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Pattern of fractures across pediatric age groups: analysis of individual and lifestyle factors

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Abstract

Background: Knowledge of the epidemiology of children's fractures is essential to develop preventive strategies. The aim of this study was to analyze the individual/lifestyle determinants of fractures across pediatric age groups.

Methods: A cross-sectional study was performed in the first six months of 2008 through questionnaire on a sample of children from an outpatient clinic for pediatric fractures. Differences in gender, anatomic site, circumstances and location of fracture occurrence, behavioural lifestyle, and calcium intake were investigated among three different age classes (pre-school children, school children, and adolescents).

Results: The sample consisted of 382 subjects (2-14 years of age) sustaining a fracture after low or moderate trauma. Males were at a higher risk of fractures than females; greater than two-thirds of injuries occurred after low-energy trauma and the upper limb was more frequently involved. With increasing age, the male/female ratio and time spent in sports participation increased ($p < 0.001$), while calcium intake and time spent in sedentary behaviors decreased ($p < 0.001$ and < 0.003, respectively). Gender discordance existed in pre-school children with respect to the anatomic location, and in school children and adolescents with respect to the dynamics. In the adolescent group, males were more physically active and also more sedentary than females. Fractures most frequently occurred in homes (41.6%), followed by playgrounds and footpaths (26.2%), sports facilities (18.3%), and educational facilities (13.9%), with gender differences existing only in adolescence. Twenty-three percent of the subjects sustained one or more fractures in the past. The percentage of recurrent fractures increased with age ($p = 0.001$), with a similar trend in both genders.

Conclusions: Gender differences were shown in the prevalence of injuries, characteristics, and circumstances across ages. These differences may be explained by the related changes in behaviors, together with attending different places. Individual and lifestyle factors can in part explain the variability in the occurrence of fractures and can also address targeted preventive strategies.

Background

Fractures are extremely common in the pediatric age group, representing a major public health problem. The lifetime risk of sustaining a fracture in childhood is approximately 42%-64% in boys and 27%-40% in girls, with remarkable variation in the estimates worldwide [1-4]. While fractures more often occur in males, girls usually sustain fractures at a younger age compared to boys [2-7]. Even though several genetic, endocrine, or systemic illnesses that affect bone metabolism may cause fractures, the majority of children with fractures are otherwise healthy. Several factors have been analyzed for their role in determining fracture risk. Bone mass and bone mineral density, low calcium intake, high body mass index (BMI), inactivity, behavioral difficulties, consumption of carbonated beverages, use of drugs (corticosteroids) have been variably associated with this kind of injury in children [7-11]. It has also been demonstrated that a first fracture at a young age is associated with an increasing risk of sustaining subsequent fractures [12,13].

Studying the epidemiology of children's fractures is essential in developing preventive strategies. The importance of analyzing the etiology of injuries, and the

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circumstances and settings in which they occur in the various stages of development is to identify risky behaviors or an unsafe environment which can be corrected by specific preventive measures appropriate for age.

The purpose of this cross-sectional study was to analyze the individual and lifestyle determinants of fractures in a series of outpatient children and adolescents. Comparison of gender, anatomic site, circumstances and location of fracture occurrence, behavioural life style, and calcium intake were analysed among three different age classes (pre-school children, school children, and adolescents).

Methods

This was a cross-sectional study conducted in the outpatient clinic of the Department of Orthopedics and Traumatology of Santobono-Pausilipon Children Hospital in Naples (southern Italy). This hospital is the largest children's hospital in the Campania region, providing inpatient and outpatient services in emergency and trauma medicine in children < 14 years of age within the metropolitan area of Naples. The study commenced on 1 January 2008 and was terminated on 30 June 2008. In 2008, the metropolitan area included 4,434,000 residents, of whom 17.3% (767,082 subjects) were < 14 years of age. The investigation was approved by the Ethical Committee of the Santobono-Pausilipon Hospital and written informed consent was obtained from all participants and/or their parents or legal guardians in accordance with the revised version of the Helsinki Declaration regarding research involving human subjects.

The inclusion and exclusion criteria are reported in table 1. Children < 2 years of age were not included because the analysis of lifestyle behaviors is hardly applicable at this very young age. The population was divided into 3 age ranges (pre-school children [2-5.9 years], school children [6.0-10.9 years], and adolescents [11-14 years]). Height and weight were measured and the BMI was calculated according to the following formula: (weight [kg]/height [m^2]). Since BMI is age- and gender-related, this parameter was transformed into a standard deviation score (SDS), based upon the established Center for Disease Control normative curves [14]. Fractures were confirmed radiographically at the time of injury. Using information about each event documented in the medical record, fractures were classified based on their anatomic site, the location of the injury occurrence (home, playground, footpath, educational facility [kindergarten or school], and sports facility), and circumstances surrounding the fracture. Children were assigned to a trauma level category based on a modified Landin's description [15] that considers the height of the fall and the landing surface [16,17], the physical activity engaged in, and whether or not any equipment was being used (Table 2). The occurrence of a previous accidental fracture confirmed by X-ray ascertained by the parents' report was elicited in the past history. The study also included a questionnaire assessment by parents regarding socioeconomic factors (parents' education) and some behavioural issues about the child, such as sports participation in the previous 12 months, weekly hours of sports activity, and daily hours of sedentary behaviours (sum of time spent in television viewing, computer, and video games). The total daily calcium intake was calculated using a food-frequency questionnaire, specifically established for a pediatric population [18]. The optimal daily calcium intake was defined according to the Italian Society for Human Nutrition guidelines [19].

Statistical analysis

The confidence interval estimation performed to determine the sample size indicated that a size of 127 produced a 99% confidence interval equal to the sample

Table 1 Criteria for inclusion and exclusion of patients

inclusion criteria	age ≥ 2 years
	resident in the Campania region
exclusion criteria	fracture due to severe trauma
	presence of any specific pathologic process known to affect bone and mineral metabolism
	presence of any specific treatment known to affect bone and mineral metabolism

Table 2 Descriptive categories of Landin's modified trauma levels (15)

Slight trauma
Falling to the ground from < 0.5 m (standing height)
Falling to a resilient surface (rubber or sand) from 0.5-3 m
Falling from a bed or cot
Playing injuries, including playground scuffles
Low-energy sporting injuries, such as ball sports, judo, karate, wrestling, and gymnastics
Moderate trauma
Falling to concrete or other non-resilient surface from 0.5-3 m
Falling from a bunkbed
Baby being dropped to the floor by an adult
Falling downstairs
Falling from a bicycle
Falls while moving on skateboards, skis, rollerblades, or skates
Severe trauma
Falling from a height exceeding 3 m
All traffic accidents not already mentioned
Being hit by a moving heavy object

proportion plus or minus 0.05 when the estimated proportion was 0.05 (according to a recent estimated incidence of 5% of fractures in children < 14 years of age [4]). All statistical analyses were carried out using the Statistical Package of Social Sciences (SPSS, Windows release 15.0; Chicago, IL, USA). A p value <0.05 was considered significant.

The results are reported as the mean ± SD. All of the continuous variables had a normal distribution, except for BMI-SDS, time spent in sports activities, and sedentary behaviors. Therefore, an independent sample t-test or a one-way ANOVA with a *post hoc* Bonferroni test were used for parametric variables, while the Mann-Whitney U test or the Kruskall-Wallis test were used for non-parametric variables. A chi-square test was used for categorical variables. Logistic regression analysis was performed to determine relationships between individual and lifestyle variables and fracture recurrence. The outcome variable was fracture recurrence, while the independent variables were gender (coded as 1 for boys and 2 for girls), age, BMI-SDS, adherence to calcium intake recommendations (0 = not adherent; 1 = adherent), time spent in sports activities, or in sedentary behaviours.

Table 3 Demographic features of subjects with fractures in the three age groups

	PRE-SCHOOL CHILDREN	SCHOOL CHILDREN	ADOLESCENTS
N	76	199	107
Boys/girls n (ratio)	42/34 (1.2)	128/71 (1.8)	91/16 (5.7)**
Age (years)	4.38 ± 1.1	8.62 ± 1.4	12.29 ± 0.8
Height (cm)	113.3 ± 11.5	135.8 ± 13.9	152.8 ± 16.9
Weight (kg)	23.5 ± 7.1	38.3 ± 11.28	54.7 ± 11.9
BMI (kg/m^2)	18.3 ± 4.3	20.2 ± 4.28	22.9 ± 4.1
BMI- SDS	0.93 ± 2.0	1.09 ± 1.10	1.16 ± 0.99
Father's education level n (%)			
Elementary	4 (6.1)	22 (11.7)	6 (6.7)
Middle school	29 (43.9)	80 (42.8)	41 (46.1)
High school	28 (42.4)	69 (36.9)	34 (38.2)
Degree	5 (7.6)	16 (8.6)	8 (9)
Mother's education level n (%)			
Elementary	6 (9.2)	21 (11)	9 (10)
Middle school	24 (36.9)	80 (42.1)	39 (43.3)
High school	30 (46.2)	78 (41.1)	30 (33.3)
Degree	5 (7.7)	11 (5.8)	12 (13.3)

** p < 0.001 pre-school children versus school children and adolescents; children versus adolescents

Results

Prevalence of fractures and lifestyle factors by age group and gender

Three-hundred eighty-two children were enrolled in the study. There were 261 boys (68.3%) and 121 girls (31.7%), with a mean age of 8.8 ± 2.9 years (range, 2-14 years). According to the age groups, there were 76 (19.9%) pre-school children, 199 (52%) school children, and 107 (28.0%) adolescents. The demographic features are shown in Table 3. Males were at a higher risk of fracture than females in every age group, with a prevalence progressively increasing with age (p < 0.001). No difference was found among the three age groups regarding BMI-SDS and parental educational level. The highest frequency of fractures occurred at 12 years of age in boys (15.3%) and 9 years of age in girls (13.2%); the lowest frequency of fractures occurred at 2 years of age in boys (2.7%) and 3 years of age in girls (2.5%). The percentage of subjects fulfilling the daily calcium recommendations significantly decreased with age (pre-school children [86.8%], school children [61.3%], and adolescents [31.8%], p < 0.001), while weekly time spent in sports activities significantly increased (pre-school children [0.38 ± 0.83 hrs/week], school children [1.73 ± 2.3 hrs/week], and adolescents [3.1 ± 3.1 hrs/week], p < 0.001). The time spent in sedentary behaviors was significantly higher in adolescents (5.6 ± 2.9 hrs/day) than pre-school children (4.3 ± 2.9 hrs/day) and school children (4.7 ± 2.8 hrs/day; p < 0.003). No gender difference in any of these behaviors existed in pre-school children, while significant differences existed in both school children in whom males were more sedentary than girls (p = 0.001), and in adolescents in whom males were more physically active (p < 0.02) and more sedentary than girls (p = 0.027; Table 4).

Dynamics of fractures

The dynamics of fractures were known in 359 children (93.9%). Fractures due to low-energy trauma occurred in 252 subjects (70.2%). After stratification by gender and age class, low-energy trauma was more frequent in male school children and adolescents (p = 0.007 and p = 0.006, respectively, table 3), while no difference existed in pre-school children.

Anatomic sites of fractures

The prevalence of fractures according to the anatomic site is shown in table 5. Except for two cases of clavicular fractures, the near totality of injuries involved the upper (84.1% cases) or lower limb (15.9%). The net prevalence of the upper limb over the lower limb was independent of age group. A slight gender discordance existed only in pre-school children in whom upper limb fractures were more frequent in boys than girls (p = 0.054). A further distinction based on upper arm, forearm and wrist, and hand showed significant differences

Table 4 Gender comparison of the characteristics of fractures, and nutritional and behavioural habits in the three age groups

	PRE-SCHOOL CHILDREN			SCHOOL CHILDREN			ADOLESCENTS		
	Males	Females	*p*	Males	Females	*p*	Males	Females	*p*
Low energy trauma (%)	66.7	61.3	*0.635*	79.8	61.8	*0.007*	72.6	30.0	*0.006*
Upper limb (%)	91.7	74.2	*0.054*	86.9	86.4	*0.920*	79.5	75.0	*0.723*
Adherence to calcium intake recommendations (%)	83.8	90.6	*0.400*	59.0	65.2	*0.398*	31.8	33.3	*0.904*
Sports participation (hours/week)	0.4 ± 0.9	0.3 ± 0.7	*0.413*	1.6 ± 1.9	2.0 ± 2.9	*0.173*	3.4 ± 3.2	1.7 ± 2.7	*0.043*
Sedentary behaviours (hrs per day)	4.4 ± 3.2	4.2 ± 2.5	*0.735*	5.2 ± 2.9	3.7 ± 2.1	*0.001*	5.9 ± 3.0	4.1 ± 2.1	*0.020*

between genders only in pre-school children (p = 0.001) in whom the upper arm was predominantly involved in girls (73.9%) and the forearm and wrist in boys (63.6%).

Locations of fracture occurrences

The home was the main location (n = 159 [41.6%]), followed by the playground and footpath (n = 100 [26.2%]), sports facility (n = 70 [18.3%]), and educational facility (n = 53 [13.9%]). Location was separately analyzed by gender and age. In males the percentage of fractures occurring in the home significantly decreased with age, while the percentage of fractures occurring in educational facilities, playgrounds and footpaths, or in sports facilities increased (p < 0.001; Figure 1, panel A). In females the home represented the most frequent location at any age, while fractures in the playground and footpath or sports facility significantly decreased with age (p = 0.026; Figure 1, panel B) and a U-shaped curve was observed regarding educational facilities. No difference between genders existed in each age group, except in adolescents, in whom the playground and footpath was the location more frequently reported by males (33.0%) and the home was more frequently reported by females (43.8%, p = 0.048).

Table 5 Distribution of fractures among the different sites

	number	%
Distal radius and physis	116	30.4
Radial shaft	92	24.1
Elbow area (distal humerus, proximal radius, and ulna)	70	18.3
Humerus (proximal and shaft)	33	8.6
Hand (carpals, metacarpals, and phalanges)	8	2.1
Clavicle	2	0.5
Tibial shaft	22	5.8
Foot (metatarsal and phalanges)	17	4.4
Ankle (distal tibia)	16	4.2
Femur (neck and shaft)	5	1.3
Other	1	0.2

Recurrent fractures

Eighty-eight subjects (23.2%) sustained one or more fractures in the past that were ascribed by parents to accidental injuries. The percentage of recurrent fractures increased from pre-school children to adolescents (from 7.9% to 40.6%, p = 0.001), with a similar trend in both genders. Subjects with recurrent fractures did not differ from those reporting only one fracture with respect to BMI-SDS, time spent in sports activities, or sedentary behaviors (data not shown). Fractures caused by low-energy trauma occurred in 74.7% of subjects with recurrent fractures and 68.7% of subjects reporting only one fracture (p not significant). Fifty-six percent of subjects with recurrent fractures did not fulfill the daily recommendations of calcium intake in comparison with 37% of subjects who reported only one fracture (p = 0.001). In order to exclude confounders, logistic regression analysis was used in which recurrence of fractures was the independent variable and age, gender, BMI-SDS, adherence to daily calcium intake recommendations, weekly time spent in sports activities, and daily time spent in sedentary behaviors were the dependent variables. Only older age was independently associated with recurrent fractures [Exp(B), 1.287; 95% CI, 1.146-1.445, p < 0.001, table 6].

Discussion

It has been reported that fractures are a common event in childhood [1-3], with considerable variations in the incidence rate from 1.2% to 5% among different studies [4,20,21]. This variability may depend on the child's condition, age, and social and environmental factors. Few data are available regarding the epidemiology of fractures in the various periods of pediatric ages [21]. These periods are characterized by different stages of physical, cognitive and social development, and may obviously explain the varying pattern of injuries across age groups [21,22]. We enrolled a population of patients receiving treatment for fractures caused by slight or moderate dynamics. In order to describe possible differences among the various developmental stages and define individual and lifestyle determinants of fractures

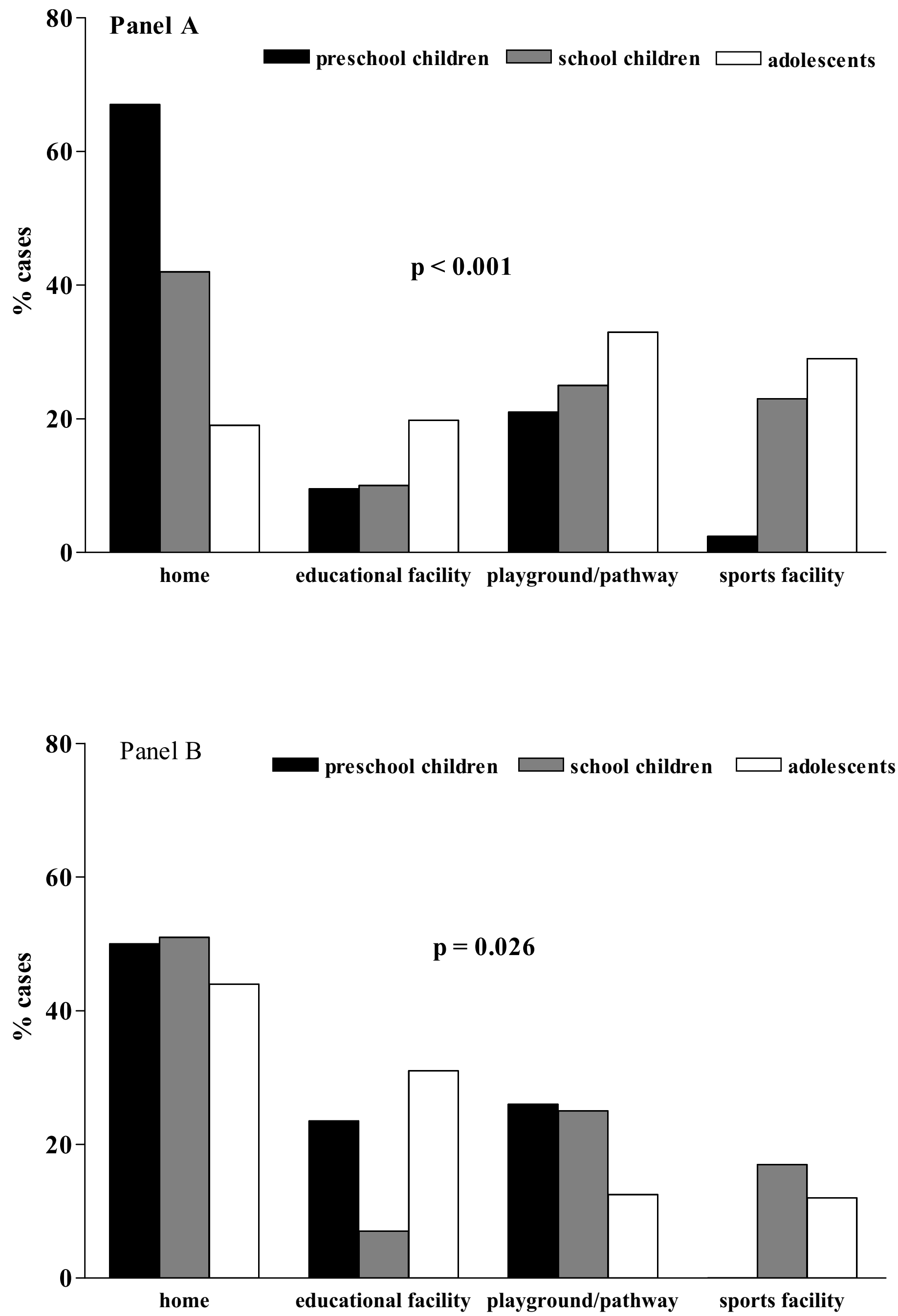

Figure 1 Main locations of injury in the different age groups (panel A, boys; panel B, girls).

according to age, this population was divided in pre-school children, school children, and adolescents. Our data indicate that males were at higher risk of fractures than females, more than two-thirds of injuries occurred after low-energy trauma, and the upper limb was more frequently involved. With increasing age, the male/female ratio and time spent in sports participation increased, while calcium intake and time spent in sedentary behaviors decreased. A gender discordance was demonstrated in pre-school children with respect to the anatomic location and in school children and adolescents with respect to the dynamics. In the adolescent group, males were not only physically more active than females, but also more sedentary. Gender differences in the incidence of fractures in the pediatric age group are well-known. The overall percentage of children from 0-

Table 6 Variables independently associated with age at fracture occurrence by multiple regression analysis in the entire sample of patients

Independent Variable: Age at fracture occurrence			
Dependent variables	B Coefficients	SE	p
Gender (1 = Male, 2 = Female)	-.683	0.29	.018
BMI-SDS	0.208	0.10	.042
Calcium intake (0 = not adherent, 1 = adherent)	-2.218	0.27	.000
Sports activities (hrs/week)	0.357	0.05	0.000
Sedentary behaviors (hrs/day)	0.166	0.05	.001

16 years of age sustaining at least 1 fracture is higher (42%) in boys than girls (27%) [23,24], and the peak incidence is roughly 3 years earlier in girls than boys (11 and 14 years, respectively) [3]. Similarly, our data confirmed that the overall fracture prevalence was higher in boys, independent of age, but the peak frequency occurred 2 years earlier than previous studies reported (9 years in girls and 12 years in boys). The increase in fracture rate during the pubertal years has been explained by a discrepancy between height gain and the accrual of bone mineralization [25]. Since the onset of puberty progressively anticipated in the last century in several European countries, including Italy [26], the 2-year anticipation of the peak frequency of fractures may be explained by the earlier peak height velocity associated with pubertal growth. We found that the male-to-female ratio significantly increased from pre-school children (1.2) to adolescents (5.7) in agreement with previous reports [27,28]. We did not find any difference in the parental educational level among the three age classes. The relationship between socioeconomic status and the risk of fractures has been analyzed with contradictory evidence. While unintentional home injuries in pre-school children is related to the main caregiver's level of education [29], no clear evidence of a socioeconomic gradient in the total incidence of fractures has been shown in childhood [8,15,30,31]. Interestingly, Williams et al. [32] reported that parental socioeconomic status was related to the circumstances in which injury events occurred in adolescents, influencing the extent and type of the risk behaviours. Seasonal variation in the incidence of pediatric fractures has been reported in several studies, with the highest peak found in the warmer months [21,33]. Subjects in our investigation were enrolled in the first 6 months of the year. A full-year review would have been valuable in order to exclude a possible enrollment bias; however, the weather in our region does not substantially influence behaviours during leisure time. Moreover, the admissions for fractures were equally distributed in the first and second semesters of the year according to the hospital report.

We showed that in 77% of cases fractures were ascribed to low-energy trauma (mainly falls) that occurred more frequently in males in school children and adolescents. Similarly, Rennie et al. [21], who analyzed the basic epidemiology for different mechanisms of fracture in British children, reported that falls accounted for 57% of all fractures, occurred at a younger age and prevailed in males.

Increased participation in both organized and informal sports, as well as the overall high levels of physical activity during adolescence, has been previously advocated to explain the increased incidence of fractures in adolescents [21,34-36]. In particular, gender difference in the incidence of injuries may be explained by age-related changes in behaviors, such as participation in activities with increased physical risks by males [37]. In a population-based case control study, Ma and Jones [6] reported that participation in sports increased the risk of upper limb fractures in boys and decreased the risk of upper limb fractures in girls, even for the same sport. This effect was independent of bone mass, suggesting gender heterogeneity in the approach to sports, and implies that the beneficial effect of physical activity on bone health [38,39] can be hindered in males, who probably are engaged in physical activities with higher potential for trauma. Indeed the relationship between physical activity, bone mass, and childhood fracture risk is complex. A positive association between vigorous physical activity and childhood fractures that was independent of bone mass was demonstrated by Clark et al. [15]. Participation in vigorous physical activity or contact sport may increase bone mass, but does not protect from the risk caused by increased exposure to injuries. The influence of physical activity on fracture risk is determined by its net effect on fall-related trauma and bone strength. Therefore, as motor ability increases, the involvement in physical activities increases and the risk of injuries increases, particularly in boys [40]. In agreement with these previous reports, we found that adolescents sustaining a fracture spent higher amounts of time in organized physical activity than their counterparts in pre-school children or school children; in addition, males were more physically active and sedentary than females. A previous study reported a dose response association between time spent in television, computer, and video viewing and wrist and forearm fracture risk in both genders [6]. It would be expected that sedentary behaviours would reduce levels of physical activity and consequently lower the risk of trauma. Indeed, several studies have not demonstrated any negative relationship between video exposition and moderate or vigorous leisure-time physical activity, indicating that these behaviours may co-exist [41]. The increased time spent watching television or playing computer games may lead to unhealthy behaviours, such as increased consumption of energy-dense snack foods or carbonated beverages, obesity, or aggressive behaviour, conditions that may place children at greater risk of fractures [42,43].

Regarding the anatomic site, the upper limb is more frequently involved in pediatric fractures, accounting for approximately two-thirds of all fractures [20]. We confirmed that the upper limb was more frequently involved at any age, representing indeed > 80% of fractures, in agreement with a previous epidemiologic study performed in various age groups [21]. This higher prevalence may be explained by the fact that 77% children in our study reported low-energy fractures, the main cause being represented by falls. Indeed, the arm is more frequently involved after a fall in children > 5 years of age [44]. In pre-school children, the upper limb was involved in 92% of cases in boys and 74% of cases in girls, despite no difference in dynamics between genders. This finding is in agreement with a larger survey on the incidence pattern for different fracture sites by age and gender in which sexual dimorphism existed for fractures of the tibia/fibula [3]; in fact, a higher incidence of fractures at this site existed in girls < 6 years of age and in boys > 14 years of age. Age-related differences at the upper site have been also described; specifically, humeral fractures tend to peak first (6-7 years in both genders) followed by radius-ulna fractures (10-11 years in girls and 12-13 years in boys), while carpal fractures peak later (12-13 years in girls and 14-15 years in boys). We found that the frequency of upper arm, forearm and wrist, and hand fractures differed between genders only in pre-school age children, when females predominantly sustained upper arm fractures (73.9%) and boys sustained forearm and wrist fractures (63.6%). These discrepancies can probably be explained by different specific causes related to fall characteristics.

Regarding the locations where fractures commonly occur, it has been reported that the home accounts for 37% of all fractures in children, while the school represents 20% [23]. In our experience as well, the home was the place where fractures most frequently occurred, and locations changed among age groups and gender. These findings are not surprising and reflect the amount of time that pre-school children spend at home in comparison with older children and adolescents who gradually spend a greater amount of their active time outside the home [22]. Significant differences between genders were found only in adolescents ($p = 0.048$) because boys mainly sustained fractures in the playgrounds and footpaths and girls sustained fractures at home.

It is well-known that children who experienced one fracture tend to be at increased risk of repeated fractures [12,13] and have lower bone mineral density and accretion than their peers [9,45,46]. We found that 23.2% of otherwise healthy children sustained one or more previous fractures, with an increasing percentage from pre-schoolers to adolescents (from 7.9% to 40.6%, $p = 0.001$) and no difference between genders. This fact is not surprising, since with increasing age there is a longer exposure time for injuries. We excluded underlying pathology or chronic illnesses that may have predisposed the subjects to reduced bone mineralization, although we could not determine whether or not these children were "accident prone," or lived in a dangerous environment. No one was suspected to be victim of physical abuse. Insufficient calcium intake was found in a large number of children with recurrent fractures. Indeed, low calcium intake has been linked with decreased bone density and fracture risk in children. Children who sustained repeated fractures had total body and lumbar spine bone size and mass significantly lower than controls; they also had a significantly lower intake of milk, lower levels of physical activity, a higher BMI, and a higher consumption of carbonated beverages [9]. We found that the association with low calcium intake disappeared in logistic linear regression analysis, where only age was independently associated with fracture recurrence. Therefore, in our sample, the association of low calcium intake with recurrent fractures was primarily mediated by age.

Conclusions

The differences which existed in the prevalence of injuries, characteristics, and circumstances across the three age groups may be explained by age- and gender-related changes in behaviors, together with attending different places. Individual and lifestyle factors ascribed to either higher sports activities or sedentary behaviors can in part explain the variability in the occurrence of fractures in older age. The incidence of paediatric fractures can be reduced with public education, implementation of safety strategies, and government legislation. Health care professionals and paediatricians can be instrumental in reducing the incidence of paediatric injuries by participating in child education, research, and programs that promote safe play.

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Authors' contributions

GV, PG, and GL provided substantial contributions to the conception and design of the study, definition of the objectives, development of the questionnaire, and analysis and interpretation of data; they revised the paper

critically for important intellectual content and gave their final approval of the version to be published.
GV, FG, and VDO provided substantial contributions to background analysis and literature research, analysis, and interpretation of data, drafting the manuscript, and gave their final approval of the version to be published.
CM and MC provided substantial contributions to acquisition of data, parent interviews, and development of the database; they inputted the data in dedicated software, contributed to drafting the manuscript, and gave their final approval of the version to be published.

Competing interests
The authors declare that they have no competing interests.

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Epidemiology of Childhood Fractures in Britain: A Study Using the General Practice Research Database

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ABSTRACT: A population-based British cohort study, including ~6% of the population, was used to derive age- and sex-specific incidence rates of fractures during childhood. Fractures were more common among boys than girls, with peak incidences at 14 and 11 years of age, respectively. At childhood peak, incidence rates were only surpassed later in life at 85 years of age among women and never among men.

Introduction: Fractures account for 25% of accidents and injuries in childhood; however, the descriptive epidemiology of childhood fractures remains uncertain.
Materials and Methods: Age- and sex-specific incidence rates for fractures at various skeletal sites were derived from the General Practice Research Database (a population-based British cohort containing computerized medical records of ~7,000,000 residents) between 1988 and 1998.
Results: A total of 52,624 boys and 31,505 girls sustained one or more fractures over the follow-up period, for a rate of 133.1/10,000 person-years. Fractures were more common in boys (161.6/10,000 person-years) than girls (102.9/10,000 person-years). The most common fracture in both sexes was that of the radius/ulna (30%). Fracture incidence was greater among boys than girls at all ages, with the peak incidence at 14 years of age among boys and 11 years of age among girls. Marked geographic variation was observed in standardized fracture incidence, with significantly ($p < 0.01$) higher rates observed in Northern Ireland, Wales, and Scotland compared with southeast England.
Conclusions: Fractures are a common problem in childhood, with around one-third of boys and girls sustaining at least one fracture before 17 years of age. Rates are higher among boys than girls, and male incidence rates peak later than those among females. At their childhood peak, the incidence of fractures (boys, 3%; girls, 1.5%) is only surpassed at 85 years of age among women and never among men. The most common site affected in both genders is the radius/ulna. Studies to clarify the pathogenesis of these fractures, emphasizing bone fragility, are now required.
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Key words: epidemiology, fracture, osteoporosis, childhood

INTRODUCTION

Few data are available regarding the epidemiology of fractures in childhood. Most information comes from Scandinavian studies that have reported that the risk of sustaining a fracture from birth to 16 years of age is 42% among boys and 27% among girls. Fractures through the distal end of the radius seem most common, followed by fractures of the phalanges of the hand.[(1)] Other studies have focused on fractures at specific sites. Thus, the mean age of supracondylar elbow fractures in a Danish cohort was found to be 7.9 years, with an annual incidence rate of 308/100,000 person-years.[(2)] In contrast, an American study that used the Hospital Discharge Database of the Maryland Health Services Cost Review Commission for the years 1990–1996 reported annual rates of femoral shaft fracture of 19/100,000, with a bimodal peak of incidence at 2 and 17 years.[(3)] Such studies depend on referral to secondary care for identification of cases and cover relatively small population samples. To address these deficiencies and to provide comprehensive information on this important childhood public health problem in the United Kingdom, we used records from the General Practice Research Database to derive age- and sex-specific fracture incidence rates for children in this country during the period 1988–1998.

MATERIALS AND METHODS

General practitioners play a key role in the UK health care system, because they are responsible for primary health care and specialist referrals. The information in this study was obtained from the General Practice Research Database

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TABLE 1. DISTRIBUTION OF FRACTURES AND INCIDENCE RATES STANDARDIZED TO THE UK POPULATION

	Boys		*Girls*		*Both*	
Fracture site	*No. of cases*	*Rate per 10,000 py*	*No. of cases*	*Rate per 10,000 py*	*No. of cases*	*Rate per 10,000 py*
All	52,624	161.6	31,505	102.9	84,129	133.1
Radius/ulna	15,209	46.0	10,062	32.2	25,271	39.3
Carpal	12,152	36.7	4,702	15.0	16,854	26.1
Greenstick	6,627	17.3	4,805	15.5	10,462	16.4
Humerus	5,317	16.3	4,143	13.4	9,460	14.9
Clavicle	4,672	14.5	2,287	7.6	6,959	11.2
Foot	4,182	12.7	2,607	8.3	6,789	10.5
Tibia/Fibula	3,655	11.3	1,997	6.7	5,652	9.1
Skull	3,393	11.3	1,404	5.3	4,797	8.4
Ankle	1,690	5.1	1,043	3.3	2,733	4.2
Femur/hip	986	3.3	438	1.8	1,424	2.5
Patella	236	0.7	104	0.3	340	0.5
Ribs	233	0.8	106	0.4	339	0.6
Vertebral	159	0.5	134	0.4	293	0.5
Scapula	197	0.6	81	0.3	278	0.4
Pelvis	125	0.4	89	0.3	214	0.3

(GPRD), which contains the computerized medical records of 682 general practices in the United Kingdom. The population in GPRD is broadly representative of the UK population in age and gender structure, with a national coverage of about 6%.[4] There is a slight under-representation of smaller practices and of practices in inner London.[4] The data accrued include demographic information about the patients, prescription details, clinical events, preventive care provided, referrals to specialist care, hospital admissions, and their major outcomes. Clinical data are stored and retrieved by means of Oxford Medical Information Systems (OXMIS) and READ codes for diseases or causes of morbidity and mortality that are cross-referenced to the International Classification of Diseases, ninth edition (ICD-9). The data quality of each entry into GPRD is measured against specific targets, developed by comparisons with external statistics, to ensure research standards are met. Only data from practices that pass this quality control are compiled to form the GPRD. The general practitioners are expected to enter a minimum 95% of prescribing and relevant patient-encounter events.[4] Several independent validation studies have shown that the database has a high level of completeness and validity.[5,6] The GPRD is owned by the Department of Health and managed by the Medicines Control Agency in the United Kingdom. We evaluated the consistency of data recording over time, but found no substantive differences over time in the number of records with medical or prescription information.

The study population consisted of all permanently registered patients <18 years of age who had a fracture recorded in their medical record during the period of time from the enrollment date of their practice in GPRD until the end of data collection. The duration of data collection was from 1988 to 1998. The fracture types were classified according to the ICD-9 categories. These included skull (ICD-9 categories 800–804), vertebra (805 or 806), rib (807), pelvis (808), clavicle (810), scapula (811), humerus (812), radius/ulna (813), carpus (814 to 817), femur/hip (820/821), patella (822), tibia/fibula/ankle (823 or 824), foot (825 or 826), or unspecified fractures.(809, 818, 819, 827–829) A high level of validity for the recording of fractures in GPRD has been reported.[7]

Age- and gender-specific fracture incidence rates in the GPRD population were calculated by dividing the number of patients with a fracture by the total person-years of follow-up (detailed incidence estimates are available from the corresponding author). The total person-time was the sum of the number of patients registered on the database at July 1 of each calendar year. In the case of a patient suffering several fractures during follow-up, only the first fracture was used in the calculation of incidence rates. A directly standardized fracture rate was estimated. This was done by applying the age- and gender-specific incidence rates of each region to the age and gender structure of the population of England and Wales in 1992. The total number of cases per 10,000 children per year was estimated. Poisson regression was used to compare the incidence of fractures across regions of the United Kingdom. The relative rates (and their 95% CIs) were adjusted for age and sex.

RESULTS

A total of 52,624 boys and 31,505 girls sustained one or more fractures over the 11-year follow-up period, giving a rate of 133.1/10,000 person-years (py). Table 1 shows the distribution of fractures and the standardized incidence rates. Fractures were more common in boys (incidence rate, 161.6/10,000 py) than in girls (102.9/10,000 py). The most common fracture in both sexes was that of the radius/ulna, with a total of 39.3/10,000 py, but hand (26.1/10,000 py), greenstick (16.4/10,000 py), and humerus (14.9/10,000 py) fractures were also frequently recorded. The least common fracture in both sexes was pelvic fracture (0.3/10,000 py).

Figure 1 shows the age- and sex-specific incidence rates for all fractures within the cohort. Fracture incidence was

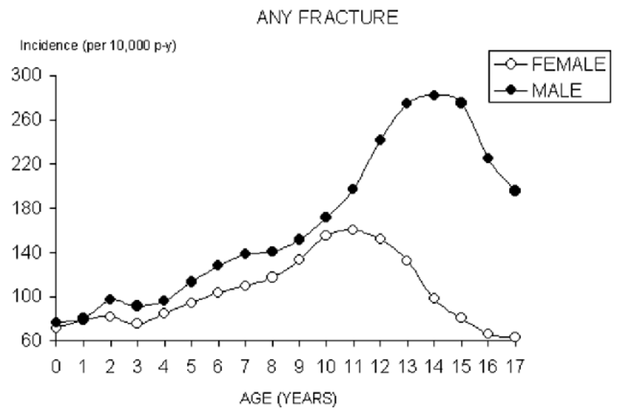

FIG. 1. Age- and sex-specific incidence of fractures at any site among children (to age 17 years) registered in the General Practice Research Database, 1988 to 1998. The figure provides rates per 10,000 person-years.

greater among boys than girls at all ages, with the peak incidence at the age of 14 years among boys and 11 years among girls; there was a sharp decline in rate thereafter.

Figure 2 shows the incidence patterns for different fracture sites by age and sex. Fracture rates increased smoothly from 4 to 17 years of age without any evidence of a plateau for rib fracture in both sexes. Rates stabilized or fell in late teenage years for the ankle, skull, patella, and tibia/fibula fractures in girls, but not in boys. The incidence of greenstick, humerus, radius/ulna, hand, foot, and clavicle fractures fell in the teenage period for both sexes. Very different patterns of tibia/fibula fracture incidence were seen in the two sexes; whereas a steady reduction in rate with age was observed in girls throughout childhood, the converse was true in boys. Hip fracture was extremely infrequent; its incidence was bimodal, with peaks observed in 0–2 year olds and a second peak in the late teenage years in boys. Scapular fracture was also uncommon in both sexes and varied little with age.

Table 2 and Fig. 3 show the distribution of fracture incidence standardized to the UK population by region. The southeast (total number of cases, 6696) was used as the reference region. Highest rates were observed in Northern Ireland (n = 2537; relative risk, 1.66; 95% CI, 1.58–1.74), Wales (n = 5147; relative risk, 1.60; 95% CI, 1.54–1.66), and Scotland (n = 3477; relative risk, 1.49; 95% CI, 1.43–1.56), with significantly elevated relative risk for fracture in all regions except Greater London (n = 6219; relative risk, 1.02; 95% CI, 0.98–1.05). There was also a marked seasonal variation in the incidence of fractures. The standardized incidence rate was 98.1 in the winter (December to February), 143.4 in the spring (March to May), 161.2 in the summer (June to August), and 129.6 in the autumn (September to November). There was no indication of a secular trend in the incidence of fractures, although the length of time period was limited. The standardized incidence rate of fracture was 138.0 in 1990 and 134.9 in 1997.

DISCUSSION

This study reports age- and sex-specific fracture incidence rates for children in England and Wales using a large, well-validated, national cohort study. We have shown that fractures were more common in boys than girls and that, while some fractures became more common in teenage years (vertebral, skull, rib, ankle, pelvis, patella), others were more common during earlier childhood (greenstick, humerus, radius/ulna, carpus, foot). Sexual dimorphism was most apparent for fractures of the tibia/fibula. Geographic variation in fracture incidence was apparent by region, which broadly replicated regional differences in standardized hip fracture incidence.

While only 6% of the total registered population of England and Wales is represented on the database, several independent validation studies have shown that the GPRD has a high general level of completeness and validity.[4] It is also broadly similar to the country as a whole in age and sex structure.

Accidents constitute a major cause of morbidity and mortality in childhood, and surveys of pediatric trauma have suggested that fractures contribute between 10% and 25% of all injuries.[8] However, few studies have attempted to describe age- and sex-specific fracture incidence rates in children or to characterize the incidence patterns at different skeletal sites. In the most comprehensive report,[1] based on the retrieval of all radiological reports of fracture in Malmo, Sweden, the overall annual incidence of fracture was 257/10,000 among boys and 165/10,000 among girls. These rates were based on around 8500 incident fractures and contrast with those in our study of 161.6/10,000 and 102.9/10,000 in boys and girls, respectively. The sites of fracture showed a remarkably similar pattern in the two studies, with fractures of the radius/ulna predominating, followed closely by fractures of the hand. The difference in overall incidence is in the same direction as the differences observed between Scandinavia and Britain in the incidence of hip and wrist fractures in later adult life. However, it may also have arisen through different methods of case ascertainment in the two studies: some of the less clinically severe fractures identified radiologically in the Malmo study may not have been reported back to primary care physicians and might not therefore have been recorded in the British study.

Landin[1] also described seasonal variation in the incidence of fractures in childhood, with high rates in May, lower rates in June/July, higher risk in autumn, and a second decline in December. Our results are in general accord with these findings, although we observed higher rates throughout the summer months. The difference might reflect a difference in the frequency and type of accidents between the two populations studied, as well as the differences in case ascertainment described above.

Other epidemiological studies have reported fracture rates in populations including children, and these include Scandinavian studies of scaphoid,[9] humerus,[10] ankle,[11] and tibial shaft[12] fractures, although breakdown of fracture rate into <10-year intervals is infrequent, making meaningful comparisons difficult. One of the few studies of the UK population[13] described the age and sex distribution of

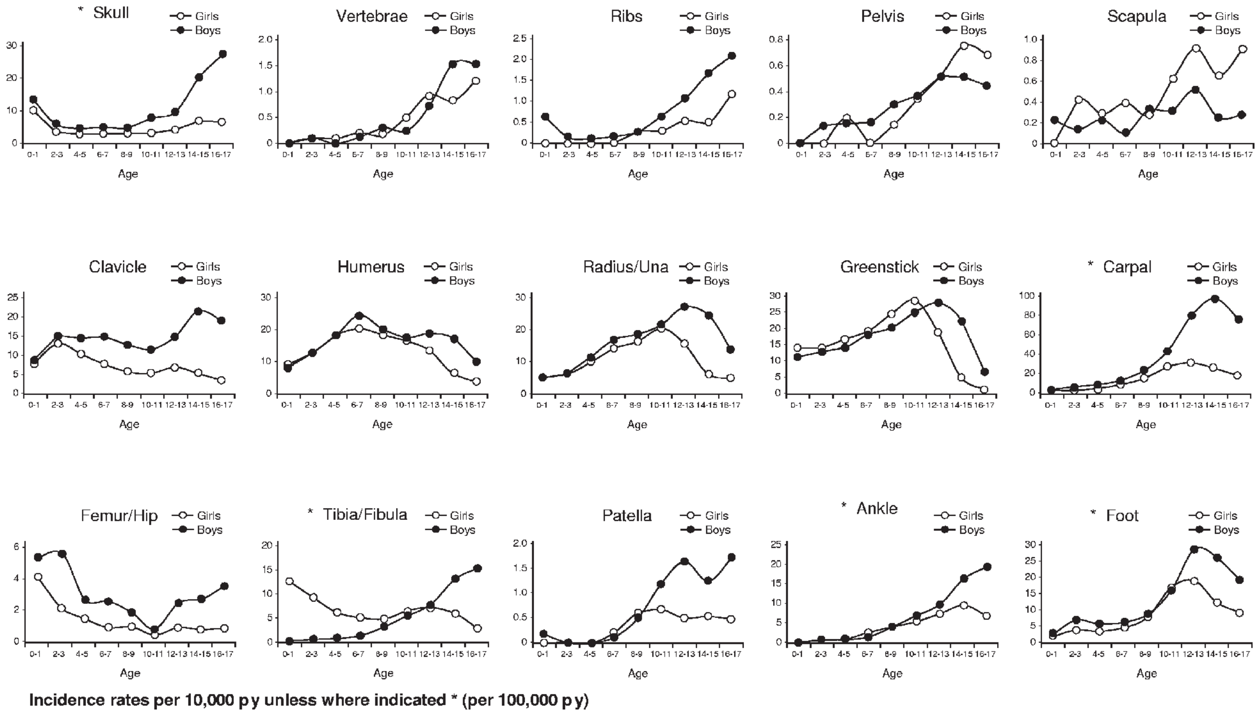

FIG. 2. Age- and sex-specific incidence of fractures at selected sites, among boys and girls (to age 17 years) registered in the General Practice Research Database, 1988 to 1998. The figure provides rates per 10,000 person-years, except where indicated.

TABLE 2. DISTRIBUTION ACROSS REGION OF THE INCIDENCE RATE STANDARDIZED TO THE UK POPULATION

Region	*No. of practices**	*No. of cases*	*Mean age of cases*	*Percent boys of cases*	*Mean duration follow-up (years)*	*Rate per 10000*	*Relative risk (95% CI)*
Scotland	30	3,477	9.8	63.5%	5.7	153.0	1.49 (1.43–1.56)
Northern and Yorkshire (Cumbria, Northumberland, Yorkshire [except South], Durham)	58	8,145	9.8	62.9%	6.6	155.8	1.51 (1.46–1.56)
North West (Cheshire, Lancashire)	103	12,190	9.7	62.4%	6.2	145.0	1.41 (1.37–1.45)
Northern Ireland	16	2,537	9.7	62.5%	6.3	169.2	1.66 (1.58–1.74)
West Midlands (Warwickshire, Staffordshire, Shropshire, Worcestershire, Hertfordshire)	77	9,857	9.8	61.9%	6.4	123.2	1.20 (1.16–1.24)
Trent (Leicestershire, Nottingham, Derbyshire, Lincolnshire, South Yorkshire)	65	9,224	9.9	62.6%	6.4	145.3	1.41 (1.37–1.46)
Eastern (Cambridgeshire, Suffolk, Norfolk, Essex, Bedfordshire, Hertfordshire)	77	11,247	9.9	62.5%	5.9	128.4	1.25 (1.21–1.29)
Wales	41	5,147	9.9	63.5%	6.4	163.1	1.60 (1.54–1.66)
South West (Cornwall, Devon, Dorset, Gloucestershire, Somerset)	70	9,388	9.9	62.0%	6.2	131.0	1.27 (1.23–1.32)
Greater London	78	6,219	9.7	63.0%	5.8	105.4	1.02 (0.98–1.05)
South East (Berkshire, Surrey, Sussex, Kent, Hampshire, Oxfordshire, Buckinghamshire, Northamptonshire)	66	6,696	9.7	62.7%	6.3	103.5	References

*Information on region was not available for one practice.

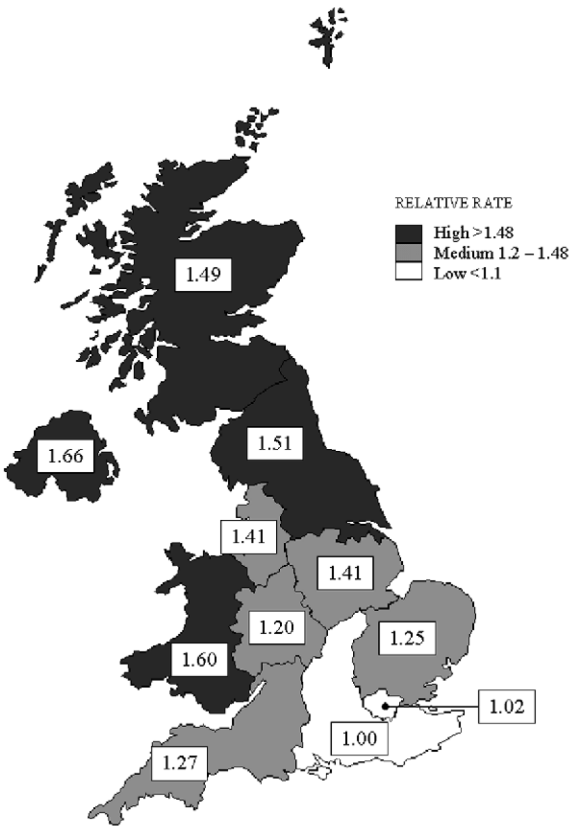

FIG. 3. Geographic variations in the age- and sex-adjusted incidence of fractures at any skeletal site among children (to age 17 years) in the United Kingdom. The figure provides relative rates for fracture in 11 geographic regions, with the southeast region as the reference value.

fractures of the humeral shaft in 249 patients, including 17 patients 12–20 years of age, but no further age breakdown was provided. Therefore, comparisons with published data are difficult. Other studies that include data from the United Kingdom date back to the 1950s.[14]

The incidence patterns for all childhood fractures are similar to those described in previous studies from Scandinavia and the United States. Incidence rates are greater among boys than among girls, with the peak age of occurrence earlier in girls (11 years) than among boys (14 years). Although investigation of the risk factors that might explain this pattern have focused on the importance of low- and high-energy trauma, recent clinical studies have suggested that children with distal forearm fractures have lower areal and volumetric BMD than age- and sex-matched controls without fracture.[15] Indeed, work over two decades ago by Landin and Nilsson[16] showed that forearm BMC was significantly reduced among children in whom fractures were caused by low-energy trauma compared with healthy age-matched children. In contrast, there was no significant difference in BMC between children sustaining fractures after high-energy trauma and controls. The gender-specific incidence patterns might also reflect a contribution from bone fragility: the peak age of fracture occurrence in boys and girls is remarkably close to the age at which the discordance between height gain and the accrual of volumetric BMD is most pronounced.[17] The third observation supporting a role for bone fragility in childhood fracture is the steep increase in age- and sex-specific incidence observed in Scandinavia between 1950 and 1979.[1,18]

Our study provides robust enough estimates of fracture incidence at different sites to explore heterogeneity in incidence patterns. Fractures at the wrist, hand, foot, ankle, rib, and patella reveal a similar pattern, with rates rising faster among boys than girls and separation between the gender-specific peaks around the time of puberty. They contrast markedly with the less frequently involved sites (humerus, hip, tibia/fibula, skull, clavicle, and scapula), which show more stable or even declining rates with advancing age. It may be that, as with fractures in later life, skeletal fragility plays a greater role in the pathogenesis of fractures at certain sites.

To our knowledge, data on the geographic variation in childhood fracture incidence within this country have not been previously reported. Our results suggest considerable differences in the rates observed in different British regions, after allowance is made for differences in the age and sex structure of the population. Of particular interest are the almost 50% higher rates observed in Northern Ireland, Scotland, Wales, and north England compared with London and southeast England. Differences in case ascertainment would seem an unlikely explanation for these findings, which are based on numerous general practices in each region. Although they might reflect a contribution of socioeconomic status to fracture risk (and accidents as a whole are known to be highly correlated with social class[19]), it is fascinating that the geographic pattern maps well to regional variation in hip fracture incidence in England and Wales.

An important limitation of our study is the classification of fracture site imposed by the coding system used by the GPRD. This uses the individual bone sustaining the fracture (e.g., radius) rather than the anatomical location (e.g., wrist). It was therefore not easy to characterize the epidemiology of fractures in particular areas within a bone, such as the diaphyseal, supracondylar, or trochanteric regions of the femur. In addition, data on fractures of the ribs and skull are likely to be less accurate than in surveys based in a single hospital because of variation in the use of radiographic evaluation among children who sustain moderate or minor degrees of trauma. Nevertheless, our incidence estimates were comparable with those observed in the previously described Swedish study,[1] as well as with those of a more recent incidence study of childhood distal forearm fracture in Rochester, MN.[20] In the latter, age- and sex-adjusted rates of distal forearm fracture in 1999–2001 were found to be 372.9/100,000 py, a figure extremely close to our estimate of 393/100,000 py for radius/ulna fractures.

In conclusion, we present a population-based epidemiological study of childhood fractures in the United Kingdom. Our results suggest that such fractures are a common problem, with around one-third of boys and girls sustaining at least one fracture before 17 years of age. Rates are higher among boys than girls, and male incidence rates peak later than those among females. Indeed, at this age, the incidence of childhood fractures (3%

among boys and 1.5% among girls) is only surpassed at 85 years of age among women and never among men. The most common site affected in both sexes is the radius/ulna (almost 30%), closely followed by the small bones of the hand and wrist. Finally, there is pronounced geographic variation in childhood fracture incidence within this country. Urgent studies to clarify the pathogenesis of these fractures are now required. If they are indeed associated with fractures in later life, particularly among women, they comprise a sufficiently frequent occurrence around which secondary preventive strategies could be based.

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The Demographics of Fractures and Dislocations Across the Entire United States due to Common Sports and Recreational Activities

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Background: There exists little nationwide data regarding fracture and dislocation patterns across a wide variety of sporting activities for all ages and sexes.

Hypothesis: Participant demographics (age and sex) will vary with regard to fracture and joint dislocation sustained during sport-related activities.

Study Design: Descriptive epidemiology study.

Level of Evidence: Level 3.

Methods: The National Electronic Injury Surveillance System All Injury Program data 2005 through 2013 were accessed; 18 common sports and recreational activities in the United States were selected. Statistical software was used to calculate the numbers of fractures and dislocations, and incidence was calculated using US Census Bureau data. Multivariate logistic regression analysis determined the odds ratios (ORs) for the occurrence of a fracture or dislocation.

Results: A fracture occurred in 20.6% and a joint dislocation in 3.6% of the emergency department visits for sports-related injuries; annual emergency department visit incidence was 1.51 for fractures and 0.27 for dislocations (per 1000 people). Most of the fractures occurred in football (22.5%). The OR for fracture was highest for inline skating (OR, 6.03), males (OR, 1.21), Asians, whites, and Amerindians compared with blacks (OR, 1.46, 1.25, and 1.18, respectively), and those older than 84 years (OR, 4.77). Most of the dislocations occurred in basketball (25.7%). The OR for dislocation was highest in gymnastics (OR, 4.08), males (OR, 1.50), Asians (OR, 1.75), and in those aged 20 to 24 years (OR, 9.04). The most common fracture involved the finger, and the most common dislocation involved the shoulder.

Conclusion: Inline skating had the greatest risk for fracture, and gymnastics had the greatest risk for joint dislocation.

Clinical Relevance: This comprehensive study of the risks of sustaining a fracture or dislocation from common sports activities across all age groups can aid sports health providers in a better understanding of those sports at high risk and be proactive in prevention mechanisms (protective gear, body training).

Keywords: fracture; dislocation; sport; recreation; demographic; NEISS

Sporting activities not only promote healthy mental and physical development but also carry a risk of injury. There are 30 to 45 million athletes participating at the youth, high school, and collegiate levels.[6,19,38,39,58,68,69] However, sporting injuries are not limited to organized sports or these particular age groups. These injuries result in financial expense as well as other costs to the injured patient (ie, school/work absences, restricted activity/athletic participation, and potential long-term effects of injury) and/or parent/spouse (ie, time missed from work, transportation costs, and other expenses).[6,38,51,68,69]

Studying the demographics of all sports- and recreation-related injuries is essential to develop effective preventive strategies, as injury patterns differ by age and activity.[41,68] Many studies have characterized the epidemiology of sports-related

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injuries for 1 specific sport, while a few have studied multiple sports- and recreation-related injuries over a short duration and in select groups (by either age or school level).[6,36-42,59] However, the results of these studies are not readily comparable because of differences in study design and selected sports. While there has been some research dedicated to fracture rates, much of the published literature focuses on injury rates as a whole, with little data regarding fractures or dislocations. Nationwide data regarding fracture and dislocation patterns across a wide variety of sporting activities for all ages and sexes are sparse. The purpose of the present study was to investigate the demographics of US sports-related fractures and dislocations across a wide range of sporting activities using a national database.

METHODS

This study was considered exempt by our local institutional review board. The data used for this study are from the National Electronic Injury Surveillance System (NEISS) All Injury Program (AIP). The NEISS is a database managed by the US Consumer Product Safety Commission (USCPSC) that collects injury data from 100 hospital having emergency departments (EDs) in the United States and its territories. It was initially created to monitor injuries associated with consumer products. However, not all injuries are associated with consumer products; thus, the USCPSC selected 65 of these hospitals to collect ED data for all injuries, regardless of the association with consumer products. This has been designated as the AIP. These data are in the public domain and housed by the Inter-University Consortium for Political and Social Research. It can be downloaded from their website at https://www.icpsr.umich.edu/icpsrweb/ICPSR/search/studies?q=all+injury+program.

The database includes date of ED visit, sex/race/age of the injured patient, diagnosis, disposition from the ED, geographic location of the injury, body part injured, and hospital strata. There are 5 hospital strata, 4 based on size (total number of ED visits reported by the hospital: small [0-16,830], medium [16,831-21,850], large [28,151-41,130], or very large [>41,130]), and 1 consisting of children's hospitals of all sizes. A national estimate of the number of injuries (N) is calculated using the actual number of injuries (n) seen in these 65 EDs.

The NEISS-AIP data for the years 2005 through 2013 were accessed. These years were chosen because 2013 was the last available year at the time the study was performed, beginning in late 2017, and data before 2005 were coded differently for many variables, making it difficult to combine the years before 2005 with those afterward. Injuries due to sporting activities were identified by the NEISS-AIP code SPORTS; there are 39 mutually exclusive sports and recreational activity codes. We selected 18 of the 39 as being representative of the most common sports and recreational activities in the United States. These 18 were football, baseball, basketball, softball, soccer, volleyball, ice hockey, ice skating, snow skiing, toboggan/sledding, inline skating, skateboarding, gymnastics, racquet sports, swimming, waterski/surfing, track and field, and combative sports. The excluded activities were nonpowder firearm, other skating, trampolines, scooters, bicycles, mopeds, go-carts, all-terrain vehicles, horseback activities, bowling, golf, miscellaneous ball games, exercise, amusement attractions, playground activities, personal watercraft, snowmobiles, fishing, camping activities, billiards, and others. It can be argued that fractures and dislocations can and do occur in these excluded activities; however, it was a calculated decision by the investigators that these activities, many of which are recreational, are not standard sporting activities for the common person in the United States (eg, fishing, billiards, all-terrain vehicles, trampolines, amusement attractions) or the designation was so nebulous as to not be discernable (eg, other skating, playground activities, other activities).

Race was classified according to Eveleth and Tanner[25] as white, black, Amerindian (Hispanic and Native American), Asian, Indo-Mediterranean (Middle Eastern and Indian subcontinent), and Polynesian. Because of the small numbers of Polynesian and Indo-Mediterranean peoples in the data set, race/ethnicity is only reported for the white, black, Amerindian, and Asian groups when racial analyses were performed.

Statistical Analysis

Because of the stratified and weighted nature of the NEISS data set, statistical analyses were performed using SUDAAN 11.0.01 software (RTI International, 2013). This software accounts for the weighted and stratified nature of the data and calculates an estimated value and 95% confidence limits [lower, upper] across the population encompassed by the data set. Throughout this study, we denote the actual number of NEISS patients as "n" and the estimated number as "N." Analyses between groups of continuous data were performed using the *t* test (2 groups) or analysis of variance (3 or more groups). Differences between groups of discrete data were analyzed by the χ^2 test. A *P* value less than 0.05 was considered statistically significant. The incidence of ED visits per year for fractures and dislocations was calculated using population data from the US Census Bureau for each year, 2005 through 2013 (https://www.census.gov/data/tables/time-series/demo/popest/intercensal-2000-2010-national.html; https://www.census.gov/programs-surveys/popest/technical-documentation/methodology.html). In this study, incidence means the estimated number of ED visits for sports-related injuries per year per 1000 people. Multivariate logistic regression analysis was used to determine the odds ratios (ORs) and 95% CI, with appropriate *P* values, for the occurrence of a fracture or dislocation. The variables entered into the logistic regression analyses were sporting activity, age group, sex, and race. The reference group was the sporting activity having the lowest odds of sustaining a fracture or dislocation.

RESULTS

There were an actual 367,300 sports- and recreation-related ED visits over the 9-year period, for an estimated 20,241,049 ED visits nationwide, resulting in an annual estimated ED visit

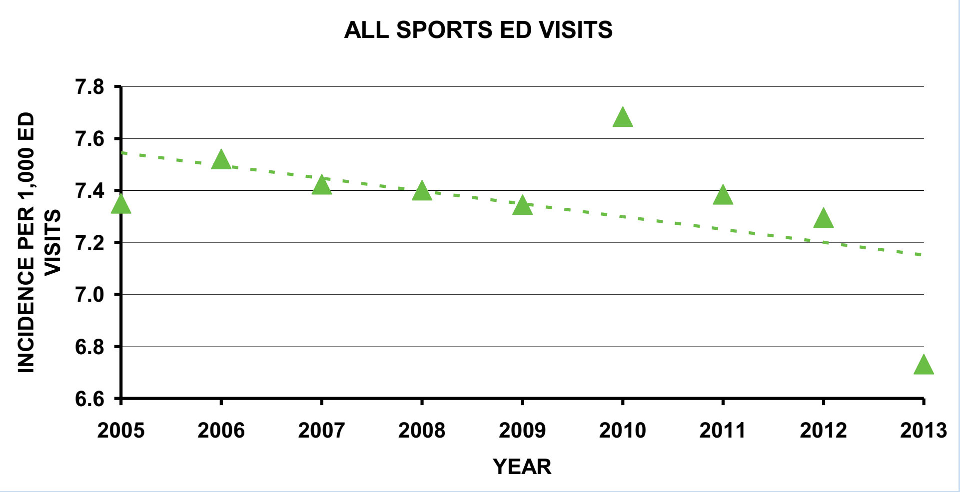

Figure 1. Annual incidence of sports- and recreation-related emergency department (ED) visits. The estimated incidence values are shown as solid triangles, and the best fit by the hatched line. This fit was not significant (r^2 = 0.27; P = 0.15), indicating no change in incidence over time.

incidence of 7.35 per 1000 people. There was no change in incidence over time (Figure 1). Fractures and dislocations accounted for 78,640 and 12,462 of the actual 367,300 ED visits, respectively, or an estimated 4,159,764 fractures and 731,866 dislocation ED visits (fractures, 20.6%; dislocations, 3.6%). This results in an annual ED visit incidence of 1.51 for fractures and 0.27 for dislocations per 1000 people.

Fractures

The greatest number of fractures occurred in football (22.5%) and males (Table 1). The majority occurred in the patients' second decade of life and occurred in the autumn and summer (see Appendix 1, available in the online version of this article). The annual incidence decreased from 2005 to 2013 (Figure 2). The majority of fractures occurred in the arm/hand (55.9%; N = 2,326,129). Detailed anatomic fracture locations for all activities are seen in Figure 3 and Appendix 2 (available online). The majority of fractures occurred at school or sporting venues. The odds of sustaining a fracture was higher in males compared with females (OR, 1.21 [95% CI, 1.14-1.27]), with bimodal peaks at 10 to 14 and >84 years. Inline skating had the greatest odds of a fracture (OR, 6.03 [95% CI, 5.1-7.13]), with swimming having the lowest odds of a fracture (reference value) (Table 2).

Joint Dislocations

The greatest number of dislocations occurred in basketball and males (Table 1). The majority occurred in the patients' second and third decades of life. The majority of dislocations occurred in the autumn and on weekends (Appendix 1). There was no change in annual incidence from 2005 to 2013 (Figure 2). Detailed anatomic dislocations for all activities are seen in Figure 3 and Appendix 3 (available online). The majority of dislocations occurred at school or sporting venues. The odds of sustaining a dislocation was higher in males compared with females (OR, 1.50 [95% CI, 1.38-1.62]), and in the third and fourth decades of life (Table 3). Gymnastics had the greatest odds of a dislocation (OR, 4.08 [95% CI, 2.55-6.54]) with toboggan/sledding having the lowest odds of a dislocation (reference value) (Table 3).

DISCUSSION

While previous studies have examined injury patterns related to sports, most of the available literature on the epidemiology of sports- and recreation-related injuries generally focuses on the organized sports population (ie, youth, high school, collegiate athletes). This study, by contrast, uses a large data set studying fractures and dislocations in detail for both organized and nonorganized situations across multiple activities, all ages, both sexes, and all racial groups. There were several major findings. A fracture occurred in 20.6% and a joint dislocation in 3.6% of the ED visits for sports-related injuries. The most common fracture involved the finger, and the activities with the 3 highest odds for a fracture were inline skating (OR, 6.03), skateboarding (OR, 3.93), and tobogganing/sledding (OR, 3.19), with swimming the lowest (1.0 Reference). Males had higher odds of a fracture compared with females (OR, 1.21). Although most of the dislocations occurred in basketball (25.7%), the activities with the 3 highest odds for dislocation were gymnastics (OR, 4.08), snow skiing (OR, 3.46), and football (OR, 3.09), with tobogganing/sledding the lowest (1.0 Reference) The most common dislocation involved the shoulder.

Fractures

The 20.6% fracture rate in sports- and recreation-related injuries using the NEISS AIP data over the 9-year period was higher

Table 1. Fractures and dislocations sustained in 18 sports and recreational activities from the NEISS-AIP database, 2005-2013[a]

Sports	Fractures n	Fractures N	Fractures %N	Dislocations n	Dislocations N	Dislocations %N
Inline skating	1306	70,430	1.7	44	3285	0.4
Ice skating	1063	48,013	1.2	72	3598	0.5
Skateboard	5976	367,529	8.8	240	23,231	3.2
Toboggan/sled	1246	72,983	1.8	52	2977	0.4
Gymnastics	3558	175,341	4.2	773	41,569	5.7
Basketball	16,244	799,328	19.2	3454	187,786	25.7
Baseball	4937	279,664	6.7	592	39,077	5.3
Softball	2663	163,839	3.9	447	27,829	3.8
Ice hockey	1879	96,761	2.3	250	14,903	2.0
Football	19,491	935,183	22.5	3061	168,191	23.0
Soccer	8811	440,426	10.6	1046	55,963	7.6
Racquet sports	620	35,343	0.8	125	7653	1.0
Volleyball	1223	75,467	1.8	380	25,163	3.4
Track/field	607	29,512	0.7	66	4497	0.6
Combative	2956	171,927	4.1	681	41,323	5.6
Swimming	1596	94,049	2.3	430	29,347	4.0
Waterski/surf	426	35,813	0.9	117	11,874	1.6
Snow skiing	4038	268,156	6.4	531	43,600	6.0

NEISS-AIP, National Electronic Injury Surveillance System All Injury Program.
[a]n = actual NEISS number; N = estimated number; %N = percentage for the estimated number.

than that reported in many other studies.[20,36,51,59,68,69] This likely reflects our inclusion of all ages, especially older populations with the comorbidity of age-related osteopenia/osteoporosis. The odds of a fracture was lowest in those aged 0 to 4 years and became 2 times greater or more by age 55 years. This has not been previously described for sporting-related fractures, as most studies only address those of college age or younger. Few studies reported the anatomic location of fracture, with most in the upper extremity.[9,12,16,45,73]

Regarding specific sports, football contributed the greatest number of fractures, similar to previous studies.[6,19,36,68,69,72] Morbidity in many of these activities is likely higher due to greater novice participation, the inability to stop effectively, and no or improper use of protective equipment (ie, outdated equipment that does not fit or function properly).[13,18,21,56] They also share 3 major risk factors for injury: speed, obstacles, and hard surfaces.[13,56] Participants may engage in riskier behavior as they underestimate their susceptibility to and severity of injury and believe the risk of injury affect others more than themselves.[18,47]

Previous studies have calculated fracture rates for high school and collegiate athletes for multiple sports as a function of athletic exposures.[36,63,68,69] We can only report proportions of injuries that were fractures and ED visit incidence from the NEISS data, as exposure data are not available in the NEISS data.

Males were more likely to sustain fractures,[19,36,51,68,69] a potential consequence of biological, behavioral, and regulatory differences between sexes.[19,36] As early as 1 year of age, sex-related behavioral differences begin to show, at least in part, as a result of learned behavior. Actions are first adapted from parents and later reinforced by mass media and popular culture,

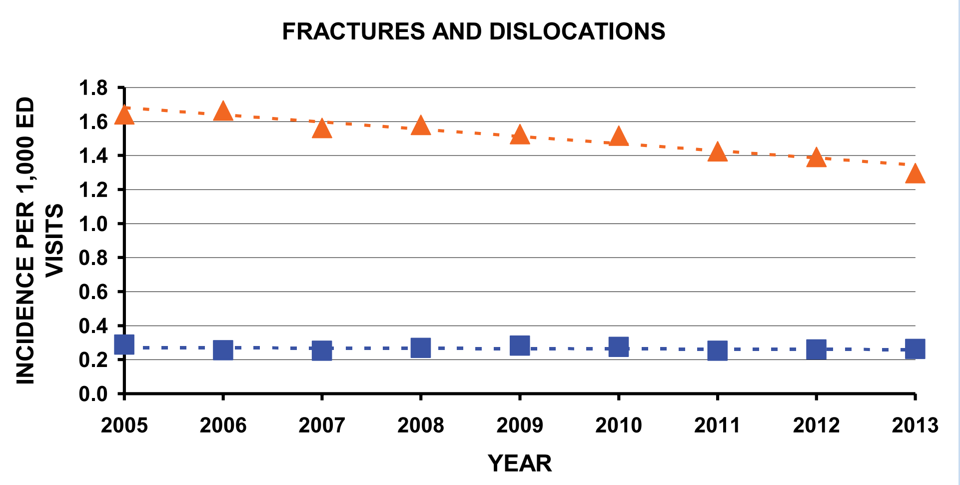

Figure 2. Annual fracture and dislocation emergency department (ED) visit incidence over time. There was a slight decrease in incidence over time for fractures (orange). The estimated incidence values are shown as solid orange triangles, and the best fit by the hatched orange line. This best fit line is represented by the equation: incidence = –86.31 – 0.042(year) ($r^2 = 0.93$; $P = 0.000034$). There was no change in incidence of dislocations (blue) over time. The estimated incidence values are shown as solid blue squares, and the best fit by the hatched blue line. This fit was not significant ($r^2 = 0.079$; $P = 0.47$).

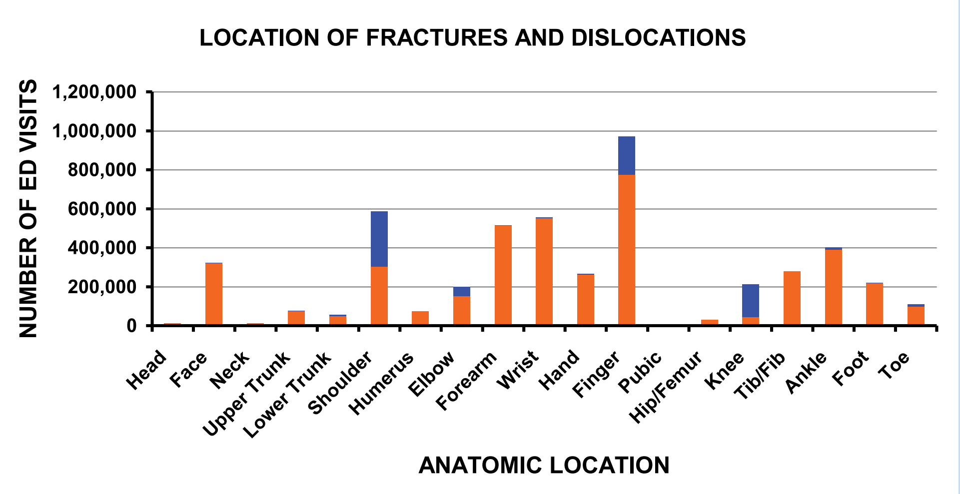

Figure 3. All sports- and recreation-related fractures (orange) and dislocations (blue) by detailed anatomic location. ED, emergency department.

school, and peer groups. Young boys have been observed to engage in more inventive and dangerous play than girls of the same age, who participate in more quiet, passive play. This correlates with the differences in injury type, as the more physically active, aggressive style of males render them more likely to sustain traumatic versus overuse injuries, opposite the injury trends in females.[36,51,60] Larger body masses lead to greater forces absorbed through soft tissues and joints while running, jumping, pivoting, and during contact, which may increase susceptibility to injury in males.[19,36] Sex-comparable sports differ in rules, regulations, and required protective equipment, likely altering injury risk exposure.[36,68]

The increased fracture risk in whites compared with blacks has been previously described in adults sustaining falls[24,55] and may be explained by known racial differences in bone mass and strength.[29] Cortical bone measurements (ie, bone mineral content, bone mineral density, periosteal and endosteal circumferences) are greater in blacks than whites during all stages of childhood and adolescence.[35,46,70] This may be partially mitigated by differences in weight and height between the

Table 2. Odds ratios (ORs) of sustaining a fracture by sport, sex, race, and age group using multivariate logistic regression analysis

	OR	95% CI		*P*
		Lower	Upper	
Sport				
Inline skating	6.03	5.1	7.13	$<10^{-4}$
Ice skating	2.82	2.31	3.44	$<10^{-4}$
Skateboarding	3.93	3.2	4.82	$<10^{-4}$
Toboggan/sled	3.19	2.65	3.82	$<10^{-4}$
Gymnastics	2.1	1.85	2.38	$<10^{-4}$
Basketball	1.92	1.69	2.18	$<10^{-4}$
Baseball	1.99	1.73	2.28	$<10^{-4}$
Softball	2.03	1.75	2.36	$<10^{-4}$
Ice hockey	1.67	1.41	1.98	$<10^{-4}$
Football	2.48	2.18	2.83	$<10^{-4}$
Soccer	2.66	2.19	3.23	$<10^{-4}$
Racquet sports	1.42	1.21	1.67	$<10^{-4}$
Volleyball	1.67	1.41	1.97	$<10^{-4}$
Track/field	1.8	1.56	2.08	$<10^{-4}$
Combative	2.54	2.18	2.96	$<10^{-4}$
Swimming	1.0 Reference	—	—	—
Waterski/surf	1.28	0.95	1.73	0.10
Snow skiing	4.5	3.85	5.25	$<10^{-4}$
Sex				
Male	1.21	1.14	1.27	$<10^{-4}$
Female	1.0 Reference	—	—	—
Race				
White	1.25	1.13	1.39	$<10^{-4}$
Black	1.0 Reference	—	—	—
Amerindian	1.18	1.06	1.31	0.004
Asian	1.46	1.33	1.6	$<10^{-4}$
Age group, y				
0-4	1.0 Reference	—	—	—
5-9	1.75	1.51	2.04	$<10^{-4}$
10-14	2.13	1.83	2.47	$<10^{-4}$

(continued)

Table 2. (continued)

	OR	95% CI		*P*
		Lower	Upper	
15-19	1.29	1.11	1.5	0.0011
20-24	1.22	1.05	1.42	0.01
25-34	1.35	1.17	1.56	0.0001
35-44	1.51	1.3	1.75	$<10^{-4}$
45-54	1.93	1.62	2.31	$<10^{-4}$
55-64	2.19	1.78	2.69	$<10^{-4}$
65-74	2.79	2.2	3.54	$<10^{-4}$
75-84	3.22	2.25	4.61	$<10^{-4}$
85+	4.77	3.24	7.04	$<10^{-4}$

races,[33,35,44] although some data suggest that there are true genetic differences beyond those accounted for by anthropometric differences.[70] There may also be racial differences in bone and mineral metabolism.[23,29,57] Another possible explanation of the higher odds of fracture in whites could be access to care or bone mineralization differences due to socioeconomic status. The studies on fracture quoted prevoiusly[24,55] used hospital admissions to indicate a severe fracture. Such data are not likely due to differences in access to care because of the fact that a person sustaining a fracture necessitating hospitalization would nearly always seek care. It is possible that patients sustaining a minor fracture not needing hospital admission might be influenced by access to care and socioeconomic status, possibly skewing the results. However, bone mineralization in the United States is minimally associated with socioeconomic status compared with physical stature.[44] Thus, we believe that the racial differences seen in this study regarding fractures are valid conclusions.

These findings can guide injury reduction strategies. Using the data from Table 1 and Appendix 2 (available online), football, basketball, soccer, and skateboarding accounted for 61.1% of all fractures. Of these 2,542,466 fractures, 53.4% were in the forearm, wrist, hand, and finger, and prevalence was similar for skateboarding (52.2%), football (56.5%), basketball (54.7%), and soccer (45.3%). Prevention strategies focusing on the distal upper extremity are an important area and involve appropriate protective equipment.[7,11,15,27,28,66,71] These areas will need further research.

Apart from the large burden of fractures in these 4 activities, other areas of focus would be on those activities having the greatest odds of a fracture, such as inline skating (OR, 6.03) and snow skiing (OR, 4.5). Increasing education regarding protective equipment should be considered, which has been shown to be effective with inline skating.[66] Protective equipment minimizing upper extremity mobility for snow skiing would likely not be advantageous due to the quickness and need for motion in the upper extremity, although to our knowledge, no studies have been done on this topic. Protective equipment has been shown to be effective in reducing snowboarding injuries,[30,34,64]especially for the novice participant.[52]

Dislocations

The majority of dislocations involved the shoulder (38.7%), finger (26.7%), and knee (23.0%) (Figure 3 and Appendix 3 [available online]). The dislocation rate of 3.6% for sports- and recreation-related injuries using the NEISS-AIP was lower than that reported in other studies.[19,20] Regarding specific activities, basketball (N = 187,786) and football (N = 168,191) contributed the greatest number of dislocations, unlike other studies where football was the leading cause followed by wrestling or hockey.[36,38] However, participants involved in gymnastics, volleyball, and snow skiing had the greatest odds of sustaining a dislocation.

Few studies have tracked overall sports- and recreation-related dislocations, as many report only specific joints.[5,22,36-39,43,48,61,62,74] Regarding knee dislocations, those in the NEISS-AIP database were most likely patellofemoral dislocations rather than femoral-tibial (knee) dislocations, which are much rarer than patellofemoral dislocations.[2,4,10,65] Femoral-tibial dislocations are usually associated with high-energy mechanisms (motor vehicle collisions, pedestrian struck, fall from height), although some have been reported in low-energy sports-related activities and spontaneous ambulatory injuries in the morbidly obese.[2,10,65]

Table 3. Odds ratios (ORs) of sustaining a joint dislocation by sport, sex, race, and age using multivariate logistic regression analysis

	OR	95% CI		*P*
		Lower	Upper	
Sport				
Inline skating	1.59	0.79	3.19	0.19
Ice skating	1.72	0.96	3.09	0.07
Skateboarding	1.39	0.82	2.35	0.21
Toboggan/sled	1.0 Reference	—	—	—
Gymnastics	4.08	2.55	6.54	$<10^{-4}$
Basketball	2.45	1.57	3.84	0.0002
Baseball	2.09	1.33	3.30	0.002
Softball	1.91	1.22	3.00	0.006
Ice hockey	1.49	0.86	2.60	0.15
Football	3.09	2.03	4.68	$<10^{-4}$
Soccer	2.16	1.37	3.41	0.001
Racquet sports	2.11	1.30	3.45	0.003
Volleyball	3.68	2.20	6.15	$<10^{-4}$
Track/field	2.17	1.33	3.54	0.002
Combative	2.98	1.92	4.63	$<10^{-4}$
Swimming	2.59	1.60	4.17	0.0002
Waterski/surf	2.29	1.48	3.56	0.0004
Snow skiing	3.46	2.20	5.43	$<10^{-4}$
Sex				
Male	1.50	1.38	1.62	$<10^{-4}$
Female	1.0 Reference	—	—	—
Race				
White	1.01	0.86	1.20	0.88
Black	1.0 Reference	—	—	—
Amerindian	1.02	0.81	1.30	0.84
Asian	1.75	1.57	1.94	$<10^{-4}$
Age group, y				
0-4	4.21	3.29	5.38	$<10^{-4}$
5-9	1.0 Reference	—	—	—
10-14	2.51	2.04	3.08	$<10^{-4}$

(continued)

Table 3. (continued)

		95% CI		
	OR	Lower	Upper	*P*
15-19	6.26	5.24	7.48	$<10^{-4}$
20-24	9.04	7.54	10.83	$<10^{-4}$
25-34	9.03	7.49	10.88	$<10^{-4}$
35-44	7.63	6.26	9.30	$<10^{-4}$
45-54	7.28	5.63	9.40	$<10^{-4}$
55-64	8.50	6.16	11.72	$<10^{-4}$
65-74	4.55	3.13	6.62	$<10^{-4}$
75-84	6.23	3.36	11.56	$<10^{-4}$
85+	5.08	1.60	16.12	0.007

Patellar instability, however, is a frequent cause of knee complaints, especially in young athletic individuals. Instability represents 2% to 3% of all knee injuries and the second most common cause of traumatic knee hemarthrosis.[53,67] The majority of first-time patellofemoral dislocations occur as a result of sports-related activities (60%-72%)[3] with a recurrence rate of 15% to 71%.[31,49,53] They usually occur secondary to a noncontact twisting mechanism but may also be associated with a direct blow to the knee. They may be transient, with the patient unaware of the event.[26]

Males were more likely to sustain dislocations, similar to many other studies[5,36,38,39,48] yet not all.[20,62,74] Contact with another person has been reported as the most common mechanism of injury, especially for full-contact (ie, football, wrestling) and partial-contact (ie, soccer, basketball) sports.[38] This may be a consequence of the aforementioned biological, behavioral, and regulatory differences between sexes as discussed for fractures.[19,36]

As with fractures, these findings can guide injury reduction strategies. Appropriate sports-specific education can be given regarding falling or other events during sporting/recreational activities,[8] especially those having high likelihood of a dislocation (gymnastics, volleyball, snow skiing) or a high number of dislocations (football, basketball). Appropriate exercise programs for the shoulder and knee should be encouraged in all these high-risk activities.[14,17,50,54] Regarding finger dislocations, as with fractures, reduction in finger dislocations might be possible with a better understanding of how such dislocations occur with ball handling and development of appropriate player education to reduce such injuries. These areas will need further research.

Limitations

Limitations of the NEISS database are many. Large data sets inherently possess some inaccuracy. NEISS data collection protocols have an 89% to 98% accuracy.[1,32] Another limitation is that the NEISS only captures those who sought care in the ED. The consequences of this are 2-fold: First, the overall number of injuries in this study underrepresent the true number, and second, patients sustaining significant injuries will likely seek immediate care in the ED, skewing the NEISS sample toward more severe injuries. This may explain the slight decrease in the ED fracture incidence over time. Furthermore, these data are descriptive and cannot be used to ascertain the reasons for the various injuries. It does not include information on risk/protective factors or mechanism of injury, limiting our understanding of any changes observed from 2005 to 2013. Finally, the uncommon event of a patient having both a fracture and a dislocation cannot be ascertained, as the NEISS data only contain 1 diagnosis. The NEISS coders are instructed to code the diagnosis by the most severe injury, which would likely be a fracture, but would be up to interpretation by each coder.

CONCLUSION

The greatest burden of fractures from common sports and recreational activities involved football and basketball, while the activities with the highest odds of a fracture were in inline skating, skateboarding, and tobogganing/sledding, with swimming the lowest. The most common fracture was in the finger followed by the wrist and forearm. Thus, the best opportunity for prevention should be focused on the mechanisms of finger fractures in football/basketball and appropriate external guards for the wrist and forearm. The greatest burden of dislocations involved basketball and football, while the activities with the highest odds of a dislocation were gymnastics, snow skiing, and football, with tobogganing/sledding the lowest. The most common joint dislocation was the shoulder followed by the finger and knee. The biggest room for prevention should again focus on the mechanisms of finger dislocations in football/basketball and appropriate rehabilitation/exercise programs for the shoulder and knee. Males have greater odds for both fractures and dislocations in these common sporting and recreational activities, but the above strategies should be equally promoted for both sexes and all races.

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Fractures during Childhood and Adolescence in Healthy Boys: Relation with Bone Mass, Microstructure, and Strength

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Context: In healthy boys, fractures result from trauma of various severity, suggesting contribution of an intrinsic biomechanical fragility.

Objectives: Our objective was to characterize bone mineral mass, microstructure, and strength in boys with and without fractures.

Participants and Design: We followed 176 healthy boys from 7.4 ± 0.5 to 15.2 ± 0.5 (mean ± SD) yr of age.

Outcomes: Areal (a) bone mineral density (BMD) was measured by dual-energy x-ray absorptiometry at radius metaphysis and diaphysis, total hip, femoral neck and diaphysis, and L2–L4 vertebrae. Volumetric (v) BMD and microstructure were assessed by high-resolution peripheral computerized tomography at both distal tibia and radius. Bone strength was evaluated by micro-finite element analysis.

Results: A total of 156 fractures were recorded in 87 of 176 boys with peak incidence between 10 and 13 yr. At 7.4 yr, subjects with fractures had lower aBMD in all sites and at 15.2 yr in femoral and spinal, but not in radius, sites. At that age, boys with fractures displayed lower trabecular (Tb) vBMD ($P = 0.029$) and number ($P = 0.040$), stiffness ($P = 0.024$), and failure load ($P = 0.016$) at distal tibia, but not distal radius. Odds ratios of fracture risk per 1 SD decrease were 1.80 ($P = 0.006$) for femoral neck aBMD and 1.46 ($P = 0.038$) for distal tibia Tb vBMD, 1.59 ($P = 0.031$) for Tb number, 1.53 ($P = 0.072$) for stiffness, and 1.60 ($P = 0.056$) for failure load.

Conclusion: In a homogeneous cohort of healthy boys, fractures recorded until 15.2±05 yr of age were associated with lower femoral neck aBMD and with lower distal tibia trabecular vBMD and number, stiffness and failure load. These deficits in bone mineral mass, microstructure and strength could contribute to the occurrence of fractures during growth. **(*J Clin Endocrinol Metab* 96: 3134–3142, 2011)**

Fractures resulting from trauma of various severity are frequently observed during childhood and adolescence in both genders. They constitute 10–25% of all pediatric trauma, with approximately 45–55% of all children breaking at least one bone before the age of 18 yr (1–5). Epidemiological studies have found an annual incidence of fracture of 103–165 and 162–257 per 10,000 person-years in girls and boys, respectively (1–5).

The peak incidence of fracture occurs approximately between 11–12 and 13–14 yr in girls and boys, respectively (1–6). This period coincides to the age of peak height velocity (PHV) and precedes by nearly 1 yr the peak of

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Abbreviations: aBMD, Areal bone mineral density; BV/TV, trabecular bone volume fraction; CI, confidence interval; CSA, cross-sectional area; CV, coefficient of variation; DXA, dual-energy x-ray absorptiometry; μFE, micro-finite element; FEA, finite element analysis; HR-pQCT, high-resolution peripheral computerized tomography; OR, odds ratio; PHV, peak height velocity; vBMD, volumetric bone mineral density.

bone mineral accrual (6–8). In both genders, the maximal differences between PHV and bone mineral mass accrual corresponds to pubertal stages P2–P3 (7). Several studies strongly suggest that the higher incidence of fracture during PHV can result from a transient fragility condition due to a relative deficit in the amount of mineralized tissue within the skeletal pieces (6–9). As another but not mutually exclusive possibility, fracture may reflect an early prepubertal expression of reduced mechanical resistance that would outlast the period of sexual maturation and thus increase the risk of osteoporosis in later life. Evidence for this latter possibility has been documented in both girls (10) and boys (11). Although trauma can be an important determinant that may explain part of the gender difference in fracture incidence (1–5), an additional intrinsic bone mechanical fragility could therefore be involved (10, 11). We investigated this hypothesis in a prospective study carried out in a cohort of healthy boys, about half of whom had experienced a fracture until a mean age 15.2 yr. Several bone variables including areal bone mineral density (aBMD), microstructure, and strength were measured by dual-energy x-ray absorptiometry (DXA), high-resolution peripheral computerized tomography (HR-pQCT), and finite element analysis (FEA) to assess whether an intrinsic bone weakness is associated with a fracture history and to explore which bone traits could contribute to this mechanical deficit.

Subjects and Methods

Study subjects

The analysis presented in this report has been carried out on data obtained in 176 healthy adolescent boys with a mean age of 15.2 ± 0.5 (mean ± SD) yr. These boys belonged to an 8-yr cohort study of healthy prepubertal Caucasian boys recruited at a mean age ± SD of 7.4 ± 0.4 yr (range, 6.5–8.5 yr) through the Public Health Youth Service of the Geneva region from September 1999 to September 2000. These boys were then examined at mean ages 8.5 ± 0.4 and 9.6 ± 0.4 yr (12). Between 7.4 and 8.5 yr of age, half of the cohort received a calcium supplementation as previously reported in detail (12). Exclusion criteria were ratio of weight to height below the third or above the 97th percentile according to Geneva reference values, presence of physical signs of puberty, chronic disease, gastrointestinal disease with malabsorption, congenital or acquired bone disease, and regular use of medication. The protocol was approved by the Ethics Committee of the Department of Pediatrics of the University Hospitals of Geneva. Informed consent was obtained from the parents and their children.

Clinical assessment

Participant's body weight and standing height using a stadiometer were measured, and body mass index (kilograms per square meter) was calculated. Tanner's pubertal stage was determined by a pediatrician at baseline, at the end of the intervention study (12), and at each follow-up visit by self-assessment based on drawings and written description of Tanner's classification. Fracture history, including skeletal site, year of event, and type of treatment, was recorded from the children and their parents at each visit. During the 7.8-yr follow-up period, no other disorder susceptible to affect the skeleton was found in the participants.

Protein and calcium intakes assessment

Spontaneous calcium and protein intake was assessed by frequency questionnaire (13, 14) at each visit. The total animal protein intake was expressed either in grams per day or grams per kilogram body weight per day. It included dairy, meat, fish, and egg proteins. The calcium intake was essentially assessed from dairy sources.

Physical activity assessment

Physical activity was assessed by questionnaire based on self-reported time spent on physical education classes, organized sports, recreational activity, and usual walking and cycling (15). Subsequently, the collected data were converted and expressed as physical activity energy expenditure (kilocalories per day) using established conversion formulas (16).

Measurement of bone variables

The aBMD was determined by DXA using a Hologic QDR 4500 instrument (Waltham, MA) at radial metaphysis, radial diaphysis, femoral neck and total hip, femoral diaphysis, and L2–L4 lumbar spine in anteroposterior view as previously reported (12). The coefficient of variation (CV) of repeated measurements at these sites as determined in young healthy adults varied from 1.0–1.6% for BMD. Volumetric bone density (vBMD) and microstructure were determined at the distal radius and tibia by HR-pQCT with an XtremCT instrument (Scanco Medical AG, Brüttisellen, Switzerland) that acquires a stack of 110 parallel computerized tomography slices (9-mm length) with an isotropic voxel size of 82 μm as previously described (17). At the distal radius, four boys had no DXA and no HR-pQCT scans because wrist fractures could have interfered with data acquisition. At this site, HR-pQCT scans of four other boys were eliminated from the study because of obvious movement artifacts. The site of the HR-pQCT scans was precisely delineated by positioning a reference line at the proximal limit of the epiphyseal growth plate of the radius (18). For subjects whose radial epiphyseal plates had fused, the remnant of the plate was still visible, enabling us to set the reference line. Scans were started at a distance 1 mm proximal to the reference line. Such a technical process ensured that despite differences in radius length, the scanned anatomic site was selected to be as identical as possible in all subjects. For the distal tibia, the first CT slice was 22.5 mm proximal to the reference line as described in a previous adult study (17). The following variables were measured: total, cortical, and trabecular volumetric bone density expressed as milligrams hydroxyapatite per centimeter cubed; trabecular bone volume fraction (BV/TV); trabecular number, thickness (micrometers), and spacing (micrometers); mean cortical thickness (micrometers); and cross-sectional area (CSA) (square millimeters). The *in vivo* short-term reproducibility of HR-pQCT at the distal radius and distal tibia assessed in 15 subjects with repositioning varied from 0.6–1.0% and from 2.8–4.9% for bone density and for trabecular architecture, respectively. These reproducibility ranges are similar to those previously published (19). DXA measurements were performed in nondominant forearm and the hip. HR-pQCT measurements in distal radius and tibia were likewise usually performed in the nondominant limb. Unless there was a fracture history on that side, the nonfractured limb was measured by both DXA and HR-pQCT techniques. One technician per device performed all the scans, as well as daily quality control phantom, to check for possible drifts in the x-ray sources.

Finite element analysis

Finite element models of the radius and the tibia were created directly from the segmented HR-pQCT images using a procedure similar to that used in earlier clinical studies (20–22). In summary, a voxel-conversion procedure was used to convert each voxel of bone tissue into an equally sized brick element (23), thus creating micro-finite element (μFE) models that can represent the actual trabecular architecture in detail. The models contained approximately 2 million elements for the radius and 5 million elements for the tibia and could be solved in approximately 3 and 5 h, respectively. Material properties were chosen: isotropic and elastic. Both cortical and trabecular bone elements were assigned a Young's modulus of 10 and a Poisson's ratio of 0.3 (21, 24). A compression test was simulated to represent loading conditions during a fall from standing height (25). Bone failure load was calculated as the force for which 2% of the bone tissue would be loaded beyond 0.7% strain (24, 26). In addition to failure load {N}, μFEA-derived variables used in our study also included stiffness (kilo-Newtons per millimeter) and the percentage of load carried by the trabecular bone at the distal and proximal surface of the volume of interest (percent load trabecular distal and percent load trabecular proximal, respectively). All μFEA were done using the FE solver integrated in the IPL software version 1.15 (Scanco Medical AG).

Expression of the results and statistical analysis

The various anthropometric and osteodensitometric variables are given as mean ± SD. The differences in density, microstructure, mechanical parameters, and clinical characteristics among healthy adolescent boys with or without a positive history of fracture were assessed by unpaired Student's *t* test or by Wilcoxon signed rank test whenever the variable was not normally distributed. For these differences in density, microstructure, and mechanical parameters, an analysis of covariance was used to control for the influence of age, height, weight, pubertal stage, calcium and protein intake, physical activity, and calcium supplement or placebo randomization between the age of 7.4 and 8.4 yr. Associations between density, microarchitecture, mechanical parameters, and fracture status were evaluated by logistic regression analysis with adjustment for age, height, weight, pubertal stage, calcium and protein intake, physical activity, and calcium supplement or placebo randomization between the age of 7.4 and 8.4 yr and expressed as odds ratio (OR) [with 95% confidence intervals (CI)] per SD decrease. The significance level for two-sided *P* values was 0.05 for all tests. The data were analyzed using STATA software, version 7.0. (StataCorp LP, College Station, TX).

TABLE 1. Characteristics of the 176 boys at a mean age of 7.4 and 15.2 yr

	Age (yr)	
	7.4 ± 0.4	**15.2 ± 0.5**
Anthropometric variables		
Height (cm)	125.5 ± 6.2	171.7 ± 9.7
Weight (kg)	25.2 ± 5.0	60.2 ± 13.2
BMI (kg/m^2)	15.9 ± 2.0	20.3 ± 3.6
Pubertal stage (n)[a]	All P1	P2 (5), P3 (13), P4 (93), P5 (65)
Dietary intake		
Calcium (mg/d)	749 ± 265	1029 ± 538
Total proteins (g/d)	46.9 ± 12.3	63.3 ± 23.7
Total proteins (g/kg BW · d)	1.78 ± 0.46	1.08 ± 0.41
Total physical activity (kcal/d)	241 ± 93	720 ± 386

All values are means ± SD. BMI, Body mass index.

[a] Pubertal maturity, with the number of boys at the corresponding Tanner stage shown within *parentheses*.

Results

The anthropometric characteristics of the cohort as assessed at 7.4 and 15.2 yr of age were within the normal values of the corresponding regional population (Table 1).

The total number of fracture was 156, occurring in 87 of the 176 boys followed up. Multiple fractures (two to five) were reported in 38 boys, accounting for two thirds of all fractures. Most common fractures were localized in forearm and wrist (39%), followed by hand/fingers (18%) and arm/shoulder (14%). Twenty percent of fractures occurred at the lower limb (including foot, ankle, tibia, and femur) and 8% at other sites. In boys having experienced more than one fracture, the upper limb was always affected. Peak fracture incidence occurred from 10–13 yr of age (Fig. 1).

Once the cohort was dichotomized according to the presence or absence of at least one fracture that occurred

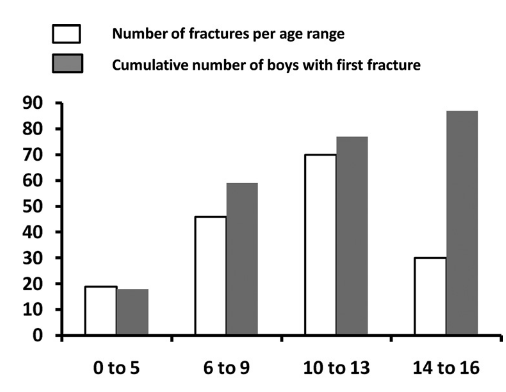

FIG. 1. Age-related distribution of total number of fractures and cumulative number of boys sustaining a first fracture. The histogram shows the age-related distribution of all fractures and cumulative number of the 87 of 176 healthy boys experiencing at least one fracture. The highest incidence is observed within the 10- to 13-yr age range.

TABLE 2. Characteristics of boys at 7.4 and 15.2 yr according to their fracture history at 15.2 yr

	Without fracture, n = 89	With fracture, n = 87	*P*	*P*[a]	Without fracture, n = 89	With fracture, n = 87	*P*	*P*[b]
Age (yr)	7.4 ± 0.4	7.4 ± 0.4			15.2 ± 0.5	15.2 ± 0.5		
Pubertal stage (n)[c]	All P1	All P1			P2 (1), P3 (7) P4 (49), P5 (32)	P2 (4), P3 (6) P4 (44), P5 (33)		
Height (cm)	126.1 ± 6.5	124.9 ± 5.7	0.173		172.2 ± 10.5	171.2 ± 8.8	0.484	
Weight (kg)	25.5 ± 5.0	25.0 ± 5.0	0.520		61.0 ± 13.0	59.4 ± 13.4	0.441	
BMI (kg/m^2)	15.9 ± 1.9	15.9 ± 2.1	0.884		20.5 ± 3.6	20.2 ± 3.6	0.579	
Calcium (mg/d)	767 ± 279	730 ± 250	0.359		1027 ± 526	1032 ± 554	0.949	
Total proteins (g/d)	48.5 ± 13.3	45.2 ± 11.1	0.082		65.4 ± 24.1	61.2 ± 23.1	0.241	
Total PA (kcal/d)	233 ± 96	249 ± 89	0.251		735 ± 449	705 ± 310	0.609	
Radial metaphysis BMD (mg/cm^2)	301 ± 28	290 ± 31	0.014	0.013	383 ± 54	379 ± 56	0.626	0.444
Radial diaphysis BMD (mg/cm^2)	481 ± 38	466 ± 37	0.010	0.034	660 ± 67	654 ± 70	0.583	0.716
Femoral neck BMD (mg/cm^2)	688 ± 70	663 ± 72	0.023	0.033	901 ± 133	847 ± 116	0.005	0.001
Total hip BMD (mg/cm^2)	690 ± 67	665 ± 72	0.017	0.032	992 ± 139	936 ± 133	0.007	0.002
Femoral diaphysis BMD (mg/cm^2)	1014 ± 85	982 ± 85	0.014	0.024	1682 ± 171	1623 ± 171	0.025	0.006
L2–L4 BMD (mg/cm^2)	568 ± 52	546 ± 57	0.010	0.017	918 ± 135	875 ± 133	0.032	0.010

All values are mean ± SD. BMI, Body mass index.

[a] *P* value after adjustment for age, height, weight, pubertal stage, calcium and protein intake, and physical activity.

[b] *P* value after adjustment for age, height, weight, pubertal stage, calcium and protein intake, physical activity, and calcium supplement or placebo randomization between 7.4 and 8.4 yr.

[c] Pubertal maturity, with the number of boys at the corresponding Tanner stage shown within *parentheses*.

from infancy to the mean age of 15.2 yr, no significant difference in anthropometric values was noted, neither at 7.4 nor at 15.2 yr of age (Table 2). There was a slight but not statistically significant lower protein intake in the fractured group at both 7.4 (−7%) and 15.2 (−6%) yr of age (Table 2). This slight reduction was not abolished after body weight adjustment (data not shown). The fractured group was not more physically active than the nonfractured group (Table 2).

At the age of 7.4 yr, aBMD values were significantly reduced at the six scanned skeletal sites, even after adjustment for age, standing height, body weight, pubertal stage, calcium and protein intake, and physical activity (Table 2). As evaluated by logistic regression and expressed as OR (95%CI) per 1 SD decrease in aBMD, the risk of fracture was significantly increased, with the highest value obtained at the femoral diaphysis [1.64 (1.07–2.52)] and the lowest value at the femoral neck [1.46 (1.03–2.08)] (Fig. 2A).

At the age of 15.2 yr, significantly reduced aBMD values adjusted for age, standing height, body weight, pubertal stage, calcium and protein intake, physical activity, and calcium supplement or placebo randomization between 7.4 and 8.4 yr were also measured at the femoral and spinal site levels, but no longer at the two radial sites (Table 2). Compared with the OR computed at the age of 7.4 yr, the corresponding OR at the femoral and spinal levels were greater, varying from 1.90 (1.15–3.14) for the femoral diaphysis to 1.62 (1.05–2.49) for the lumbar spine (Fig. 2B). In contrast, the OR of the two radial sites were much lower, very close to the unit value (Fig. 2B).

At mean age 15.2 yr, microstructure measurements by HR-pQCT indicate that boys with a fracture history displayed significantly lower distal tibia trabecular vBMD (volumetric bone density or BV/TV) and number (Tb.N), and greater trabecular spacing (Tb.Sp) (Table 3). The statistical significance of these differences remained after adjustment for standing height, body weight, calcium and protein intake, physical activity, pubertal stage, and calcium supplement or placebo randomization between age 7.4 and 8.4 yr (Table 3). Total vBMD was also significantly lower in the fractured group after this adjustment (Table 3).

Bone strength evaluated by FEA at the age of 15.2 yr, showed that both stiffness and failure load at the distal tibia were 5.8% lower in fractured group (Table 3). There was no difference in the percentage of load carried by the trabecular or cortical bone at the distal and proximal surface between the fractured and nonfractured group (data not shown).

The risk of fracture as related to tibial microstructure measurements and strength estimates are depicted in Fig. 3. The OR was significantly higher than 1.0 for both trabecular volumetric density and number. A trend for significantly increased OR was computed for both stiffness and failure load estimates (Fig. 3).

In contrast, and in keeping with the DXA aBMD values monitored at the age of 15.2 yr, none of the distal radius

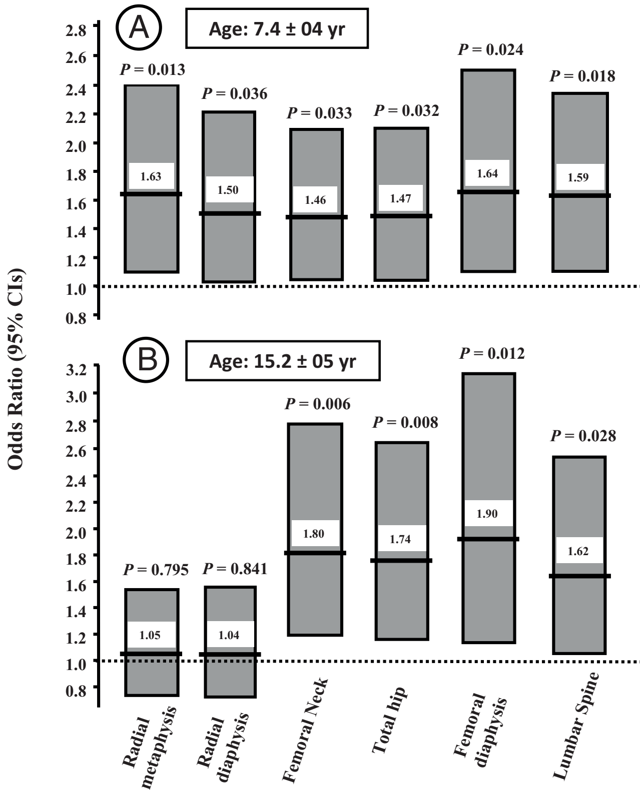

FIG. 2. Fracture risk in healthy boys: OR and 95% CI/SD decrease in aBMD measured by DXA at six skeletal sites. DXA scans were performed at mean age ± SD of 7.4 ± 0.4 and 15.2 ± 05 yr in a cohort of 176 healthy boys of whom 87 experienced at least one fracture until mean age of 15.2 yr. OR were calculated using logistic regression analysis. The OR are depicted by the *horizontal lines* within the columns of which the upper and lower limits correspond to the 95% CI. The statistical significance is indicated above each column of the skeletal site examined. A, At 7.4 yr, OR were adjusted for age, height, weight, pubertal stage, calcium and protein intake, and physical activity; B, at 15.2 yr, OR were adjusted for age, height, weight, pubertal stage, calcium and protein intake, physical activity, and calcium supplement or placebo randomization between 7.4 and 8.4 yr.

microstructure measurements and strength estimates made by HR-pQCT and FEA, respectively (Table 3) were significantly different between the fractured and the nonfractured group.

Discussion

The reported prospective study carried out in a homogeneous cohort of healthy fractured boys shows deficiencies in bone mineral density, microstructure, and strength as assessed by three technical approaches using DXA, HR-pQCT, and FEA.

Over the last decades, several studies carried out in both healthy girls and boys have consistently reported an inverse relationship between the incidence or prevalence of fractures occurring during childhood and adolescence and aBMD as measured by DXA (10, 11, 27–33). Thus, like in adults (34–36), low aBMD is associated with fractures in growing individuals. In adults, a site specificity for aBMD and fracture risk has been documented (34). In children and adolescents, some but not all studies support a site specificity for fracture prediction (10, 30, 31, 33, 37, 38). In a case control study of upper limb fractures in both girls and boys aged 9–17 yr, there was a trend for arm aBMD to be more predictive than other skeletal sites for wrist and forearm fractures in girls but not in boys (30). This apparent gender difference in site specificity of fracture prediction (30) would be, at least in part, consistent with our previous prospective study in girls showing significant lower bone mineral content in the radius diaphysis at 8.0 yr of age and still present 8.5 yr later (10) and the present investigation in boys in whom the fracture associated reduction in radial bone strength as measured before puberty was no longer observed at 15.2 yr of age.

The usual observation of reduced aBMD associated with fracture occurring during childhood and adolescence contrasts with diverse findings on the putative nature of the bone components that might explain this reduction. Particularly, it remains uncertain whether the mechanical weakness would be related to differences in bone size, geometry, and/or in vBMD of the cortical or trabecular compartments. Differences in the identification of the deficient bone components involved may be due to several factors including technical approaches, skeletal sites examined, and/or age at time of bone trait analysis. Our study illustrates two of these factors, *i.e.* age at time of bone assessment and the skeletal sites examined. At the age of 7.4 yr, aBMD at all skeletal sites was significantly lower in the group with than without fracture. Note that 74% of all fractures (115 of 156) occurred and 61% of boys (53 of 87) broke their bones after this first examination that clearly identified a relative weakness at both axial and appendicular sites, including radial metaphysis and diaphysis. This homogeneity among skeletal sites in the prediction of fracture risk at mean age of 7.4 yr as depicted in Fig. 2 was no longer present several years later. When reexamined at a mean age of 15.2 yr, aBMD remained lower in spinal and femoral sites but no longer in the radius. From 7.4–15.2 yr of age, the CV at the radial metaphysis level of the whole cohort (n = 176), increased from 10.1 to 14.4%. Such an age-dependent wider range of aBMD values could be expected to reduce the power for detecting a statistically significant difference in relation to the occurrence or not of fracture. However, an increase in aBMD CV of similar magnitude was observed in the femoral neck (from 10.7–14.5%) and spine (from 10.1–15.2%) levels, although the difference between boys with and without fracture remained highly significant (Table 2). Furthermore, bone microstructure and strength variables as as-

TABLE 3. Microstructure and FEA of distal tibia and distal radius in 15.2-yr-old boys according to their fracture history

	Distal tibia				Distal radius		
	Without fracture, n = 89	With fracture, n = 87	*P*	*P*[a]	Without fracture, n = 87	With fracture, n = 81	*P*
D tot (mg HA/cm^3)	272 ± 45	262 ± 44	0.125	0.038	257 ± 38	255 ± 44	0.830
D cort (mg HA/cm^3)	730 ± 56	735 ± 52	0.551	0.766	637 ± 73	642 ± 72	0.688
D trab (mg HA/cm^3)	205 ± 27	196 ± 27	0.029	0.012	195 ± 27	192 ± 34	0.542
BV/TV (%)	17.1 ± 2.3	16.3 ± 2.2	0.030	0.012	16.2 ± 2.3	16.0 ± 2.8	0.544
Tb.N (mm^{-1})	2.13 ± 0.31	2.04 ± 0.26	0.040	0.036	2.23 ± 0.20	2.20 ± 0.21	0.351
Tb.Th (μm)	81.1 ± 10.6	80.8 ± 10.7	0.875	0.252	72.6 ± 8.4	72.4 ± 10.9	0.872
Tb.Sp (μm)	398 ± 62	418 ± 60	0.028	0.020	379 ± 41	387 ± 53	0.404
Ct.Th (μm)	851 ± 336	807 ± 293	0.464	0.332	388 ± 219	383 ± 209	0.890
CSA (mm^2)	888 ± 151	858 ± 132	0.167	0.400	333 ± 61	322 ± 56	0.209
Stiffness (kN/mm)	259.6 ± 54.7	244.6 ± 48.6	0.060	0.024	87.2 ± 21.6	83.5 ± 19.3	0.249
Estimated failure load (N)	12430 ± 2559	11706 ± 2235	0.050	0.016	4239 ± 996	4044 ± 894	0.189

All values are mean ± SD. D tot, D cort, and D trab, total, cortical, and trabecular volumetric density, respectively, expressed in milligrams of hydroxyapatite (HA); Tb.N, Tb.Th, and Tb.Sp, trabecular number, thickness, and spacing, respectively; Ct.Th, cortical thickness.

[a] *P* value after adjustment for age, height, weight, pubertal stage, calcium and protein intake, physical activity, and calcium supplement or placebo randomization between 7.4 and 8.4 yr.

sessed by HR-pQCT and FEA at 15.2 yr at the distal radius corroborated the absence of an aBMD difference measured by DXA at that age. It is quite possible that the lower radial aBMD values observed at 7.4 yr may have contributed to the increased fracture incidence, observed during the prepubertal years until the time of PHV, particularly those fractures localized in the upper limbs. The question whether the apparent favorable evolution of the radial bone mineral mass in the fractured group corresponds to a transient or lasting recovery remains open. Only new measurements of radius and other skeletal sites of this cohort at the time of peak bone mass attainment will enable discrimination between these two possibilities. It might be argued that in some boys, the forearm fractures might have artifactually overestimated the radius bone measurements made at 15.2 yr. For instance, the fracture callus could have been included in the region of interest in 10 of 87 fractured boys. Alternatively, the side of the measurement could have been switched at the age 15.2 yr from the nondominant to the dominant arm in nine of 87 fractured boys. These two situations may thus have canceled out the forearm deficiency recorded at the age of 7.4 yr. Removing from the statistical analysis these few boys did not modify the nondifference of the radial measurements between the fractured and nonfractured group.

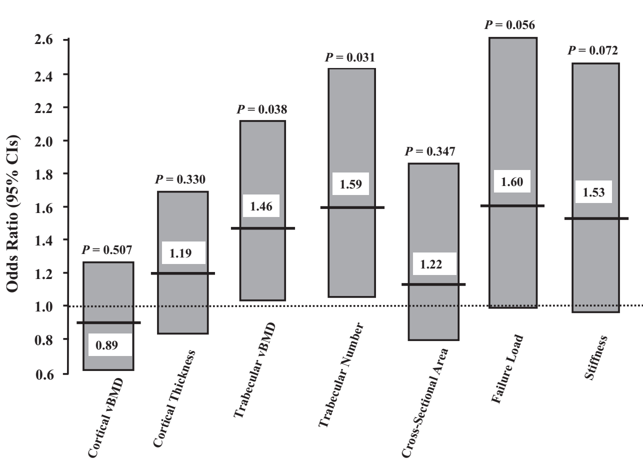

FIG. 3. Fracture risk in healthy boys: OR and 95% CI/SD decrease of several tibial bone microstructure and strength components. Measurements were performed at mean age ± SD of 15.2 ± 0.5 yr by HR-pQCT and FEA for the tibia microstructure and strength components, respectively. OR are depicted by the *horizontal lines* within the columns of which the upper and lower limits correspond the 95% CI. The statistical significance is indicated above each column of the skeletal site examined. OR were adjusted for age, height, weight, pubertal stage, calcium and protein intake, physical activity, and calcium supplement or placebo randomization between 7.4 and 8.4 yr.

In our study, the measurements by HR-pQCT technique at the level of the distal tibia indicate that the bone mineral mass deficit detected by DXA in the femoral sites of the fractured group was associated with significant lower distal tibial trabecular vBMD (−4.4%). The magnitude of this fracture-associated reduction in trabecular vBMD was virtually identical with that reported (−4.6%) in a large group of young men aged 18.9 ± 0.6 yr in whom distal tibia was measured by pQCT (39). Using HR-pQCT in our study, we further documented that the lower vBMD in the fractured group was essentially due to a significant reduction in the number of trabeculae (−4.3%), without any decrease in their thickness. In our study, the lower, by 5.2 and 3.4%, respectively, cortical thickness and CSA were not statistically significant. The important interindividual variability of these two bone size components, as indicated by the large CV, about 36–40 and 15–17% in cortical thickness and CSA, respectively, suggest that in our study, the statistical power was insufficient to establish possible significant contribution to the increased fracture risk.

The mechanical competence of the distal tibia as assessed by FEA was lower, but not statistically significantly so, in the fractured group. The relatively low stiffness and failure load suggest that the microstructural trabecular abnormality mainly characterized by reduced number and increased separation have compromised bone strength. Of note, both bone strength estimates at distal tibia were highly related to femoral neck aBMD with correlation coefficient r of 0.82 and 0.83 ($P < 0.001$) for stiffness and failure load, respectively. However, the correlation was less with trabecular number ($r = 0.56$), the main alteration observed at the level of the tibia microstructure. This suggests that other nontrabecular components could play a nonnegligible role in the mechanical competence deficit observed in the fractured group. Other studies have provided evidence that a transient cortical weakness could be implicated in the increased fragility occurring during the period of PHV (18, 40). This deficit may be due to a decreased cortical thickness associated with a putative increase in cortical porosity (18, 40). In our study, there was a lower, although not significant, value in cortical thickness in the distal tibia of the fractured group. Thus, in addition to the clearly detectable trabecular deficit, FEA (23) may have included this cortical component in the estimates of bone stiffness and failure load in relation to childhood and adolescent fracture.

This study has some limitations. The reported fractures by the parents were not confirmed by a direct radiological examination by the investigators. However, taken into account both the prospective study design and the parental concern of the event affecting the health of their children and requiring urgent medical care, it is unlikely that the number of recorded fractures substantially differs from the reality. The magnitude of the trauma was not categorized; therefore, any fractures resulting from some severe trauma were included in our analysis. Such inclusion may have attenuated some of the bone trait observed differences. In this respect, a previous study has documented that bone fragility contributes to the risk of fracture in children even after severe trauma (41). Still, the relative small number of subjects may have limited the statistical power of our study for ascertaining a statistically significant contribution of either cortical thickness or CSA to the increased fracture risk.

One can only speculate on the role of genetic and/or environmental factors that might explain the bone deficit observed in the fractured group. The fact of detecting the deficit at mean age 7.4 yr, which is before the peripubertal period during which the fracture risk culminates as shown in Fig. 1, could speak in favor of a role for a genetic component. From birth to maturity, bone development of each healthy individual follows a given trajectory that can be moderately modified by environmental factors (42). The genes responsible for the large interindividual variability of aBMD, as measured once peak bone mass is attained in early adulthood, still remain to be clearly identified (42). A previous study in girls indicated that fractures during growth are associated with relatively low bone mass from the beginning to the end of pubertal maturation (10), which suggested that the increased fracture risk was predetermined very early in life and remained unabated until the end of the skeletal development period (10). Regarding the role of environmental factors, physical activity as well as both calcium and protein consumptions as surveyed at 7.4 or 15.2 yr (Table 2) did not show any significant differences between the fracture and the non fracture group.

Our study has some strengths compared with other cross-sectional reports comparing children of both genders with wide age and pubertal maturation ranges. Boys were prospectively followed up for a period of 7.8 yr, starting from prepuberty and covering for most of them the PHV years during which the greatest incidence of fractures was recorded in previous studies as in the present study. Finally, the fact that bone investigation methods including DXA and HR-pQCT were applied in each subject during the same visit by a single technician also provides a certain strength to our study.

In conclusion, in a homogeneous cohort of healthy boys, fractures recorded until 15.2 ± 0.5 yr of age were associated with lower femoral neck aBMD measured by DXA and with a lower distal tibia trabecular vBMD and number as assessed by HR-pQCT, whereas FEA indicated a decrease in stiffness and failure load. These deficits in bone mineral mass, microstructure, and strength could contribute to the occurrence of fractures during growth.

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A Review of Epidemiological Distribution of Different Types of Fractures in Paediatric Age

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Abstract

Introduction

Treating paediatric patient fractures comprises a large part of any orthopaedic trauma service. The majority of fractures take place during sports and recreational activities. In this study, we examined the incidence of fractures and their distribution according to patient age.

Methods

We collected retrospective data from all the paediatric age group patients (under age 18) referred to our orthopaedic service from August 2015 to July 2016. We collected data for 1022 patients during one calendar year.

Results

We noted 1022 paediatric fracture presentations in one calendar year, with a 48.63% incidence in male patients and 51.36% in female patients. The age with the highest incidence was 16 years in boys and 11 years in girls. Upper limb fractures were more common than lower limb fractures in most of the subgroups.

Conclusions

These insights into paediatric fracture distribution provide an opportunity to evaluate the resources in hospitals allocated to emergency and orthopaedic departments regarding their capacity to treat fractures in paediatric patients.

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Introduction

Paediatric injuries comprise a large subset of emergency and orthopaedic outpatient presentations. The high number of paediatric injuries and fractures can be attributed to the enthusiasm typically seen in paediatric patients as they discover and experience new things while remaining unaware of the consequences. Bone properties of patients in this age group will also influence the incidence and pattern of fracture. Paediatric fractures constitute approximately 25% of all paediatric age group injuries [1]. The majority of fractures in paediatric patients are not life-threatening and are treatable [2]. Although there are many

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systemic and metabolic diseases that can cause or contribute to the fractures, the majority of these fractures are secondary to trauma [3].The aim of our study is to look at the incidence of fractures in paediatric patients, the prevalence of the different types of fractures, their gender distribution, and their relationship to certain activities or sports.

Materials And Methods

Our study is based on a retrospective collection of data of paediatric patients who presented with fractures to the orthopaedic outpatient services of University Hospital Kerry, as well as patients admitted for inpatient treatment. Patients under 18 years of age who presented to the University Hospital Kerry from August 2015 to July 2016 with fractures were included in the study. The epidemiological data was collected from the hospital and departmental medical records. All X-rays were reviewed to ensure that non-fracture or soft-tissue injuries were excluded. The data was collected on Microsoft Excel sheets and analysed using the Statistical Package for the Social Sciences (SPSS (version 19.0) IBM, New York, USA).

Results

The total population of County Kerry (located in Southwest Ireland) is 147,554. The paediatric population (those under 18 years of age) is 34,940, comprising 24.013% of the total population. A total of 1022 paediatric patients presented with fractures to the orthopaedic outpatient department, making the incidence rate 29.23 fractures/1000/year. The detailed results of the epidemiological distribution of fractures are shown in Table *1*.

Fracture	Frequency	Percent	Age (year)	Sex (Male:Female)
Clavicle	53	5.2	9.21	74:26
Proximal humerus	18	1.8	11.56	44:56
Distal humerus/Supracondylar	142	13.9	6.89	51:49
Radius/Ulna diaphysis	36	3.5	9.42	50:50
Radius metaphysis	58	5.7	8.41	41:59
Distal radius /Buckle	278	27.2	8.48	54:46
Scaphoids	35	3.4	13.37	40:60
Metacarpals	51	5.0	14.02	47:53
Phalanx fingers	85	8.3	12.85	39:61
Tibia diaphysis	13	1.3	8.00	46:54
Distal tibia	9	0.9	5.00	67:33
Femur diaphysis	19	1.9	14.42	42:58
Proximal tibia	25	2.4	8.56	88:12
Patella	7	0.7	13.29	29:71
Ankle	94	9.2	12.36	40:60
Toe phalanx	16	1.6	12.88	44:56
Metatarsals	26	2.5	11.23	54:46
Pubic rami	3	0.3	16.00	0:100
Olecranon	11	1.1	7.27	18:82
Hook of hamate	7	0.7	14.00	57:43
Ulnar styloid	18	1.8	12.00	100:0
Radial head	18	1.8	8.33	33:67

TABLE 1: Common fractures and their epidemiological distribution according to age, sex, and frequency of different types of fractures

The most common fracture was distal radial/buckle fractures (27.2%), followed by distal humerus /supracondylar fracture (13.9%), ankle fractures (9.2%), phalanx fractures (8.3%), and radial/ulnar metaphysis fractures (5.7%). Figure *1* presents the nine most common fractures and their ratios.

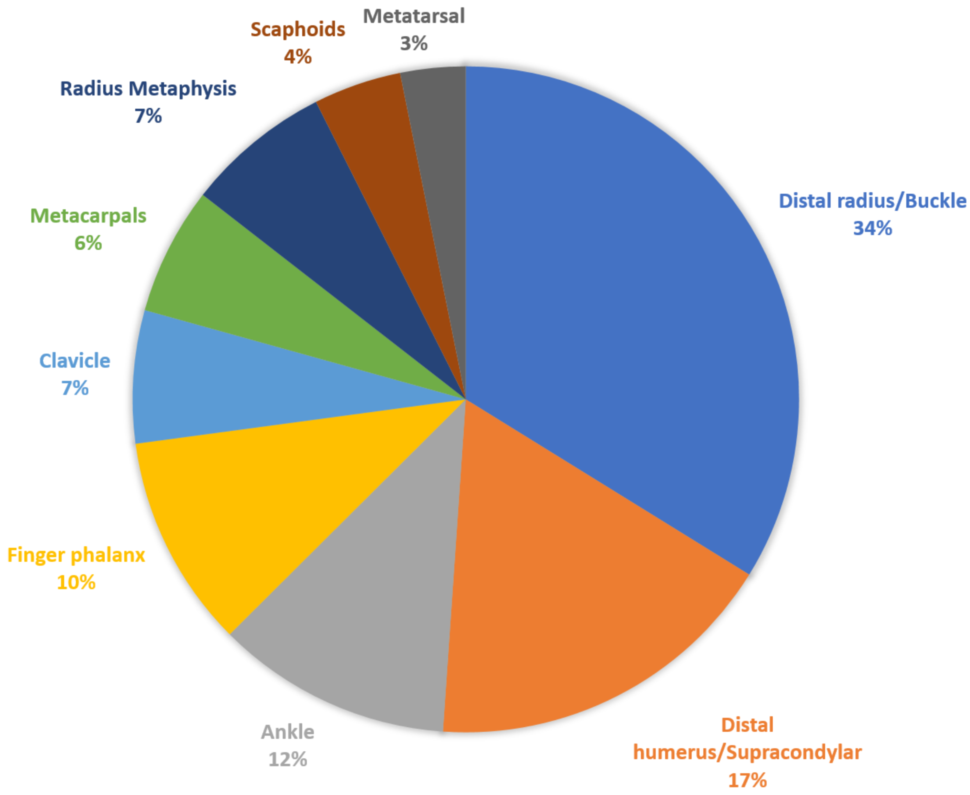

FIGURE 1: The nine most common fractures and their ratios

The mean age of paediatric patients presenting with distal radial fracture was 8.48 years with a male/female (M/F) ratio of 54:46. The mean age of paediatric patients presenting with distal humerus fracture was 6.89 years with an M/F ratio of 51:49. The mean age of patients with ankle fractures was 12.36 years with an M/F ratio of 40:60. The mean age of patients with a phalanx fracture was 12.85 years with an M/F ratio of 39:61. Finally, the mean age of patients with a radial/ulnar metaphysis fracture was 8.41 years with an M/F ratio of 41:59. Table 2 presents fracture data according to age, M/F ratio, limb distribution, and common fractures.

Age group (years)	Male (%):Female (%)	Upper:Lower Limb (%)	Five Most Common Fractures (%)	
0-2	33:67	100:0	Distal radius /buckle fracture	29.17
			Distal humerus/supracondylar	25
			Clavicle	25
			Ankle	12.5
3-6	50:50	81:19	Distal humerus/supracondylar	32.35
			Distal radius /buckle fracture	32.35
			Radius metaphysis	9.66
			Clavicle	7.56
			Proximal tibia	6.3
7-12	45:55	74:26	Distal radius/buckle fracture	37.28
			Distal humerus/supracondylar	11.61
			Ankle	8.93
			Phalanx fingers	8.705
			Radius/ulna diaphysis	8.036
13-17	54:46	66:34	Ankle	14.74
			Phalanx fingers	14.74
			Metacarpals	13.78
			Distal radius /buckle fracture	8.65
			Scaphoids	8.33

TABLE 2: Paediatric subgroups according to age with sex ratio, limb distribution, and common fracture distribution

Up to the age of two years, the most common fractures were distal radial buckle fractures (29.17%), followed by distal humerus/supracondylar fractures in 25% of patients in this age group. Between the ages of three and six years, the most common fractures presented were distal humerus/supracondylar fractures (32.35%), distal radial/buckle fractures (32.35%), and radial/ulnar metaphysis fractures (9.66%). Between age seven and age 12, the most common fractures were distal radial/buckle fractures (37.28%), followed by supracondylar fractures (11.61%) and ankle fractures (8.93%). In patients aged 13 to 17, the most common fractures were ankle fractures (14.74%), phalanx fractures (14.74%), followed by metacarpal fractures (13.78%). Table *3* presents the fracture epidemiology according to activities.

Activity or Mechanism	Mean Age (years)	Male (%): Female (%)	Upper: Lower Limb (%)	Most Common Fractures (%)	
Blunt trauma	11.417	40:60	54:46	Metacarpals	25
				Phalanx fingers	12.0
				Toe phalanx	12.0
Cycling	9.889	22:78	83:17	Clavicle	33.3
				Proximal humerus	33.3
				Phalanx fingers	16.6
				Metatarsals	16.6
Fall from bed/chair	5.737	49:51	74:26	Clavicle	21.0
				Distal hum/supracondylar	20
				Proximal tibia	13.6
				Distal radius/buckle fracture	10.5
				Scaphoids	6.32
Fall on outstretched hand	7.864	66:34	98:2	Distal radius/buckle fracture	72.4
				Radius metaphysis	9.5
				Scaphoids	7.24
Gaelic Soccer	14	23:77	84:16	Distal radius/buckle fracture	17.2
				Clavicle	13.5
				Phalanx fingers	13.5
				Radius metaphysis	12.3
Hockey	13.034	76:24	90:10	Phalanx fingers	34.4
				Metacarpals	27.5
				Olecranon	10.3
				Ankle	10.3
Hurling	13.567	80:20	93:7	Phalanx fingers	20
				Distal radius/buckle fracture	20
				Proximal humerus	20
				Metacarpals	10

				Scaphoids	10
Camogie	12.667	100:0	67:33	Phalanx fingers	33.3
				Ankle	33.3
				Radius/ulna diaphysis	33.3
Rugby	14	0:100	100:0	Clavicle	66.6
				Phalanx fingers	33.3
Soccer	10.937	45:55	69:31	Distal radius/buckle fracture	35.4
				Ankle	21.7
				Radius/ulna metaphysis	10.2
Trampoline/monkey bar	7.256	46:54	95:5	Distal humerus/supracondylar	80.8
				Distal radius/buckle fracture	9.6
				Ankle	4.8

TABLE 3: Common fractures caused during different sports/activities

A commonly reported cause of injury was blunt trauma, occurring in 54% of the fractures of the upper limb and 46% of the fractures of the lower limb. The most common fractures due to blunt trauma were metacarpal fractures (25%), finger phalanx and foot phalanx fractures (12% each), followed by ankle fractures (11.11%). Another common mechanism was falling on an outstretched hand, and the associated fractures were distal radial fractures (72.4%), radial metaphysis fractures (9.5%), scaphoid fractures (7.24%), and radial head fractures (2.71%). Fractures associated with trampolines, monkey bars, and bouncing castles were common in younger children. The most common fracture pattern seen in these activities was distal humerus/supracondylar fractures (80.8%), distal radial/buckle fractures (9.6%), followed by ankle and phalanx fractures (4.8% each). The fracture pattern seen resulting from Gaelic football injuries were distal radial/buckle fractures (17.28%), clavicle fractures (13.58%), finger phalanx fractures (13.58%), radial/ulnar fractures (12.35%), and distal humerus/supracondylar, metacarpals, and tibia fractures (7.41% each). Fractures associated with hurling (a popular outdoor stick and ball field sport) were finger phalanx, distal radius, and proximal humerus fractures (20% each), followed by metacarpal and scaphoid fractures (10% each).

In the female population, camogie (a sport similar to hurling) and hockey are very popular activities. The most common fracture seen in camogie players were the ankle, phalanx, and radial/ulnar shaft fractures (33.3% each). For hockey players, finger phalanx fractures were most common (34.48%), followed by metacarpal fractures (27.59%), ankle (10.34%), and olecranon fractures (10.34%). Fractures associated with soccer were distal radial/buckle fractures (35.43%), ankle fractures (21.7%), and radial/ulnar metaphysis fractures (10.29%).

The other common activities/mechanisms reported included cycling, road and traffic accidents

(RTA), and falls from beds or chairs. See Table 3 for common fractures during those activities. The distribution of fractures in male/female population and the fracture distribution according to age is shown in Figure 2.

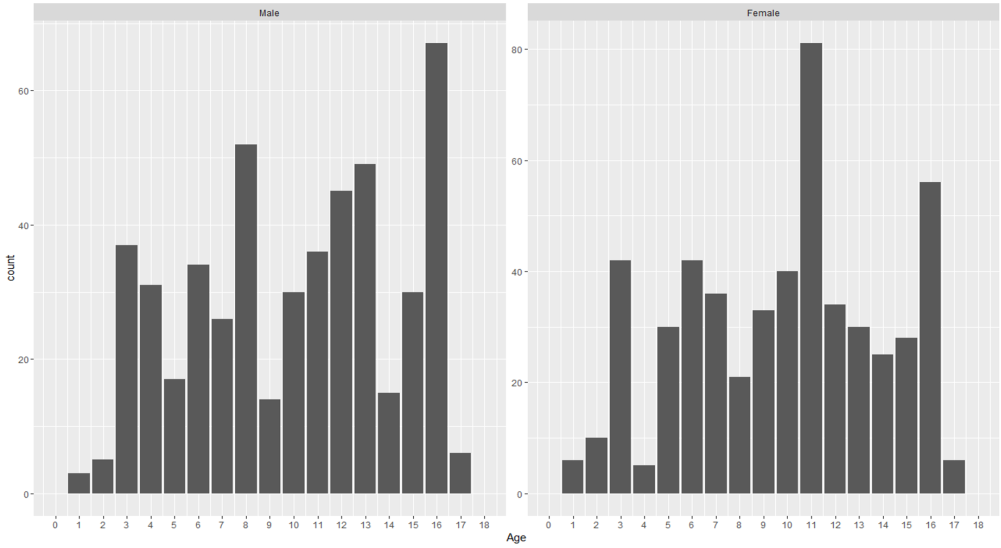

FIGURE 2: Distribution of fractures in the male/female population and fracture distribution according to age

Discussion

Fractures commonly occur in paediatric and elderly patients because of relatively weaker points of physis and metaphysis, and in elderly patients because of deteriorated bone quality [4]. The incidence rate of fractures in the paediatric population has ranged from 12.8/1000 as reported by Kopjar, et al. in Norway [2] to 36.1/1000 as described by Lyons, et al. [5] in Wales. The incidence rate in our study was 29.2/1000, near the higher end of the range. Many variables can affect the incidence, including the size of the paediatric population and the social emphasis on encouraging physical activity. The distribution of fractures between the upper and lower limbs has a certain pattern depending on the age. Early in life, children's activities utilise upper limbs rather than lower limbs, but as they start walking and running, the incidence of lower limb fractures increases.

According to our findings, the distribution of upper and lower limb fractures show specific trends that are quite representative of the nature of the sports related to those fractures. The distribution of fractures among male and females is shifted more towards males in our study, which may be due to the difference in activity levels. In the literature, distal radial fractures are the most common fractures in all paediatric age groups, which aligns with our findings [6]. The incidence and pattern of the fractures differ by location due to lifestyle differences such as rural vs. urban, area topography, and social and economic parameters.

Conclusions

This study provides an accurate assessment of the fractures in paediatric patients distributed by type, age, gender, and activity. This information can help allocate resources for dealing with these injuries in emergency and outpatient departments. These findings may also help healthcare professionals educate parents, guardians, school staff, paramedic staff, hospital staff, and the public in general, on common injuries in children and their relations to certain activities, in efforts to help minimise those injuries.

Additional Information

Disclosures

Human subjects: Consent was obtained by all participants in this study. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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Archived - Health behaviour in school-aged children 2002, student response to question: What were the main results of the most serious injury?[1, 2, 3]

Frequency: Every 4 years

Help

Table: 13-10-0254-01 (formerly CANSIM 110-0068)

Save my customizations

Release date: 2010-03-30

Geography:

Customize table

Geography :

Canada

Result of injury :

Bone was broken, dislocated or out of joint (includes broken and/or chipped teeth)

Apply

Add/Remove data Download options

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		Geography	Canada
		Result of injury	Bone was broken, dislocated or out of joint (includes broken and/or chipped teeth)
Sex	**Age group**	**Student response**	**2002**
			Percent
Males	11 years	Yes	25
		No	75
	13 years	Yes	28
		No	72
	15 years	Yes	38
		No	62
Females	11 years	Yes	22
		No	78
	13 years	Yes	23
		No	77
	15 years	Yes	22
		No	78

How to cite: Statistics Canada. Table 13-10-0254-01 Health behaviour in school-aged children 2002, student response to question: What were the main results of the most serious injury?
DOI: https://doi.org/10.25318/1310025401-eng

Related information

▶ Source (Surveys and statistical programs)

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