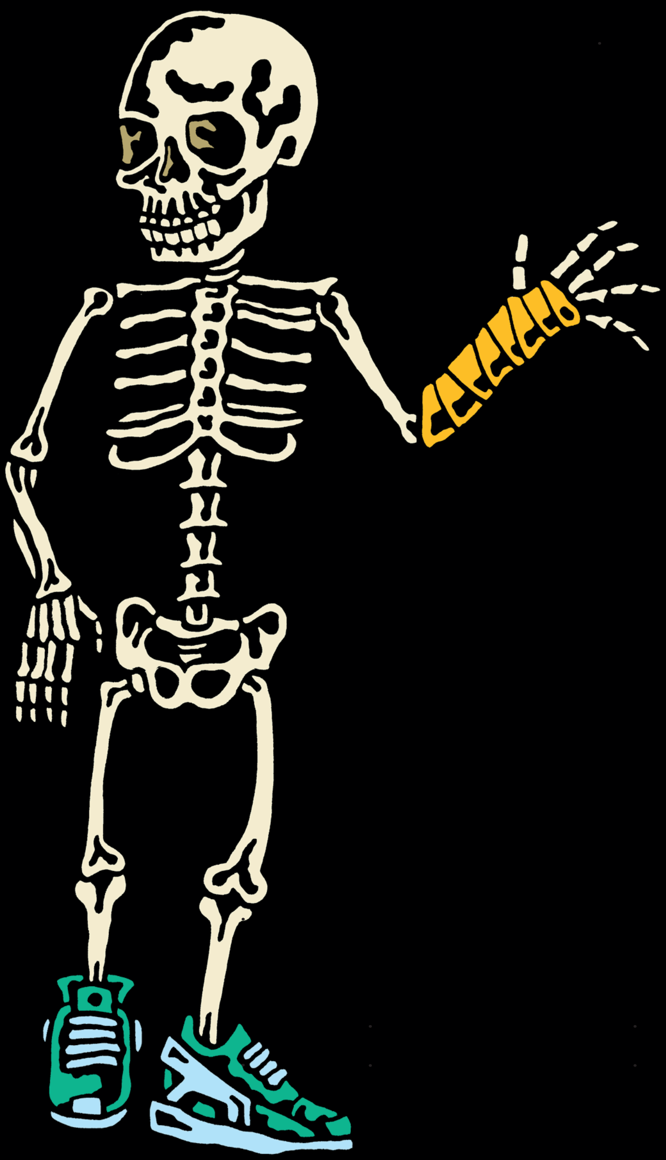
FRACTURES IN CHILDREN

A population-based study from northern Sweden

Erik Hedström



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To my family

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Abstract

Fractures and other injuries are notoriously common in childhood and adolescence and a major cause of morbidity. They place a heavy burden on individuals, families, health systems and society. In a population-based study using data from the Injury Database at Umeå University Hospital we analysed injuries, and especially fractures, in Umeå and its five surrounding municipalities to increase knowledge on the epidemiology of injuries in children.

We found an injury rate requiring visits to the hospital's emergency department of 110/1000 person-years among those 0-19 years of age. For the same age group, the incidence of injuries resulting in admittance to hospital was $132/10^4$ person-years. The incidence of fractures was $201/10^4$ person-years. The accumulated risk of sustaining a fracture before 17 years of age was 34%, and the peak sex-specific incidence of fractures coincided with the pubertal growth spurt in both sexes. Fractures were more common from May-September when temperatures were warmer and days longer. The most common activity at injury in toddlers and preschool children was play, whereas teenagers were more often injured in sports and traffic-related activities.

In an analysis of fracture incidence between municipalities we noted that children and adolescents growing up in rural communities appeared to sustain fewer fractures than their peers in an urban municipality, risk ratio 0.81 (95 % confidence interval 0.76-0.86). We speculated that this observation might be due to differences in behaviour and activities among teenagers in rural and urban communities.

In a further analysis we combined data from the Injury Database with socioeconomic microdata. By linking data between individual children and their parents/families we could analyse the relevance of socioeconomic variables and the number of siblings on fracture rate. We observed that children in households with higher incomes sustained significantly more fractures. Comparing the highest and lowest quintiles for income, the rate ratio was 1.40 (1.28-1.54). We also found that having siblings correlated with an increased risk of fractures, rate ratio 1.28 (1.19-1.38). Parents' education level and family type did not influence the prevalence of fractures significantly. It appeared that the association between variables at the individual level and fractures was stronger than the association between municipality and fractures.

Conclusions Our results show that the incidence of fractures varies with sex, age, developmental stages, skeletal growth, activities of daily life, and seasons. However, it is also influenced by place of residence, family's socioeconomic status and having siblings. Refined methods and data allowing an analysis of subsets of fractures and other injuries on the individual/family- and area-level simultaneously should lead to further insights into the possible causal mechanisms underlying observed correlations.

Abbreviations

CI – Confidence interval

ED – Emergency department

IDB – Injury Database

NRBV – The four municipalities of Nordmaling, Robertsfors, Bjurholm, and Vindeln.

PIN - personal identification number

PYs – Person-years

RR – Rate ratio, or Risk ratio

SCB – Statistics Sweden (Statistikmyndigheten, previously Statistiska Centralbyrån)

SIMSAM – Accronym for ”Swedish Initiative for Research on Microdata in the Social and Medical Sciences”

YOA – Years of age

Original papers

Hedström EM, Bergström U, Svensson O, Michno P. Epidemiology of fractures in children and adolescents: a population-based study from northern Sweden. Acta Orthopaedica 2010; 81(1): 148-53

Hedström EM, Bergström U, Svensson O, Michno P. Injuries in children and adolescents-Analysis of 41,330 injury related visits to an emergency department in northern Sweden. Injury 2012; 43(9):1403-8

Hedström EM, Waernbaum I. Incidence of fractures among children and adolescents in rural and urban communities: analysis based on 9,965 fracture events. Injury Epidemiology 2014; 1(1): 1-5

Hedström EM, Crnalic S, Kullström A, Waernbaum I. Socioeconomic impact on the incidence of fractures in children and adolescents – a population-based study from northern Sweden. Manuscript

Populärvetenskaplig sammanfattning

Skador är vanliga bland barn och unga: ca 9 % av alla barn uppsöker akutsjukvården någon gång per år på grund av skador. Skador och olycksfall är fortfarande den vanligaste dödsorsaken bland barn och unga.

I Umeå samlades data om skadehändelser som föranledde besök på akutmottagningen på Norrlands universitetssjukhus mellan 1993 och 2014 i en skadedatabas. Med data från denna skadedatabas har vi haft möjlighet att utforska skadepanoramat i Umeå och dess omkringliggande kommuner för att bättre förstå skadorna och deras orsaker. Fokus har legat på frakturer eftersom vi tror att antalet registrerade frakturer med större säkerhet avspeglat det sanna antalet frakturer i upptagningsområdet. Andra skador såsom sårskador och kontusioner kan i större utsträckning antas påverkas av befolkningens tendens att uppsöka vård och av tillgången till vård.

I de första två arbetena beskrev vi förekomsten av frakturer, men också andra skador, som föranlett besök på sjukhusets akutmottagning. Skadefrekvensen varierade med kön, ålder och över tid. Det totala antalet skador som föranlett besök på akutmottagningen var i snitt 110/1000 personår, dvs ca 10 % av alla barn per år, och av dem sjukhusvårdades 12 %. Antalet frakturer var 201/10 000 personår. Risken för att ett barn skulle drabbas av minst en fraktur under sin uppväxt var ca 35 %.

Skademönstret avspeglade barn och ungas utveckling, till exempel varierade den aktivitet som föregått skadan med ålder. Barn i förskoleålder skadade sig oftast i samband med lek medan barn i skolålder oftare skadade sig i samband med idrott och i trafiken. Barn i tillväxtspurten drabbas av flest frakturer. Under den period som benet växer som mest hinner det inte bli starkt i samma takt och det orsakar en relativ skörhet som leder till ökad risk för frakturer. Årets säsonger avspeglades också, exempelvis var det vanligare med frakturer under det ljusare och varmare sommarhalvåret än under det mörkare och kallare vinterhalvåret. Fall var den vanligaste orsaken till frakturer. Den vanligaste lokalisationen för frakturer var den nedre delen av underarmen/handleden (26 %) följt av nyckelben och fingrar. Fördelningen av frakturlokalisation varierade med ålder.

Den idrott som orsakade flest frakturer var fotboll bland både pojkar och flickor vilket avspeglar att detta är den absolut populäraste och mest utövade idrotten bland barn i Umeå. De andra idrottsaktiviteter som oftast föregick fraktur var utförsåkning på snowboard/skidor och ridning (bland flickor), samt ishockey (bland pojkar).

I det tredje delarbetet ville vi undersöka om antalet frakturer varierade beroende på hemkommun. Vi jämförde därför frakturförekomsten i de sex kommuner som tillhör sjukhusets primära upptagningsområde och fann att barn och unga som bodde i de mer landsbygdspräglade kommunerna Vindeln, Nordmaling, Robertsfors och Bjurholm hade 19 % lägre frekvens frakturer, än de barn som bodde i Umeå och Vännäs. Skillnaderna var tydligast för barn äldre än 10. Vi spekulerade att det framförallt i åldersgruppen 10–19 uppstod skillnader i ungas aktivitetsmönster mellan stad och landsbygd. En möjlig orsak som vi identifierade var deltagande i idrottsaktiviteter eftersom det till största delen var idrottsrelaterade frakturer som förekom i lägre omfattning i landsbygdskommunerna.

I det fjärde delarbetet undersökte vi om det fanns en association mellan socioekonomiska variabler hos barnen och deras familjer och risken för fraktur. Vi kombinerade data från skadedatabasen med socioekonomiska data hämtade från Statistikmyndigheten (SCB). Vi kontrollerade samtidigt för de variabler som vi tidigare funnit hade association med frakturer; nämligen ålder, kön och hemkommun. I analysen hade barn från familjer med högre inkomster och barn med syskon ökad risk för fraktur. Vi har resonerat att det kan bero på att barn i familjer med bättre ekonomiska förutsättningar i större utsträckning har tillgång till exempelvis studsmattor, skidor och cyklar samt har större möjlighet att delta i organiserade idrottsaktiviteter och föreningsliv. Det finns stöd för detta i nationella rapporter som visar att barn i familjer med högre ekonomiskt kapital i större utsträckning deltar i föreningsidrott. Vi har spekulerat att barn med syskon kan tänkas interagera med andra barn under en större del av dagen än ensambarn och därför är risken för frakturer bland barnen utan syskon mindre. Föräldrarnas utbildningsnivå och huruvida föräldrar var ensamstående eller sammanboende tycktes inte ha betydelse för frakturrisken. Vi fann också att de socioekonomiska variablerna i högre utsträckning bidrog till att förklara variationer i frakturrisk än hemkommun.

De observerade associationerna säger inget säkert om orsakssambandet mellan olika variabler och frakturrisk men indikerar att det kan finnas intresse av att undersöka detta närmare med hjälp av ytterligare data och förfinade metoder. Resultaten väcker också frågor om skillnader i beteenden och aktiviteter mellan barn på olika platser och med olika typer av socioekonomiska förutsättningar, skillnader som kanske inte bara har betydelse för skadeförekomsten.

Thesis at a glance

	Questions	Method	Results	Conclusions
I	What is the incidence of fractures in Umeå and its surroundings? What is the pattern of fractures for sex and age?	A descriptive epidemiological study using data from the Injury Database.	The incidence of fractures among children and adolescents was $201/10^4$. Fracture incidence is affected by such factors as age, sex, and time of year.	Fractures are common in children. Rates and patterns relating to mechanisms, activities, and location are largely similar over time and between widespread geographic locations.
II	What is the spectrum of injuries seen at the emergency department (ED) in Umeå?	A descriptive study using data from the Injury Database.	In Umeå, 10% of children sought medical assistance at the hospital ED for some injury each year. Injury patterns vary with age and sex.	Similar to fractures, the developmental and behavioural changes seen in children's growth are reflected in the injury panorama.
III	How is fracture incidence affected by place of residence?	Poisson regression analysis was performed to investigate the importance of place of residence on fracture incidence while controlling for sex and age.	Fractures were less common in older children, living in rural communities.	Differences in fracture incidence between Umeå and its surrounding municipalities may reflect differences in adolescent lifestyle and activities.
IV	How is fracture incidence affected by socioeconomic and demographic variables?	Poisson regression analysis was conducted to determine the importance of socioeconomic factors on fracture incidence while controlling for sex, age and place.	The incidence of fractures was correlated to parents' income and having siblings.	Fracture risk may be influenced by the family´s financial means; likewise, the number of children in a family is linked to the risk of fractures.

Introduction

The burden of injuries

Fractures and other injuries are common in childhood and adolescence. Indeed, so common that injuries might be regarded as a normal characteristic of any childhood. The Swedish National Board of Health and Welfare have estimated that 9% of all children in Sweden seek medical attention because of an injury each year (1), and also that between 2010 and 2013, the incidence of injuries requiring hospitalisation was 95/10^4 person-years (PYs). The Center for Disease Control and Prevention in the USA estimated the average rate of non-fatal injuries resulting in emergency department (ED) visits among those 0-19 years between 2001 and 2010 at 117.4/1000 PYs (2). The actual number of injuries is likely to be even greater given that many injuries do not come to the attention of emergency services and hospitals. According to WHO's Global Burden of Disease data, road traffic injuries and falls in 2002 were among the top 15 causes of disability-adjusted life years (3). An estimated 700 000 children under the age of 15 years are killed by an injury worldwide. In Sweden, injuries are still the leading cause of death in the age group 1-17 years of age (YOA)(1).

Society has an enormous interest in decreasing the number of injuries causing significant morbidity. Fatal injuries among children were largely reduced in Sweden during the past century through incentives to improve traffic- and home-safety, by creating safe areas for children to play in, and avoiding exposure to dangerous substances, electricity, open water and other hazards. Much of this work was initiated through the "Joint Committee for Prevention of Childhood Accidents" and later the Child Environment Council (4). In 1970, 421 children lost their lives in Sweden due to "accidents", in 2016, the number of children was 49 (1). In 2004, the rate of deaths due to accidents among children <4 years, in northern Sweden was 5.1/10^5 PYs (5). Although the number of deaths has fallen dramatically, the remaining injuries cause a significant burden on society in terms of health care expenditures and their impact on individuals and families. Fractures, concussions, and poisonings may lead to hospital admission, days away from school, absence from activities, and loss of workdays.

Epidemiological research

There have been few recent epidemiological studies describing the pattern of all injuries in children and adolescents. Reasons for this are the difficulties in defining injuries and collecting representative data on injuries within designated catchment areas. Most studies focus on a subset of injuries such as those requiring medical attention or specific injury types such as fractures. Through a sample survey, Danseco et al. estimated that the rate of temporarily disabling and medically attended injuries among US children was 25% per year (6). According to Simon and colleagues, in 1998, the rate of injury-related visits to EDs in the USA was 15.4% among children and adolescents 0-18 years old (7). Agran et al. found the rate of injuries causing hospitalization or death to be $38/10^4$ PYs among those aged 0-19 years in California (8).

Several epidemiological studies on fractures appear in the literature. One of the most cited is Lennart Landin's 1983 thesis on fractures in Malmö Sweden(9). Since then, several follow-up studies have reported the incidence of fractures over time in Malmö and many other populations worldwide. While the incidence of fractures has varied with place and time, there are many similarities between studies regarding the age- and sex-related pattern of fractures. In practically all populations the most common fracture site is the distal forearm, and the most common mechanism of injury is a fall. In the majority of studies reporting age- and sex-specific rates the peak incidence of fractures coincides with the pubertal growth spurt for boys and girls. It is also common for the activity at injury to vary with age. Table 1 summarizes the main findings of a large number of epidemiological studies on fractures, including recent papers (10-21).

Table 1. Summary of epidemiological studies on fractures in children.

First Author	Age group	Study period	Incidence per 10 000	Most common fracture site	Most common mechanism of injury
Landin	0-16	1950-1979	212	Distal forearm 23%	Falls
Cooper	0-17	1988-1998	133	Forearm 30%	N.A.
Kopjar	0-12	1992-1995	128	Distal radius 27%	Falls 71%
Tiderius	0-16	1993-1994	193	Distal forearm 26%	Falls on ground level 40%
Lyons*	0-14	1996-1996	156-178	Forearm 20%	Falls
Lyons†	0-14	1996-1996	361	Forearm 36%	Falls
Brudvik	0-15	1998-1998	245	Distal forearm 27%	N.A.
Rennie	0-15	2000-2000	202	Distal forearm 33%	Falls <1m 37%
Mäyränpää	0-15	2005	163	Distal radius 30%	Falls
Randsborg	3-16	2010-2011	180	Distal radius 31%	N.A.
Lempesis	0-16	2005-2006	183	Distal forearm	Falls <0.5 m
Larsen	0-15	1980-2018	255	Distal forearm 29%	
Bergman	0-15	2014-2016	179	Distal forearm 31%	Falls <0.5 m
Our results	0-19	1993-2007	201	Distal forearm 26%	Falls <0.5 m 24%

**Lyons' results from Scandinavian districts. †Lyons' results from Welsh district*

Importance of place

Incidence rates have been shown to differ between and within countries. A majority of European and North American studies estimate the incidence of fractures among children to be between 150 and 250/10^4 PYs (10, 13, 15-19, 21). The highest reported incidence of fractures known to us is from a Welsh population of individuals 0-14 years (14). This study compared the fracture rate between children in Wales and a number of Scandinavian districts and found the fracture rate to be twice as high in the Welsh population. The fracture rate was also markedly higher than what has been reported from other parts of the United Kingdom (11, 16). The authors could not identify the reason for this disparity, but suggested it might have been due to differences in registration, climate, or activities among the children, or a combination of these factors (14).

Other studies have compared the incidence of injuries in rural and urban areas. The definition of what counts as a rural or urban area differs between studies because it is often relative within the catchment areas. As might be expected, results have been mixed. In 2007, Jiang reported lower rates of medically attended injuries and fractures in large compared to small metropolitan areas (22), and Rose in 2008 reported lower rates of self-reported sports injuries among adolescents in rural compared to large urban centers (23). Xinjun, in 2008, reported higher rates of injuries admitted to hospitals in cities compared to small towns (24).

Socioeconomic impact

The possible association between socioeconomic factors and injuries has been investigated in several studies. Very few studies, however, have measured socioeconomic variables at the individual or family level. Instead, most are ecological studies in which geographical units (such as parishes or electoral wards) are described and compared with respect to socioeconomic variables and injury rates. A few studies have been designed to analyze the importance of socioeconomics on the individual- and area-level simultaneously in multilevel designs.

Many studies have reported an association between socioeconomic deprivation and injuries. Higher rates of injuries resulting in visits to EDs have been reported in areas with lower socioeconomic status defined by the Townsend index (25, 26) and the percentage of people living below the poverty line (27). The Townsend index is a measure of material deprivation made up of several measures including: unemployment, house ownership, car ownership, and household overcrowding. Originally described by sociologist Peter Townsend in 1998 (28), the index has been used in several studies from the UK investigating socioeconomic impact on health. Other studies have used variations of compound socioeconomic scores. Overpeck reported a greater number of medically attended injuries among children in single-parent households (29). In the case of fractures, Stark (30) and Menon (31) described higher fracture rates in children from deprived compared to affluent neighbourhoods.

Other studies have shown no significant association between socioeconomic variables and fractures (32, 33). There are also studies that indicate a reverse relationship for subsets of injuries. For example, while Ramaesh and colleagues reported that children from deprived families were more likely to sustain fractures in traffic accidents, children from affluent families were more likely to sustain fractures in connection with sporting activities (34).

Injury prevention

Injuries are not random events. Rather, they are explained as an interaction of variables that influence the occurrence, and consequences of the event. These variables may be intrinsic to the individual or the environment. If specific variables are identified to be associated with injuries, this may be the first step towards injury preventive measures. Preventive measures are often discussed within the three "Es" of injury prevention: education, engineering, and enforcement (of policy) (3). Some preventive measures shown to reduce observed injuries, or variables predisposing injuries consist of: structured warm up, training, and fitness education to decrease injuries in young athletes (35-37), thermostats on household taps to reduce scalds (38), home-safety educational programs to increase the use of stair gates and restrict children from hazardous areas (39), and education, distribution, and lawmaking to promote the use of child safety seats and reduce injuries in motor vehicle accidents (40).

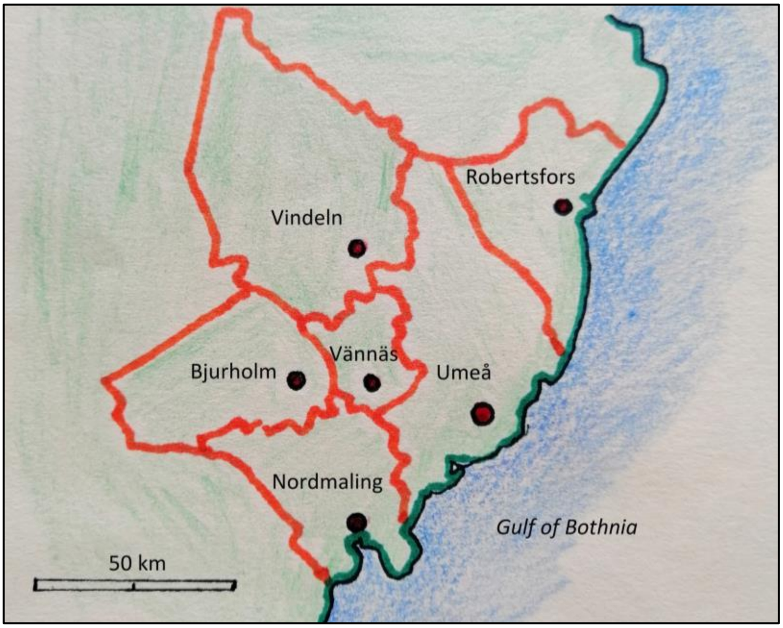
Umeå

Umeå, Sweden, situated at the Gulf of Bothnia (64°N Reykjavik Iceland, Anchorage Alaska), experiences substantial seasonal variations. Snow and ice are common between November and April. The hours of daylight in winter are limited, especially in December when the time from sunrise to sunset may be <4.5 hours. In summer, the mean temperature varies from 13-15° C and there are up to 21 hours of daylight. Umeå itself is mainly urban and offers a wide variety of sports and leisure activities.

Umeå University Hospital is the only hospital serving the population of Umeå. The nearest other hospitals are situated at a distance of 110-136 km. The catchment area, which includes five surrounding municipalities (Vännäs, Nordmaling, Robertsfors, Bjurholm, Vindeln), has a number of primary health care centers. Patients with major trauma are seen primarily at Umeå University

Hospital's ED, while patients with minor injuries often seek care at primary health care centers; they are referred to the hospital when there is a need for radiography or an orthopedic or surgical consultant. In Umeå, fractures, often come to the Orthopaedic Clinic's attention through the hospital ED and radiology department because they are diagnosed by radiography and treatment frequently requires casting and sometimes manipulation or even surgery. Health care is free of charge for all children and adolescents.

During the period 1993-2011, when the data for this thesis were collected, the average annual population aged 0-19 years in the region was 33 653.



Map of Umeå and the surrounding municipalities.

Thesis aim

This thesis aims to increase the understanding of injuries and, more specifically, fractures within a population of children and adolescents in northern Sweden. In the first two papers we sought to describe the epidemiology of injuries and fractures within a population in a well-defined catchment area over time. In the third paper we investigated possible associations between place of residency (municipality) and fractures. In the fourth paper we examined associations between socioeconomic variables and fractures.

Each paper was driven by the following research questions:

I. What is the incidence and pattern of fractures in relation to age, sex, and time?

II. What types of injuries are seen at the ED of Umeå University Hospital? How do different injuries vary with age, sex and time?

III. Are there differences in risk of fracture depending on whether children live in a more urban or more rural setting?

IV. How do variables such as number of siblings, family income, family type or parents' education influence the risk of fractures in children?

Materials and Methods

The Umeå Injury Database

Between 1993 and 2014 patients with injuries seeking attention at Umeå University Hospital's ED were registered in the Injury Database (IDB). Data were gathered through a questionnaire given to the patient or next of kin on arrival at the ED. Further information was collected from the physician's report and ambulance reports. Data were registered in the database by staff from the hospital's accident surveillance group. Non-residents were excluded. Residents injured elsewhere were registered if they were identified at follow-up visits. The database was cross-checked with the hospital's registry of inpatients to ensure that all injuries leading to hospitalisation were included. Starting from 1998, the registry of the ED's reception desk was also cross-checked to estimate the number of cases lost due to lack of registration among non-hospitalised patients. To ensure consistency, quality, and validity of the data the surveillance group met continually to discuss relevant issues (e.g., the definitions of variables).

In most cases fractures were confirmed radiographically, except for nose and rib fractures. In a small number of cases undisplaced fractures were diagnosed only by indirect signs on radiographs (e.g., soft tissue swelling). When the injury was treated as if it were a fracture, it has been processed as a fracture in this study.

SIMSAM

SIMSAM (short for "**S**wedish **I**nitiative for research on **M**icrodata in the **S**ocial **A**nd **M**edical sciences") is aimed at promoting interdisciplinary, innovative register-based research. The data used in this study originated from the IDB at Umeå University Hospital and Statistics Sweden (SCB). In the dataset each individual had a unique personal identification number (PIN) that enabled us to link children/adolescents with siblings and parents/caretakers sharing the same household. This link enabled us to define values for socioeconomic variables on the individual and family level. Data from SCB contained information on annual employment status, disposable income, highest attained educational level, and civil status for the adults.

Paper one

Paper one was an epidemiological description of fractures among children and adolescents in the hospital's catchment area between 1993 and 2007. The study also included validation of the accuracy of coding of fractures in the database.

We extracted 10,203 injury events from the database among individuals aged 0-19 years resulting in 10,327 fractures. Almost all fractures were confirmed radiographically. Events were analysed with respect to mechanisms and activities at injury. Falls on the same plane were defined as falls on ground level or from a height of <0.5 m. Falls between planes were defined as falls from a height of >0.5 m. Downhill falls were defined as falls when moving on a downhill surface (e.g. on skis, a snowboard, or a sledge).

To validate fracture site recording, we reviewed the radiographs of randomly selected cases (10%) from 2002-2007. These years were chosen because films were digitised. For long bone fractures, we used a definition of proximal, diaphyseal, and distal in accordance with AO (Arbeitsgemeinschaft für Osteosynthesefragen) principles, where the proximal and distal segments are defined by the broadest part of the physis (41). We found that in the sample 99.5% were confirmed fractures and not other injuries, but only 81% of the sample was categorised correctly with respect to fracture site. This observation led us to review all radiographs in 2006 and 2007 (1,520 cases). Fracture site distribution is presented for these 2 years only.

Paper two

Paper two was a descriptive analysis of injuries seen at the hospital ED between 1998 and 2008. The average population at risk per year (age <20 YOA), in 1998-2008 was 33,781. For this age group and period, the database contained 41,330 injury events. For each event data included information on sex, date, injury type, mechanism of injury, activity at injury, and treatment.

Concussions were defined as trauma to the head resulting in either loss of consciousness or one or more of the following symptoms: amnesia, confusion, vertigo, or nausea. Activities at injury and mechanism at injury were defined in the same manner as in paper one.

Paper three

This study analysed the possible difference in fracture occurrence between the municipalities in the catchment area between 1998 and 2011. There were 10,292 events resulting in at least one fracture during this period. The distance from each municipal center to the ED was as follows: Umeå 2 km, Vännäs 34 km, Vindeln 58 km, Nordmaling 55 km, Robertsfors 59 km, and Bjurholm 61 km. The municipality of residence was coded in the database but was missing in 327 of the cases (3.2%). These cases were excluded from the Poisson regression analysis leaving 9,965 events. For the analysis, the municipalities of Nordmaling, Robertsfors, Bjurholm, and Vindeln were considered a unit (NRBV). Vännäs was considered by itself as the demographic profile lay somewhere between Umeå and the other municipalities. Population at risk figures were collected from SCB. The average population per year aged 0-19 years in Umeå and the five surrounding municipalities in 1998-2011 was 33,653. The age variable was divided into four categories (0-4, 5-9, 10-14, 15-19). For the subgroup analysis, we also used information on activity at injury recorded in the database.

Table 2. Description of the municipalities in catchment area.

Municipality	Population all ages	Population 0-19 years of age	Child density /km² †	Principle areas of employment (other than health care)*
Umeå	112 728	25 790	11.1	Education, Trade, Manufacturing
Vännäs	8 357	2 276	4.3	Manufacturing, Education
Nordmaling	7 276	1 831	1.5	Manufacturing, Trade
Robertsfors	6 900	1 831	1.4	Manufacturing
Vindeln	5 613	1 338	0.5	Manufacturing
Bjurholm	2 516	587	0.4	Manufacturing, Agriculture

†Population density 0-19 YOA in 1998-2011
**In all municipalities health care and social services employ 19-22% of the workforce. The table shows other principal areas of employment within each municipality*

Paper four

To investigate the possible association between socioeconomic variables on the individual and family level and fractures while controlling for age, sex, and place of residence we compiled a dataset with information on fractures and socioeconomic characteristics for the whole population at risk. The socioeconomic variables were family income, family type (single parents or cohabiting parents), parents' educational attainment, parents' occupational status, and the number of siblings. The municipality of residence of each family was known. We had data on fracture events from the IDB including sex, age, and fracture date. In the SIMSAM lab these data were combined with socioeconomic data for the entire population at risk in 1998-2010. This period was chosen because we had more knowledge about the validity and quality of the IDB data. The population at risk was defined as all children 0-17 YOA living in Umeå and its five surrounding municipalities. Through the PIN children could be linked with families and caregivers so that socioeconomic data could be assigned to each child. Socioeconomic data and the number of fractures were recorded per year. In total 55 758 individuals were part of the population at risk at some point in time. For these individuals the mean exposure time was 7 years. Age was analysed as a discrete continuous variable and in age groups according to stages in development and schooling. Income was equivalised to family size and divided into quintiles. Other variables were divided into categories. For all variables, the percentage of missing values ranged from 0.1-0.6%. Cases with missing values were excluded from the regression analysis.

Statistics

Papers one and two

We calculated all incidences as incidence density and presented these per 10 000 PY with 95% confidence intervals (CIs), if not otherwise stated. Using SCB data the population at risk used for each year and age was an approximated mid-year population. For comparisons over time, we calculated age- and sex-adjusted, or age-adjusted and sex-specific incidence. We employed Swedish national figures for 2000 as the standard population. To evaluate the significance of differences between groups and over time, we calculated incidence ratios with 95% CIs.

Paper three

We performed a Poisson regression analysis using the rate of fractures as the outcome measure. We evaluated the association of fractures with place (defined as the municipality the child lived in), while adjusting for sex and age. For the Poisson family of distributions generalised additive models (GAMs) were fitted with a log link function (42). In GAM models smoothing terms are allowed, producing flexible, nonlinear modelling of selected covariates. The smoothing terms were used for the time trend (year) and implemented by a penalised regression spline approach. As is customary for the Poisson model, the response variable is a rate rather than a count. Hence, the population size in the respective age-sex group was included as an offset. Each variable (age, sex, municipality) was tested for significant dependence in a univariate model and added to the multivariate model according to the strength of dependence. We also incorporated a model adding an interaction variable for age and sex. This variable had a negligible effect on the proportion of variability and was therefore left out of the final GAM analysis.

The Statistical software R was applied for the computations in papers three and four (43). The GAM models were fitted with gam and ANOVA.gam from the package mgcv (Mixed GAM Computation Vehicle). Incidences were presented as age and sex-adjusted incidence density rates, unless otherwise specified. Once again, we used national figures for Sweden in 2000 as the standard population. Subgroups were compared by calculating risk ratios with 95% CIs.

Paper four

The outcome (the number of fractures/year) is count data, possibly zero-inflated, and accordingly, a Poisson regression model was first fitted. In addition, to take into account the repeated measurement for individuals, a generalised linear mixed-effects model was used, incorporating a random effect for individuals and fixed effects for the demographic and socio-economic risk factors.

For each individual we used yearly records from linked administrative data from 1998-2010. A zero-inflated generalized linear mixed model for count data was fitted considering the dependence structure of the data. All analyses were performed in the statistical software R (43). For the model fit we used the glmmTMB package and the glmmTMB function. The CIs for the risk factors were obtained by the delta method using package msm and the function delta method implemented in the R package.

Ethics

Ethical approval was obtained for papers I, II and III under the heading "Injuries in children and adolescents-a population-based study" (Dnr 2009-1407-31). Regional Ethics Committee, Umeå.

Ethical approval for the use of socioeconomic data in paper IV was procured within the SIMSAM project under the heading "Childhood diseases and injuries in a social context" (Dnr: 2010-157-31). Regional Ethics Committee, Umeå.

Results

Paper one

The incidence of all fractures in the 0–19-year-old age group was 201 (95% CI 197–205)/10^4. The incidence for children 0–16 YOA was 208 (204–212)/10^4. The accumulated risk of sustaining a fracture before 17 YOA was 34%. The crude incidence of admittances due to fractures was 40 (38–42)/10^4. Sex- and age-specific incidences are depicted in Figure 1. Boys accounted for 61% of all fracture events. The overall male-to-female incidence ratio was 1.5 (95% CI 1.5–1.6).

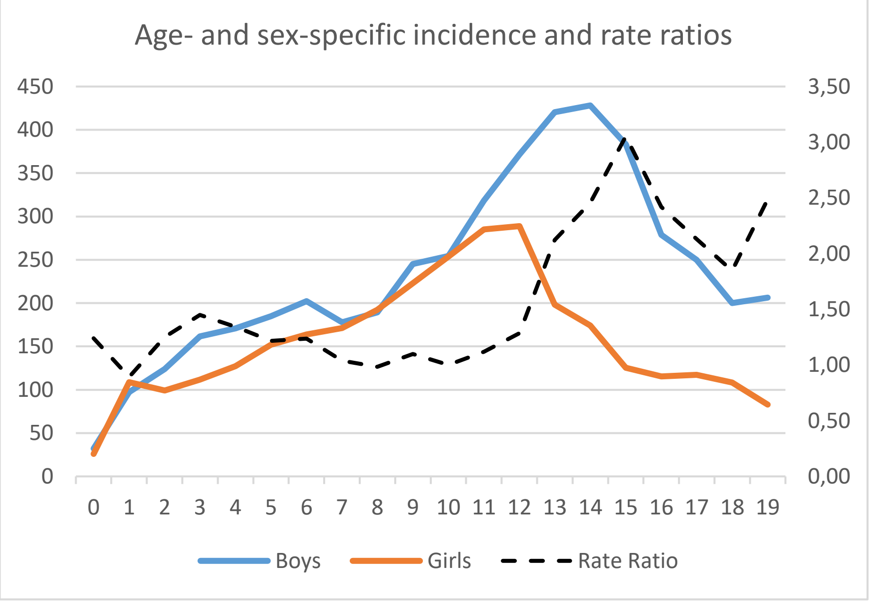


Figure 1. Age- and sex-specific incidence of fractures and rate ratio for boys and girls.

The most common fracture localisation was the distal forearm (26%), followed by the clavicle and fingers. The distribution of fracture sites and site-specific incidence rates for 2006-2007 are shown in Table 3. The most common fracture requiring hospitalisation was a fracture of the localization distal forearm (24%), followed by the tibial/fibular shaft (13%), and the forearm shaft (11%). The distribution of fracture sites according to age is given in Table 4. Preschool children sustained a greater proportion of clavicle, supracondylar, and lower extremity fractures, whereas fractures to the facial skeleton and hand/fingers were common in teenagers.

The distribution of fractures and fracture mechanism according to month is illustrated in Figure 2. The greatest number of fractures were seen in May-June and August-September, whereas the least number of fractures occurred in December. A substantial number of fractures from downhill falls occurred from January to March. Most traffic-related fractures occurred from May to September. Falls on the same plane were the most common cause of fractures (24%) and were frequent all year.

The activity at injury varied with age. Small children, toddlers, and preschool children were most often injured during play. In contrast, older kids, especially teenagers, were often injured when participating in sporting activities and traffic. The most common sporting activities associated with fractures were football, snowboarding, ice hockey, and equestrian sports. The distribution of sports-related fractures is displayed by sex in Figure 3.

Table 3. Distribution of fracture sites, crude incidence, and percentage of all fractures in 2006-2007.

Fracture site	Number of fractures	Incidence /10^5 p.y.	Proportion (%)
Distal forearm	393	591	26
Clavicle	163	245	11
Fingers	149	224	10
Ankle	108	162	7
Toes	83	125	5
Metatarsals	79	119	5
Distal humerus	78	117	5
Metacarpals	78	117	5
Facial skeleton	51	77	3
Tibial/fibular shaft	47	71	3
Proximal forearm	46	69	3
Forearm shaft	46	69	3
Proximal humerus	38	57	3
Carpals	32	48	2
Proximal tibia/fibula	18	27	1
Ribs	17	26	1
Femoral shaft	15	23	1
Thoracolumbar spine	14	21	1
Distal femur	13	20	1
Tarsals	12	18	1
Humeral shaft	10	15	1
Skull	8	12	1
Other sites	22	33	1

Table 4. Distribution of fracture site by age group: percentages within each age group.

	Age group				
	<2	2-5	6-9	10-14	15-19
Axial (skull/spine/pelvis)	4.2%	1.1%	0.7%	1.2%	4.4%
Facial skeleton	1.0%	0.7%	0.9%	1.9%	7.9%
Clavicle	24.0%	16.1%	7.1%	8.7%	9.7%
Humerus prox+shaft	3.1%	1.3%	4.7%	4.5%	1.4%
Distal humerus	7.3%	16.3%	11.2%	1.5%	1.1%
Forearm prox+shaft	11.5%	8.5%	6.5%	4.3%	4.5%
Distal forearm	13.5%	19.4%	34.1%	31.9%	17.2%
Carpal+metacarpal	0%	0.4%	2.2%	7.2%	16.6%
Fingers	2.1%	7.1%	9.1%	13.7%	9.1%
Femur	3.1%	2.0%	1.9%	2.0%	1.9%
Tibia prox+shaft	11.5%	10.9%	6.7%	2.4%	3.3%
Ankle	13.5%	4.9%	4.5%	6.6%	8.2%
Talar+metatarsal	4.2%	8.9%	5.6%	6.0%	5.5%
Toes	1.0%	2.2%	4.7%	6.6%	5.0%
Other	0%	0%	0.2%	1.4%	4.2%

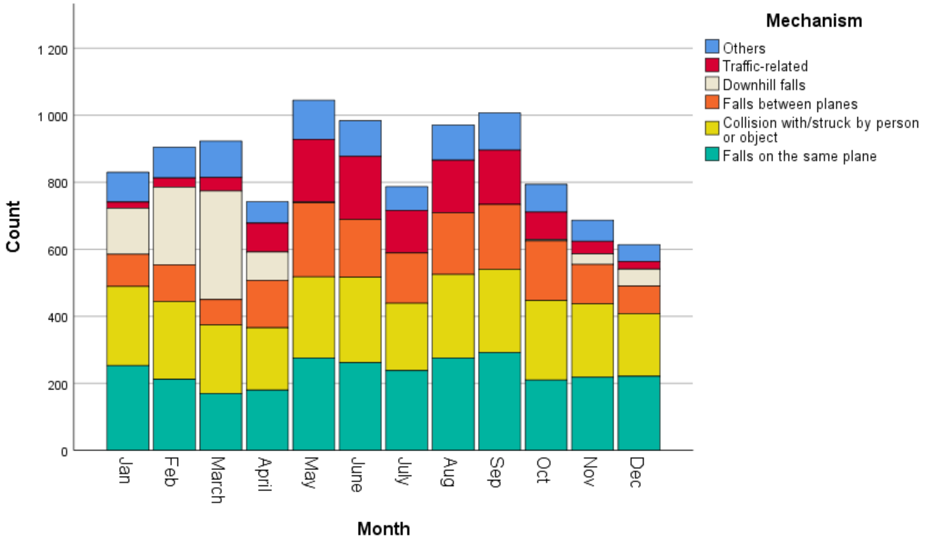


Figure 2: Seasonal distribution of fractures and fracture mechanism.

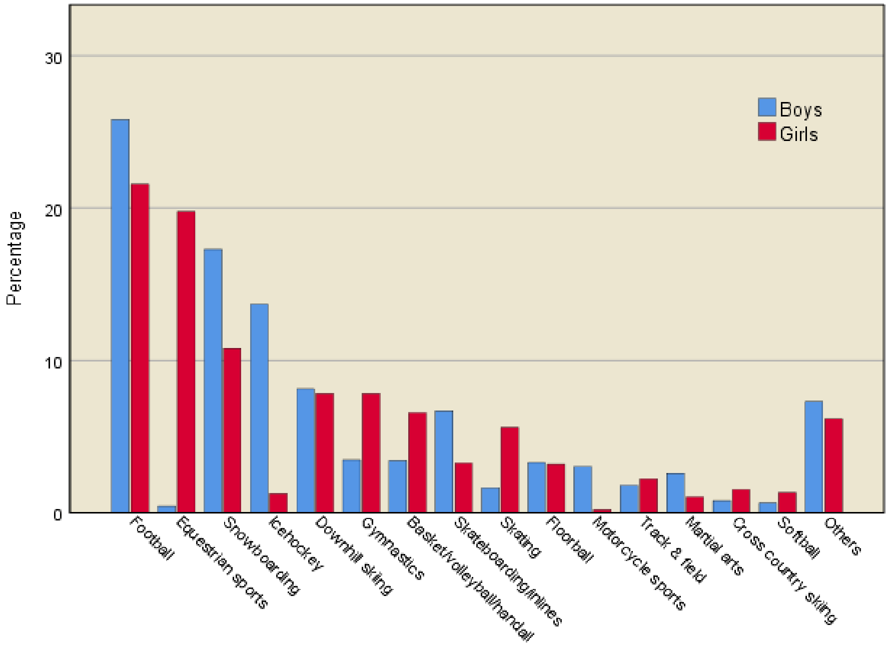


Figure 3; Distribution of sports-related fractures (percentages per sex).

Paper two

The incidence of injuries resulting in visits to the hospital ED was 110 (109-111)/1000 PYs. The most common type of injury resulting in a visit to the ED was a contusion (24%), followed by an open wound/abrasion (21%), and a fracture (19%) (Table 5). Some 60% of the injuries resulted in treatment and the patient being discharged, while 12% needed to be admitted to hospital for further treatment and observation. The incidence of injuries resulting in admission to a ward was 13.2 (12.8-13.6)/1000 PYs. The incidence of visits increased over time but not the incidence of injuries resulting in admission to a ward. The most common type of primary injury resulting in hospitalisation was a concussion (33%), followed by a fracture (29%) (Table 5).

The distribution of age-specific activity at injury was similar to that observed in fractures, i.e. smaller children were more often injured while playing, whereas older children were more often injured during sporting activities, in traffic, and in school (Figure 4).

Table 5. Distribution of primary injury complaint.

Primary Injury	Events	%*	Admitted to ward	%**
Contusion	9 955	24.1	687	15.9
Open wound / abrasion	8 526	20.6	308	6.2
Fracture	7 949	19.2	1 449	29.3
Sprain	7 032	17.0	-	
Concussion	2 196	5.3	1 614	32.6
Foreign body	1 031	2.5	-	
Dislocation	907	2.2	57	1.2
Burn	508	1.2	60	1.2
Poisoning	401	1.0	302	6.1
Other injury	1 974	4.8	469	9.5
No injury.	851	2.1	-	
Total	41 330		4 946	

** Percentage of all injuries seen at the ED ** Percentage of patients hospitalized*

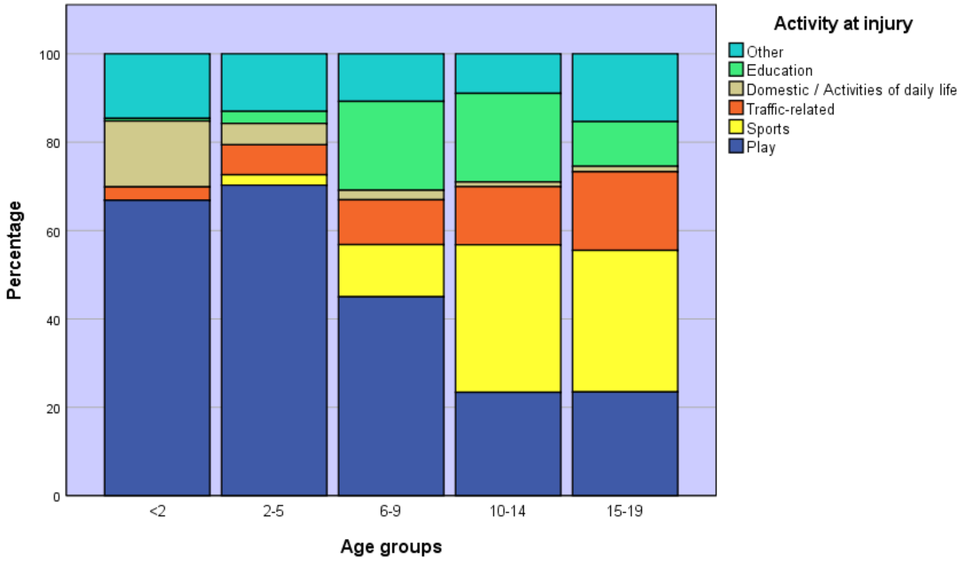


Figure 4. Distribution of activity at injury in the different age groups, displayed as percentages within each age group.

The most common sport associated with injuries was football, which accounted for 29% of all sports-related injuries. The most common injury associated with participation in football was a sprain 38%. Girls had a significantly higher proportion of sprains, ratio 1.32 (1.19-1.48), while boys had a higher proportion of fractures, 1.27 (1.11-1.48). Girls had a higher proportion of knee injuries, ratio 1.43 (1.21-1.68).

Other sports commonly associated with injuries were ice-hockey, snowboarding, floorball and equestrian sports. These sports together accounted for 61% of all sports related injuries.

The incidence of concussions was 60 (58-63)/10^4 PYs. Calculation of age-specific incidence showed a bimodal pattern with peaks in the second year of life and the early teens (Figure 5). Variations over time were observed, but no continuous trend towards an increase or decrease. The sex-specific incidence was 68 (67-70)/10^4 PYs in boys and 51 (50-53)/10^4 PYs in girls. The incidence ratio was 1.32 (1.21-1.44). The boy:girl ratio was most pronounced in 7-year-olds, where it was 2.52 (1.59-4.02).

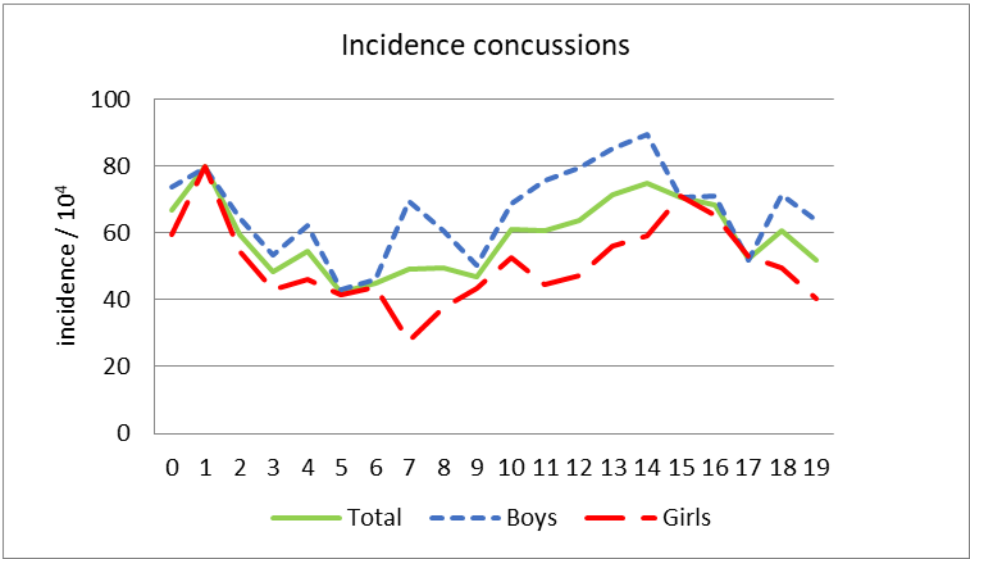


Figure 5. Sex- and age-specific incidence of concussions/10^4 PY.

The most common injury registered as a dislocation was in fact a benign subluxation of the proximal radius, known as a nurse maid's elbow (42%), followed by dislocations of the patella (16%) and shoulder (14%).

The incidence of poisonings showed a bimodal pattern over age with peaks in the 2nd (rate=22 (14-29) /10^4) and 18th (rate=40 (31-49)/10^4) year of life (Figure 6). Small children, 0-5 YOA, were mostly seen because of accidental poisoning by exposure to toxic agents (e.g., prescription drugs, cleaning products, kerosene). By contrast, teenagers were more often seen because of poisoning with alcohol, illegal substances and prescription drugs. In the teenage group intake was in most cases intentional. Some 78% of patients seen because of poisonings were hospitalised.

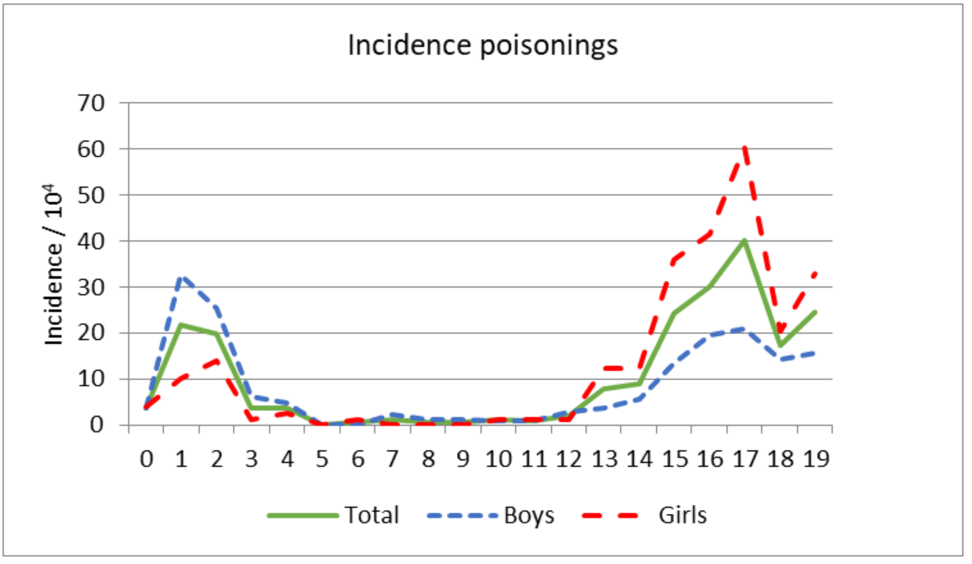


Figure 6. Sex- and age-specific incidence of poisonings/10^4 PY.

Some 1,039 visits resulted from interpersonal violence (crude rate=28 (26-30)/10^4). These cases were most common in the 15–19-year-old age group, with sex-specific crude rates of 125 (120-130)/10^4 in boys and 34 (29-39)/10^4 in girls.

The most common mode of transport in traffic-related injuries was a bicycle (50%). Moped riders accounted for 54% of the traffic-related injuries in the 15-year-olds. Injuries sustained as a driver or passenger of a car or truck accounted for 56% of the traffic-related injuries in 18-19-year-olds.

Paper three

The incidence of fractures was 223 (219-228)/10^4 PYs. The sex-specific age-adjusted incidence was 264 (258-271)/10^4 PYs for boys and 187 (181-193)/10^4 PYs for girls. The incidence per municipality was as follows: Umeå 224 (219-229)/10^4

PYs, Vännäs 223 (206-239)/10^4 PYs, and the four rural municipalities (NRBV) 182 (173-192) /10^4 PYs.

Using each variable (age, sex, municipality) in a univariate model showed a significant dependence with fracture incidence. Subsequently, each variable was added to the model according to the strength of the dependence. Results of the full model are shown in Table 6. The incidence ratio between rural municipalities and Umeå was 0.81 (0.76-0.86).

Table 6. Fitted GAM coefficients.

ANOVA	Exp(β)	95% CI for exp(β)	P-value
Intercept			<0.0001
Smooth term (Year)			<0.0001
Age 5-9 years*	1.83	1.70-1.96	<0.0001
Age 10-14 years	2.97	2.78-3.17	<0.0001
Age 15-19 years	1.68	1.57-1.80	<0.0001
Sex (boys)	1.52	1.46-1.58	<0.0001
Area (Vännäs)†	1.01	0.93-1.09	0.76
Area (NRBV)† **	0.81	0.76-0.86	<0.0001

* With age 0-4 as the reference † With Umeå as the reference

**NRBV (Nordmaling, Robertsfors, Bjurholm, Vindeln)

(Example of parameter interpretation: Given the time trend, sex and area the estimated rate for children aged 5-9 years is 1.83 times that for the younger group aged 0-4 years) R^2: 0.81.

Further sub-group analysis was focused on Umeå and the four rural municipalities. This analysis showed a significant difference in those 10-19 YOA, most pronounced in boys 10-14 YOA, RR 0.72 (0.64-0.86), and girls 15-19 YOA, RR 0.74 (0.59-0.89). Further analysis comparing the incidence between Umeå and NRBV depending on the activity at injury revealed that the observed difference was mainly explained by a significant RR for sports-related fractures and, to a lesser extent, activity in school (other than sports). There was no significant difference in the incidence of traffic-related fractures between municipalities.

Paper four

A significant association was seen between sex, age and fracture incidence in the fitted Poisson regression model. Results from the analysis are summarised in Table 7, including estimates of the regression coefficient β, RR with 95% CI, and p-values. Boys had a RR of 1.44 (1.36-1.52) in comparison to girls. There was a significant association between family income level and fracture incidence. Those in families with the highest quintile for income had a RR of 1.40 (1.28-1.52) in comparison to the lowest quintile families. Children with siblings had a significantly higher fracture rate than those who lived in single-child households, RR 1.28 (1.18-1.38) for 2-3-child families and RR 1.35 (1.24-1.47) if there were ≥3 children. There was no significant association between fracture incidence and parents' educational attainment or single-parent households. The RR of children living in Umeå compared to children living in the most rural municipalities (NRBV) was 1.08 (1.00-1.66) p=0.051.

Table 7. Results of Poisson regression.

	Estim. β	RR	95% CI for RR	P-value
Intercept	-5.872			
Age 0-5 years	ref.			
6-11 years		1.80	1.68-1.92	<0.001
12-17 years		1.89	1.77-2.03	<0.001
Sex (boys, girls as ref.)	0.361	1.44	1.36-1.52	<0.001
Rural municipalities NRBV	ref.			
Umeå	0.0766	1.08	1.00-1.16	0.051
Income 1st quintile	ref			
2nd quintile	0.1043	1.11	1.03-1.20	0.009
3rd quintile	0.2043	1.23	1.13-1.33	<0.001
4th quintile	0.2695	1.31	1.21-1.42	<0.001
5th quintile	0.3361	1.40	1.28-1.52	<0.001
Siblings none	ref.			
Siblings (1-2)	0.248	1.28	1.19-1.38	<0.001
Siblings (≥3)	0.302	1.35	1.24-1.47	<0.001
Single parent (cohabiting as ref.)	-0.035	0.97	0.90-1.03	0.304
Both parents only primary education	ref.			
No parent with university education	0.200	1.22	0.98-1.53	0.081
One parent with university education	0.148	1.16	0.93-1.45	0.198

Rate ratios (RR) with 95% confidence interval (CI) and p-values. For categorical values, the RR is interpreted such that the given RR is relative to the reference category within that variable.

Discussion

Paper one

The incidence of fractures was similar to results reported in populations in Sweden and Scotland (10, 13, 16, 19). Differences in relation to other populations in Scandinavia and Europe (11, 12, 14, 17, 20) could be the result of actual differences. It could also reflect variations in population age composition, access to health care services, the definition of a fracture, and study design.

Our other findings were largely in line with previous reports. The peak incidence of fractures is reached around the pubertal growth spurt in both boys and girls (10, 16). This is explained by a relative fragility of the bone as it is not mineralised and strengthened at the same rate that it is growing at the physis (44). The peak incidence in our population closely coincided with the peak pubertal growth in the general Swedish population of children (45).

It might also be hypothesised that the sudden pubertal growth spurt leads to a temporary decline in balance skills and body control. We found no support for this theory in our data on other injuries. Falls resulting in injuries other than fractures did not show a similar age-specific peak. Also, in a gate lab study examining motor control relative to a sudden increase in growth Bisi and colleagues found no relative loss of stability with a sudden growth of >3 cm in 3 months (46).

The distribution of fracture sites was similar to previous studies (9, 16, 17) and could be linked to the children's activities at different ages. For example, while children of all ages can sustain tibial fractures while skiing and in traffic accidents, toddlers and preschool children more often sustain these injuries when falling from stairs, furniture, and playground equipment. Facial skeleton fractures are rare among pre-adolescent children, whereas teenagers sustain such injuries more often when participating in contact sports or fights (sometimes play fights but also as an example of interpersonal violence). Similar variations in the distribution of fracture sites as a function of age have been noted in previous studies (9, 16).

Similarly, the activity at injury reflected activities of daily life at different ages. As expected, and reported by previous authors, the most common activity at injury in children up to age 6-7 years is play; thereafter, an increasing number of injuries are sustained while participating in sporting activities and in traffic (9, 16). It is common for children in Sweden to participate in organised sports from 6 YOA when they start school. For both boys and girls, participation in organised sports often decreases in their late teens. The most common sport associated with fractures in both sexes was football, as can be expected, given this was by far the most popular sport among boys and girls in Sweden (47). A report from 2016 presented the participation in sports among children and adolescents (7-20 YOA) in Umeå from 2012-2014 (48). In 2012, the most popular sports among boys were: football (58%), floorball (43%), track and field (12%), martial arts (11%), and icehockey (11%). Among girls they were: football (54%), floorball (34%), track and field (14%), gymnastics (12%), and equestrian sports (11%). We could not determine whether any sport was linked to an increased risk of fractures given that fracture rates could not be related to hours of exposure during the study period. This issue was beyond the scope of our study but has been investigated by Randsborg and colleagues. Their study of 3–16-year-olds found that snowboarders had a fourfold higher fracture rate than football players, in relation to exposure time (18). In a meta-analysis of sports injuries among children Caine et al. reported that ice hockey and football had higher rates of injury per time unit exposure than other sports (e.g. gymnastics) (49).

In most studies, falling is the most common mechanism of injury. Falls are responsible for a large percentage of fractures in all age groups. Our category of downhill falls is unique to this study and was chosen because of the many injuries sustained during skiing, snowboarding, and related winter sports. These falls are hard to classify as traditional falls in the same plane or between planes. They could be assumed to be higher energy falls than most falls <0.5 m due to slope and velocity. Categorising the precise mechanism of injury is generally difficult. It can be a combination of mechanisms, and sometimes from the information at hand, it is difficult to pinpoint the direct cause.

While other authors have described seasonal variations in incidence (9, 13, 14), the high incidence of fractures in March is a unique feature of our data. This finding is explained by the occurrence of a "sports holiday" (Swedish: sportlov) a week at the beginning of March when children are traditionally encouraged to participate in winter sports. December, the month with the lowest fracture rates, was also the month with the lowest percentage of outdoor fractures. This finding could be related to December also being the month with the least hours of daylight. While fractures were more common in May-June and August-September, we observed a lower rate in July. This is the month when much of the workforce take summer vacations. Organized activities for children and adolescents are paused, which might result in less exposure to fracture-associated activities. Also, peers are separated as families travel to spend time away from home, which might cause children to interact less in groups.

The increase in incidence over time was thoroughly discussed in our original report. Data from later years, included in our later studies, showed that the increase over time was inconsistent. Lempesis et al. highlighted the importance of making comparisons over time using age- and sex-adjusted rates with a given standard population, and not comparing single years. They re-examined the incidence of fractures in Malmö using age-adjusted rates for the 1950s, 1970s, 1990s and 2000s. While previous analyses (9, 13), using unadjusted rates, found significant variations over time, the re-evaluation with age-adjusted rates led to the conclusion that there was only a significant change over time when comparing the 1950s to later decades (19). We agree that caution should be exercised when assessing and interpreting changes over time.

Fluctuations over time could have several explanations, most importantly the quality and completeness of the data, which likely explains most of the variation in our data prior to 1998. If age- and sex-adjusted rates are not used, variations could merely reflect a change in the age-composition of the population. The fluctuation could also be due to variations in the population, such as children's activity level (50), participation in sports (47), weight (51), and diet. The importance and direct impact of any individual factor on our population could not be estimated. Fritz et al. conducted a prospective study of how physical activity levels may influence fractures (52). The study, conducted in Southern Sweden (city of Malmö), investigated how children in different schools were affected by having either curriculum-based 60 minutes (min)/week of physical activity (PA) (control group) or an increased 40 min/school day (200 min/week) of PA (intervention group) during their primary schooling. The authors found that children in the intervention group had significantly more fractures during the initial study period but also that with time the intervention group had significantly fewer fractures than the control group. Moreover, the intervention group showed signs of increased activity levels outside school and improved bone mineral density, which the authors speculated can be beneficial in lowering fracture rates and benefit health in a long-time perspective.

Paper two

Our results showed that injuries resulting in visits to the hospital ED. were common in Umeå. The incidence of injuries was higher but similar to the estimates by the National Board of Health and Welfare in Sweden (1) and also similar to estimates of injuries seen at EDs in the United States (2, 7).

The most common types of injury are consistent with findings from other parts of Sweden reported by the National Board of Health and Welfare (1). When this paper was first published, there were no national estimates published for subsets of injuries causing hospitalization; however, since then, it has been reported that the most common injuries causing hospitalisation in Sweden are fractures (29.5%) followed by concussions (19.3%) (1). Nationally, the rate of concussions causing hospitalisation was lower compared to our results. This discrepancy could be explained by differences in the indications and routines for treatment and hospitalization in different parts of the country. It could also be due to regional differences in the definition of concussions, or the completeness of data (i.e. the degree to which all concussions are accurately registered in the data set). Comparisons should be made, bearing in mind that there is variation in how these injuries are defined, diagnosed, and treated in different settings.

As discussed in paper one, the mechanism and activity at injury reflect children´s cognitive and motor development stages. From infancy through childhood and adolescence, we develop domains of what is commonly referred to as executive functions (e.g. attention control, cognitive flexibility, goal setting, information processing) (53). With these developments, we become better adapted to coping with situations that can result in injury. However, with increased independence children/adolescents are exposed to new environments and risks. An example illustrating differences in the risks and skills at different ages is the rate of poisonings observed at different ages. The rate was bimodal, with peaks in the 2nd and 18th years of life. Toddlers were most often seen because of accidental poisonings as they were exposed to prescription drugs, cleaning products, or kerosene in their exploration of the immediate surroundings. In contrast, teenagers were more often seen because of poisoning with alcohol, illegal substances, and prescription drugs. In these latter cases, intake was most often intentional. The poisoning is sometimes done out of curiosity and a desire to feel intoxicated, but some intend to harm themselves as an expression of emotional ill health or mental stress. Poisoning in teenagers was one of the few subgroups in which girls were seen more commonly than boys. In an international survey ("Health Behaviour in School-aged Children") it was found that Swedish girls aged 13 and 15 years more often reported symptoms associated with stress and affective disorders than boys of the same age (54). The observed rate of intentional poisonings among teenagers points to a continued need for information in schools to raise awareness of the effects of alcohol and drugs and address mental health problems among adolescents, particularly girls.

Another example illustrating developmental stages is the distribution of traffic-related injuries. Preschool children are rarely seen as a result of these injuries. However, as children grow older and learn to e.g. ride a bike, these injuries make up a larger proportion in each age group. With increased independence and new modes of transportation, fresh opportunities arise and new challenges need to be overcome. We noted that the peak incidence of moped-related injuries coincided with the legal age (15 years) for being allowed to drive a moped. This might indicate a need for better training in preparation for moped driving. Since 2009 adolescents in Sweden are required to complete an educational program and pass a written exam in order to receive a driving certificate for mopeds. A study comparing injury- and death rates before and after the new legislation reported a 50% decrease of injuries, and a 60% decrease of moped-related deaths in those 15-17 YOA (55).

Sports-related injuries were more common in the second decade of life. As with fractures, the type of sport associated with injuries reflected the popularity of different sports in the population with football being the most common sport leading to injuries. Without exposure data, we could not evaluate whether some sports had a disproportionate rate of injuries. Similar differences between football players (boys and girls) in the distribution and type of injuries have been described previously (56). These results may indicate a need for sex-specific preventive measures, training regimes, and recommendations on rest and rehabilitation. There are numerous examples for which such incentives have shown reduced injury rates among young athletes (35-37, 57, 58).

We noted higher rates of injuries due to interpersonal violence than previously reported in Sweden (1). Even so, the true rate is likely to be even greater in that injuries resulting from violence between peers, domestic violence, and neglect are likely to be underreported because of reluctance to seek medical care or because the circumstances of the injury are not reported truthfully or accurately at presentation.

Paper three

Consistent with previous studies, the Poisson regression analysis showed a significant association between sex, age, and fractures (9, 11, 16, 59). Boys and older children were more likely to sustain fractures, which we have already discussed. It also appears that living in one of the most rural municipalities (NRBV) had a protective effect, decreasing the fracture risk. A plausible explanation could be that the distance to the hospital can cause reluctance to seek emergency care. Therefore, we repeated the analysis, excluding minor fractures such as nose, rib, finger, and toe fractures that may be more sensitive to this type of confounding. However, even with these fractures excluded the RR remained significantly lower in NRBV. We concluded that hesitancy to seek emergency care due to distance was most likely not the explanation for the observed differences in fracture incidence.

Another possible explanatory factor is the number of children living in an area or neighbourhood. This factor may influence the types of activity that occur; For example, the possibility of gathering two teams for a football match, or the number of children observed playing “king of the hill” on the nearest snow mound. Living in a rural community with only a few peers living close by is likely to influence the interactions of children and the dynamics of these.

A sub-group analysis showed that the differences between Umeå/Vännäs and NRBV were most pronounced in the 10–19-year-old, for sports-related fractures and, to a lesser extent, activities at school. This finding may suggest a difference in the type of sports practiced or the amount of sports participation. Still, without knowledge on average exposure to sports activities per municipality, we cannot confirm this hypothesis. Recent data (2018) from the Swedish Sports Confederation (Riksidrotssförbundet) indicate that children and adolescents in Umeå participate in organised sports more frequently than children in NRBV (60). Rose and colleagues reported that exposure (hours/week) was the variable most strongly linked to sports injuries (23). Contrary to our results, they also reported lower rates of sports-related injuries in urban youth (Calgary and Edmonton) than youth from smaller metropolitan and rural areas.

We found no disparities in traffic-related fractures. Traffic density would be expected to be less in rural communities. On the other hand, children living in less densely populated communities would be expected to travel further to visit friends and attend school. Previously, injuries sustained by motor vehicle occupants were reported to be more common in rural communities (61-63), whereas pedestrian injuries were more common in urban communities (62, 63).

Our findings are contrary to several previously reported injury rates among youth in rural and urban settings (6, 62, 64, 65). These studies have noted higher rates in rural populations for: self-reported medically attended injuries (6), injuries resulting in visits to an ED collected from registry data (63, 66), and fatal injuries (61-64). Gilbride and colleagues (67) reported results similar to ours. They compared rates for all medically attended injuries retrieved through an administrative registry, finding that children and adolescents aged 0-17 years in Alberta, Canada presented higher rates of injuries in urban communities than in rural communities' RR 1.06 (1.05-1.07). This study defined rural communities as those with less than 4000 points of call.

Paper four

The explanation for the higher rate of fractures in families with higher incomes may be that these children more often have access to injury-inducing activities and playing equipment (e.g. skis, trampolines, bicycles). As children become older and start to engage in organised sports, the cost of membership fees, equipment, and so on may influence the child's possibilities depending on the family's economic resources. In a study from the Swedish Research Council for Sport Science children from families with greater economic capital were more likely to participate in sports (68). Because visits to the hospital ED were free of charge, we do not believe the association between fracture rates and income is explained by lower access to health care services among low-income families.

Conflicting associations between socioeconomic measures and injuries have been reported. For example, contrary to our results, Menon and colleagues reported an association between fractures and economic deprivation (31), and Stark and colleagues found that children living in deprived areas had significantly more fractures than their peers in affluent areas (30). Lyons et al. found no correlation between fractures in general and socioeconomic variables; however, they reported higher rates of sports-related fractures in affluent areas (14). Ramaesh et al. reported that children from wealthier households were more likely to sustain fractures in connection with sports, whereas children from more deprived families suffered more fractures from road traffic accidents, falls, and blows (34). Baker et al. found no association between fractures and deprivation measures in a UK study (33). Studies that look at other types of injuries (e.g. burns, poisonings, pedestrian traffic injuries) often report a correlation between deprivation and injury rate (25-27, 33, 69, 70). The lack of consistency concerning fractures might be due to the choice of socioeconomic variables, and of course the the socioeconomic gradient that defines each study.

Why children with siblings appeared to be at higher risk of fractures could be because these children interact with their siblings differently from how they interact with other children. Also, the possible interaction time would be longer compared to most children who interact with non-siblings only. Reading reported more injuries in children aged 0-4 years in families with many children (26). Besides this study, we are not aware of other research investigating the relationship with multiple children and fractures.

We found no association between parental educational level and fractures, nor did we find a reliable association between single-parent households and fracture incidence. As in our previous study, we found a higher rate of fractures in Umeå than in the four most rural municipalities (NRBV), but the association was weaker and did not show statistical significance. This is explained by the inclusion of explanatory variables at the individual and family level that could have acted as confounders in the previous analysis. This finding does not rule out the importance of place and environment. Analysing variables at the area level or using a different division of areas could have yielded other results. In a study by Eriksson et al., the authors investigated the association between social capital and injuries in Umeå using a multilevel approach and found that some of the variance in child injuries was explained at the neighbourhood level, even if it was less than the proportion of variance explained at the household level (71).

Limitations & Strengths

For all papers we used data from the IDB. This data set has its limitations in that it is not a complete representation of the injuries that occur within the population. As an example, the proportion of non-hospitalised injuries that were lost to registration was estimated to be 7%. Also, minor fractures may not have been properly diagnosed or may not have warranted a hospital ED visit. Therefore, the rate of fractures is likely to have been underestimated. We do not believe this to have effected the association between independent variables and fractures, nor our interpretation of the findings in papers three and four.

Some of the variables in the IDB may have been inconsistently coded, as our validation of the fracture site variable showed. This limited our use of this variable.

The analysis of the association between place of residence and fractures might have yielded other results if we had been able to analyse smaller and more homogenous geographical areas. Municipalities can be assumed to be less homogenous in terms of socioeconomic variables, environment, and demographics than e.g. neighbourhoods.

Results and interpretations may not apply to other populations. Also, as this is an observational study it doesn't allow us to draw conclusions on the causal mechanisms between independent variables and the outcome. In retrospect, it would have been prudent to have used the activity at injury variable in the dataset for paper four. This variable could have added to the understanding of which fractures were influenced by socioeconomic status, and how the effect of independent variables was mediated on the outcome.

A strength of this study is that it is population based, within a well-defined catchment area. The IDB was collected over a long period of time which allowed the injury surveillance group to reach consensus on coding for many variables and develop a way of working to optimize the quality and completeness of data. Socioeconomic variables for paper four were collected at the individual family level, using registry data based on tax records. In many previous studies data were inferred to the individual level from area-level data such as postcodes or parishes. Fractures were well defined, and in most cases radiologically confirmed.

Conclusions

In a population-based study we estimated rates of injuries such as concussions and fractures leading to visits to a university hospital ED. Injuries were common, affecting >1/10 children per year, and the estimated risk of sustaining one or more fractures before 17 YOA was 34%. The pattern of fractures and other injuries reflected the developmental stages of children and adolescents, their growth and activities, but also seasonal variations such as weather and hours of daylight. When studying the incidence of fractures between different municipalities, we found that children living in more rural municipalities had a lower risk of fractures. However, this observed difference and the importance of place were no longer statistically significant after adding additional individual and family variables to the model. Instead, we found an increased risk of fractures in families with higher income and among children with siblings. We were unable to draw conclusions on causal explanations but reasoned that the difference in injury rates could be due to differences in exposure to risk-related products and activities, as well as differences in interactions between children. Our results emphasise that the causes of fractures and other injuries are complex, where a combination of individual, social, and environmental factors is involved. Many variables interact to cause events that are by no means random. Continued research to gain a deeper understanding of these interactions is the next step towards preventive measures.

Future perspectives To enhance our understanding of fractures and other injuries I believe future studies should include timely and relevant information on the injury and injury event. Explanatory variables such as age, sex, family characteristics and socioeconomic factors on the individual level, need to be included. At the same time, we need to understand and consider the importance of environment and place. An additional dimension is behaviour and personality traits, which we have not touched on in this thesis. The choice of variables is determined by the research questions and will ultimately be limited by the skills and expertise of the researchers involved and the resources available. The formation of multidisciplinary research teams will likely contribute to the quality of future research.

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