The supervised environments at school are generally safe, and the overall annual rate of injury (total percentage of children injured in a single year) in the school environment ranges from 2.8% to 16.5%.[73] Most injuries occur as a result of use of playground or recreational equipment or participation in athletic activity. True rates may be higher because of inaccurate reporting, especially of mild injuries. The annual fracture rate of school injuries is thought to be low. Of all injuries sustained by children at school in a year, only 5% to 10% involved fractures.[52] In Worlock and Stower's series of children's fractures from England,[25,59,93] only 20% occurred at school. Most injuries (53%) occurring in school are related to athletics and sporting events,[114] and injuries are highest in the middle school children, with one study citing a 20% fracture rate in school-aged children of those injured during physical education class.[59]

ETIOLOGY OF FRACTURES IN CHILDREN

THREE BROAD CAUSES

Broadly, fractures have three main causes: accidental trauma, nonaccidental trauma (child abuse), and pathologic conditions. Accidental trauma forms the largest etiologic group and can occur in a variety of settings, some often overlapping others. Nonaccidental trauma and fractures resulting from pathologic conditions are discussed in later chapters of this book.

SPORTS-RELATED ACTIVITIES

The last two decades have seen an increase in youth participation in organized athletic participation, especially among younger children. Wood et al. studied at the annual incidence of sports-related fractures in children 10 to 19 years presenting to hospitals in Edinburgh. The overall incidence was 5.63/1,000/yr with males accounting for 87% of fractures. Soccer, rugby, and skiing were responsible for nearly two-thirds of the fractures among the 30 sporting activities that adolescents participated in. Upper-extremity fractures were by far the most common injury accounting for 84% of all fractures with most being low-energy injuries and few requiring operative intervention.[75] A retrospective study over a 16-year time period from an emergency department at a level 1 trauma center in the Netherlands examined risk factors for upper-extremity injury in sports-related activities. Most injuries occurred while playing soccer and upper-extremity injuries were most common. Risk factors for injury were young age and playing individual sports, no-contact sports, or no-ball sports. Women were at risk in speed skating, in-line skating, and basketball, whereas men mostly were injured during skiing and snowboarding.[113]

In the United States, football- and basketball-related injuries are common complaints presenting to pediatric emergency departments, with fractures occurring more frequently in football.[22] In a 5-year survey of the NEISS National Electronic Injury Surveillance System (NEISS)-All Injury Program, injury rates ranged from 6.1 to 11 per 1,000 participants/year as age increased, with fractures and dislocations accounting for nearly 30% of all injuries receiving emergency room evaluation.[69]

Recreational Activities and Devices

In addition to increasing participation in sports, new activities and devices[85] have emerged that expose children to increased fracture risk. Traditional activities such as skateboarding, roller skating, alpine sports, and bicycling have taken on a new look in the era of extreme sports where such activities now involve high speeds and stunts. Many of these activities have safety equipment available but that does not assure compliance.

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