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Time Trends in Bone Mass and Fracture Incidence in Children

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Time Trends in Bone Mass and Fracture Incidence in Children

Erika Bergman

DOCTORAL DISSERTATION

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Abstract

Background: It is currently estimated that one third of all children will sustain fractures. However, there may also be time trends in pediatric fracture incidence. When predicting future fracture incidence, it is further important to evaluate bone mass, as low bone mass is a strong predictor of fractures. Such evaluation would help the society to allocate health care resources adequately.

Aims: The aims of this thesis were to in children (i) update fracture epidemiology/etiology, (ii) identify possible time trends in fracture incidence, and (iii) identify possible differences in bone mass over time.

Methods: In the epidemiological studies we included all types of fractures (*Paper I*), and the two most common type of fractures, distal forearm fractures (*Paper II*), and hand fractures (*Paper III*), that Malmö children aged 0–15 years had sustained in 2014–2016. Fractures were identified through the Skåne University Hospital (SUS) diagnosis registry, the radiological archive and medical charts. We compared these data with published data from 14 evaluated years during the period 1950–2006. Time trends were evaluated using joinpoint regression analysis and differences between two specific periods with incident rate ratios (IRRs) with 95% confidence intervals (95% CIs).

We also measured distal forearm bone mineral density (BMD; g/cm^2) by single photon absorptiometry (SPA) in 442 children aged 7–15 during the years 2017–2018 and compared these data with BMD in 116 children aged 7–15 measured in 1979–1981 (*Paper IV*). We present BMD versus age in the two cohorts as scatter plots with fitted linear regression slopes with 95% CI. Predicted BMD at age 16 was estimated with help of the slopes, with the difference between the two cohorts presented as proportional difference (%) and difference in standard deviation (SD).

Results: The pediatric fracture incidence in 2014–2016 was $1{,}786/10^5$ person-years, for distal forearm fractures $546/10^5$ person-years, and for hand fractures $339/10^5$ person-years. The pediatric age-adjusted fracture incidence increased from 1950 to 1979 and was thereafter stable, the age-adjusted distal forearm fracture incidence increased from 1950 to 2016, while the age-adjusted hand fracture incidence increased from 1950 to 1979 and decreased after that. The only difference in age-adjusted incidences, when comparing the period 2014–2016 with the most recent evaluated period 2005–2006, was a higher incidence in girls for all types of fractures in 2014–2016. Sports and playing injuries were common fracture-related activities.

Children measured in 2017–2018 had an inferior BMD versus age slope than children measured in 1979–1981 (–5.6 mg/cm^2/year, 95% CI: –9.6 to –1.5). The predicted BMD in 16-year-old boys in 2017–2018 was about 10% (–0.9 SD) lower than the predicted BMD value in 16-year-old boys 1979–1981. The corresponding value for 16-year-old girls in 2017–2018 was about 11% lower (–1.1 SD) than the predicted BMD value in 16-year-old girls 1979–1981.

Conclusions: Pediatric age-adjusted fracture incidences have been stable in recent decades, while some fractures, such as distal forearm fractures, have increased, and others, such as hand fractures, have decreased. Children seem nowadays to develop lower BMD than four decades ago, changes that may indicate the risk of a future increase in the prevalence of osteoporosis and incidence of fractures.

Key words: fractures, epidemiology, etiology, distal forearm, hand, bone mineral density, BMD, time trends, children, boys, girls

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Cover photo “Broken branch” in Bölarp, Laholm, Sweden, by Erika Bergman

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MADE IN SWEDEN

To my friends and family

“All we have to decide is what to do with the time that is given us.”
– J.R.R. Tolkien, The Fellowship of the Ring

Table of Contents

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List of papers

I. **Time trends in pediatric fractures in a Swedish city from 1950 to 2016**

Erika Bergman, Vasileios Lempesis, Jan-Åke Nilsson, Lars Jehpsson, Björn E Rosengren, Magnus K Karlsson

Acta Orthopaedica 2020;91(5):598-604

II. **Childhood Distal Forearm Fracture Incidence in Malmö, Sweden 1950 to 2016**

Erika Bergman, Vasileios Lempesis, Lars Jehpsson, Björn E. Rosengren, Magnus K. Karlsson

Journal of Wrist Surgery 2021;10:129-135

III. **Time trends in pediatric hand fracture incidence in Malmö, Sweden, 1950–2016**

Erika Bergman, Vasileios Lempesis, Lars Jehpsson, Björn E. Rosengren, Magnus K. Karlsson

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IV. **Downturn in Childhood BMD**

Björn E. Rosengren*, Erika Bergman*, Jessica Karlsson, Henrik Ahlborg, Lars Jehpsson, Magnus K. Karlsson

*contributed equally

Submitted

Abbreviations

aBMD	areal Bone Mineral Density
ALF	Avtal om Läkarutbildning och Forskning (Swedish for “Agreement on Compensation for Medical Education and Research”)
AO	Arbeitsgemeinschaft für Osteosynthesefragen (German for “Association of the Study of Internal Fixation”)
APC	Annual Percent Change
BMC	Bone Mineral Content
BMD	Bone Mineral Density
BMI	Body Mass Index
BMU	Basic Multicellular Unit
CI	Confidence Interval
CT	Computed Tomography
DPA	Dual Photon Absorptiometry
DXA	Dual-Energy X-ray Absorptiometry
FoUU	Forskning, Utveckling och Utbildning (Swedish for “Research, Development and Education”)
GH	Growth Hormone
ICD	International Statistical Classification of Diseases and Related Health Problems
IGF-1	Insulin-like Growth Factor 1
IRR	Incident Rate Ratio
MRI	Magnetic Resonance Imaging
NCECI	NOMESCO (Nordic Medico-Statistical Committee) Classification of External Causes of Injuries
PBM	Peak Bone Mass

pQCT	peripheral Quantitative Computed Tomography
QUS	Quantitative Ultrasound
SD	Standard Deviation
SPA	Single Photon Absorptiometry
SPSS	Statistical Package for the Social Sciences
SUS	Skånes universitetssjukhus (Swedish for “Skåne University Hospital”)
SXA	Single-Energy X-ray Absorptiometry
vBMD	volumetric Bone Mineral Density
WBIC	Weighted Bayesian Information Criterion
WHO	World Health Organization

Introduction

Bone

The human skeleton has several important functions; it keeps the body upright, protects vital organs, is an attachment for muscles and tendons, and is a reservoir for minerals such as calcium. The bone marrow, found in the center of several bones, is the site for hematopoiesis and for mesenchymal stem cells.

Bone tissue

Bone tissue is a specialized type of connective tissue that contains cells and matrix. The matrix is made of organic components (mainly type I collagen), inorganic components (primarily hydroxyapatite, which is a naturally occurring calcium phosphate), also called bone mineral, and water[1,2]. The types of cells in the bone tissue are osteoblasts, osteocytes, and osteoclasts. Osteoclasts are derived from hematopoietic stem cells and are responsible for bone resorption[2]. Osteoblasts are derived from mesenchymal stem cells and they produce new organic matrix and regulate matrix mineralization[3]. The osteoblasts are called osteocytes when the osteoblasts are embedded in calcified matrix. The osteocytes are the most common of the bone cells, situated within small spaces called lacunae and connected to each other through small tunnels named canaliculi. The osteocytes support bone structure and metabolism. They also act as "sensors" and respond to mechanical stimuli[3,4].

Bone tissue can be divided into two groups, cortical and trabecular bone (Figure 1). Cortical (also called compact) bone is found in the outer layer of bones, is dense and comprise 80% of bone mass. In the cortical bone there are cylindrical structures called osteons, consistent with rings of layers (lamellae) with a canal in the center – Haversian canal – that contains vessels and nerves. Another canal, called Volkmann's canal, runs transverse in relation to the osteonal axis. This canal provides a radial path for blood supply in the bones. A membrane called periosteum covers the external surface of the compact bones. This membrane contains nerve fibers, blood vessels, and stem cells[3,5]. The trabecular (spongy or cancellous) bone, which stands for 20% of the total skeletal mass, is often found at the ends of the long bones, vertebra bodies, and pelvis. Trabecular bone comprises interconnecting rods and plates of bones (trabeculae)[3].

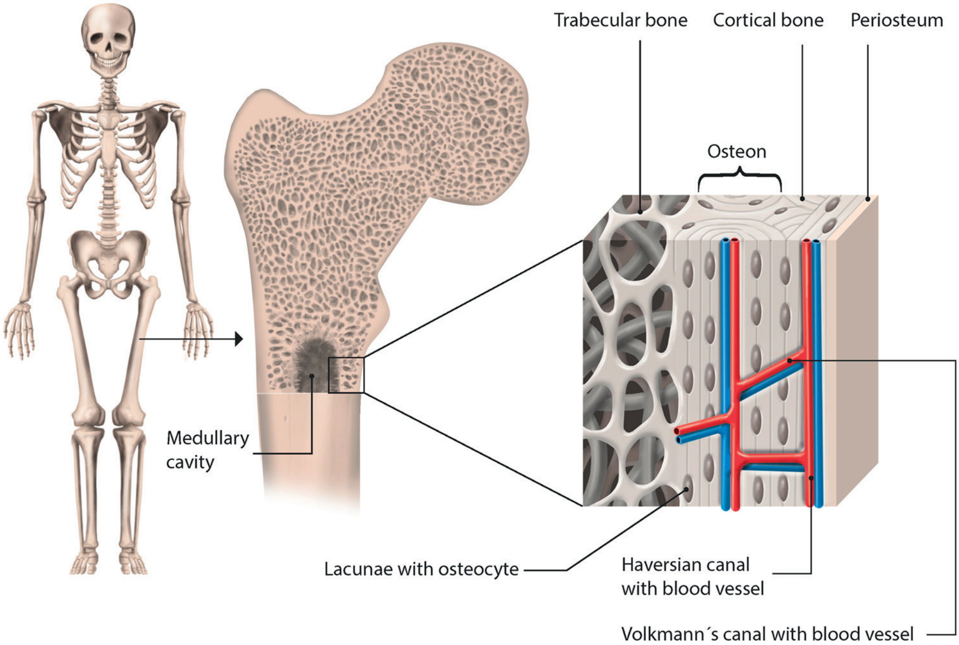

Figure 1.
Bone structure in long bones. With permission from the illustrator Pontus Andersson.

There exist different types of bones in the human body, such as long bones (i.e. humerus), short bones (i.e. talus), flat bones (i.e. sternum) and irregular bones (i.e. vertebra). The long bones are divided into the diaphysis (the shaft) with both ends of the diaphysis regions referred to as the metaphysis. During growth there is at the ends of the long bones a cartilage plate (the growth plate), with the region closest to the joint called the epiphysis. At the end of the growth period the growth plate is replaced by bone, and the term "epiphysis", should then not be used.

Growth, modeling, and remodeling in bones

Longitudinal/axial growth occurs in the epiphyseal growth plate, a structure of cartilage between the epiphysis and the metaphysis. Growth hormone (GH) and insulin-like growth factor 1 (IGF-1) are important hormonal contributors to bone acquisition during childhood, through osteoblast differentiation and proliferation. At puberty the sex hormone levels increase, which affects the bone formation positively, directly and indirectly, through rising the levels of GH and IGF-1[6-8]. GH and IGF-1 regulate growth at the growth plate[9]. The axial growth via the epiphyseal plate accelerates in puberty, leading to a period of relative skeletal weakness in the metaphysis due to a dissociation between bone expansion and bone mineralization[8,10]. The epiphyseal plates close in late puberty and the growth stops[11]. The diameter of the bones increases by appositional growth with the help of osteoblasts in the periosteum[3]. The process when the bone is changing size and shape is called bone modeling. In contrast, during bone remodeling, the bone is rebuilt without changes in shape or size. Remodeling is a process when old bone is replaced by new bone, reconstructing the material composition and microarchitecture[12]. The bone remodeling occurs due to the combined action of osteoblasts, osteoclasts, and osteocytes in what is called the basic multicellular unit (BMU). The remodeling cycle starts with a phase where osteoclasts are recruited and activated, leading to a period of bone resorption. Thereafter, the osteoclasts undergo apoptosis (programmed cell death), whilst osteoblasts are recruited. The final phase is the longest, comprising bone formation and mineralization. The remodeling cycle, with a shorter time in cortical than trabecular bone, takes around 200 days in trabecular bone (with the majority of the time, around 150 days, being bone formation, and around 30–40 days being bone resorption period)[13,14].

Bone mass and peak bone mass

Bone mass is a non-specific term used in general discussions when referring to the amount of mineral in the skeleton. This unit is often measured in Bone Mineral Content (BMC) or Bone Mineral Density (BMD). BMC is the amount of measured mineral (g) in the path of the beam and is a one-dimensional estimate. BMD is bone mineral related to bone size, usually and in the clinical situation related to the scanned area (cm^2) (two-dimensional estimation of bone size) or in research often related to the bone volume (cm^3) (three-dimensional estimation of bone size). To calculate BMD, bone mineral content is divided by the scanned area, resulting in an estimate that is referred to areal Bone Mineral Density (aBMD; g/cm^2). It is then important to realize that since aBMD does not take the depth of the bone into consideration, this is not a true density. Another way to calculate BMD is bone mineral content divided by the scanned volume, resulting in a volumetric Bone Mineral Density (vBMD; g/cm^3), which thus also takes bone depth into consideration.

aBMD is the gold standard for bone mass measurements when predicting fracture risk and when diagnosing osteoporosis. The reason for this is that the older types of bone densitometries (for example Single Photon Absorptiometry; SPA and Dual-Energy X-ray Absorptiometry; DXA) cannot calculate vBMD. Another reason is that the World Health Organization's (WHO) definition of osteoporosis (see *Osteoporosis*) is based on aBMD measured by DXA and that this method nowadays is most validated for fracture prediction and when following bone mass after treatment. In the following thesis BMD and aBMD are used synonymously.

Bone mass increases during childhood and adolescents with as much as 25% of the adult bone mass gained during two years in puberty[15]. The maximum level of bone mass, the peak bone mass (PBM), is highest around the third decade of life. The age at which the PBM is reached is dependent on skeletal location and sex (with men having higher values than women)[15-17]. For example, the lumbar spine PBM occurs at around 30–40 years of age and the hip BMD at around 15–20 years of age in women[17], with men also having later PBM in the lumbar spine than in the hip[18,19]. Genetics is the most important determinant of bone mass, with around 60–80% of the variance in bone mass being determined by heredity. However, lifestyle is also important[20], with physical activity being one of the most significant lifestyle determinants of bone mass[21].

After PBM, bone mass is gradually lost with aging[22], and because low bone mass is one of the strongest risk factors for fractures[23,24], the fracture incidence increases. The PBM is also an important factor in the development of osteoporosis[16,25], as a 10% increase in PBM is expected to delay osteoporosis development by 13 years[25]. Thus, the higher the PBM, the lower the risk of future fractures. Furthermore, around 50% of the variance in the bone mass in old ages is estimated to be predicted by PBM[26].

Bone mass and physical activity

A high level of physical activity in all ages is linked to high bone mass[27-30] and generally low fracture risk[23,31]. The skeletal response to mechanical load, such as from physical activity, is particularly great in the pre- and early pubertal years[32]. Having high levels of physical activity during growth leads therefore to higher bone mass in childhood[29,30] but also high bone mass and low fracture incidence in adulthood[33-37].

Fractures and measurements

Bone strength

Bone strength refers to the maximal amount of load endured before structural failure occurs[38,39], although bone strength is used more as a general term without a specified definition. Bone strength is multifaceted and dependent on different factors that include BMD and bone quality (bone micro- and macroarchitecture, and material properties of the bones such as collagen and mineral)[40].

Bone measurement

Bone measurement

As previously stated, bone is composed of hydroxyapatite, which includes calcium. Calcium absorbs more radiation than the soft tissue, thus radiation can be utilized to estimate the amount of bone mineral.

Bone mineralization can be measured with two different methods: ionizing and non-ionizing radiation (Table 1). There are two types of ionizing radiation methods: gamma radiation and X-ray. Single Photon Absorptiometry (SPA) and Dual Photon Absorptiometry (DPA) use gamma radiation and Single-Energy X-ray Absorptiometry (SXA), Dual-Energy X-ray Absorptiometry (DXA), and peripheral Quantitative Computed Tomography (pQCT) use X-ray. The non-ionizing methods are Quantitative Ultrasound (QUS) and Magnetic Resonance Imaging (MRI)[41].

BMD is a reliable measurement to predict fracture risk[42-44], with a low BMD being associated with high fracture risk[45]. In the clinical situation BMD is most often measured with DXA, in the research situation often accompanied by pQCT. Distal forearm bone density evaluated by SPA (see *Single photon absorptiometry*) is an older method, but with a strong correlation with DXA measurements and with a fracture predictive ability similar to the DXAtechnique[23,24,46,47].

Table 1.
Different bone mineral measuring methods.

Ionizing radiaton		Non-ionizing radiation
Gamma radiation	**X-ray**	
Single Photon Absorptiometry (SPA)	Single-Energy X-ray Absorptiometry (SXA)	Quantative Ultrasound (QUS)
Dual Photon Absorptiometry (DPA)	Dual-Energy X-ray Absorptiometry (DXA)	Magnetic Resonance Imaging (MRI)
	peripheral Quantitative Computed Tomography (pQCT)	

Osteoporosis

Osteoporosis is defined by the WHO as “a disease characterized by low bone mass and microarchitectural deterioration of bone tissue, leading to enhanced bone fragility and a consequent increase in fracture risk”[48]. Osteoporosis develops due to an imbalance between bone forming and bone resorption, with a tendency to favor bone resorption. Primary osteoporosis is caused by normal aging, menopause-associated estrogen deficiency, and lifestyle factors and secondary osteoporosis due to diseases such as stroke with paralyses and medications such as cortisone[41].

WHO defined a BMD value more than 2.5 standard deviations (SD) below the mean BMD value of young healthy adults of the same sex (original definition only young healthy women) as osteoporosis (Table 2)[48]. The number of SDs that the measured

BMD value varies from the mean BMD value in the reference cohort is called the T-score. The gold standard for diagnosing osteoporosis is DXA.

Table 2.
Definiton of osteoporosis by T-scores according to WHO[48].

Bone Mineral Density	T-score
Normal	Above –1 SD
Osteopenia	Between –1 and –2.5 SD
Osteoporos	Below –2.5 SD
Severe or established osteoporosis	Below –2.5 SD and at least one osteoporosis-related fracture

Single photon absorptiometry

Single photon absorptiometry was presented in 1963 by Cameron and Sörenson[49] and by Bo Nilsson at the Department of Orthopedics at Malmö General Hospital in 1964[50,51]. The method, estimating the amount of mineral in the bone in a non-invasive way, revolutionized bone research. The technique includes a rectilinear scan with a gamma radiation source (in Malmö Americium-241) and a detector moving simultaneously across a peripheral bone (Figure 2)[52]. In the 1970s the anatomical scan in Malmö was altered, from measuring femoral condyles to distal forearm, because it was easier to find an appropriate anatomical site in the forearm[34].

The calculation of mineral thickness in the pathway of the beam is dependent on the assumption that the soft tissue thickness in the area of measurement is constant. This is ensured by a rubber cuff filled with water, with the same density as the soft tissue, around the measured forearm. The thickness of the mineral can be estimated by calculating the relation between the absorption in the bone and the soft tissue/water.

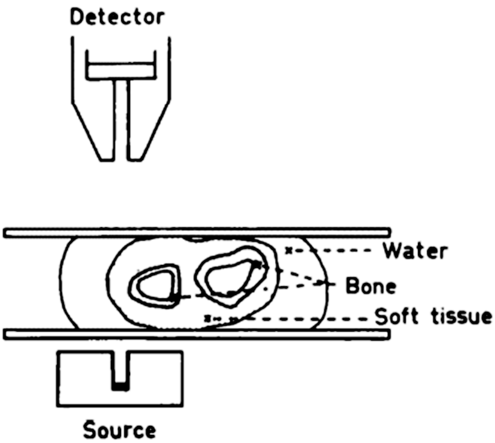

Figure 2.
Single photon absorptiometry measuring geometry[53].

Fractures in children

Bone in children differs from adult bone. In children, the periosteum is thicker, the bones have more collagen, and the bones are less mineralized and thus more elastic than the bone in adults. Due to the different bone characteristics, there is a different fracture pattern in children than in adults. The typical fractures in children are bending fractures/plastic deformation**,** torus fractures, greenstick fractures, and complete fractures (Figure 3).

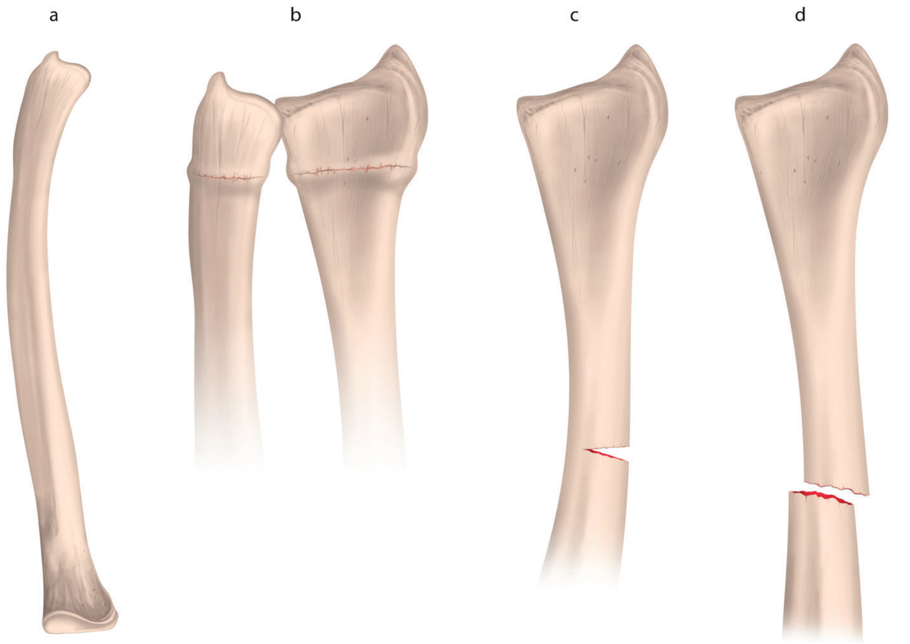

Figure 3.
Different fracture types in children: a) bending fracture/plastic deformation, b) torus fracture, c) greenstick fracture, and d) complete fracture. With permission from the illustrator Pontus Andersson.

As previously stated, the bone is weaker around the epiphyseal plate during pubertal growth, leading to a higher risk of obtaining fractures in that location. Fractures in children can occur in the epiphyseal plate, which are reported to account for 15–30% of all fractures in children[54,55] and they were defined by Salter et al. in 1963 and classified into five fracture types, Salter-Harris I–V (Figure 4)[56].

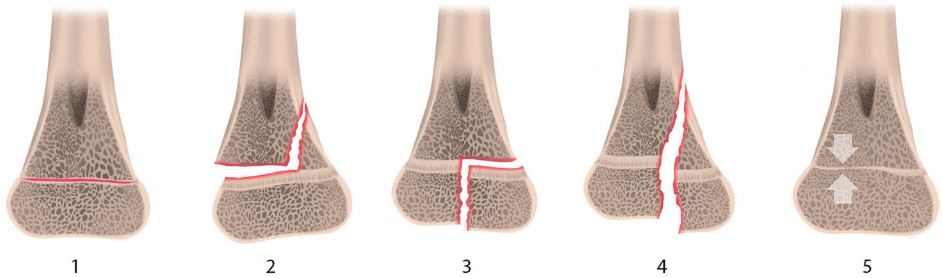

Figure 4.
Salter-Harris classification 1–5 of epifyseal fractures. Type 1: fracture through the growth plate. Type 2: fracture through the growth plate and the metaphysis. Type 3: fracture through the growth plate and the epiphysis. Type 4: fracture through the growth plate, metaphysis and epiphysis. Type 5: compression fracture of the growth plate. With permission from the illustrator Pontus Andersson.

Fractures in children can lead to inactivity and missed school days, and reduced time at work for the child's guardian. Fractures could furthermore be complicated by conditions such as mal-union, neurovascular complications, and compartment syndrome, all increasing the morbidity[57]. If a fracture requires surgery there is additionally a risk of complications through neural injuries and infections[58].

Fracture epidemiology

Epidemiology is traditionally defined as "the study of the distribution and determinants of health-related states or events in specified populations, and the application of this study to control of health problems"[59].

In 1959 epidemiological data on fractures in children and adults were presented by Buhr[60]. This was the beginning of many epidemiological studies in different geographical areas regarding fractures. In Malmö, Alffram conducted a study regarding forearm fractures in all age classes during the years 1953–1957[61], and saw that the fracture incidence in children was highest around 10–14 years and that the incidence in males and females was about the same until the age of 40, after which fracture incidence was higher in females than in males.

Pediatric fractures

Many studies report that around one third of children suffer a fracture under the age of 17[62,63], although the proportion of children sustaining a fracture differs between studies. There are also studies reporting lower proportions, as one study reported that 30% of boys sustain a fracture and 19% of girls[64].

The most common fractures in children are, according to the literature, distal forearm fractures, followed by hand fractures, and fractures of the clavicle (Figure 5)[63,65,66]. There are also more fractures in the upper than in the lower extremities[66,67] and in most reports a seasonal variation[68] with more fractures in the warm than in the cold season[63,66]. It should then be noted that this observation is opposed in some studies[65]. Most fractures in children are usually also reported in the left rather than in the right arm[66,67,69]. However, the side preponderance changes in relation to fracture location, for example with more ankle fractures occurring in the right side[68], and with no side preponderance in hand fractures[70,71] or in the lower extremities[66,67].

Figure 5.
A distal forearm fracture in the left arm in a child.

Factors affecting fracture incidence

Fracture incidence is affected by many factors such as age, sex, time periods, geographical areas, ethnicity, and socioeconomic status.

Age and sex

The risk of sustaining fractures changes with age. The incidence peaks in ages 13–14 in boys and in ages 10–12 in girls (Figure 6)[63,65,67,68]. These periods coincide with the relative bone weakness during the pubertal growth spurt in both sexes[10]. However different fractures may have different patterns in relation to age, with some, for example, having an increasing pattern throughout growth, a decreasing pattern, an irregular pattern, or a bimodal pattern[65,68].

Most studies infer that boys have a higher pediatric fracture incidence than girls[62,65,72,73] and that the peak fracture incidence is reached in younger ages in girls than in boys[63,65-67]. The fracture distribution also differs in boys and girls, with boys having a higher proportion of hand fractures than girls, and girls having a higher proportion of distal humerus fractures than boys[67,72].

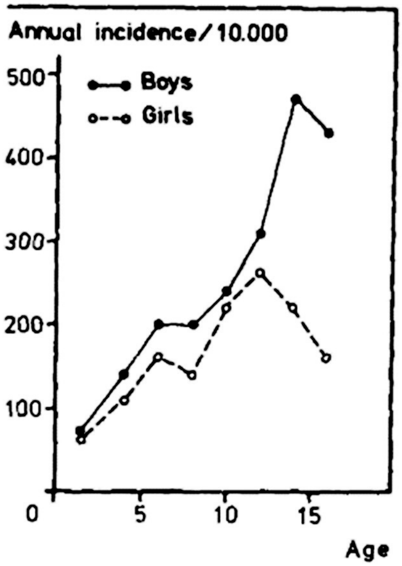

Figure 6.
Fracture incidence in boys and girls aged 0–16 in Malmö, Sweden, in 1975–1979[68].

Geography, ethnicity, and socioeconomic status

Different countries seem to have different pediatric fracture incidences[63,65,74]. The fracture incidence in children is further reported to be different in rural and in urban areas, even within the same country, with higher fracture incidences found in rural than in urban areas[62,64].

There also seems to be a variation in pediatric fracture incidence in relation to ethnicity, with higher fracture incidence found in children with white ethnicity compared to children with black, south Asian, or mixed ethnicity[64,75].

Some studies have also found that socioeconomic deprivation is associated with a higher pediatric fracture incidence[76,77], although this view is opposed by other studies[78].

Time periods

The literature reports contradictory inferences as regards time trends in pediatric fracture incidence. There are studies that have found a higher pediatric fracture incidence in 2007 than in 1998 in Sweden[63], higher in 1999–2007 than in 1979–1987 in Japan[73], and higher in 2015 than in 2005 in Australia[79]. However, one study from Finland has in contrast reported a lower incidence in 2005 than in 1983[65]. These discrepancies could be due to actual differences in time trends between geographic regions and countries and/or different years having been included in the comparisons. Furthermore, most studies compared incidences between two periods, not taking the natural variation in fracture incidences between years into account.

Fractures in children in Malmö city were first studied by Landin (1983) regarding the years 1950–1979[68], followed by Tiderius[66] with updated fracture incidence in 1993–1994 and Lempesis[67] in 2005–2006. These studies infer a higher age- and sex-adjusted pediatric fracture incidence during the years 1976–1979 than in 1950–1955, much the same incidences during the years 1976–1979 as in 1993–1994, and similar incidence during the years 1993–1994 and in 2005–2006[67].

Fracture etiology

Etiology means "the science of causes, causality; in common usage, cause"[59].

Classification systems

In 1983 Landin presented a classification system where he gathered information about trauma activity, trauma mechanism and trauma severity. This system was used when classifying fractures between 1950 and 1979[68], and the system has also been used in the following pediatric fracture studies from Malmö[66,67].

Apart from the Malmö studies, there have been a number of articles that have evaluated fracture etiology in children, but with etiology classified by different systems[63,65,70,80-85]. The International Statistical Classification of Diseases and Related Health Problems tenth revision (ICD-10) tries to make the classification of etiology more structured and comparable between studies. Another classification system is NOMESCO (Nordic Medico-Statistical Committee) Classification of External Causes of Injuries (NCECI)[86], another attempt to make the classification more organized and comparable. These attempts are of most relevance, as updated etiology data could identify fracture-prone activities, either old or new, in need of prevention, and make it possible to evaluate whether fracture-preventive strategies have been effective. In most published etiology studies in children, sport injuries are the main cause of fractures[63,67,70,81] with falling as the most common trauma mechanism[63,65,66,84,85].

Injury prevention in Sweden

As early as 1954, a committee was appointed in Sweden to deal with accidents in children, the “Barnolycksfallskommittén”[87]. Since this committee was set up there have been a series of improvements concerning children’s safety. Much attention has been focused on safety improvement in the home environment and in traffic, since many severe accidents in the early days occurred in these environments. Child Health Care (“Barnhälsovården”) now informs and educates parents about safety issues in the home. There are regulations regarding car seats adapted for children and seat belts in cars and busses which aim to reduce the number and severity of traffic injuries. Nowadays there are also bicycle helmet laws, traffic education in school, and improved city and traffic planning, by separating the cars from the pedestrians and cyclists, which contribute to a safer society[88,89].

Aims

The aims of this thesis were:

- to evaluate pediatric fracture epidemiology and fracture etiology in Malmö during 2014–2016 and by use of existing fracture data from children in the same city during different years in the period 1950–2006 to evaluate possible time trends
    - for all fractures (*Paper I*)
    - for distal forearm fractures (*Paper II*)
    - for hand fractures (*Paper III*)
- to evaluate bone mass in Malmö children measured in 2017–2018 and by use of existing data from Malmö children measured in 1979–1981 to evaluate differences in bone mass between the periods (*Paper IV*)

Patients and methods

Papers I–III

Population

Malmö is the third largest city in Sweden, situated in the south of the country, in a region called Skåne. In 2014 Malmö had a population of 318,107 inhabitants (58,585 <16 years of age), in 2015 a population of 322,574 (60,519 <16 years of age) and in 2016 a population of 328,494 (62,513 <16 of age)[90]. This population is provided with trauma care from only one hospital – the Skåne University Hospital (SUS).

The city population data were requested from Statistics Sweden ("Statistiska centralbyrån"), which is a government agency responsible for official statistics and other government statistics in Sweden. Its main task is supplying statistics for research, debate, and decision making to users and customers[91].

Data collection 1950 to 1994

For more than a century and until 2001, the radiographs, radiographical reports, referrals, and medical charts at SUS in Malmö have been kept in an archive[92]. The radiographs have been organized according to diagnosis, year of injury, and anatomical location. From the archive, together with supplementary information from record rooms at different departments, pediatric fracture data have been collected and used in studies that have evaluated pediatric fracture epidemiology/etiology for the years 1950, 1955, 1960, 1965, 1970, 1975–1979[68], and 1993–1994[66].

Data collection 2005 to 2016

In 2001 the Department of Radiology at SUS altered their system from using analog physical radiographs to digital radiographs. At the same time a new digital archive was created for the radiographs. Since 2001 this archive has included all digital radiographs taken within the public health care system of Region Skåne. The radiographs are now organized according to the 10-digit patient-specific personal identity number, date, and anatomical location. It was thus not possible to collect the fracture data with the same method as before. To be able to identify fracture cases we instead used the in- and outpatient diagnosis database at SUS. This database includes diagnostic codes according to ICD-10, which were documented during in- and outpatient visits, the personal identity number of the patient, and name and address (both previous and current). In the database the name, sex, and address of the patient were retrieved automatically from the Swedish Tax Agency ("Skatteverket").

In the studies included in this thesis we searched for visits by Malmö city residents aged 0–15 years during 2014–2016 at four departments (Emergency Department, Department of Orthopedics, Department of Hand Surgery and Department of Otorhinolaryngology) with fracture diagnosis codes S02.3–S02.4, S02.6–S02.9, S12.0–S12.2, S12.7, S22.0–S22.1, S32.0–S32.8, S42.0–S42.9, S52.0–S52.9, S62.0–S62.8, S72.0–S72.9, S82.0–S82.9, or S92.0–S92.9. We identified 7,326 visits of which 1,814 concerned distal forearm fractures and 1,632 concerned hand fractures. For each case, medical charts, referrals, and radiographic reports were reviewed by the author (EB). Radiographs were reviewed in cases of distal forearm fractures, hand fractures and in ambiguous cases. An orthopedic surgeon (VL), who collected the data in 2005–2006, was consulted when fracture diagnosis or fracture classification was uncertain.

Validation

To validate the new ascertainment method in 2005–2006, Vasileios Lempesis[67] searched the digital in- and outpatient diagnosis register at SUS for fractures in Malmö city residents <17 years during two months in 2005 (January 1 to February 28). This method identified 103 fractures. A review of all skeletal radiographs in the digital radiological archive (regardless of reason for referral or referring unit), with the same criteria as above was then done. This method, intended to simulate the fracture ascertainment method in the earlier studies, found 103 fractures. These two methods found the same 100 unique fractures and three other fractures each, resulting in a total of 106 fractures. Three fractures were thus missed by each method, corresponding to a misclassification rate of 3%.

Fracture registration

The same fracture registration protocol has been used in all pediatric fracture studies in Malmö since introduced by Lennart Landin[68]. Also, we followed this protocol when we registered information on sex, age, fracture date, fractured location, fracture side, trauma activity, trauma mechanism, and trauma severity (*Appendix 1*).

The trauma severity according to Landin[68] is classified as slight, moderate or severe as follows:

- *Slight:* falls from less than 0.5 meters (m), for instance falls from the ground, falls from chairs, and beds. Most of the sport injuries, such as ball sports, skiing, contact sports, and gymnastics (but not fall from more than 0.5 m). Skateboard and roller-skating injuries and most playing injuries were also slight injuries.
- *Moderate*: falls from 0.5–3 m, such as falls from a bunkbed, falls downstairs, falls from bicycle, falls from horseback, and falls from slides and swings. Being hit by a bicycle is also comprised in this category.
- *Severe:* falls from heights more than 3 m, such as falls from windows and roofs. Traffic injuries with motor vehicles involved and being hit by a moving heavy object were included in this category.

It should be noted, as Landin also emphasizes, that the degree of the injury was difficult to evaluate in many cases.

Apart from the classification system initiated by Landin, we also classified the fracture etiology according to NCECI[86] in 2014–2016 (*Appendix 2*).

Multiple fractures were largely classified as separate fractures and bilateral fractures as two separate fractures. However, two fractures of the same bone were classified as one fracture, and for example one fracture in the radius and one fracture in the ulna in the same arm were recorded as one fracture. Multiple fractures of the phalangeal bones and multiple fractures in the metacarpal bones and/or the carpal bones were recorded as one fracture (excluding the scaphoid bone, which were recorded separately). Calcaneus and the talus bone were classified separately, whereas other tarsal and metatarsal bones were classified together as one fracture. Fractures of the rib, nose, teeth, skull, sternum, and traumatic amputations were excluded. We choose this classification system following the former protocol in Malmö, to be able to compare our incidences with the historic incidences.

To differentiate between the diaphyseal and the distal forearm, the point at which the cortex attained a constant thickness was chosen as border between the diaphysis and the distal forearm, as in previous studies[66-68]. Regarding hand fractures, we used a second registration method where all hand fracture types were classified separately. This was done to be able to report in detail the anatomical distribution of the hand fractures, and to be able to compare our results with other studies which have classified hand fractures in this way. This same registration for hand fractures was also done in 2005–2006[93].

The historic Malmö studies[66,68] have included patients aged 0–16 years when evaluating fractures in children. When processing older material from 1950–1979[68] in the study by Lempesis et al.[67], the researchers noticed an anomaly concerning the manner in which patients age 16 were included. The inclusion criterion regarding age was based on birth years, with the result that a part of the 16-year-old children were missed. In the 2005–2006 study it was therefore decided to remove patients 16 years and above from the older collected material, and instead use the inclusion age span criteria of 0–15 years. We followed this approach, and thus included children from the day of birth until age 15 years and 364 days.

Statistics

We used Microsoft Excel 2016 and SPSS Statistics 24 and 26 for management of the database and for statistical calculations. We calculated age- and sex-adjusted incidence rates (fractures per 10^5 person-years), referred to as "incidence" in our studies, through direct standardization. The average Malmö city pediatric population (in one-year classes) during the study period was chosen as the standard population. We arranged the 17 years examined into six decades (1950/1955, 1960/1965, 1970/1975–1979, 1993–1994, 2005–2006, and 2014–2016) and calculated incident rate ratio (IRR) between two decades. In *Paper I* and *Paper II* we calculated IRR, but only adjusted for age, while we in *Paper III* calculated IRR, but adjusted for both age and sex. We therefore re-calculated the IRR age- and sex-adjusted for all children regarding *Paper I* and *Paper II*. We then found no major difference in IRR that would alter our conclusions in *Paper I* and *Paper II* (see *Appendix 3*). Time trends in the entire period 1950–2016 were calculated by joinpoint regression analysis and presented as annual percent changes (APC) (see *Joinpoint*). Uncertainty was defined as 95% confidence interval (95% CI). A p-value below 0.05 was considered to represent a statistically significant difference. Due to the large proportion of fractures with unknown etiology, a proportion that varied greatly between the study periods, we chose to present these data only as descriptive data.

Joinpoint

For time trend analysis in the epidemiology studies, the Joinpoint Regression Program was used. Joinpoint Regression Program is a statistical software package, created by National Cancer Institute, that analyses joinpoint models. The program takes trend data, for example cancer rates, and finds points where the trend changes ("joinpoints"), dividing the data into segments that each have its own linear trend. It also allows testing of whether or not a trend change is statistically significant. The joinpoint software calculated age-adjusted rates with provided information about the number of fractures (dependent variable), population, standard population, age groups (adjustment variable), year (independent variable), and sex (by variable). The default Grid Search Method was used to find the joinpoints. Linear regression with log-transformed dependent variable was used to fit the trend lines, making the parameter estimates interpretable as annual percent change (APC). Weighted Bayesian Information Criterion (WBIC) was used to select the model with the optimal number of joinpoints[94,95].

Paper IV

Population and study participants

Malmö city had a population of 235,111 (38,651 <16 years) in 1979, 233,803 (37,440 <16 years) in 1980, 231,532 (36,279 <16 years) in 1981, 333,633 (64,309 <16 years) in 2017, and 339,313 (66,114 <16 years) in 2018[91].

In 1979–1981 116 children (55 boys and 61 girls) in Malmö city, aged 7–15, all Caucasians, were included in a non-population-based manner as volunteers from Malmö[96]. There is no information available on how many children declined participation after invitation to take part in the study. In 2017–2018, 442 children (238 boys and 204 girls) were included, of which 95% were Caucasians. They were students at three government-funded primary schools (Broskolan, Gottorpskolan, and Sundsbroskolan), where the children were assigned according to their home address. All three schools were situated in the Malmö city district of Bunkeflostrand, which is considered a socioeconomic middle-class area. The attendance rate was 45%.

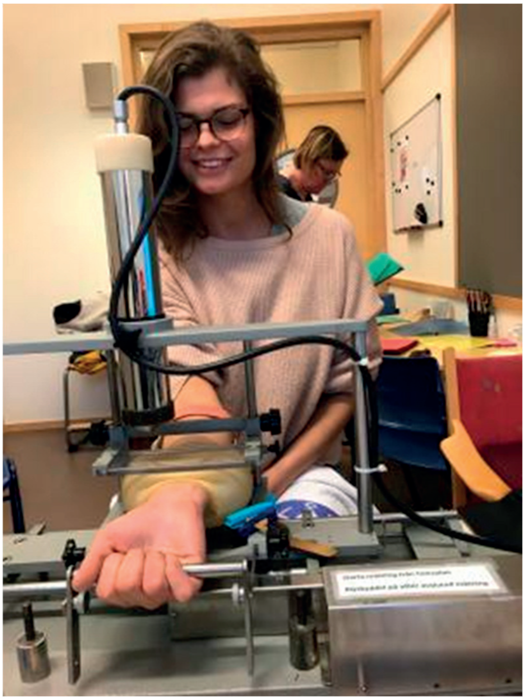

Figure 7.
The author’s distal forearm being measured by the SPA machine and collegue Åsa Almgren in the background at Sundsbroskolan.

Measurements

BMD in the forearm was measured at 6 cm proximal to ulnar styloid by an SPA apparatus, according to method described by Nauclér et al.[52]. The same densitometer was used in both study periods (Figure 7). Both arms were scanned, and the mean value of the arms was used. If a study participant had a fracture in a forearm within one year before the measurement, that arm was not measured. If the scan quality made the plotting impossible, the data from that arm were excluded. In total, 19 children had measurements based on one arm (4 children in 1979–1981 and 15 children in 2017–2018). Standard equipment was used to evaluate body weight, and body height, and from these data we calculated body mass index (BMI).

In 1979–1981 one technician and in 2017–2018 two technicians made the SPA measurements. All measurements were performed according to the standard protocol for scanning of the distal forearm bone[22]. When the measurements were done, one of the researchers (EB) performed inspections and analysis of all plots for both study periods, in random order. Before starting with the plotting, the researcher discussed with one of the co-authors (HA), who has written his thesis based on SPA measurements and who is most familiar with the method for plotting the scans[22,97,98]. HA was also consulted during the analyzing process when questions arose and when it was difficult to define the plotting.

The coefficient of variation (precision) of the SPA measurements, when determined by 311 standardized phantom measurements, was 2.7% and, when determined by three repeated measurements of 20 arms, after repositioning, was 4.8%. The long-term drift during the period of the study was 0.1% per year (95% CI: –0.2 to 0.4), calculated by a standardized phantom. The radiation source was replaced in 1980, which led to all bone mass measurements being adjusted according to the phantom measurements.

Statistics

Multiple linear regression models, with age, sex, and cohort as predictors, were utilized to examine the difference between the cohorts. The BMD versus age data are presented in scatter plots with linear slopes with 95% confidence intervals (95% CI). Due to the fact that some of the children were very close to age 16 when they were measured, the predicted sex-specific BMD difference at age 16 (estimated as the difference between two slope values at this age) was presented. The estimated BMD difference at age 16 was presented as an absolute difference, a proportional difference (%) and as a standard deviation difference. From published data[99], normative forearm BMD values in men and women 30–45 of age were retrieved and used to define one SD in SPA-measured distal forearm BMD. A p-value of <0.05 was regarded as a statistically significant difference. R version 4.0 and RStudio version 1.3 were utilized for statistical calculations.

Ethics

The studies were approved by the Regional Ethical Review Board in Lund, Sweden (reference number 2016/1080). The bone mass measurements were also approved by the Radiation Committee at the Skåne University Hospital (SUS). The studies were conducted according to the Declaration of Helsinki. The authors had no competing interests.

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Summary of papers

Paper I

Introduction: Our aim was to update the fracture epidemiology and etiology for all pediatric factures in children during the years 2014–2016, and with the help of published fracture data in our city to evaluate time trends since 1950.

Patients and methods: Diagnosis registry, the radiological archive and medical charts from the only hospital in the city (Skåne University Hospital) were used to identify fractures in Malmö city residents aged 0–15 years in 2014–2016. These results were compared to data from 1950–2006. Joinpoint regression was used to analyze time trends and the results are presented as annual percentage changes (APC) with 95% confidence interval to describe uncertainty (95% CI). Differences between different periods are presented as incident rate ratios (IRRs) with 95% CI.

Results: We found 3,244 fractures in 2014–2016, resulting in a pediatric fracture incidence of 1,786 per 10^5 person-years (boys 2,135 and girls 1,423). During 1950–1979 the age-adjusted fracture incidence increased in both boys (APC 1.5%, 95% CI: 1.2 to 1.8) and girls (APC 1.6%, 95% CI: 0.8 to 2.5). The incidence remained stable in 1979–2016 in boys (APC 0.0%, 95% CI: –0.3 to 0.3) and in girls (APC –0.2%, 95% CI: –1.1 to 0.7). In girls, the age-adjusted incidence in 2014–2016 was higher than in 2005–2006 (IRR 1.1, 95% CI: 1.03 to 1.3), but not in boys (IRR 1.0, 95% CI: 0.9 to 1.1). Sport and playing injuries were the most common cause of fractures in 2014–2016, as in all other study periods.

Conclusions: Pediatric age-adjusted fracture incidence in girls was 2014–2016 higher than in 2005–2006. With 17 measuring points (years) and joinpoint regression for analysis of the entire period 1950–2016, we found that age-adjusted fracture incidence increased in boys and girls until 1979 and after this was stable until 2016.

Paper II

Introduction: Fractures in the distal forearm are the most common fractures in children. Studies have described time trends in distal forearm fracture incidence. Our study aim was to update the epidemiology/etiology of distal forearm fractures in Malmö children in 2014–2016 and calculate time trends in 1950–2016.

Patients and methods: We utilized the hospital diagnosis registry, the radiological archive, and medical records to identify fractures in the distal forearm in children aged <16 years in 2014–2016. We included published data from 1950–2006 and used joinpoint regression to estimate annual percent changes (APC), to be able to calculate long-term trends. Differences between two periods were described as incident rate ratios (IRRs) and uncertainty was described as 95% confidence interval (95% CI).

Results: Pediatric fracture incidence in the distal forearm was $546/10^5$ person-years (660 in boys and 427 in girls) in 2014–2016. In 2014–2016 the age-adjusted incidence was similar to 2005–2006 (in boys: IRR 1.0, 95% CI: 0.9 to 1.2 and in girls: IRR 1.1, 95% CI: 0.9 to 1.3). In the entire period 1950–2016, time trend analyses disclosed an increase in the age-adjusted incidence in both sexes (boys: APC 0.9%, 95% CI: 0.7 to 1.2; girls: APC 0.6%, 95% CI: 0.3 to 0.9). The most common cause of distal forearm fractures in 2014–2016, as well as in the other five decades, were sport injuries.

Conclusions: Childhood age-adjusted distal forearm fracture incidence was similar in both sexes in 2014–2016 to that in 2005–2006. The age-adjusted fracture incidence increased in boys and girls during entire study period of 1950–2016.

Paper III

Introduction: The second most fractured location in children is the hand. Our aim was to describe the hand fracture epidemiology and etiology in 2014–2016 and make comparisons with previous studies, to be able to identify time trends.

Patients and methods: The hospital radiological archive, diagnosis registry, and medical charts were utilized to identify hand fractures during 2014–2016 in Malmö city residents aged 0–15 years. The data were compared to data from previous studies in the same city. The total 17 evaluated years were divided into six decades/periods. Both unadjusted and age- and sex-adjusted incident rate ratios (IRRs) with 95% confidence intervals (95% CIs) were calculated to show differences between two periods. Joinpoint regression was used to estimate time trends in the period 1950–2016, with the result presented as annual percent changes (APC) with 95% CI.

Results: Fractures in the phalangeal bones accounted for 71% of all hand fractures, fractures in the metacarpal bones for 24%, and fractures in the carpal bones for 5% during the years 2014–2016. There were in total 615 hand fractures (419 in boys and 196 in girls) identified during 181,617 person-years in 2014–2016, corresponding to an unadjusted fracture incidence of $339/10^5$ person-years (in boys, $452/10^5$ person-years and in girls $220/10^5$ person-years). In 2014–2016 the age-adjusted incidence in both sexes was similar to the most recently evaluated period in 2005–2006 (boys: IRR 0.9; 95% CI: 0.8 to 1.01, and girls: IRR 1.0; 95% CI: 0.8 to 1.2). During the entire period 1950–2016, the age-adjusted hand fracture incidence increased in both sexes in 1950–1979 (boys APC 3.8%; 95% CI: 3.0 to 4.5, and girls APC 3.9%; 95% CI: 2.8 to 5.0), while it decreased in both sexes in 1979–2016 (boys APC –0.7%; 95% CI: –1.4 to –0.003, and girls APC –1.3%; 95% CI: –2.4 to –0.1). Sport injuries were the most common cause of hand fractures in 2014–2016 as well as all other study periods.

Conclusions: Most fractures in the hand occur in the phalangeal bones, followed by the metacarpal bones. In 1950–1979 the age-adjusted hand fracture incidence increased whereafter it decreased in both sexes in 1979–2016. There was no difference in age-adjusted fracture incidence in either boys or girls when the period 2014–2016 was compared with the most recently evaluated period, 2005–2006.

Paper IV

Introduction: There is a concern, since physical inactivity has increased and because physical activity is a determinant of bone mass, that bone mass in children is lower today than previously. A lower bone mass in the population could then lead to more fractures. The aim of this study was to examine bone mass in children measured in 2017–2018 and compare it to the bone mass in children measured in 1979–1981.

Patients and methods: The same single photon absorptiometry (SPA) apparatus was used in both periods to measure distal forearm bone mineral density (BMD; g/cm^2). In 2017–2018, a normative cohort of 442 children (238 boys and 204 girls) aged 7–15 years were included. BMD in this cohort was compared to BMD in a normative cohort of 116 children (55 boys and 61 girls) aged 7–15 years measured in 1979–1981. To compare BMD in relation to age in the cohorts, we used a multiple linear regression with age, cohort, and sex as predictors. With the help of the slopes, we estimated the predicted level of BMD at age 16.

Results: The BMD versus age slope was flatter in children in 2017–2018 than in children in 1979–1981 (–5.6 mg/cm^2/year, 95% CI: –9.6 to –1.5). The predicted BMD at age 16 in 2017–2018 was around 10% lower (–0.9 SD) in boys and around 11% lower (–1.1 SD) in girls than in boys and girls in 1979–1981.

Conclusions: Our data suggest that children today have an inferior bone mass development compared to four decades ago. This is troublesome since if children reach a lower peak bone mass, they have probably higher risk of developing osteoporosis and sustaining fragility fractures as they get older.

Additional results in Malmö 1950–2016

The following chapter reports unpublished epidemiology and etiology data regarding the seven most common fractures from Malmö in children aged 0–15 in 2014–2016 (excluding the already published fracture types – distal forearm fractures and hand fractures). The results are compared to published data in Malmö during 1950–2006.

For each fracture type there is registered facture data, presented as text, tables and figures. The fracture locations studied are:

- Clavicle
- Proximal Humerus
- Distal Humerus
- Proximal Forearm
- Diaphyseal Forearm
- Diaphyseal Tibia
- Foot

Fractures in the clavicle

We found 258 clavicle fractures in 2014–2016 (169 in boys and 89 in girls), which comprises 8% of all fractures (9% in boys and 7% in girls), corresponding to a fracture incidence of $142/10^5$ person-years (182 in boys and 100 in girls). The age-adjusted boy-to-girl incident rate ratio (IRR) was 2.0 (95% CI: 1.5 to 2.5).

We found no statistically significant side preponderance in clavicle fractures (left-to-right IRR 1.3, 95% 0.98 to 1.6). The peak fracture incidence in the age span 0–15 years was 14–15 in boys and 2–3 in girls.

The age- and sex-adjusted incidence in all children was lower in 2014–2016 than in 1970/1975–1979. In girls the age-adjusted incidence was lower in 2014–2016 than in 1950/1955, in 1970/1975–1979, and in 1993–1994. The incidence in 2014–2016 was similar to the incidence in 2005–2006 for all children, boys and girls (Table A1).

Joinpoint regression analysis indicated that there was no statistically significant change during 1950–2016 regarding age-adjusted clavicle fracture incidence in boys (APC 0.0%, 95% CI: –0.4 to 0.4) or in girls (APC –0.5%, 95% CI: −1.2 to 0.3).

In 2014–2016 the most common trauma activity in our cohort was playing injuries (33%), followed by sport injuries (22%). Fall was the most common trauma mechanism and slight injury the most common trauma severity. During different decades the most common cause of fractures has differed, from traffic injuries to playing injuries to fractures acquired in the home environment to sporting injuries. Fall was the most common trauma mechanism and slight injury the most common trauma severity during all evaluated periods (Table A2).

Clavicle fracture incidence in boys and girls 2014–2016 in Malmö, Sweden, in relation to age (A), incidence related to age in three different time periods in boys (B) and girls (C), and age-adjusted incidence with joinpoint regression in boys and girls (D).

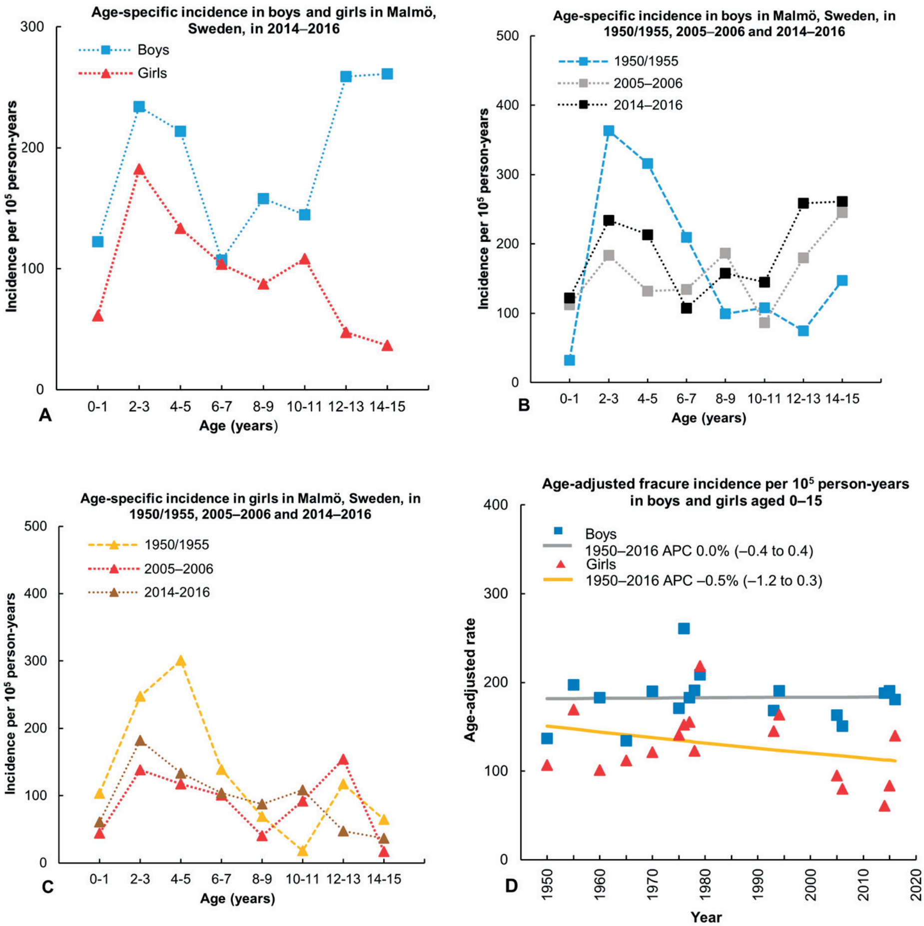

Table A1.
Unadjusted and age- and sex-adjusted clavicle fracture incidence in all children and unadjusted and age-adjusted fracture incidence in boys and girls separately in children 0–15 years in Malmö, Sweden, during the years 2014–2016 compared with 1950/1955, 1960/1965, 1970/1975–1979, 1993–1994, and 2005–2006. Incident rate ratio (IRR) with 95% confidence interval (95% CI) is used to describe the difference between two chosen time periods.

	Nominator Denominator	2014–2016 1950/1955	2014–2016 1960/1965	2014–2016 1970/1975–1979	2014–2016 1993–1994	2014–2016 2005–2006
All children	Unadjusted	0.9 (0.7 to 1.1)	1.1 (0.9 to 1.3)	0.8 (0.7 to 0.97)	0.8 (0.7 to 1.02)	1.2 (0.9 to 1.4)
	Age- and sex-adjusted	0.9 (0.8 to 1.2)	1.1 (0.9 to 1.3)	0.8 (0.7 to 0.9)	0.9 (0.7 to 1.05)	1.2 (0.9 to 1.4)
Boys	Unadjusted	1.0 (0.8 to 1.4)	1.2 (0.9 to 1.5)	0.9 (0.8 to 1.1)	1.0 (0.8 to 1.3)	1.2 (0.9 to 1.5)
	Age-adjusted	1.1 (0.8 to 1.4)	1.2 (0.9 to 1.5)	0.9 (0.8 to 1.1)	1.0 (0.8 to 1.4)	1.2 (0.9 to 1.6)
Girls	Unadjusted	0.7 (0.5 to 1.01)	1.0 (0.7 to 1.4)	0.7 (0.5 to 0.9)	0.6 (0.5 to 0.9)	1.2 (0.8 to 1.7)
	Age-adjusted	0.7 (0.5 to 0.997)	0.9 (0.6 to 1.3)	0.6 (0.5 to 0.8)	0.6 (0.4 to 0.9)	1.1 (0.7 to 1.6)

Table A2.
Clavicle fracture etiology in Malmö children 0–15 years during six periods. Etiology is described as trauma activity, trauma mechanism, and trauma severity. Data are presented as proportions (%) of known trauma etiology.

	1950/1955	1960/1965	1970/1975–1979	1993–1994	2005–2006	2014–2016
TRAUMA ACTIVITY						
Known	**36**	**51**	**58**	**54**	**65**	**76**
Unknown	**64**	**49**	**42**	**46**	**35**	**24**
Home	**25**	**32**	**25**	**25**	**3**	**13**
Day nursery	**2**	**0**	**3**	**3**	**3**	**14**
School	**4**	**0**	**4**	**3**	**4**	**10**
Work	**0**	**0**	**0**	**0**	**0**	**0**
Traffic injuries	**26**	**29**	**20**	**17**	**15**	**7**
Bicycle	19	6	14	13	8	6
Pedestrian hit by vehicle	6	16	4	1	3	1
Moped, motorcycle	0	3	1	0	4	1
Car passenger	2	1	2	0	0	0
Other	0	3	0	3	0	0
Playing injuries	**26**	**26**	**17**	**27**	**22**	**33**
Playground	4	12	3	13	9	13
In-lines, skateboard	2	0	0	1	4	5
Sledge, other “snow”	4	4	2	5	0	1
Other	17	10	12	7	8	14
Sport injuries	**17**	**12**	**20**	**20**	**43**	**22**
Ball-game	0	3	4	7	27	15
Ice-hockey, skating	4	6	5	0	4	2
Gymnastics and athletics	0	0	0	1	0	0
Horse injuries	8	1	4	7	4	1
Wrestling, boxing, etc. “Contact sport”	4	1	6	5	3	2
Skiing	2	0	0	0	5	2
Other	0	0	0	0	0	2
Fights	**0**	**1**	**1**	**4**	**11**	**0**
Other	**0**	**0**	**11**	**1**	**0**	**2**
TRAUMA MECHANISM						
Known	**82**	**90**	**96**	**96**	**100**	**97**
Unknown	**18**	**10**	**4**	**4**	**0**	**3**
Falls	**95**	**87**	**88**	**79**	**79**	**90**
On the same plane	69	52	60	49	54	49
Between planes	26	34	28	30	25	41
Mechanical force	**3**	**11**	**6**	**8**	**11**	**8**
Non-classifiable	**2**	**2**	**6**	**13**	**10**	**2**
TRAUMA SEVERITY						
Known	**82**	**92**	**97**	**98**	**97**	**97**
Unknown	**18**	**8**	**3**	**2**	**3**	**3**
Slight	**68**	**55**	**62**	**68**	**68**	**67**
Moderate	**24**	**31**	**28**	**30**	**24**	**28**
Severe	**5**	**13**	**4**	**1**	**5**	**2**
Non-classifiable	**3**	**2**	**7**	**0**	**3**	**4**

Fractures in the proximal humerus

We found 82 proximal humerus fractures in 2014–2016 (40 in boys and 42 in girls), which comprises 3% of all fractures (2% in boys and 3% in girls), corresponding to a fracture incidence of $45/10^5$ person-years (43 in boys and 47 in girls). The age-adjusted boy-to-girl IRR was 0.9 (95% CI: 0.6 to 1.4).

Of the proximal humerus fractures in all children, we found no statistically significant side preponderance with a left-to-right fracture IRR (1.5; 95% 0.9 to 2.3). The peak fracture incidence was at ages 10–11 in both boys and girls.

The age- and sex-adjusted incidence in all children and the age-adjusted incidence in boys and girls was higher in 2014–2016 than in 1950/1955. The incidence in 2014–2016 was similar to the incidence in 2005–2006 for all children, boys and girls (Table B1).

In 1950–2016 joinpoint regression analysis showed an increase in pediatric age-adjusted proximal humerus fracture incidence in boys (APC 1.0%, 95% CI: 0.3 to 1.7). In girls an increase in 1950–1993 was seen (APC 2.8%, 95% CI: 0.4 to 5.3), followed by a not statistically significant change in age-adjusted incidence in 1993–2016 (APC –2.4%, 95% CI: –5.1 to 0.5).

In 2014–2016 the most common trauma activity in our cohort resulting in proximal humerus fractures was playing injures (38%). Fall was the most common trauma mechanism and slight injuries the most common trauma severity. During different decades the most common cause of fractures has differed, from playing injuries to sporting injuries to fractures acquired in the home environment. Fall was the most common trauma mechanism during all periods. Slight injury was the most common trauma severity during 1993–1994 and 2005–2006. Moderate injury was the most common trauma severity during 1960/1965 and 1970/1975–1979. In 1950/1955 slight injury was as common as moderate injury (Table B2).

Proximal humerus fracture incidence in boys and girls 2014–2016 in Malmö, Sweden, in relation to age (A), incidence related to age in three different time periods in boys (B) and girls (C), and age-adjusted incidence with joinpoint regression in boys and girls (D).

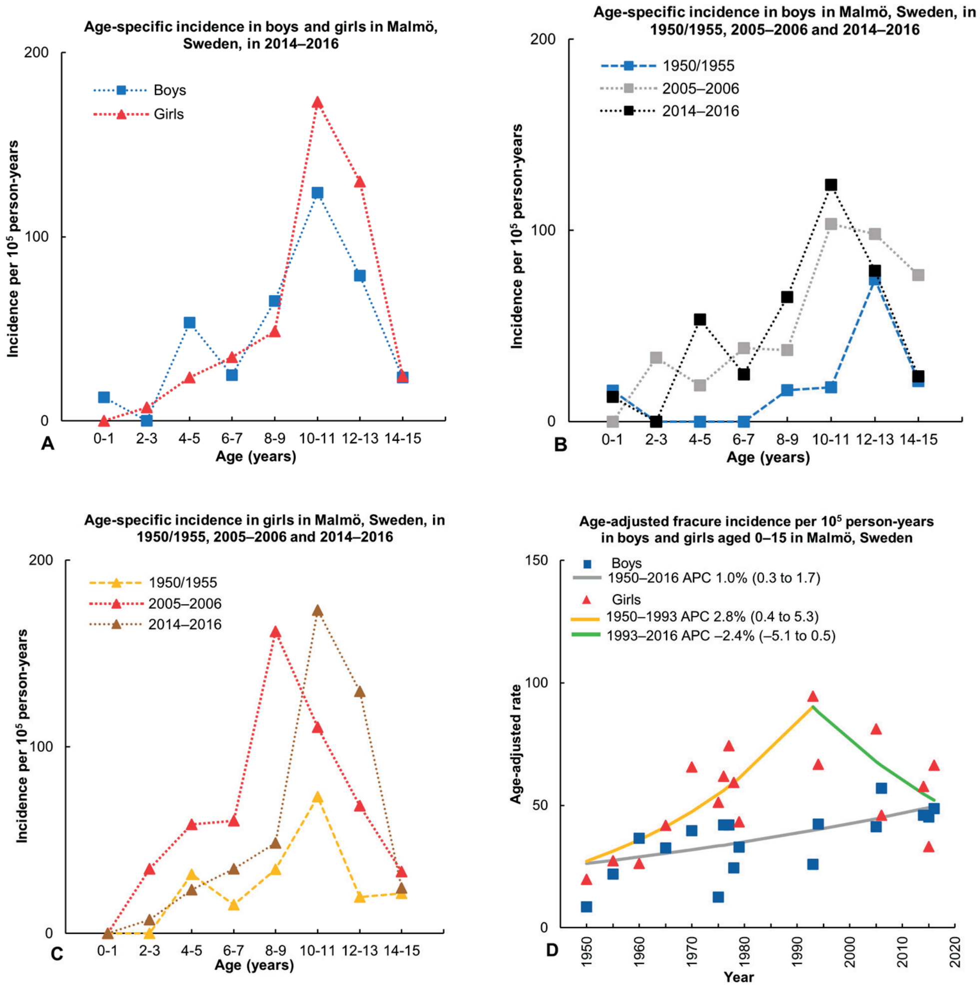

Table B1.
Unadjusted and age- and sex-adjusted proximal humerus fracture incidence in all children and unadjusted and age-adjusted fracture incidence in boys and girls separately in children 0–15 years in Malmö, Sweden, during the years 2014–2016 compared with 1950/1955, 1960/1965, 1970/1975–1979, 1993–1994, and 2005–2006. Incident rate ratio (IRR) with 95% confidence interval (95% CI) is used to describe the difference between two chosen time periods.

	Nominator Denominator	2014–2016 1950/1955	2014–2016 1960/1965	2014–2016 1970/1975–1979	2014–2016 1993–1994	2014–2016 2005–2006
All children	Unadjusted	2.2 (1.3 to 3.6)	1.3 (0.8 to 1.9)	0.9 (0.7 to 1.2)	0.8 (0.6 to 1.2)	0.8 (0.6 to 1.1)
	Age- and sex-adjusted	2.4 (1.5 to 3.9)	1.4 (0.96 to 2.1)	1.1 (0.8 to 1.4)	0.9 (0.6 to 1.2)	0.9 (0.6 to 1.2)
Boys	Unadjusted	2.6 (1.2 to 5.2)	1.2 (0.7 to 2.1)	1.2 (0.8 to 1.9)	1.3 (0.7 to 2.4)	0.9 (0.5 to 1.4)
	Age-adjusted	2.7 (1.2 to 5.3)	1.3 (0.8 to 2.3)	1.4 (0.9 to 2.2)	1.3 (0.7 to 2.4)	0.9 (0.6 to 1.6)
Girls	Unadjusted	2.0 (0.99 to 3.7)	1.3 (0.7 to 2.3)	0.7 (0.5 to 1.1)	0.6 (0.4 to 0.98)	0.8 (0.5 to 1.2)
	Age-adjusted	2.2 (1.1 to 4.2)	1.6 (0.9 to 2.7)	0.9 (0.6 to 1.3)	0.7 (0.4 to 1.05)	0.8 (0.5 to 1.3)

Table B2.
Proximal humerus fracture etiology in Malmö children 0–15 years during six periods. Etiology is described as trauma activity, trauma mechanism, and trauma severity. Data are presented as proportions (%) of known trauma etiology.

	1950/1955	1960/1965	1970/1975–1979	1993–1994	2005–2006	2014–2016
TRAUMA ACTIVITY						
Known	**53**	**57**	**77**	**62**	**79**	**74**
Unknown	**47**	**43**	**23**	**38**	**21**	**26**
Home	**40**	**14**	**3**	**7**	**2**	**3**
Day nursery	**0**	**0**	**0**	**4**	**2**	**3**
School	**10**	**0**	**6**	**0**	**7**	**21**
Work	**0**	**0**	**0**	**0**	**0**	**0**
Traffic injuries	**10**	**24**	**10**	**21**	**5**	**8**
Bicycle	10	14	6	11	5	8
Pedestrian hit by vehicle	0	0	0	11	0	0
Moped, motorcycle	0	5	3	0	0	0
Car passenger	0	5	1	0	0	0
Other	0	0	0	0	0	0
Playing injuries	**20**	**33**	**31**	**32**	**34**	**38**
Playground	0	10	8	14	22	15
In-lines, skateboard	0	0	1	4	0	13
Sledge, other “snow”	0	5	1	4	2	2
Other	20	19	20	11	10	8
Sport injuries	**20**	**29**	**49**	**36**	**46**	**25**
Ball-game	0	0	3	0	17	3
Ice-hockey, skating	0	0	2	7	2	3
Gymnastics and athletics	10	0	3	0	2	3
Horse injuries	10	24	40	18	15	8
Wrestling, boxing, etc. “Contact sport”	0	5	0	7	2	0
Skiing	0	0	0	0	7	7
Other	0	0	1	4	0	0
Fights	0	0	0	0	2	0
Other	0	0	1	0	0	2
TRAUMA MECHANISM						
Known	**84**	**97**	**99**	**96**	**100**	**98**
Unknown	**16**	**3**	**1**	**4**	**0**	**2**
Falls	**94**	**100**	**98**	**79**	**90**	**98**
On the same plane	50	44	40	47	48	54
Between planes	44	56	59	33	42	44
Mechanical force	**6**	**0**	**2**	**16**	**2**	**3**
Non-classifiable	**0**	**0**	**0**	**5**	**8**	**0**
TRAUMA SEVERITY						
Known	**84**	**97**	**100**	**100**	**96**	**96**
Unknown	**16**	**3**	**0**	**0**	**4**	**4**
Slight	**50**	**44**	**40**	**60**	**60**	**63**
Moderate	**50**	**50**	**53**	**33**	**40**	**35**
Severe	**0**	**6**	**7**	**7**	**0**	**1**
Non-classifiable	**0**	**0**	**0**	**0**	**0**	**0**

Fractures in the distal humerus

We found 263 distal humerus fractures in 2014–2016 (138 in boys and 125 in girls), which comprises 8% of all fractures (7% in boys and 10% in girls), corresponding to a fracture incidence of $145/10^5$ person-years (149 in boys and 140 in girls). The age-adjusted boy-to-girl IRR was 1.1 (95% CI: 0.9 to 1.4).

Of the distal humerus fractures in all children, we found more fractures in the left arm than the right arm, with a left-to-right fracture IRR of 1.4 (95% CI: 1.1 to 1.8). The peak fracture incidence was at ages 6–7 in boys and in girls at ages 2–3.

The age- and sex-adjusted incidence in all children was higher in 2014–2016 than in 1970/1975–1979, and 1993/1994. In girls the age-adjusted incidence was higher in 2014–2016 than in 1960/1965, and in 1970/1975–1979. The incidence in 2014–2016 was similar to the incidence in 2005–2006 for all children, boys and girls (Table C1).

Joinpoint regression analysis indicated that there was no statistically significant change in age-adjusted distal humerus fracture incidence during 1950–2016 in boys (APC –0.1%, 95% CI: –0.6 to 0.4), but an increase in girls (APC 0.6%, 95% CI: 0.1 to 1.2).

In 2014–2016 the most common trauma activity in our cohort resulting in distal humerus fractures was playing injures (52%). Fall was the most common trauma mechanism and slight injuries the most common trauma severity. During the examined decades the most common cause of fractures has been playing injuries. Fall was the most common trauma mechanism during all periods. Slight injury was the most common trauma severity during all evaluated periods, although in 2005–2006 slight injury was as common as moderate injury (Table C2).

Distal humerus fracture incidence in boys and girls 2014–2016 in Malmö, Sweden, in relation to age (A), incidence related to age in three different time periods in boys (B) and girls (C), and age-adjusted incidence with joinpoint regression in boys and girls (D).

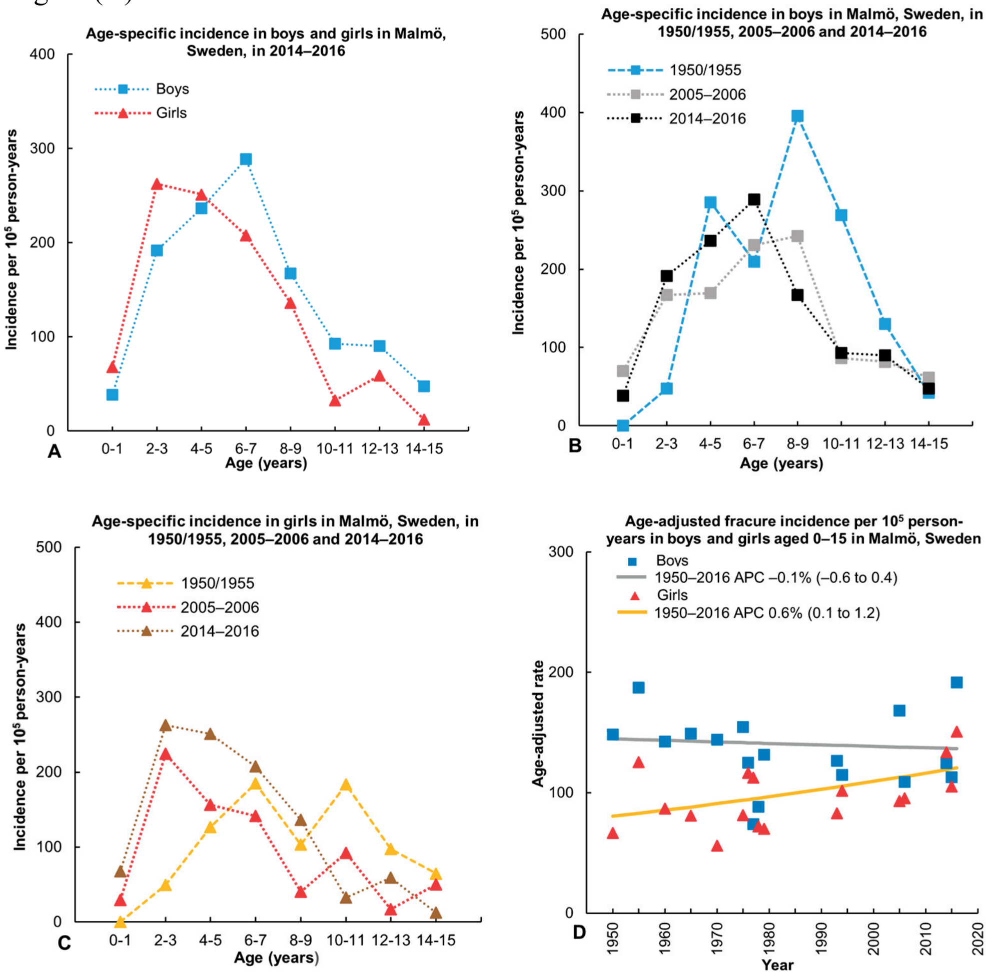

Table C1.
Unadjusted and age- and sex-adjusted distal humerus fracture incidence in all children and unadjusted and age-adjusted fracture incidence in boys and girls separately in children 0–15 years in Malmö, Sweden, during the years 2014–2016 compared with 1950/1955, 1960/1965, 1970/1975–1979, 1993–1994, and 2005–2006. Incident rate ratio (IRR) with 95% confidence interval (95% CI) is used to describe the difference between two chosen time periods.

	Nominator	2014–2016	2014–2016	2014–2016	2014–2016	2014–2016
	Denominator	1950/1955	1960/1965	1970/1975–1979	1993–1994	2005–2006
All children	Unadjusted	1.0 (0.8 to 1.3)	1.3 (1.02 to 1.6)	1.4 (1.2 to 1.7)	1.3 (1.05 to 1.7)	1.3 (1.02 to 1.6)
	Age- and sex-adjusted	1.0 (0.8 to 1.3)	1.2 (0.95 to 1.5)	1.3 (1.1 to 1.6)	1.3 (1.001 to 1.6)	1.2 (0.9 to 1.5)
Boys	Unadjusted	0.8 (0.6 to 1.1)	1.0 (0.8 to 1.4)	1.2 (0.95 to 1.5)	1.2 (0.9 to 1.7)	1.1 (0.8 to 1.5)
	Age-adjusted	0.9 (0.6 to 1.1)	1.0 (0.7 to 1.3)	1.2 (0.9 to 1.5)	1.2 (0.9 to 1.6)	1.0 (0.8 to 1.4)
Girls	Unadjusted	1.4 (0.97 to 1.9)	1.7 (1.2 to 2.4)	1.7 (1.3 to 2.2)	1.5 (1.02 to 2.1)	1.5 (1.1 to 2.2)
	Age-adjusted	1.3 (0.9 to 1.8)	1.6 (1.1 to 2.2)	1.6 (1.2 to 2.0)	1.4 (0.96 to 2.0)	1.4 (0.96 to 1.9)

Table C2.
Distal humerus fracture etiology in Malmö children 0–15 years during six decades. Etiology is described as trauma activity, trauma mechanism, and trauma severity. Data are presented as proportions (%) of known trauma etiology.

	1950/1955	1960/1965	1970/1975–1979	1993–1994	2005–2006	2014–2016
TRAUMA ACTIVITY						
Known	**45**	**47**	**60**	**65**	**67**	**75**
Unknown	**55**	**53**	**40**	**35**	**33**	**25**
Home	**8**	**15**	**12**	**16**	**6**	**12**
Day nursery	**0**	**0**	**1**	**3**	**0**	**12**
School	**5**	**5**	**8**	**3**	**13**	**7**
Work	**0**	**0**	**0**	**0**	**0**	**0**
Traffic injuries	**20**	**22**	**18**	**5**	**6**	**6**
Bicycle	19	16	17	5	6	6
Pedestrian hit by vehicle	0	4	1	0	0	0
Moped, motorcycle	0	0	1	0	0	1
Car passenger	2	2	0	0	0	0
Other	0	0	0	0	0	0
Playing injuries	**47**	**45**	**44**	**41**	**50**	**52**
Playground	12	15	21	21	36	22
In-lines, skateboard	0	0	1	3	4	5
Sledge, other “snow”	2	0	1	0	3	1
Other	34	31	20	17	7	24
Sport injuries	**15**	**13**	**16**	**31**	**20**	**12**
Ball-game	2	2	4	10	7	3
Ice-hockey, skating	7	4	4	2	3	1
Gymnastics and athletics	2	0	1	9	4	2
Horse injuries	2	2	6	5	3	4
Wrestling, boxing, etc. “Contact sport”	0	5	1	3	0	1
Skiing	0	0	0	2	1	1
Other	3	0	0	0	1	1
Fights	**2**	**0**	**0**	**0**	**6**	**0**
Other	**2**	**0**	**1**	**0**	**0**	**0**
TRAUMA MECHANISM						
Known	**85**	**86**	**93**	**98**	**100**	**95**
Unknown	**15**	**14**	**7**	**2**	**0**	**5**
Falls	**97**	**97**	**98**	**95**	**88**	**96**
On the same plane	63	58	57	51	39	35
Between planes	34	39	40	45	48	61
Mechanical force	**3**	**3**	**2**	**3**	**2**	**4**
Non-classifiable	**0**	**0**	**0**	**1**	**11**	**0**
TRAUMA SEVERITY						
Known	**85**	**86**	**93**	**99**	**95**	**95**
Unknown	**15**	**14**	**7**	**1**	**5**	**5**
Slight	**64**	**59**	**59**	**55**	**48**	**52**
Moderate	**36**	**37**	**40**	**45**	**48**	**46**
Severe	**0**	**3**	**1**	**0**	**1**	**1**
Non-classifiable	**0**	**1**	**0**	**0**	**2**	**1**

Fractures in the proximal forearm

We found 94 proximal forearm fractures (51 in boys and 43 in girls), which comprises 3% of all fractures (3% in boys and 3% in girls), corresponding to a fracture incidence of $52/10^5$ person-years (55 in boys and 48 in girls). There was no difference in boys and girls regarding proximal forearm fractures, with an age-adjusted boy-to-girl IRR of 1.2 (95% CI: 0.8 to 1.8).

Of the proximal forearm fractures in all children, we found no statistically significant side preponderance with a left-to-right fracture IRR (1.5; 95% 0.96 to 2.2). The peak fracture incidence in the age span 0–15 years were at ages 14–15 in boys and in girls at ages 10–11.

The age- and sex-adjusted incidence in all children was higher in 2014–2016 than in 1950/1955, 1960/1665, 1970/1975–1979, 1993–1994, and 2005–2006. In boys the age-adjusted incidence was higher in 2014–2016 than in 1960/1965, and 1970/1975–1979. In girls the age-adjusted incidence was higher in 2014–2016 than in 1950/1955, 1960/1965, and in 2005–2006 (Table D1).

In 1950–2016 joinpoint regression analysis showed an increase in pediatric age-adjusted proximal forearm fracture incidence in boys (APC 0.9%, 95% CI: 0.2 to 1.6) and an increase in girls (APC 1.1%, 95% CI: 0.3 to 2.0).

In 2014–2016 the most common trauma activity in our cohort resulting in proximal forearm fractures was playing injuries (37%). Fall was the most common trauma mechanism and slight injuries the most common trauma severity. During different decades the most common cause of fractures has differed, from traffic injuries to playing injuries to sporting injuries. Fall was the most common trauma mechanism for all decades. Slight injury was the most common trauma severity under all examined periods, except for 1993–1994, when moderate injury was most common (Table D2).

Proximal forearm fracture incidence in boys and girls 2014–2016 in Malmö, Sweden, in relation to age (A), incidence related to age in three different time periods in boys (B) and girls (C), and age-adjusted incidence with joinpoint regression in boys and girls (D).

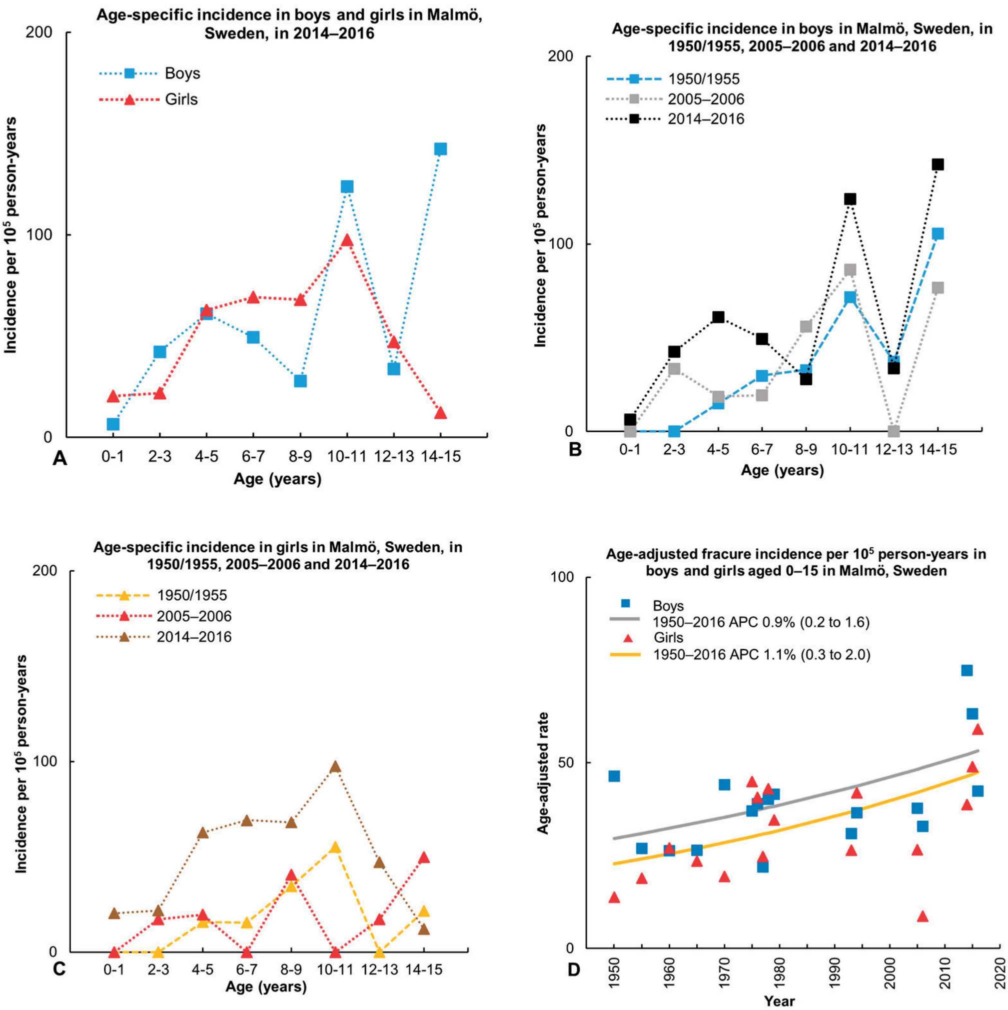

Table D1.
Unadjusted and age- and sex-adjusted proximal forearm fracture incidence in all children and unadjusted and age-adjusted fracture incidence in boys and girls separately in children 0–15 years in Malmö, Sweden, during the years 2014–2016 compared with 1950/1955, 1960/1965, 1970/1975–1979, 1993–1994, and 2005–2006. Incident rate ratio (IRR) with 95% confidence interval (95% CI) is used to describe the difference between two chosen time periods.

	Nominator Denominator	2014–2016 1950/1955	2014–2016 1960/1965	2014–2016 1970/1975–1979	2014–2016 1993–1994	2014–2016 2005–2006
All children	Unadjusted	2.0 (1.3 to 3.1)	2.0 (1.3 to 3.0)	1.4 (1.01 to 1.8)	1.6 (1.02 to 2.4)	1.9 (1.2 to 2.9)
	Age- and sex-adjusted	2.1 (1.3 to 3.2)	2.1 (1.4 to 3.2)	1.5 (1.1 to 2.0)	1.6 (1.05 to 2.4)	2.0 (1.3 to 3.1)
Boys	Unadjusted	1.6 (0.9 to 2.8)	2.1 (1.1 to 3.7)	1.4 (0.9 to 2.0)	1.7 (0.9 to 2.9)	1.5 (0.9 to 2.6)
	Age-adjusted	1.7 (0.97 to 2.9)	2.3 (1.2 to 4.0)	1.6 (1.1 to 2.4)	1.8 (0.97 to 3.1)	1.7 (0.96 to 2.9)
Girls	Unadjusted	2.8 (1.3 to 5.5)	1.9 (0.99 to 3.4)	1.3 (0.9 to 2.1)	1.5 (0.8 to 2.7)	2.7 (1.3 to 5.4)
	Age-adjusted	2.9 (1.3 to 5.9)	1.9 (1.02 to 3.6)	1.5 (0.9 to 2.3)	1.5 (0.8 to 2.6)	2.8 (1.3 to 5.7)

Table D2.
Proximal forearm fracture etiology in Malmö children 0–15 years during six periods. Etiology is described as trauma activity, trauma mechanism, and trauma severity. Data are presented as proportions (%) of known trauma etiology.

	1950/1955	1960/1965	1970/1975–1979	1993–1994	2005–2006	2014–2016
TRAUMA ACTIVITY						
Known	**33**	**56**	**56**	**63**	**80**	**76**
Unknown	**67**	**44**	**44**	**37**	**20**	**24**
Home	**13**	**7**	**5**	**6**	**0**	**11**
Day nursery	**0**	**0**	**2**	**0**	**0**	**10**
School	**0**	**7**	**13**	**6**	**10**	**15**
Work	**0**	**0**	**0**	**0**	**0**	**0**
Traffic injuries	**38**	**27**	**22**	**47**	**10**	**13**
Bicycle	25	13	15	47	10	10
Pedestrian hit by vehicle	13	13	4	0	0	0
Moped, motorcycle	0	0	4	0	0	3
Car passenger	0	0	0	0	0	0
Other	0	0	0	0	0	0
Playing injuries	**50**	**47**	**29**	**24**	**35**	**37**
Playground	0	7	15	18	20	14
In-lines, skateboard	0	0	4	0	10	7
Sledge, other “snow”	0	0	0	0	5	0
Other	50	40	11	6	0	15
Sport injuries	**0**	**13**	**27**	**18**	**40**	**13**
Ball-game	0	7	7	0	15	4
Ice-hockey, skating	0	7	4	6	0	0
Gymnastics and athletics	0	0	5	0	10	0
Horse injuries	0	0	5	6	5	4
Wrestling, boxing, etc. "Contact sport"	0	0	5	6	0	3
Skiing	0	0	0	0	0	0
Other	0	0	0	0	10	1
Fights	**0**	**0**	**0**	**0**	**5**	**1**
Other	**0**	**0**	**2**	**0**	**0**	**0**
TRAUMA MECHANISM						
Known	**88**	**93**	**98**	**100**	**100**	**98**
Unknown	**13**	**7**	**2**	**0**	**0**	**2**
Falls	**95**	**92**	**96**	**93**	**100**	**91**
On the same plane	76	60	69	41	60	38
Between planes	19	32	27	52	40	53
Mechanical force	**5**	**8**	**4**	**0**	**0**	**8**
Non-classifiable	**0**	**0**	**0**	**7**	**0**	**1**
TRAUMA SEVERITY						
Known	**88**	**93**	**98**	**100**	**100**	**95**
Unknown	**13**	**7**	**2**	**0**	**0**	**5**
Slight	**76**	**60**	**69**	**48**	**60**	**54**
Moderate	**24**	**32**	**25**	**52**	**40**	**43**
Severe	**0**	**8**	**5**	**0**	**0**	**2**
Non-classifiable	**0**	**0**	**1**	**0**	**0**	**1**

Fractures in the diaphyseal forearm

We found 203 diaphyseal forearm fractures in 2014–2016 (129 in boys and 74 in girls), which comprises 6% of all fractures (7% in boys and 6% in girls), corresponding to a fracture incidence of $112/10^5$ person-years (139 in boys and 83 in girls). The age-adjusted boy-to-girl IRR was 1.7 (95% CI: 1.3 to 2.3).

We found no statistically significant side preponderance of the diaphyseal forearm fractures, with a left-to-right fracture IRR of 1.1 (95% CI: 0.8 to 1.5). The peak fracture incidence was at ages 6–7 in both boys and girls.

The age- and sex-adjusted incidence in all children was higher in 2014–2016 than in 1950/1955, 1960/1965, 1970/1975–1979, and 1993–1994. In boys the age-adjusted incidence was higher in 2014–2016 than in 1960/1965, and 1970/1975–1979. In girls the age-adjusted incidence was higher in 2014–2016 than in 1970/1975–1979, and 1993–1994. There was no difference in the incidence in 2014–2016 and the incidence in 2005–2006 in all children and boys and girls (Table E1).

During the period 1950–2016 joinpoint regression analysis showed an increase in pediatric age-adjusted diaphyseal forearm fracture incidence in boys (APC 0.6%, 95% CI: 0.2 to 1.1), but no statistically significant incidence changes in girls (APC 0.6, 95% CI: –0.1 to 1.4).

In 2014–2016 the most common trauma activity in our cohort resulting in diaphyseal forearm fractures was playing injuries (48%). Fall was the most common trauma mechanism and slight injury the most common trauma severity. During different decades the most common cause of fractures was playing injuries, except in 1993–1994 when playing injuries were as common as sport injuries. Fall was the most common trauma mechanism during all evaluated periods. Slight injury was the most common trauma severity during all periods, except for 2005–2006, when moderate injury was most common (Table E2).

Diaphyseal forearm fracture incidence in boys and girls 2014–2016 in Malmö, Sweden, in relation to age (A), incidence related to age in three different time periods in boys (B) and girls (C), and age-adjusted incidence with joinpoint regression in boys and girls (D).

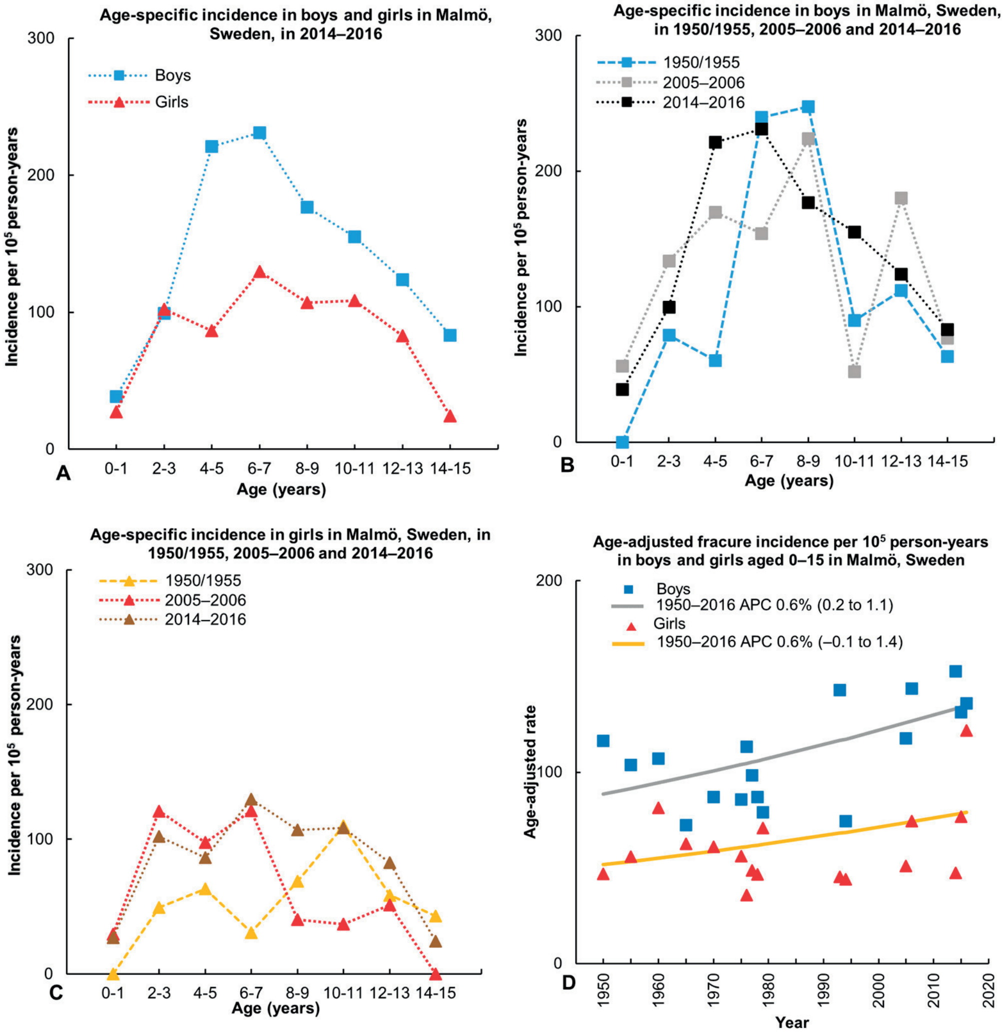

Table E1.
Unadjusted and age- and sex-adjusted diaphyseal forearm incidence in all children and unadjusted and age-adjusted fracture incidence in boys and girls separately in children 0–15 years in Malmö, Sweden, during the years 2014–2016 compared with 1950/1955, 1960/1965, 1970/1975–1979, 1993–1994, and 2005–2006. Incident rate ratio (IRR) with 95% confidence interval (95% CI) is used to describe the difference between two chosen time periods.

	Nominator Denominator	2014–2016 1950/1955	2014–2016 1960/1965	2014–2016 1970/1975–1979	2014–2016 1993–1994	2014–2016 2005–2006
All children	Unadjusted	1.3 (1.03 to 1.7)	1.4 (1.1 to 1.8)	1.5 (1.2 to 1.8)	1.5 (1.1 to 1.9)	1.2 (0.9 to 1.5)
	Age- and sex-adjusted	1.4 (1.1 to 1.8)	1.4 (1.1 to 1.8)	1.5 (1.3 to 1.9)	1.4 (1.1 to 1.9)	1.1 (0.9 to 1.5)
Boys	Unadjusted	1.2 (0.9 to 1.7)	1.5 (1.1 to 2.1)	1.5 (1.1 to 1.9)	1.3 (0.9 to 1.8)	1.1 (0.8 to 1.5)
	Age-adjusted	1.3 (0.9 to 1.8)	1.5 (1.1 to 2.1)	1.5 (1.2 to 2.0)	1.3 (0.9 to 1.8)	1.1 (0.8 to 1.4)
Girls	Unadjusted	1.6 (0.99 to 2.5)	1.1 (0.8 to 1.7)	1.6 (1.1 to 2.2)	1.8 (1.1 to 3.0)	1.4 (0.9 to 2.1)
	Age-adjusted	1.6 (0.997 to 2.5)	1.1 (0.8 to 1.7)	1.6 (1.1 to 2.2)	1.8 (1.1 to 3.0)	1.3 (0.8 to 2.0)

Table E2.
Diaphyseal forearm fracture etiology in Malmö children 0–15 years during six periods. Etiology is described as trauma activity, trauma mechanism, and trauma severity. Data are presented as proportions (%) of known trauma etiology.

	1950/1955	1960/1965	1970/1975–1979	1993–1994	2005–2006	2014–2016
TRAUMA ACTIVITY						
Known	**42**	**46**	**61**	**65**	**69**	**76**
Unknown	**58**	**54**	**39**	**35**	**31**	**24**
Home	**3**	**15**	**11**	**7**	**5**	**11**
Day nursery	**3**	**0**	**0**	**5**	**2**	**9**
School	**21**	**18**	**15**	**5**	**15**	**6**
Work	**0**	**0**	**0**	**0**	**0**	**0**
Traffic injuries	**12**	**18**	**26**	**20**	**8**	**10**
Bicycle	12	8	22	15	8	9
Pedestrian hit by vehicle	0	8	2	0	0	0
Moped, motorcycle	0	0	1	2	0	0
Car passenger	0	3	1	2	0	1
Other	0	0	0	0	0	0
Playing injuries	**45**	**41**	**28**	**32**	**43**	**48**
Playground	15	5	11	12	30	18
In-lines, skateboard	0	3	2	5	7	8
Sledge, other "snow"	0	0	3	0	5	1
Other	30	33	12	15	2	21
Sport injuries	**12**	**8**	**16**	**32**	**27**	**16**
Ball-game	6	5	7	12	13	9
Ice-hockey, skating	0	0	0	5	2	1
Gymnastics and athletics	3	3	1	5	10	2
Horse injuries	0	0	3	0	2	1
Wrestling, boxing, etc. "Contact sport"	0	0	3	7	0	1
Skiing	3	0	0	2	0	1
Other	0	0	2	0	0	1
Fights	**3**	**0**	**2**	**0**	**0**	**0**
Other	**0**	**0**	**3**	**0**	**0**	**1**
TRAUMA MECHANISM						
Known	**83**	**88**	**94**	**97**	**100**	**96**
Unknown	**17**	**12**	**6**	**3**	**0**	**4**
Falls	**97**	**93**	**93**	**92**	**89**	**93**
On the same plane	74	67	62	59	38	39
Between planes	23	27	31	33	51	55
Mechanical force	**3**	**7**	**7**	**7**	**7**	**5**
Non-classifiable	**0**	**0**	**1**	**2**	**5**	**2**
TRAUMA SEVERITY						
Known	**86**	**88**	**96**	**98**	**99**	**92**
Unknown	**14**	**12**	**4**	**2**	**1**	**8**
Slight	**70**	**67**	**64**	**63**	**45**	**55**
Moderate	**24**	**25**	**30**	**31**	**51**	**43**
Severe	**1**	**5**	**4**	**5**	**0**	**1**
Non-classifiable	**4**	**3**	**2**	**2**	**3**	**2**

Fractures in the diaphyseal tibia

We found 176 diaphyseal tibia fractures in 2014–2016 (92 in boys and 84 in girls), which comprises 5% of all fractures (5% in boys and 7% in girls), corresponding to a fracture incidence of $97/10^5$ person-years (99 in boys and 94 in girls). The age-adjusted boy-to-girl IRR was 1.1 (95% CI: 0.8 to 1.5).

Of the diaphyseal tibia fractures in all children, we found no statistically significant side preponderance, with a left-to-right IRR of 1.1 (95% 0.8 to 1.5). The peak fracture incidence was at ages 2–3 in boys and girls.

The age-adjusted incidence in boys was lower in 2014–2016 than in 1970/1975–1979, and 1993–1994. The incidence in 2014–2016 was similar to the incidence in 2005–2006 for all children, boys and girls (Table F1).

Joinpoint regression analysis showed no statistically significant changes in age-adjusted incidence in pediatric diaphyseal tibia fractures in boys 1950–1993 (APC 0.9, 95% CI: –0.3 to 2.0), but a decrease in 1993–2016 (APC –2.3, 95% CI: –4.0 to –0.6). In girls the change in age-adjusted incidence was not statistically significant (APC 0.3%, 95% CI: –0.3 to 0.8) in 1950–2016.

In 2014–2016 the most common trauma activity in our cohort resulting in diaphyseal tibia fractures was playing injuries (36%). Fall was the most common trauma mechanism and slight injury the most common trauma severity. During 1950/1955, 1960/1965, 1970/1975–1979, and 1993–1994 the most common cause of diaphyseal tibia fractures was traffic injuries and in 2005–2006 it was sport injuries. Fall was the most common trauma mechanism, and slight injury the most common trauma severity during all evaluated periods (Table F2).

Diaphyseal tibia fracture incidence in boys and girls 2014–2016 in Malmö, Sweden, in relation to age (A), incidence related to age in three different time periods in boys (B) and girls (C), and age-adjusted incidence with joinpoint regression in boys and girls (D).

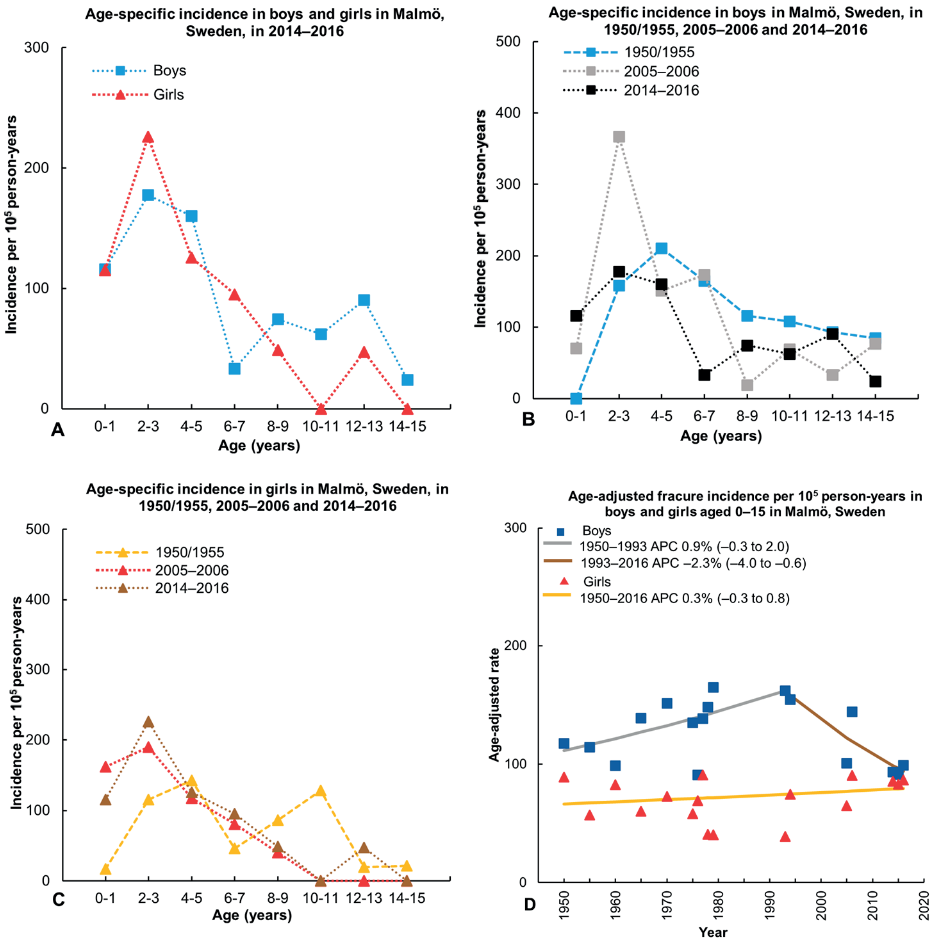

Table F1.
Unadjusted and age- and sex-adjusted diaphyseal tibia fracture incidence in all children and unadjusted and age-adjusted fracture incidence in boys and girls separately in children 0–15 years in Malmö, Sweden, during the years 2014–2016 compared with 1950/1955, 1960/1965, 1970/1975–1979, 1993–1994, and 2005–2006. Incident rate ratio (IRR) with 95% confidence interval (95% CI) is used to describe the difference between two chosen time periods.

	Nominator	2014–2016	2014–2016	2014–2016	2014–2016	2014–2016
	Denominator	**1950/1955**	**1960/1965**	**1970/1975–1979**	**1993–1994**	**2005–2006**
All children	Unadjusted	1.0 (0.8 to 1.3)	1.0 (0.8 to 1.3)	0.9 (0.8 to 1.2)	0.9 (0.7 to 1.1)	1.0 (0.8 to 1.3)
	Age- and sex-adjusted	1.0 (0.7 to 1.2)	0.9 (0.7 to 1.2)	0.9 (0.7 to 1.1)	0.8 (0.6 to 1.1)	0.9 (0.7 to 1.1)
Boys	Unadjusted	0.8 (0.6 to 1.2)	0.9 (0.6 to 1.2)	0.7 (0.5 to 0.9)	0.6 (0.4 to 0.9)	0.8 (0.6 to 1.2)
	Age-adjusted	0.8 (0.6 to 1.1)	0.8 (0.6 to 1.1)	0.7 (0.5 to 0.9)	0.6 (0.4 to 0.8)	0.8 (0.5 to 1.1)
Girls	Unadjusted	1.3 (0.8 to 1.9)	1.3 (0.9 to 2.0)	1.5 (1.1 to 2.0)	1.6 (0.99 to 2.4)	1.2 (0.8 to 1.9)
	Age-adjusted	1.2 (0.8 to 1.8)	1.2 (0.8 to 1.8)	1.4 (0.98 to 1.9)	1.5 (0.9 to 2.3)	1.1 (0.7 to 1.6)

Table F2.
Diaphyseal tibia fracture etiology in Malmö children 0–15 years during six periods. Etiology is described as trauma activity, trauma mechanism, and trauma severity. Data are presented as proportions (%) of known trauma etiology.

	1950/1955	1960/1965	1970/1975–1979	1993–1994	2005–2006	2014–2016
TRAUMA ACTIVITY						
Known	**66**	**65**	**81**	**78**	**71**	**77**
Unknown	**34**	**35**	**19**	**22**	**29**	**23**
Home	**17**	**16**	**9**	**13**	**3**	**8**
Day nursery	**0**	**2**	**0**	**4**	**5**	**10**
School	**7**	**2**	**1**	**1**	**5**	**4**
Work	**0**	**0**	**0**	**1**	**0**	**0**
Traffic injuries	**43**	**48**	**36**	**32**	**20**	**16**
Bicycle	22	19	16	14	9	13
Pedestrian hit by vehicle	20	25	12	10	8	1
Moped, motorcycle	0	2	5	6	3	0
Car passenger	0	2	1	1	0	1
Other	2	2	2	1	0	0
Playing injuries	**13**	**20**	**24**	**17**	**27**	**36**
Playground	7	5	5	10	13	21
In-lines, skateboard	0	0	2	3	2	1
Sledge, other “snow”	3	3	7	3	6	1
Other	3	13	10	1	6	13
Sport injuries	**20**	**13**	**27**	**31**	**38**	**25**
Ball-game	3	0	5	14	13	5
Ice-hockey, skating	13	11	3	6	0	2
Gymnastics and athletics	0	0	0	0	0	0
Horse injuries	0	0	0	1	0	0
Wrestling, boxing, etc. “Contact sport”	0	0	0	1	2	0
Skiing	3	2	19	8	23	18
Other	0	0	0	0	0	0
Fights	**0**	**0**	**1**	**1**	**3**	**0**
Other	**0**	**0**	**1**	**0**	**0**	**1**
TRAUMA MECHANISM						
Known	**81**	**89**	**93**	**96**	**100**	**85**
Unknown	**19**	**11**	**7**	**4**	**0**	**15**
Falls	**69**	**72**	**75**	**52**	**68**	**62**
On the same plane	39	41	47	38	42	32
Between planes	30	31	27	15	26	31
Mechanical force	**30**	**28**	**25**	**41**	**19**	**32**
Non-classifiable	**1**	**0**	**0**	**7**	**13**	**6**
TRAUMA SEVERITY						
Known	**81**	**89**	**95**	**98**	**99**	**94**
Unknown	**19**	**11**	**5**	**2**	**1**	**6**
Slight	**42**	**44**	**52**	**56**	**57**	**70**
Moderate	**41**	**29**	**22**	**31**	**26**	**23**
Severe	**8**	**20**	**20**	**13**	**7**	**1**
Non-classifiable	**9**	**8**	**6**	**0**	**10**	**5**

Fractures in the foot

We found 321 fractures in the foot in 2014–2016 (194 in boys and 127 in girls), which comprises 10% of all fractures (10% in boys and 10% in girls), corresponding to a fracture incidence of 177/10^5 person-years (209 in boys and 143 in girls). The age-adjusted boy-to-girl IRR was 1.5 (95% CI: 1.2 to 1.8).

Of the fractures in the foot in all children, we found no statistically significant side preponderance, with a left-to-right fracture IRR of 0.9 (95% CI: 0.7 to 1.1). The peak fracture incidence was at ages 12–13 in boys and in girls at ages 10–11.

The age- and sex-adjusted incidence in all children was higher in 2014–2016 than in 1950/1955, 1960/1965, 1970/1975–1979, 1993–1994, and 2005–2006. In boys the age-adjusted incidence was higher in 2014–2016 than in 1950/1955, 1960/1965, and 1970/1975–1979. In girls the age-adjusted incidence was higher in 2014–2016 than 1950/1955, and 1960/1965 (Table G1).

Joinpoint regression analysis shows an increase in pediatric age-adjusted foot fracture incidence during the entire period 1950–2016 in boys (APC 0.7%, 95% CI: 0.1 to 1.3) and in girls (APC 0.8%, 95% CI: 0.1 to 1.4).

In 2014–2016 the most common trauma activity in our cohort resulting in foot fractures was sport injuries (43%). Fall was the most common trauma mechanism and slight injury the most common trauma severity. Sport injures were the most common cause of fractures also in 1950/1955 and in 2005–2006, and during the other periods playing injures were the most common cause of fractures in the foot. Fall was the most common trauma mechanism, and slight injury the most common trauma severity during all studied periods (Table G2).

Fracture incidence in the foot in boys and girls 2014–2016 in Malmö, Sweden, in relation to age (A), incidence related to age in three different time periods in boys (B) and girls (C), and age-adjusted incidence with joinpoint regression in boys and girls (D).

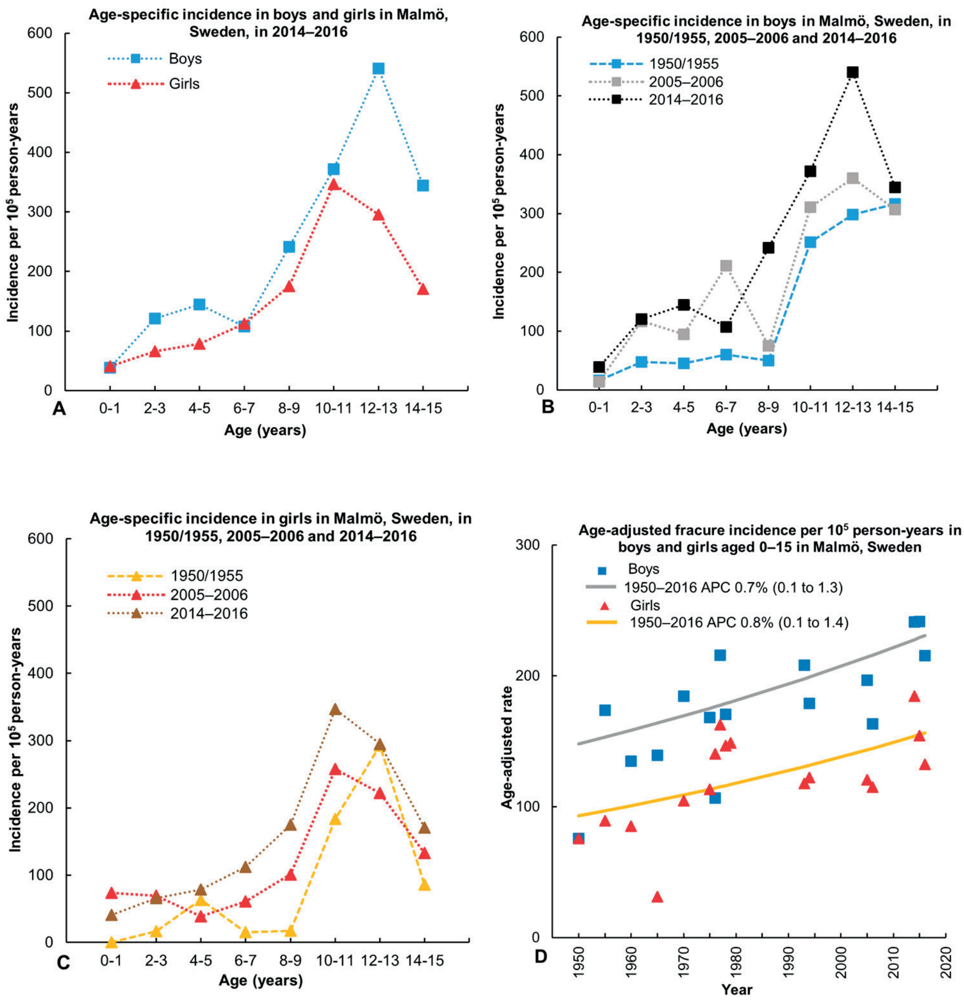

Table G1.
Unadjusted and age- and sex-adjusted foot fracture incidence in all children and unadjusted and age-adjusted fracture incidence in boys and girls separately in children 0–15 years in Malmö, Sweden, during the years 2014–2016 compared with 1950/1955, 1960/1965, 1970/1975–1979, 1993–1994, and 2005–2006. Incident rate ratio (IRR) with 95% confidence interval (95% CI) is used to describe the difference between two chosen time periods.

	Nominator Denominator	2014–2016 1950/1955	2014–2016 1960/1965	2014–2016 1970/1975–1979	2014–2016 1993–1994	2014–2016 2005–2006
All children	Unadjusted	1.7 (1.4 to 2.2)	1.7 (1.4 to 2.1)	1.0 (0.9 to 1.2)	1.1 (0.9 to 1.4)	1.1 (0.9 to 1.4)
	Age- and sex-adjusted	1.8 (1.4 to 2.3)	2.0 (1.6 to 2.4)	1.2 (1.04 to 1.4)	1.2 (1.01 to 1.5)	1.3 (1.1 to 1.6)
Boys	Unadjusted	1.7 (1.3 to 2.2)	1.4 (1.1 to 1.9)	1.0 (0.9 to 1.3)	1.1 (0.8 to 1.4)	1.1 (0.9 to 1.5)
	Age-adjusted	1.8 (1.3 to 2.3)	1.7 (1.3 to 2.2)	1.2 (1.01 to 1.5)	1.2 (0.9 to 1.5)	1.3 (0.998 to 1.7)
Girls	Unadjusted	1.8 (1.2 to 2.6)	2.3 (1.6 to 3.4)	1.0 (0.8 to 1.3)	1.2 (0.9 to 1.7)	1.2 (0.9 to 1.6)
	Age-adjusted	1.9 (1.3 to 2.7)	2.7 (1.8 to 3.9)	1.2 (0.9 to 1.5)	1.3 (0.9 to 1.8)	1.3 (0.96 to 1.8)

Table G2.
Foot fracture etiology in Malmö children 0–15 years during six periods. Etiology is described as trauma activity, trauma mechanism, and trauma severity. Data are presented as proportions (%) of known trauma etiology.

	1950/1955	1960/1965	1970/1975–1979	1993–1994	2005–2006	2014–2016
TRAUMA ACTIVITY						
Known	**38**	**42**	**53**	**58**	**53**	**57**
Unknown	**62**	**58**	**47**	**42**	**47**	**43**
Home	**11**	**13**	**12**	**23**	**0**	**4**
Day nursery	**0**	**0**	**2**	**7**	**1**	**8**
School	**17**	**16**	**10**	**4**	**8**	**12**
Work	**8**	**2**	**0**	**1**	**0**	**0**
Traffic injuries	**14**	**20**	**9**	**7**	**16**	**4**
Bicycle	8	9	3	4	7	2
Pedestrian hit by vehicle	3	4	3	3	7	2
Moped, motorcycle	3	7	3	0	3	1
Car passenger	0	0	0	0	0	0
Other	0	0	0	0	0	1
Playing injuries	**19**	**27**	**37**	**31**	**31**	**27**
Playground	3	2	6	12	11	12
In-lines, skateboard	0	0	0	0	5	4
Sledge, other “snow”	0	0	1	3	1	2
Other	17	24	29	16	13	10
Sport injuries	**31**	**20**	**27**	**27**	**39**	**43**
Ball-game	22	11	15	11	25	33
Ice-hockey, skating	3	0	1	0	0	0
Gymnastics and athletics	3	2	3	8	3	3
Horse injuries	0	2	3	5	1	0
Wrestling, boxing, etc. “Contact sport”	0	0	3	0	5	3
Skiing	0	0	0	0	0	0
Other	3	4	2	3	4	4
Fights	**0**	**0**	**0**	**0**	**5**	**0**
Other	**0**	**2**	**3**	**0**	**0**	**2**
TRAUMA MECHANISM						
Known	**82**	**89**	**94**	**92**	**100**	**90**
Unknown	**18**	**11**	**6**	**8**	**0**	**10**
Falls	**67**	**76**	**80**	**58**	**46**	**45**
On the same plane	54	49	53	30	28	20
Between planes	13	27	26	28	18	25
Mechanical force	**33**	**22**	**20**	**35**	**41**	**43**
Non-classifiable	**0**	**2**	**0**	**7**	**13**	**12**
TRAUMA SEVERITY						
Known	**82**	**88**	**96**	**93**	**99**	**93**
Unknown	**18**	**12**	**4**	**7**	**1**	**7**
Slight	**71**	**57**	**64**	**64**	**66**	**72**
Moderate	**13**	**26**	**25**	**34**	**21**	**17**
Severe	**4**	**9**	**8**	**2**	**6**	**3**
Non-classifiable	**13**	**7**	**3**	**0**	**7**	**8**

General discussion

Method in Papers I–III

Our city has only one hospital that provides trauma care for the city residents. Since the end of the 19th century the hospital has been called Malmö Allmänna Sjukhus (MAS), the name later changed to Universitetssjukhuset MAS (UMAS). However, from January 1, 2010, the hospital in Malmö was merged with the hospital in Lund (Universitetssjukhuset i Lund), and the two hospitals became one hospital called Skånes universitetssjukhus (Skåne University Hospital)[100]. This ultimately led to the Department of Orthopedics in Malmö being merged with the Department of Orthopedics in Lund. Both units continued with trauma care within their respective region, but subspecialized units were localized at either of the units. For example, pediatric orthopedics, responsible for most of the surgeries and elective follow-up visits in children, was thereafter placed in Lund. The 2014–2016 evaluation is thus the first study regarding fracture epidemiology in Malmö children since the two hospitals were merged.

To be included in our study, the patient had to be a resident in Malmö and aged 0–15 years when sustaining the fracture. The inclusion criteria and registration schedule, when evaluating the pediatric fracture epidemiology, were the same as in 2005–2006[67]. Since emergency patients primarily should seek acute care in the hospital unit where they live, we reviewed the in- and out diagnosis registry from the Emergency Department in Malmö. But we also reviewed the same registries at the Department of Hand Surgery in Malmö (all hand surgery visits localized in the Malmö unit) and the Departments of Orthopedics and Otorhinolaryngology in both Malmö and Lund (one clinic but localized at two sites), with the aim of capturing follow-up visits after a fracture. When doing this, we used the same ascertainment method as was used in 2005–2006, an ascertainment method that missed fractures in Malmö children if they had their fracture examined and treated out of Malmö with no follow-up visit to the departments in Lund or Malmö. Apart from SUS, there are a few private orthopedic surgeons working in Malmö, but they evaluate scheduled patients without offering emergency service. Furthermore, if a patient with a fracture first seeks primary health care, the physician there refers the patient to the Radiology Department at SUS. If a fracture is verified through the radiological examination, the patient is automatically transferred to the Emergency Department at SUS, a visit that will lead to a registration with an ICD-code at the Emergency

Department. There are also some private radiographical units in the city, which may receive referrals from the primary health care centers. If these departments identify a fracture, this patient too is automatically transferred to the Emergency Department at SUS for treatment. A previous study by Jonsson[101] in 1993 evaluated the system of private radiographic units, and found that 3% of the fractures in adults diagnosed at a private radiographic unit were not found in the archives at the hospital. Jonsson reported further that out of all fractures in adults the patients recollected and stated that they had been treated for at our hospital, 7% were not found in the archives at the hospital. This could be due to lack of registration, misclassification, or recall bias by the patients. It is then also of interest to be aware that when only identifying fracture by recall, and comparing this to objectively verified and registered fractures, the recall bias may be up to a 40% underreporting of fractures[101,102].

We must also acknowledge that fractures that do not achieve a registration with a fracture ICD-code at any of the departments we evaluated, are missed in our registration. We will also miss patients with fractures, which are registered with a diagnosis ICD-code that does not refer to one of our fracture diagnosis codes, and patients with a fracture which for some reason was not sent for radiographic evaluation. Another reason for missing a pediatric fracture would be if children did not attend any health care examination at all.

Our ascertainment method included fracture identification through a number of defined ICD-10 fracture codes. However, some ICD-codes that actually may also describe fractures, were not included. Such an example is diagnosis code P13 (birth injury to skeleton), a code we excluded in order to follow the ascertainment system that was used in the 2005–2006 evaluation[67]. Furthermore, the Department of Neonatology, which would use such a diagnosis code, was not included in the survey. This too followed the 2005–2006 ascertainment system[67]. These shortcomings could affect our incidences in new-born children, perhaps especially for clavicle fractures, comprising the majority of all birth fractures[103,104]. However, we speculate that the great variability between numbers of birth fractures between the years in the first two pediatric fracture epidemiology studies in Malmö indicate that there were problems with registration of birth fractures already then[66,68]. Another fact that may increase the uncertainty is that birth fractures are often only diagnosed clinically, and since we only included objectively verified fractures, these fractures would likewise not be included in our registration.

The following ICD-codes (M84.3, T02, T08.9, T10.9, T12.9 and Z09.4) are codes that are referred to fractures but not included in our review, thus following the 2005–2006 ascertainment, with the aim of making our results more comparable with the 2005–2006 data. This could also lead to misclassification. For example, stress fractures are included in our registration, but stress fractures could also receive the more general ICD-code M84.3 than a specific fracture code. The ICD-codes T02 (fractures involving multiple body regions), T08.9, T10.9, and T12.9 (fractures in an unspecified level in the spine, upper limbs, and lower limbs) are other fracture diagnosis codes not included in our review. However, we speculate that these codes are rarely used, as they are not described by the Swedish Orthopaedic Association ("Svensk Ortopedisk Förening; SOF"), when recommending fracture codes to be used[105]. The ICD-code Z09.4 may also render problems, as a code describing "follow-up examination after treatment of fracture". This code should be combined with a specific fracture ICD-code. However, if just the Z09.4 code was registered, this visit would not be included in our registration. But once more, we adopted this registration method as we wanted to follow the 2005–2006 system.

Another issue to discuss is where the border that differentiate distal forearm fractures from diaphyseal forearm fractures should be placed on the radiographs, as there are different opinions as to where to place this border. The AO (Arbeitsgemeinschaft für Osteosynthesefragen) principles[106] use the "rule of the square" for definitions of distal and diaphyseal fractures; thus, in the forearm the distal end of the square is drawn through the physis, and the width of the square is decided by the width of both forearm bones. There is another system to differentiate distal from diaphyseal forearm fractures, also with a square, but with just the distal end width depending on the physis of the radius[107]. However, in our studies the border between the diaphysis and metaphysis was defined as the point where the cortex attained a constant thickness, which was also used in the earlier studies in Malmö[66-68].

There are also concerns as regards how to classify the fracture etiology. The classification system initiated by Lennart Landin[68] does not enable registration of both place and activity. The NCECI classification takes this problem into consideration, making it possible to register both activity and place at the same time. In *Paper I* and *Paper II* we referred to this classification as the NOMESCO classification, as a couple of other articles did[108,109]. Though, in *Paper III*, and in this thesis, we refer to the classification as the NCECI classification, which we believe to be a more correct abbreviation. This abbreviation is for example used by the National Board of Health and Welfare ("Socialstyrelsen")[110]. That is, even when using different abbreviations, we refer to the same classification.

Method in Paper IV

One major problem with the SPA method is that the technique is limited to measuring bone in body regions with minimal soft tissue padding, in addition to being surrounded with a tissue-equivalent material. Thus, the SPA could be used to measure peripheral skeleton sites such as the distal femur or distal forearm, but not deeper situated structures such as the total body, the hip, or the spine. These body regions could be evaluated by DXA, therefore now the gold standard for bone mass measurements and osteoporosis evaluations. However, to conduct *Paper IV* we had to use SPA, as the DXA technique was not available in 1979–1981. By choosing SPA we could further conduct our measurements not only with the same method, but even with the same scanner, as the scanner we used was one of the first bone scanners ever presented[50,51]. We regarded this as an appropriate approach, since studies have reported that SPA and DXA measurements in the distal forearm are closely correlated, and since both methods predict fractures similarly[23,24,46,47].

One advantage of the SPA apparatus is that it is small and easy to move, in contrast to total body DXA machines. This made it possible in 2017–2018 for us to measure the children in the schools, thus making it more convenient and time-saving for the children than conducting the measurements at our research laboratory. With our approach, the whole process, collecting the children from the classrooms, including information, checking questionnaires, and conducting the scanning, took no more than around 30 minutes for each child. We therefore speculate that the 45% attendance rate was partly the result of this approach. Another advantage is the short scanning time (minutes), increasing the probability that especially the youngest children could be motionless during the scanning. The few scans we had to exclude based on technical errors and inability to conduct the plotting were therefore low (none 1979–1981 and four 2017–2018). Since only one person did all the plotting and analyses of the scans from both time periods, we excluded any inter-individual variability. The plotting was also conducted in random order to minimize the risk of systematic errors.

We conducted further measurements with standard equipment when evaluating height and weight, and calculated BMI according to the generally used formula weight/height^2. In other words, height and weight were based on measurements, and not recall. We then found that that there were similar trait versus age slopes in these traits when comparing the 2017–2018 and the 1979–1981 cohorts of children, suggesting that time trends in these traits had minor influence on the SPA-estimated bone mass development.

Pediatric fracture incidence

There have been a variety of studies that have evaluated pediatric fracture incidence in different geographic regions as well as during different time periods (Table 3).

Table 3.
The reported pediatric fracture incidence in different studies.

First Author	Age-group	Study period	Geographic region	Incidence in all fractures per 10^5 person-years	Incidence in distal forearm fractures per 10^5 person-years	Incidence in hand fractures per 10^5 person-years
Bergman (Papers I–III)	0–15	2014–2016	Malmö, Sweden	1,786	546	339
Christoffersen[72]	0–17	2010–2011	Norway	2,040	439	–
Cooper[62]	0–17	1988–1998	UK	1,331	–	–
Hedström[63]	0–19	1993–2007	Umeå, Sweden	2,010	591*	389*
Jerrhag[111]	0–16	1999–2010	Skåne, Sweden	–	634	–
Khosla[112]	0–19	1999–2001	USA	–	571	–
Kopjar[85]	0–12	1992–1995	Norway	1,280	–	–
Landin[68]	0–16	1975–1979	Malmö, Sweden	2,120	481	577
Lempesis[67,93,113]	0–15	2005–2006	Malmö, Sweden	1,832	564	448
Lyons[74]	0–14	1996	Wales	3,609	–	961
Lyons[74]	0–14	1996	Finland	1,775	–	383
Lyons[74]	0–14	1996	Jämtland, Sweden	1,547	–	307
Lyons[74]	0–14	1996	Norway	1,686	–	695
Mahabir[82]	0–15	1996–2001	Canada	–	–	24
Mamoowala[83]	0–16	2007–2014	UK	–	337**	–
Mäyränpää[65]	0–15	2005	Finland	1,630	496	344
Moon[64]	0–17	1988–2012	UK	1,370	–	–
Moustaki[114]	0–14	1996–1998	Greece	1,200	–	224
Naranje[115]	0–19	2010	USA	1,800	–	–
Randsborg[116]	0–15	2010–2011	Norway	1,801	560**	–
Rennie[84]	0–15	2000	Scotland	2,020	665	489
Südow[117]	0–17	2005–2013	Sweden	–	529**	–
Tiderius[66]	0–16	1993–1994	Malmö, Sweden	1,930	498	470
Vadivelu[118]	0–16	2000	UK	–	–	418
Wilcke[119]	0–17	2004–2010	Stockholm, Sweden	–	530**	–

*Based on the years 2006–2007. **Based on distal radius fractures.

In *Paper I* we found a pediatric fracture incidence of 1,786 fractures per 10^5 person-years. This should be compared with the highest reported incidence in the literature, 3,609 fractures per 10^5 person-years in Wales in 1996[74], and the lowest reported incidence of 1,200 fractures per 10^5 person-years in Greece in 1996–1998[114]. We also found that the most affected anatomical location was the distal forearm, followed by the fingers, distal humerus, and clavicula (Table 4). This too supports most previous reports, in that distal forearm fractures are the most common pediatric fractures, generally followed by finger fractures (Table 4).

Table 4.
The reported most common types of pediatric fractures in different studies.

First Author	Age-group	Study period	Geographic region	1st most common fracture location	2nd most common fracture location	3rd most common fracture location	4th most common fracture location
Bergman (Papers I–III)	0–15	2014–2016	Malmö, Sweden	Distal forearm (31%)	Fingers (14%)	Distal humerus (8%)	Clavicle (8%)
Christoffersen[72]	0–17	2010–2011	Norway	Fingers (22%)	Distal forearm (22%)	Toes (16%)	Clavicle (9%)
Hedström[63]	0–19	2006–2007	Umeå, Sweden	Distal forearm (26%)	Clavicle (11%)	Fingers (10%)	Ankle (7%)
Landin[68]	0–16	1975–1979	Malmö, Sweden	Distal forearm (23%)	Fingers (19%)	Carpal/ metacarpal (8%)	Clavicle (8%)
Lempesis[67]	0–15	2005–2006	Malmö, Sweden	Distal forearm (31%)	Fingers (15%)	Carpal/ metacarpal (10%)	Clavicle (7%)
Mäyränpää[65]	0–15	2005	Finland	Distal forearm (30%)	Fingers (16%)	Clavicle (6%)	Distal humerus (6%)
Rennie[84]	0–15	2000	Scotland	Distal forearm (33%)	Fingers (15%)	Metacarpal (8%)	Distal humerus (7%)
Tiderius[66]	0–16	1993–1994	Malmö, Sweden	Distal forearm (26%)	Fingers (16%)	Clavicle (9%)	Metacarpal (7%)

There are data supporting obvious differences in fracture incidence not only between countries, but also within the same country[62,64]. Differences in demography between countries and geographic regions may explain some of the reported variations[63,64,67]. Such differences could be different proportions of boys and girls in different studies, different proportions of children around the ages of the peak fracture incidence, and different proportion of children living in rural and urban areas, all of which are factors associated with the fracture incidence[62,67]. Other factors of importance could be differences in lifestyle and fracture-prone activities in different countries/geographic regions/time periods, differences in the preventive safety work, and differences in climate conditions, as in Sweden with a colder climate and thus a more snowy and icy environment in the north than in the the south[120].

Another factor of importance is ethnicity, as higher fracture incidences have been reported in children with white ethnicity than in children with black and South Asian ethnicity[64]. The reason could at least partly be explained by differences in bone mass[121], but it seems probable that differences in lifestyle, such as participation in sports[122] and other trauma-prone activities, may also contribute. In Malmö, where our studies took place in 2014–2016, 46% of all children had foreign background (defined by Statistics Sweden as born abroad or having two parents born abroad)[90,123]. This is substantially higher than the proportion of immigrants in the city of Umeå in northern Sweden[124], where pediatric fracture incidence was reported to be higher in the study by Hedström et al.[63], than in our study. It would therefore have been of great interest if we had had access to ethnicity data, to be able to evaluate fracture incidence in different ethnic subgroups, and to adjust for differences in ethnicity when comparing different studies or time periods.

When making comparisons between studies is it important to be aware that different studies use different classification systems. As previously explained (see *Discussion Page 61*), the different studies for example could use different distal forearm fracture classifications. Different ascertainment methods (study designs and data sources), different included age spans, and different included years could also affect the reported incidences.

We found a seasonal variation in pediatric fracture incidence in our studies. The general fracture incidence, along with the distal forearm fracture incidence, were highest in May and September, and lowest in December. This supports data in the literature that generally report higher incidences during the warmer than during the colder season[63,66,117]. We also speculate that the low incidence of fractures in July, most evident for hand fractures, could be influenced by the school break and thus absence of risk activities in schools for fractures, and that many sports have a summer break with no scheduled competitions during July[125]. This could then lead to less trauma exposure. These speculations are supported by our hand fracture etiology data, inferring that 42% of known etiology data occur during sports and 20% following activities in school. Furthermore, we cannot exclude that many families left Malmö during the vacation, so that fractures during this period were treated in other hospitals, with follow-up in Malmö not until August or with no follow-up visits at all. Such fractures will then be missed with our registration system. It is also important to acknowledge that there may be different seasonal variation for different types of fractures[126]. We also saw a difference in our studies, with the lowest fracture incidence for distal forearm fractures registered in December but the lowest incidence for hand fractures registered in July. We have no plausible explanation for this, but it seems reasonable that different types of activities are associated with different types of fractures, and that different seasons render different types of activity.

We also found obvious differences between the sexes in fracture incidences. We found that boys had higher incidences than girls, in respect of all types of fractures (*Paper I*), distal forearm fractures (*Paper II*), and hand fractures (*Paper III*), thus supporting data in the literature[63,65,72,93,113,118]. The differences between the sexes could be caused by differences in spare-time activities, with boys in general being more physically active than girls[127,128], and then being more exposed to trauma. Another sex difference could be due to differences in risk-taking behavior.

Girls had peak fracture incidence earlier than boys, for all types of fractures (*Paper I*), distal forearm fractures (*Paper II*), and hand fractures (*Paper III*). The discrepancy between boys and girls is supported by the literature[63,65,71,119,129]. The sex difference is often attributed to girls reaching puberty earlier than boys, and hence also the period when the peak in bone growth precedes the peak in bone mineralization, temporarily creating a weaker bone[10]. Another possible explanation is that the increase in fracture incidence could be due to sex-specific changes in lifestyle around puberty, including physical activity pattern and risk-taking behavior.

Fractures occurred in our study more often in the left than in the right arm (*Paper I*), this too supporting data in the literature[66,67] However, side preponderance varied depending on type of fracture. For example, distal forearm fractures were more commonly found in the left than in the right arm (*Paper II*), while metacarpal/carpal fractures were more commonly found in the right than in the left hand (*Paper III*). Similar data have been reported previously[68], as well as the fact that right-handed children most often sustain fractures in the non-dominant hand[130,131]. For left-handed children, the literature about dominant/non-dominant arm is conflicting. There are data both reporting that left-handed children most often sustain fractures in their dominant than non-dominant hand[130], but also the opposite[131]. We (and others) speculate that a non-dominant preponderance may depend on how we use the hands. It is possible that the dominant hand more often than the non-dominant arm is occupied by activity or holding an object during the trauma event, that a child consciously or unconsciously protects the dominant hand during a trauma and/or that the dominant hand is stronger and has better bone mass and muscle defense than the non-dominant hand and hence resists a trauma to a greater extent than the non-dominant arm[32,130,131].

Time trends in pediatric fracture incidence and pediatric bone mass

There have been a variety of studies that have evaluated time trends in pediatric fracture incidence in different geographic regions as well as during different time periods (Table 5).

Table 5.
The reported time trends in pediatric fracture incidence in different studies.

First Author	Age-group	Study period	Geographic region	Incidence in all fractures	Incidence in distal forearm fractures	Incidence in hand fractures
Bergman (Paper I–III)	0–15	2014–2016	Malmö, Sweden	Increase in 1950–1979 & stable 1979–2016	Increase in 1950–2016	Increase in 1950–1979 & decrease in 1979–2016
de Putter[132]	5–14	1997–2009	The Netherlands	–	Higher in 2009 than in 1997*	–
Hedström[63]	0–19	1998–2007	Umeå, Sweden	Higher in 2007 than in 1998	–	–
Jenkins[79]	0–16	2005–2015	Australia	Higher in 2015 than in 2005	–	–
Khosla[112]	0–19	1969–2001	USA	–	Higher in 1999–2001 than in 1969–1971	–
Koga[73]	6–14	1979–2007	Japan	Higher in 1999–2007 than in 1979–1987	–	–
Larsen[133]	6–15	1994–2018	Denmark	–	–	Lower in 2015–2018 than in 1994–1999**
Lempesis[67,93,113] (including data from Landin[68] and Tiderius[66])	0–15	1950–2006	Malmö, Sweden	Higher in 1976–1979 than in 1950/1955 & similar in 2005–2006 and 1976–1979	Higher in 1993–1994 than 1950/1955 & similar in 2005–2006 and in 1993–1994	Higher in 1976–1979 than in 1950/1955 & similar in 2005–2006 and 1976–1979
Mäyränpää[65]	0–15	1983–2005	Finland	Lower in 2005 than in 1983	Higher in 2005 than in 1983***	Lower in 2005 than in 1983
Orces[134]	0–19	2001–2015	USA	–	–	Decreasing from 2001 to 2015****
Südow[117]	0–17	2005–2013	Sweden	–	Lower in 2008–2013 than in 2005*****	–
Wilcke[119]	0–17	2004–2010	Stockholm, Sweden	–	Decreasing from 2004 to 2010*****	–

*Based on carpal fractures and distal radius fractures. **Based on metacarpal fractures. ***Based on forearm fractures. ****Based on fall-related fractures. *****Based on distal radius fractures.

We found in *Paper I* that there was a higher age-adjusted incidence of pediatric fractures in girls in 2014–2016 than in 2005–2006. In contrast, we found similar age-adjusted incidence for pediatric fractures in boys (*Paper I*) and in distal forearm fractures (*Paper II*) and hand fractures (*Paper III*) for both girls and boys in 2014–2016 and 2005–2006. Our results differ slightly from other published studies during this period, with a reported higher incidence in western Australia in 2015 than in 2005[79], a lower distal radius fracture incidence in Sweden in 2008–2013 than in 2005[117], and in the US during the period 2001–2015 a decreasing incidence in hand fractures[134].

When using joinpoint regression to evaluate time trends in pediatric fracture incidence, instead of just comparing the incidences between two periods, we found an increase in age-adjusted fracture incidence in 1950–1979, but after this similar incidence in 1979–2016 (*Paper I*). For distal forearm fractures the age-adjusted incidence increased during the entire period 1950–2016 (*Paper II*), and the age-adjusted incidence in hand fractures increased in 1950–1979 but decreased in 1979–2016 (*Paper III*).

The reported time trends (*Papers I–III*) may have occurred following concurrent time trends in society, such as the changes in proportion of children living in urban and rural areas[135], improvements in traffic and home safety work[89], a higher pediatric immigration during recent years[136], change in the proportion of children that attend fracture-prone sports activities and the introduction of totally new fracture-prone activities such as trampolines, skateboards, and mountain bikes. The general increase in screen time activities and the general decline in physical activity in children of today compared to historically[137-139], with now only 9–23% of Swedish children aged 11–15 years meeting the WHO recommendations of physical activity[140,141], could be other factors that influence the fracture incidence. With so many factors affecting fracture risk, it is difficult to use surrogate endpoints to predict the actual fracture risk. For example, a high level of physical activity is associated with high bone mass and high bone mass is associated with low fracture risk[29,31]. But very high level of physical activity is also associated with a high risk of sustaining fracture, independent of the prevalent bone mass value[142]. It is also possible that the increase in sedentary activities followed by a decrease in physical activity leads to less exposure to trauma and hence fewer fractures, perhaps explaining the stable age-adjusted fracture incidence 1979–2016 (*Paper I*) in spite of the indications that bone mass was inferior during the later years (*Paper IV*). Thus, lower bone mass (*Paper IV*) in conjunction with less exposure to trauma may overall result in unchanged age-adjusted fracture incidence (*Paper I*). It could also be that lower bone mass in childhood predominantly will be transferred to higher incidence in fragility-related fractures such as in the distal forearm. We therefore speculate that this could be one reason why in *Paper II* we found an increasing age-adjusted incidence in distal forearm fractures until 2016. We must then once more acknowledge that the fracture risk is dependent on many factors beyond bone mass, and no causal conclusions could be drawn based solely on bone mass. Furthermore, other bone traits are also of importance for fracture risk, such as bone geometry[20]. It could thus be that the lower bone mass in children measured in 2017–2018 compared to children measured in 1979–1981 (*Paper IV*) is compensated by geometrical changes in the skeleton that counteract a decline in bone mass. Further studies ought to be undertaken to evaluate this speculation.

In spite of the speculations above, bone mass is generally regarded as a strong risk factor for all types of fractures[23] and in children low bone mass is also generally related to fracture risk[143]. Since physical activity is one of the strongest determinants of bone mass[20], it is therefore of great concern to register a declining level of physical activity in children[137,140], which coincides, as we showed in *Paper IV*, with lower bone mass development during growth. In *Paper IV* we actually found indications that the predicted bone mass value at age 16 in 2017–2018 was around one SD lower that the predicted value in 1979–1981. Based on data in the literature, this could be translated into a doubled fracture risk[23,24,144]. It is then promising to also find data in the literature inferring that increased physical activity during childhood results in higher gain in bone mass and higher gain in muscle strength[29,30,145], followed by gradually reduced fracture risk[31]. We therefore speculate that the development of inferior bone mass suggested in *Paper IV* could be counteracted by lifestyle changes. But the concern still remains, since data corroborate that low bone mass in childhood is associated with high fracture risk in adulthood[33,35,36]. We are worried about what will happen with the fracture incidence when the children in *Paper IV* with one SD lower peak bone mass than historically become adults.

We cannot rule out however that the expansion of the health care sector during this period could have influenced our registrations and thus our inferences. It is possible that people in the 1950s were less inclined to seek health care and/or that physicians were more hesitant to send individuals to X-ray examination and used clinical diagnosis to larger extent than decades later when there were more available doctors and more available radiographic possibilities. Sweden had also a personal fee for X-ray examinations that was removed in 1970, possibly leading to a reluctance to participate in X-ray examinations for some individuals. In other words, it is possible that the proportion of fractures that was not objectively verified by radiographs (and then also missed with our identification system) was greater in 1950 than decades later. Furthermore, the inclusion of computed tomography (CT) and magnetic resonance imaging (MRI) in the diagnostic toolbox in more recent decades has also improved the ability to diagnose fractures.

Pediatric fracture etiology

We chose to use the Landin classification system[68] in *Papers I–III* to be able to compare our results with previous studies from Malmö[66-68], but also the NCECI system[86] to be able to register both place and activity related to the fracture-prone activity. By doing so we hoped to achieve a more accurate description of the trauma activities that resulted in fractures. There are different opinions on how to present etiology data. Some researchers prefer to present all included patients, also those with unknown fracture etiology, while others prefer to include only those with known fracture etiology to be able to compare proportions between fracture-prone activities[65,93]. The majority of the etiology tables in the papers present proportions based on known fracture activities. The tables based on all fracture data, including unknown, have been edited to reflect only known fracture data and appended as *Appendix 3*.

The most common injuries that resulted in fractures were in the Landin classification system sport injuries and in the NCECI classification playing injuries (*Paper I*). In both classification systems the most common injuries that resulted in distal forearm fractures were sport injuries followed by playing injuries (*Paper II*). Finally, the most common injuries that resulted in hand fractures were according to Landin classification sport injuries, and fractures acquired at school and according to the NCECI classification sporting injuries followed by playing injuries (*Paper III*). The finding that sport injuries and playing injuries are the most common fracture-prone activities in children is supported in the literature[63,66,67] However, it should then be acknowledged that it could be difficult to compare different studies as there are great discrepancies in the different etiology classification systems[63,65,70,80-85].

The most common sports activity that resulted in a fracture was ball sports (*Paper I–III*), with soccer being the most common ball game (*Paper I*). Soccer is the most popular sport in Sweden, which attracts most participants among children[127], often reported in the literature, at least in Europe, as the sports activity that leads to most fractures[65,84,146,147]. In our study fall was the most common trauma mechanism when evaluating all fractures together (*Paper I*) as well as distal forearm fractures (*Paper II*), supporting data in the literature that most fractures are the result of falls[66,67,76,84,85]. Mechanical force (caught or squeezed, bites, blows, and hit by moving object) was the most common trauma mechanism for hand fractures (*Paper III*), often occurring after the hand been squashed in a door, or hit by a football or following a blow to the hand. Finally, most fractures in children occurred after a slight injury (*Papers I–III*), this too supporting data in the literature[63,66,68].

We must also acknowledge that our data could be questioned due to the high amount of unknown etiology, that also varied between the decades (*Papers I–III*). This is also why we choose to present descriptive data but without any statistical calculations to draw conclusions as regards time trends. Due to this, we only speculate that the traffic safety work has resulted in fewer traffic fractures, with a lower proportion of fractures in 2014–2016 than in 1950/1955 (*Papers I–III*). We also hypothesize that the high proportion of playing injuries in *Paper I* in comparison to 1950/1955 is possibly due to changed playing patterns, with the introduction of trauma-prone activities such as trampolines, hoverboards, rollerblades, Segways, and kick scooters.

Strengths and limitations

Study strengths in *Papers I–III,* where pediatric fractures were registered in the period 2014–2016, include data collection with the same classification system and with participants living in the same city as in previous examinations. The use of ascertainment methods with validated low misclassification rates, and inclusion of only objectively verified fractures, without the risk of double counting, are other strengths. Joinpoint regression analysis, a method that better allows taking variations between periods into consideration, rather than just comparing two periods with each other, is also a strength when evaluating time trends. The inclusion of the NCECI classification system is another strength, which enabled us to collect information on both activity and place, not possible with the Landin classification system.

Study strengths in *Paper IV* include the possibility to evaluate Malmö children who were born almost four decades apart, that the children studied were from the same city, measurements were done by the same bone scanner, the same skeletal anatomic location was scanned, and phantom measurements conducted during the entire study period made it possible to adjust for the long-term drift of the apparatus. Another strength is that the scans, after being done were plotted in a random order by a single researcher.

Weaknesses in *Papers I–III* include the use of two different ascertainment methods. This was inevitable due to the change of the radiological archive system in 2001. Other weaknesses include the risk that fractures are not registered because they were assigned the wrong fracture ICD diagnosis code or that a summarized fracture diagnosis code was chosen (see *Discussion Page 60*), not included in our survey. Furthermore, fractures treated in another hospital with no follow-up visit in our hospital would also be missed. However, this ought to be a minor problem as the standard practice in Sweden is to have a follow-up visit to the home hospital, a visit where the fracture will be registered (if registered with an ICD-code included in our studies). Another problem is the small number of some fractures, for example scaphoid fractures in *Paper III*, rendering a high risk of type II errors, in this case making us refrain from statistical calculations. The vast proportion of fractures with unknown etiology, that varied greatly between periods, is another problem, making statistical calculations of differences between periods or estimating time trends in fracture etiology questionable. We must also acknowledge that more than 17 evaluated years during a total evaluated 66 years would also have provided greater power in the time trend analyses.

Weaknesses in *Paper IV* include the small simple size in children measured in 1979–1981 and that these children were not randomly selected, which could lead to selection bias. However, as bone mass in both cohorts was similar in the youngest ages and then became increasingly different over the ages, makes it more probable that differences in lifestyle during growth between the two cohorts could explain our findings, rather than selection bias. The inclusion of virtually only children of Caucasian ethnicity and from similar socioeconomic backgrounds makes it questionable whether our inferences could be generalized beyond these groups of children. It would also have been an advantage to have lifestyle factors evaluated, to be able to speculate on why we found the reported discrepancies between the two cohorts. Today we would probably also have used the most clinically used bone scanner when estimating bone mass, dual-energy X-ray absorptiometry (DXA), and then measured the regions normally used when predicting fractures in the clinical setting: total body less head, lumbar spine, and/or the hip[41]. However, DXA scanners were not available in our laboratory in 1979–1981 and as shown in the literature, SPA-assessed BMD in the forearm correlates to DXA measurements, and predicts fractures similar to DXA measurements[23,46,47]. It would also have been an advantage to have the bones measured by pQCT or even better high-resolution pQCT when comparing the children born 40 years apart.

Conclusions

- We found during the years 2014–2016 a total fracture incidence in all children of $1{,}786/10^5$ person-years.
- We found during the years 2014–2016 a distal forearm fracture incidence of $546/10^5$ person-years.
- We found during the years 2014–2016 a hand fracture incidence of $339/10^5$ person-years.
- The age-adjusted pediatric fracture incidence increased in both sexes in 1950–1979 and was stable in 1979–2016.
- The age-adjusted pediatric distal forearm fracture incidence increased in both sexes in 1950–2016.
- The age-adjusted pediatric hand fracture incidence increased in both sexes in 1950–1979 and decreased in 1979–2016.
- The age-adjusted fracture incidence in girls was higher in 2014–2016 than in 2005–2006 while the age-adjusted fracture incidence in boys was similar in 2014–2016 and 2005–2006.
- The age-adjusted distal forearm and hand fracture incidence in girls and boys was similar in 2014–2016 and 2005–2006.
- There were indications that children aged 7–15 in 2017–2018 develop lower bone mass compared to children in 1979–1981.
- There were indications that children aged 16 in 2017–2018 have around one SD lower bone mass than 16-year-old children in 1979–1981.
- Sports and playing injuries were among the three most common fracture-related activities in all fracture locations, in distal forearm fractures and in hand fractures.

Future perspectives

New studies within the same geographic area should be performed with regular time frames, to be able to follow fracture patterns in children. This would enable us to better predict future fracture burden and conduct improved priorities for the health care resources and health care planning. Pediatric fracture registries could also facilitate fracture analyses. It is also important to repeatedly conduct new etiology studies to identify new emerging fracture-prone activities in need of preventive work and to be able to evaluate whether historical fracture preventive work has been effective.

Our bone mass study must also be repeated in larger sample sizes and with all children included in a population-based manner, to confirm or to reject our findings. Such studies should preferably also use the more modern densitometric techniques when estimating bone mass. We regard our bone mass findings only as indications, which still lead to great concern, but that these should be verified or opposed in larger studies before inferences can be communicated to society at large. We also urge researchers to follow fracture epidemiology in those who were children at the beginning of this century, to evaluate whether children who grow up with general availability of screen time activities and with a lower general level of physical activity develop lower bone mass and higher fracture incidence compared to children who grew up four decades ago. At this moment, we cannot exclude our concern that that there may be a possibility of an increasing prevalence of osteoporosis and a higher fracture incidence in the future, time trends that would render more individual suffering due to fractures, and a substantial increase in health care burden and costs for society.

Populärvetenskaplig sammanfattning (Summary in Swedish)

En tredjedel av alla barn beräknas någon gång under uppväxten drabbas av ett benbrott (fraktur), där den vanligaste frakturen uppkommer i handleden och den näst vanligaste i handen. Studier har dock visat att frakturförekomsten, eller begreppet incidens som ofta används (insjuknandegraden, i detta fall antalet inträffade frakturer under ett år bland 100 000 individer), kan ha förändrats över tid. Även fördelningen mellan olika frakturer, samt varför en fraktur uppkommer, kan ha förändrats.

När vi ska bedöma risken för frakturer, bör vi ta hänsyn till den generella benmassan i befolkningen. Detta bör göras då låg benmassa är en riskfaktor för benbrott. Lyckas vi identifiera individer med hög frakturrisk (där benmassan ofta är del i denna bedömning), kan vi initiera förebyggande insatser för att förhindra frakturer. Då benbrott inte bara leder till stora individuella besvär, utan även hög sjukvårdsbelastning och höga samhällskostnader, bör detta vara ett prioriterat arbetsområde. Vi bör därför skaffa bästa möjliga grunddata inför våra beslut, genom att först identifiera den nuvarande frakturförekomsten, för att sedan värdera om det skett förändringar i frakturförekomsten. Vi bör även undersöka varför frakturer uppkommer, om orsakerna till frakturer har förändrats över tid, samt om benmassan hos barn har förändrats. Dylik information kan bidra till att politiker och tjänstemän inom hälso- och sjukvården kan förutse kostnader och kan prioritera och optimera sjukvårdsresurser på ett fördelaktigt sätt. Identifieras dessutom aktiviteter som ofta leder till frakturer, kan förebyggande åtgärder riktas mot dessa aktiviteter, något som förhoppningsvis kan minska antalet frakturer.

I de tre första delarbetena i avhandlingen inkluderades barn 0–15 år gamla, boende i Malmö, med minst ett besök på någon av fyra avdelningar inom Skånes universitetssjukhus (SUS) som tar mot misstänkta frakturpatienter, och där individen fått en frakturkod. Vi gick igenom dessa patientbesök under åren 2014–2016. Därefter kontrollerades diagnosregister, röntgenarkiv och journaler för att identifiera benbrott och samla information om bland annat ålder, kön, frakturlokalisation, fraktursida och hur frakturerna uppkom. Vi samlade data för samtliga frakturer och analyserade dessa, men även specifikt för de två vanligaste förekommande typerna, handledsfrakturer och handfrakturer. Därefter jämförde vi data från 2014–2016 med data publicerade i tre tidigare studier från Malmö, för att se hur frakturförekomsten har förändrats sedan 1950. Vi jämförde dels den absoluta frakturincidensen, och dels efter statistisk omräkning dvs. hur det hade sett ut om befolkningen i Malmö hade varit helt oförändrad under 1950–2016.

I det fjärde delarbetet i avhandlingen mätte vi, under åren 2017–2018, benmassan i handleden hos barn i Malmö i åldrarna 7–15 år med en apparat som benämns single photon absorptiometry (SPA). Detta är en mätteknik av benmassan som använder gammastrålning, och som utvecklades i Malmö på 1960-talet. Då en liknande studie hade utförts i Malmö med samma mätapparat på barn i samma åldrar under åren 1979–1981, kunde vi jämföra hur benmassan ser ut i en grupp barn mätta med ungefär 40 års mellanrum.

I de tre första studierna fann vi att frakturer var vanligare bland pojkar än bland flickor, och att de vanligaste åldrarna för ett drabbas i regel skedde något eller några år tidigare för flickor än för pojkar. Förekomsten av frakturer hos barn ökade från 1950 till 1979 men var från 1979 till 2016 stabil. Förekomsten av frakturer i handleden ökade däremot under hela perioden (1950 till 2016), medan frakturförekomsten i handen ökade från 1950 till 1979, men minskade från 1979 till 2016. Det verkar således som olika frakturtyper uppvisar olika förändring över tid. Sport- och lekolyckor var under perioden 2014–2016 bland de vanligaste orsakerna till frakturer, och bland sportolyckor skedde detta oftast vid utövning av bollsporter.

I den fjärde studien fann vi att barn under tillväxten som mättes 2017–2018 verkade utveckla en lägre benmassa än barn som mättes 1979–1981. När vi uppskattade skillnaden i benmassa hos barn vid 16 års ålder, hade såväl pojkar som flickor mätta 2017–2018, cirka 10% lägre benmassa än vad barnen hade för ungefär 40 år sedan. Då en av de viktigaste faktorerna som påverkar nivån på individens benmassa är graden av fysisk aktivitet, spekulerar vi i om den mer stillasittande livsstilen som har utvecklats hos dagens ungdomar, i takt med den allmänna introduktionen av datorer, surfplattor, smartmobiler och TV-spel, kan ha påverkat denna utveckling.

Sammanfattningsvis har våra studier presenterat uppdaterade data för barn rörande frakturförekomst, typ av aktiviteter som leder till frakturer samt generell benmassa bland barn. Dessa data gör att man bättre kan uppskatta kommande frakturbörda, och med det prognosticera och besluta hur sjukvårdens resurser skall fördelas. På så sätt kan vi öka möjligheterna att på bästa sätt optimera samhällets framtida sjukvårdsresurser. Med ledning av de data som identifierar frakturorsaker, kan vi även utvärdera om frakturförebyggande effekter varit effektiva, men även lokalisera nytillkomna aktiviteter som i hög grad bidrar till uppkomsten av benbrott, för att initiera nya frakturförebyggande åtgärder. Vi såg dessutom tecken till längre benmassa nu än för fyra årtionden sen, vilken kan förebåda en kraftig framtida ökning av benskörhet och antalet frakturer, men detta behöver bekräftas av fler studier.

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Appendix

Appendix 1

The protocol used for registration of fracture information – fracture type, trauma activity, trauma mechanism, and trauma severity – forms the Landin classification system[68].

Fracture type
Axial skeleton
• Facial bones
• Cervical vertebrae
• Thoracic vertebrae
• Lumbar vertebrae
• Sacrum
• Other pelvic bones
Appendicular skeleton
• Upper extremity
o Scapula
o Clavicle
o Humerus, collum chirurgicum
o Humerus, physiolysis proximal
o Humerus, diaphysis
o Humerus, supracondylar
o Humerus, physiolysis distal
o Humerus, lateral condyle
o Humerus, medial epicondyle
o Humerus, medial condyle
o Humerus, distal Y-fracture or comminuted, condyle
o Radius, proximal physiolysis
o Radius collum
o Radius caput
o Ulna, olecranon
o Radius and ulna proximal + diaphysis
o Radius diaphysis only
o Ulna diaphysis only
o Monteggia
o Galeazzi
o Radius and ulna distal
o Radius distal
o Radius distal, physiolysis
o Ulna distal, including physiolysis
o Scaphoid
o Other carpal bones or metacarpal bones
o Phalanges of the fingers
• Lower extremity
o Femur, collum
o Femur trochanteric fractures
o Femur subtrochanteric
o Femur diaphysis
o Femur, supracondylar
o Femur, medial condyle
o Femur, lateral condyle
o Femur distal, Y-shaped or comminuted
o Femur distal physiolysis
o Patella
o Tibia, medial condyle
o Tibia, lateral condyle
o Tibia, both condyles
o Tibia, eminentia
o Tibia, proximal physiolysis
o Tibia, proximal, other
o Tibia, diaphysis up to distal metaphysis
o Fibula proximal + diaphysis (without a tibia fracture)
o Tibia, distal physiolysis
o Fibula, lateral malleolus
o Fibula, lateral malleolus, physiolysis
o Tibia, medial malleolus
o Bimaleollar ankle fracture
o Other ankle fracture
o Calcaneus
o Talus
o Other tarsal and metatarsal bone
o Phalanges of the toes
Trauma activity
Home
Nursing, home, day-care center
School

• School yard
• School sports
Play activities
• Playground
• Playground fixture such as swings and slides
• Sleigh
• Pedal car
• Tricycle
• Skateboard
• Roller-skates
• Playground scuffles
• Other play accidents
Traffic
• Bicycle injuries (single injuries, falling off bicycle, collisions with pedestrians, other cyclists or unmoving objects, passenger on a bicycle, collision of bicycles)
• Cyclist hit by car or other heavier vehicle
• Extremity caught in bicycle wheel (spoke injuries)
• Pedestrian hit by bicycle or moped
• Pedestrian hit by car, bus, motor-cycle or streetcar
• Passenger or driver of car or tractor
• Passenger or driver of moped or motorcycle in single accidents or collision with pedestrian, bicycle or unmoving object
• Passenger or driver of moped or motorcycle in collision with car, bus or streetcar
• Other traffic accidents
Labor accidents
• Falling
• Injuries from tools, tractor, harvesting machine, chain saw or other machinery
• Other labor accidents
Sports

• Ball sports
• Skiing
• Ice-hockey – skating
• Water sports
• Gymnastics, athletics
• Contact sports such as wrestling, karate, judo, and boxing
• Falling from horse
• Horse-bites or kicks
• Other sport injuries
Fights
Not classified
Unknown
Trauma mechanism
Falling in the same level or similar trauma
Falling from height
Caught or squeezed
Bites
Blows
Hit by moving object
Birth injury
Battered child
Repeated minor trauma – stress fracture
Not classified
Unknown
Trauma severity
Slight
Moderate
Severe
Not classified
Unknown

Appendix 2

Protocol regarding place and activity from NCECI (NOMESCO Classification of External Causes of Injuries)[86].

Place of occurrence
Transport area
• Pavement, pedestrian mall
• Cycle ways
• Motorway
• Public road outside urban area
• Public road inside urban area
• Road, unspecified
• Bus station, railway area, freight terminal, etc.
• Quay, track way and vehicle access route in docks
• Transport area, other specified
• Transport area, unspecified
Residential area
• Kitchen
• Living room, bedroom
• Bathroom, washroom
• Stairs, indoors
• Residence indoors, other
• Residence, outdoors
• Playground in residential area
• Garden
• Private driveway, yard, parking area, garage, carport, path, walking area
• Residential area, other and unspecified
Production and workshop area
• Farm, market garden
• Forest and plantation as production area
• Mine, quarry, gravel pit, etc.
• Workshop, factory, shipyard
• Public works
• Buildings and roads under construction/demolition
• Warehouse, storage
• Administrative premises
• Production and workshop area, other specified
• Production and workshop area, unspecified
Retail, commercial and service area
• Shop, wholesale and retail area, auction building, market stall
• Private service area
• Hotel, motel
• Retail, commercial and service area, other specified
• Retail, commercial and service area, unspecified
School, institutional area and public premises
• Day-care institution for children and adolescents
• School, university, college
• School yard
• Playground in institutional area
• Buildings and offices accessible to the public
• Hospital, outpatient clinic, health center
• Nursing home, home for the sick, institution for the disabled
• Military institution
• School, institutional area, and public premises, other specified
• School, institutional area, and public premises, unspecified
Sports area
• Sports hall, gymnasium
• Sports ground (outdoors)
• Swimming pool
• Riding school
• Racetrack
• Indoor ice rink, skating rink
• Skiing and alpine facility
• Exercise/jogging-, ski trail
• Sports area, other specified
• Sports area, unspecified
Amusement, entertainment, and park area
• Restaurant, cafeteria, pub
• Discotheque, jazz club, dance hall
• Cinema, theatre, concert hall
• Amusement park, etc.
• Playground in park area, etc.
• Public gardens
• Grand-stand indoors/outdoors
• Amusement, entertainment, and park area, other specified
• Amusement, entertainment, and park area, unspecified
Open nature
• Uncultivated land
• Beach incl. foreshore
• Ice cap, glacier
• Camping site
• Military training area
• Open nature, other specified
• Open nature, unspecified
Sea, lake and river
• Sea, inlet
• Lake
• River, stream, canal
• Vessel
• Off-shore installation

• Ice on water
• Sea, lake and river, other specified
• Sea, lake and river, unspecified
Place, other and unspecified
• Place, other specified
• Place, unspecified
Activity
Paid work and transport
• Transportation as paid work
• Transportation between work places
• Paid work and transport, other specified
• Paid work and transport, unspecified
Paid work (not transport)
• Production, manufacturing
• Construction work
• Agricultural work
• Maintenance, repair work
• Cleaning, waste management
• Services
• Paid work, other specified
• Paid work, unspecified
Transport (excl. paid work)
• Transport to/from paid work
• Transport to/from educational inst.
• Transport, other specified
• Transport unspecified
Domestic activity (unpaid work)
• Cooking
• Cleaning, maintenance

• Garden work
• Do-it-yourself work
• Caring for child/relative
• Shopping
• Moving about in home
• Domestic activity, other specified
• Domestic activity, unspecified
Education
• Education, training
• Sports during education time
• Play during education time
• Educational activity, other specified
• Educational activity, unspecified
Sports and exercise
Play and other leisure activity
• Play
• Leisure/hobby activity
• Entertainment
• Recreation/holidaying
• Play and other leisure activity, other specified
• Play and other leisure activity, unspecified
Vital activity
• Taking meals
• Sleeping, resting
• Personal hygiene
• Vital activity, other specified
• Vital activity, unspecified
Activity, other specified
Activity, unspecified

Appendix 3

Re-calculations of tables in Paper I

Re-calculation of Table 2 in Paper I and presenting comparisons between age- and sex-adjusted incidences

Appendix 3 Table 1.
Unadjusted and age- and sex-adjusted incidence in all children aged 0–15 years in Malmö, Sweden, in 2014–2016 in all fracture types in comparison to 1950/1955, 1960/1965, 1970/1975–1979, 1993–1994, and 2005–2006. Incident rate ratio (IRR) with 95% confidence interval (95% CI) is used to describe the difference between two chosen time periods. The asterisk indicates a difference between the added calculations and the table in *Paper I.*

	Nominator	**2014–2016**	**2014–2016**	**2014–2016**	**2014–2016**	**2014–2016**
	Denominator	**1950/1955**	**1960/1965**	**1970/1975–1979**	**1993–1994**	**2005–2006**
All children	Unadjusted	1.32 (1.24 to 1.41)	1.23 (1.16 to 1.31)	0.92 (0.88 to 0.96)	0.95 (0.89 to 1.01)	0.97 (0.92 to 1.03)
	Age- and sex-adjusted	1.40 (1.31 to 1.49)	1.34 (1.26 to 1.43)	1.03 (0.98 to 1.07)	0.98 (0.93 to 1.04)*	1.05 (0.99 to 1.11)

* In *Paper I* the lower end of the CI in 1993–1994 was 0.92.

Re-calculation of Table 4A in Paper I after excluding all children with unknown fracture etiology

Appendix 3 Table 2.
Fracture etiology according to the NCECI classification in children aged <16 years in Malmö, Sweden, in 2014–2016, based on known fracture data and presented in defined places with activity leading to a fracture. Data are proportions (%). Comprising all places, 43% of known trauma was sporting activities, 45% playing activiites and 13% other.

Activity / **Place**	**Home**	**Day care**	**School**	**Sports area**	**Playing area**	**Other**	**Unknown**
Known	39	51	66	99	99	96	37
Unknown	61	49	34	1	1	4	63
Sporting activities	3	0	69	99	0	0	2
Playing activities	72	100	28	1	100	3	90
Other activities	25	0	3	0	0	97	8
Total	100	100	100	100	100	100	100

Re-calculation of Table 3 in Paper I after excluding all children with unknown fracture etiology

Appendix 3 Table 3.
All fracture etiology in Malmö children 0–15 years during six periods. Etiology is described as trauma activity, trauma mechanism, and trauma severity. Data are presented as proportions (%) of known trauma etiology.

	1950/1955	1960/1965	1970/1975–1979	1993–1994	2005–2006	2014–2016
TRAUMA ACTIVITY						
Known	**46**	**52**	**60**	**66**	**71**	**75**
Unknown	**54**	**48**	**40**	**34**	**29**	**25**
Home	**12**	**11**	**8**	**10**	**2**	**6**
Day nursery	**0**	**0**	**1**	**2**	**2**	**7**
School	**9**	**7**	**7**	**5**	**9**	**13**
Work	**1**	**0**	**0**	**1**	**0**	**0**
Traffic injuries	**25**	**25**	**19**	**18**	**13**	**8**
Bicycle	18	10	11	13	9	7
Pedestrian hit by vehicle	5	9	3	2	2	0
Moped, motorcycle	1	2	2	2	2	1
Car passenger	1	2	2	1	0	1
Other	0	1	0	1	0	0
Playing injuries	**25**	**28**	**26**	**25**	**27**	**31**
Playground	6	6	6	10	13	12
In-lines, skateboard	0	0	2	3	6	6
Sledge, other “snow”	2	1	3	2	2	1
Other	17	21	14	11	6	13
Sport injuries	**25**	**25**	**32**	**33**	**39**	**32**
Ball-game	8	10	15	15	24	22
Ice-hockey, skating	12	9	5	5	3	2
Gymnastics and athletics	1	1	1	4	2	1
Horse injuries	2	2	5	4	3	2
Wrestling, boxing, etc. “Contact sport”	1	1	2	3	2	1
Skiing	1	1	3	2	4	3
Other	1	1	1	1	1	1
Fights	**2**	**3**	**4**	**4**	**8**	**1**
Other	**1**	**0**	**2**	**1**	**0**	**1**
TRAUMA MECHANISM						
Known	**84**	**91**	**95**	**96**	**100**	**94**
Unknown	**16**	**9**	**5**	**4**	**0**	**6**
Falls	**83**	**82**	**83**	**70**	**68**	**70**
On the same plane	59	55	59	43	42	38
Between planes	24	28	24	28	26	33
Mechanical force	**16**	**17**	**16**	**24**	**24**	**26**
Non-classifiable	**1**	**1**	**1**	**5**	**8**	**4**
TRAUMA SEVERITY						
Known	**85**	**91**	**96**	**98**	**98**	**96**
Unknown	**15**	**9**	**4**	**2**	**2**	**4**
Slight	**65**	**60**	**67**	**65**	**66**	**67**
Moderate	**25**	**24**	**21**	**30**	**25**	**25**
Severe	**5**	**9**	**6**	**4**	**4**	**2**
Non-classifiable	**6**	**7**	**5**	**0**	**5**	**6**

Re-calculations of tables in Paper II

Re-calculation of Table 1 in Paper II and presenting comparisons between age- and sex-adjusted incidences

Appendix 3 Table 4.
Unadjusted and age- and sex-adjusted incidence in all children aged 0–15 years in Malmö, Sweden, in 2014–2016 in distal forearm fractures in comparison to 1950/1955, 1960/1965, 1970/1975–1979, 1993–1994, and 2005–2006. Incident rate ratio (IRR) with 95% confidence interval (95% CI) is used to describe the differences between two chosen time periods. The asterisk indicates a difference between the added calculations and the table in *Paper II*.

	Nominator	**2014–2016**	**2014–2016**	**2014–2016**	**2014–2016**	**2014–2016**
	Denominator	**1950/1955**	**1960/1965**	**1970/1975–1979**	**1993–1994**	**2005–2006**
All children	Unadjusted	1.4 (1.2 to 1.6)	1.5 (1.3 to 1.6)	1.2 (1.1 to 1.3)	1.1 (0.9 to 1.2)	1.0 (0.9 to 1.1)
	Age- and sex-adjusted	1.5 (1.3 to 1.7)	1.6 (1.4 to 1.8)	1.4 (1.2 to 1.5)	1.1 (0.998 to 1.2)*	1.0 (0.9 to 1.2)

* In *Paper II* the lower end of the CI in 1993–1994 was 0.996.

Calculation of NCECI in Paper II after excluding all children with unknown fracture etiology

Appendix 3 Table 5.
Distal forearm fracture etiology according to the NCECI classification, in children aged <16 years in Malmö, Sweden, in 2014–2016, based on known fracture data and presented in defined places with activity leading to a fracture. Data are proportions (%). Comprising all places, 48% of known trauma was sporting activities, 44% playing activiites and 8% other.

Place / Activity	Home	Day care	School	Sports area	Playing area	Other	Unknown
Known	31	68	65	99	99	96	40
Unknown	69	32	35	1	1	4	60
Sporting activities	0	0	63	99	0	0	1
Playing activities	64	100	37	1	100	2	96
Other activities	36	0	0	0	0	98	3
Total	100	100	100	100	100	100	100

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