

From THE DEPARTMENT OF WOMEN'S AND CHILDREN'S HEALTH
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FEMUR SHAFT FRACTURES IN CHILDREN:
AN EPIDEMIOLOGICAL AND BIOMECHANICAL STUDY

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Stockholm 2014

Cover illustration “Femur shaft fracture”, by Carl Heideken

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Published by Karolinska Institutet. Printed by Åtta.45 Tryckeri AB, Solna.

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To my family

ABSTRACT

Aims: The purpose of this thesis is to describe trends in the epidemiology and treatment of femur shaft fractures in children, to identify risk factors for femur shaft fractures and to compare the stability of various configurations of intramedullary nails to manage these fractures.

Background: There are no prior national epidemiologic studies of femur shaft fractures in children. Research indicates that sociodemographic factors are associated with increased incidence of childhood injuries. A child who suffers a fracture or a soft-tissue injury at a young age faces an increased risk of subsequent injuries during childhood. Intramedullary elastic nails are typically used to treat length-unstable femur shaft fractures among school age children. Another possible treatment is a semi-rigid pediatric locking nail.

Methods: In **Study I-III**, children with a diagnostic ICD-code for femur shaft fracture were selected from the Swedish national inpatient register and compared with age and sex matched controls. Demographic, socioeconomic and injury data were based on record linkage between six Swedish registers. The following cohorts were studied: **Study I:** Children (n = 4,984), 0-14 years of age, diagnosed in 1987 to 2005. **Study II:** Children (n = 1,874), 0-14 years of age, diagnosed in 1997 to 2005 compared with matched controls (n = 18,740). **Study III:** Children (n = 1,404), 1-3 years of age, diagnosed in 1990 to 2005 compared with matched children (n = 13,814). In **Study IV** twenty-four femur models with a length-unstable oblique midshaft fracture were used. Three groups with different combinations of titanium elastic nails (TEN) with end caps and one group with a pediatric locking nail (PLN) were biomechanically tested.

Results: Study I-III: The incidence of femur shaft fractures declined by 42% between 1987 and 2005. Treatment modalities shifted toward an increased use of operative treatment. Hospital stay decreased by 81%, from 26 days in 1987 to 5 days in 2005. Children whose parents had a university education had a reduced risk of femur shaft fractures during childhood. Fracture risk increased for older boys with younger parents and for older girls from low-income households. Neither family composition, number of siblings, birth order nor receiving social welfare influenced fracture risk. Boys with a femur shaft fracture at one to three years of age appeared to be at greater risk for a lower leg fracture that required inpatient care during childhood, but there was no significantly increased risk for upper-limb fractures or soft-tissue injuries. **Study IV:** PLN provided the greatest stability in all planes compared to TEN models with end caps, even though the difference from the two 4.0 mm or four 3.0 mm TEN models was small.

Conclusions: During the study period of 1987-2005, the incidence of femur shaft fractures decreased, there was a shift in treatment modalities and the length of hospital stay became shorter. Data indicate that sociodemographic variables influenced the rate of femur shaft fractures; in older children the influence differs between boys and girls. The risk for subsequent fractures in the lower leg that required inpatient care during childhood increased for boys but not for girls with a femur shaft fracture between the ages of one and three. PLN gives a biomechanically more stable construct than TEN in a model of a length-unstable oblique midshaft femur fracture.

LIST OF PUBLICATIONS

This thesis is based on the following original papers and manuscripts that will be referred to by their Roman numerals as indicated below:

- I. **Incidence and trends in femur shaft fractures in Swedish children between 1987 and 2005**
von Heideken J, Svensson T, Blomqvist P, Haglund Åkerlind Y, Janarv P-M.
J Pediatr Orthop. 2011 Jul-Aug;31(5):512-9.
- II. **Sociodemographic factors influence the risk for femur shaft fractures in children: a Swedish case-control study, 1997-2005**
von Heideken J, Svensson T, Iversen M, Blomqvist P, Haglund Åkerlind Y, Janarv P-M.
Acta Paediatr. 2013 Apr;102(4):431-7.
- III. **Femur shaft fracture at a young age and the risk of subsequent severe injuries during childhood: a cohort study**
von Heideken J, Svensson T, Iversen M, Ekbohm A, Janarv P-M.
BMC Pediatrics. 2014 Mar; 14:62
- IV. **Biomechanical comparison of semi-rigid pediatric locking nail versus titanium elastic nails in a femur fracture model**
Flinck M*, von Heideken J*, Janarv P-M, Wätz V, Riad J.
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Manuscript Submitted.

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LIST OF ABBREVIATIONS

AO	Arbeitsgemeinschaft für Osteosynthesefragen (German for “Association for the Study of Internal Fixation”)
ADHD	Attention deficit/hyperactivity disorder
CI	Confidence intervals
E-codes	External causes according to International Classification of Diseases
HR	Hazard ratio
ICD	International Classification of Diseases
IQR	Interquartile range (25th percentile to 75th percentile)
Kg	Kilogram
mm	millimeter
N	Newton
NAT	Non-accidental trauma
Nm	Newton meter
OR	Odds ratio
p	Probability
PLN	Semi-rigid pediatric locking nail
TEN	Titanium elastic nails

SUMMARY OF THE STUDIES

STUDY I: Incidence and trends in femur shaft fractures in Swedish children between 1987 and 2005.

Aim and methods: The aim of the study was to calculate the incidence of pediatric femur shaft fractures in Sweden by age, sex, cause of injury, severity of injury and seasonal variation during the period 1987 to 2005. The study also aimed to analyze the temporal changes in incidence, treatment modalities and length of hospital stay. Children (n = 4,984), 0-14 years of age, with a diagnostic code for femur shaft fracture in Sweden between 1987 and 2005 were selected from the Swedish Inpatient Register.

Results and conclusions: The overall annual incidence per 100,000 children was 16.4; 22.9 in boys and 9.5 in girls. The incidence declined by 42% between 1987 and 2005, with an average of 3% per year. The decline might to some extent be explained by broad society-based childhood safety prevention measures designed to reduce all injuries in children over the past few decades. The most common cause of injury in children younger than 4 years of age was a fall from a height of less than 1 meter. For children 4 to 12 years of age, sports accidents were the most frequent cause of injury, whereas traffic accidents were the most frequent cause of fracture for children 13 and 14 years old. During the study period, treatment modalities shifted from the use of traction to the increased use of external fixation and elastic intramedullary nailing. The length of hospital stay decreased by 81% between 1987 and 2005, from 26 days in 1987 to 5 days in 2005. However, change in length of stay had no correlation with the introduction of new surgical treatment methods. The change in length of stay might be explained by the introduction of home traction and increased pressure on the healthcare system to reduce costs.

STUDY II: Sociodemographic factors influence the risk for femur shaft fractures in children: a Swedish case-control study, 1997-2005.

Aim and methods: The aim of this population-based case-control study was to investigate how sociodemographic factors relate to the risk of femur shaft fractures in children and how this relationship differs by gender and age. Swedish children (n = 1,874) 0-14 years of age with a femur shaft fracture occurring between 1997 and 2005 were selected from the Swedish Inpatient Register and compared with matched controls (n = 18,740). Demographic, socio-economic and injury data were based on record linkage between six Swedish registers.

Conditional logistic regression was used to calculate adjusted odds ratio (OR) for the risk of the risk of femur shaft fracture and the cause of injury.

Results and conclusions: The risk of femur shaft fracture increased for children with younger parents and those living in low-income households. Having a parent with a university education was associated with a reduced risk of femur shaft fractures during

childhood. Stratifying for gender and age group, the association between parents' age was evident only for boys 7-14 years of age, and the association between living in low-income households and fracture rate was seen only in girls 7-14 years. Family composition, number of siblings, birth order or receiving social welfare did not influence fracture risk.

STUDY III: Femur shaft fracture at a young age and the risk of subsequent severe injuries during childhood: a cohort study.

Aim and methods: The purpose of this nationwide cohort study was to estimate the association between a femur shaft fracture at a young age and the subsequent risk of hospitalization for injuries during childhood. The subsequent risk of hospitalization for injuries during childhood among 1,404 children who were age one to three years of age when they suffered a femur shaft fracture was compared to the risk among 13,814 randomly selected, gender- and age-matched femur fracture free children.

Hazard ratios (HR) for severe injuries defined as fractures, or soft-tissue injuries requiring hospital admission, were estimated in a Cox proportional hazards model.

Results and conclusions: For children age one to three who had suffered a femur shaft fracture, boys exhibited a 162% increased risk of suffering a lower leg fracture requiring hospital admission. The fracture risk was not significant for girls. There were no significantly increased risks for upper-limb fractures or soft-tissue injuries for either boys or girls. This increased fracture risk is probably not simply the result of greater risk-taking among boys. The explanation might relate to factors affecting the bone quality of the lower leg.

STUDY IV: Biomechanical comparison of semi-rigid pediatric locking nail versus titanium elastic nails in a femur fracture model.

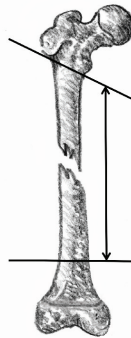
Aim and methods: The aim of this biomechanical study was to compare the stability of a length-unstable oblique midshaft fracture in a synthetic femur model stabilized with various combinations of titanium intramedullary elastic nails (TEN) to a pediatric locking nail (PLN). Twenty-four femur models with an intramedullary canal diameter of 10.0 mm were used. Three groups with various combinations of two or four TEN with end caps and one group with a PLN were tested. An oblique mid-shaft fracture was created, and the models underwent shortening, rotation, flexion/extension, and varus/valgus tests, with the forces corresponding to those generated during walking.

Results and conclusions: PLN provides the greatest stability in all planes compared to TEN models with end caps, although with a small difference compared to two 4.0 mm or four 3.0 mm TENs with end caps.

INTRODUCTION

Approximately one percent of all fractures in children are femur shaft fractures.¹ The Arbeitsgemeinschaft für Osteosynthesefragen (AO) definition of the femur shaft in children is the area between the greater trochanter and the distal metaphyseal area. The metaphysis is defined by a square whose side has the same length as the widest part of the distal femoral physis (Figure 1).² In this thesis, children are operationally defined as being between ages 0 and 14 years old. Almost all children with a femur shaft fracture require inpatient care. Compared to other pediatric fractures, the direct and indirect costs of femur shaft fractures are higher.³

Figure 1. Anatomic definition of femur shaft fracture according to AO.



OCCURRENCE OF FEMUR SHAFT FRACTURES IN CHILDREN

Femur shaft fracture incidence in children has been studied in the Scandinavian countries, the US, South Korea and South Africa (Table 1).⁴⁻¹² These studies have reported an annual incidence of femur shaft fractures between 9.5-13.3 in girls and 21.9-37.0 in boys per 100,000 children. However, epidemiologic studies of femur shaft fractures in children cannot be directly compared with each other. These studies differ according to the age of children included and age distribution probably differs between populations. Some studies have analyzed the medical records of children with femur shaft fractures,^{4,7,12} whereas others are based on registry data.^{5,8-11} Some studies include pathological fractures and fractures in patients with neuromuscular disorders.^{4-9,11,12} Other studies exclude them.¹⁰

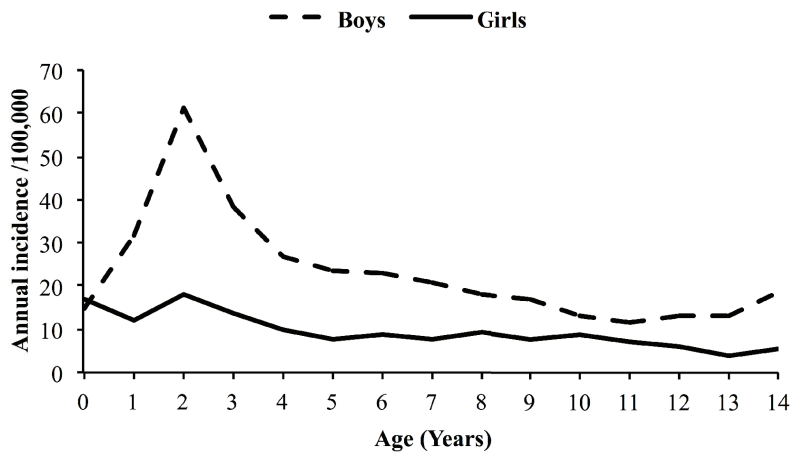
Pediatric femur shaft fractures are more common in boys than in girls in all age groups (Figure 2).¹⁰ The incidence of femur shaft fractures for boys and girls peaks among children aged one to three years.¹³ In this age group, the incidence is three times higher among boys than among girls.¹⁰ Although all types of fractures are more frequent in boys, such a great gender difference in this age group does not occur for other types of pediatric fractures.^{4,14} For children in this age group, the overall incidence of injuries and fractures is almost equal among boys and girls.^{4,15}

Table 1. Studies on the epidemiology of pediatric femur shaft fractures.

Scandinavian studies		
Author	Landin ⁴	Hedlund and Lindgren ⁵
Study area	Malmö	Stockholm
Time period	1975-1979	1971-1981
Number of patients	52	851
Age group	0-16	0-19
Annual incidence rate per 100,000 children	The incidence is not calculated for the study group but presented for 2-year age groups in boys and girls.	The incidence is not calculated for the study group but presented for 2-year age groups in boys and girls.
Boy/Girl Ratio	2.3:1	2.6:1
Author	Miettinen et al. ⁶	Nafei et al. ⁷
Study area	Kupio	Greater Aarhus
Time period	1976-1985	1977-1986
Number of patients	131	144
Age group	0-15	0-14
Annual incidence rate per 100,000 children	21.6 (not stratified for gender)	Boys: 37.0 (95% CI, 29-47) Girls: 13.3 (95% CI, 6-35)
Boy/Girl Ratio	Not presented	2.6:1
Author	von Heideken et al. ¹⁰ (Study I)	
Study area	Sweden	
Time period	1987-2005	
Number of patients	4 984	
Age group	0-14	
Annual incidence rate per 100,000 children	Boys: 22.9 (95% CI, 22.1-23.6) Girls: 9.5 (95% CI, 9.0-10.0)	
Boy/Girl Ratio	2.4:1 (95% CI, 2.3-2.6)	

Studies from the US		
Author	Hinton et al. ⁸	Rewers et al. ⁹
Study area	Maryland	Colorado
Time period	1990-1996	1998-2001
Number of patients	1485	851
Age group	0-17	0-17
Annual incidence rate per 100,000 children	Boys: 27.0 (95% CI, 25.4-28.7) Girls: 10.9 (95% CI, 9.8-11.9)	Boys: 27.4 (95% CI, 25.3-29.5) Girls: 11.5 (95% CI, 10.1-13.1)
Boy/Girl Ratio	2.5:1	Not presented
Studies from South Korea and South Africa		
Author	Park et al. ¹¹	Mughal et al. ¹²
Study area	South Korea	Cape town
Time period	2005-2009	2005-2009
Number of patients	Not presented	759
Age group	0-18	0-12
Annual incidence rate per 100,000 children	25 (95% CI, 24-26) (not stratified for gender)	21.9 (95% CI, 20.5-23.6) (not stratified for gender)
Boy/Girl Ratio	Not presented	2.2:1

Figure 2. Age-specific overall annual incidence rate for boys and girls in Sweden 1987-2005.



RISK FACTORS FOR FRACTURES IN CHILDREN

Inherited factors, lifestyle factors (e.g. nutritional factors, obesity and vigorous physical activity), behavioral characteristics of the child, the family, and the social and physical environment are some of the risk factors for fractures in children identified in previous studies.¹⁶⁻¹⁸

Data indicate that children without obvious metabolic bone diseases who experience their first fractures early in life are especially vulnerable to further fractures.^{4,19,20} One potential explanation for this finding could relate to lower-than-average bone-mineral density.²¹⁻²⁵ A recent meta-analysis by Clark et al. concluded that children who experience fractures have lower bone-mineral density than children who do not experience fractures.²⁶ This concurs with the first study on the subject by Landin and Nilsson, who analyzed bone-mineral content in children with fractures.²² A re-examination of the patients almost 30 years later showed that males with a fracture in childhood had a lower bone mass and smaller bone size at follow-up.²⁷

Regardless of location and the child's age, fracture risk is higher among boys than among girls. It has been suggested that greater skeletal fragility relative to body size contributes to this gender difference.²⁸ There is also a possibility that factors act together. Impaired bone strength, for example, may affect both girls and boys but increases the risk for subsequent lower limb fractures only among boys due to their greater tendency to engage in high-risk activities.

Sociodemographic variables such as parents' age, family composition, family size, birth order, having older siblings, including socio-economic factors such as parental education and family income, are associated with increased incidence of childhood injuries.²⁹⁻³³ However, research on the relationship between childhood fractures and sociodemographic variables is limited.^{8,9,34-40} One study conducted in the U.S. shows that femur shaft fractures in children are more common in areas of social deprivation.⁸ This result was confirmed in two studies – one from Denver, Colorado, and one from the West Midlands region of England. These studies included all types of femur fractures, not only femur shaft fractures, and compared fracture rate with sociodemographic variables for residential areas.^{9,34}

CAUSE OF INJURY

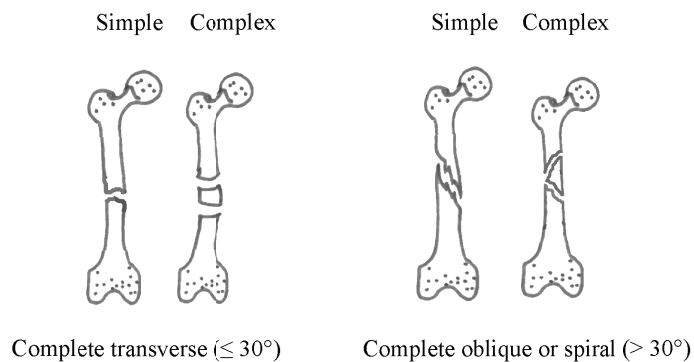
The etiology of femur shaft fractures in children depends on age and level of development. The most common cause of injury in younger children is a fall. Among older children, sports and traffic accidents (including single-bicycle crashes) are the most common causes of femur shaft fractures.¹⁰

In young children, especially under the age of one, there is a link between femur shaft fractures and non-accidental trauma (NAT).^{8,41,42} The American Association of Orthopedic Surgeons recommends that children younger than thirty-six months diagnosed with a femur shaft fracture should be evaluated for child abuse.⁴³ According to a recent review article by Kemp et al., there is no specific femur shaft fracture pattern indicating child abuse.⁴¹

FRACTURE CLASSIFICATION

Femur shaft fractures can be classified in a number of ways. One method of classification is according to fracture characteristics (Figure 3).²

Figure 3. AO comprehensive classification of pediatric long bone fractures. The angle is measured between the fracture line and the line transverse to the bone axis.



However, classifying a fracture according to AO reveals no information regarding the location of the fracture on the femoral shaft (proximal, mid or distal), whether the fracture is open or closed, or cause, e.g. traumatic or pathological. Nor does it tell us the age of the child, whether the fracture is a low-energy or high-energy fracture, or whether there are any associated injuries.

ANATOMICAL CONSIDERATIONS

The femur shaft changes in size, shape and bone structure during childhood. There is a change in the biomechanical properties, including increased bone strength, at about 1-2 years of age, when a child starts walking.⁴⁴ The cross-section of the femur shaft is rounded and thin in early childhood compared to the asymmetric shape and increased cortical thickness seen in adults.^{45,46}

The displacement of the femur shaft fracture is related to the forces exerted by muscles attached to the different fragments. In proximal shaft fractures, the pull of the iliopsoas, abductor and short external rotator muscles may cause the proximal fragments to flex, abduct and externally rotate. To align the fracture, the surgeon may need to flex the knee and abduct the leg in combination with traction. Midshaft and more distal fragments are usually better aligned due to the adductor and extensor muscles of the femur.⁴⁷

TREATMENT OF FEMUR SHAFT FRACTURES

There are at least 9 methods for treating femur shaft fractures in children (Table 2).^{48,49} The choice of method depends on the age and weight of the child, the type of fracture, additional injuries and the surgeon's experience. Non-surgical treatment is the first-line treatment for femoral shaft fractures in young children. However, in recent decades there has been a shift toward increased use of surgery and various types of home traction methods to enable faster mobilization and a shorter hospital stay.^{10,48,50} This shift has occurred without good evidence to support any specific treatment modality.⁴³

Table 2. Treatment of femur shaft fractures in children in various age groups

Treatment	Suggested age group
<i>Non-operative treatment</i>	
Pelvic harness	< 6 months
Padding	< 6 months
Hip spica cast	7 months-5 years
Skin traction (can be followed by hip spica cast)	7 months-2 years (\leq 15 kg)
Skeletal traction	2-4 years
<i>Operative treatment</i>	
External fixation	4-15 years
Elastic intramedullary nails	4-15 years
Semi-rigid pediatric locking nail	9-15 years
Submuscular plating	6-15 years

Pelvic harness or padding

The American Academy of Orthopedic Surgeons concluded in their 2009 evidence based report that a pelvic harness (Figure 4) is an option for treating femur shaft fractures in children younger than 6 months.⁴³ Another option for this age group is to wrap the leg in soft padding (Figure 5). Both methods avoid the need for sedation and the risk of skin problems related to spica cast. In this age group, healing of femur shaft fractures is rapid and the remodeling is better and therefore demands on reduction are less rigid. The harness or padding can be removed after 2-4 weeks.

Figure 4. Pelvic harness



Figure 5. Padding



Hip spica cast

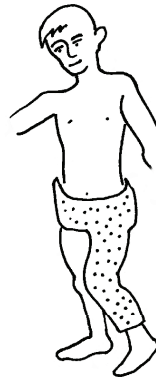
In the U.S., spica cast (Figure 6) is the preferred treatment for children age 7 months to approximately 5 years.⁴⁸ The cast is applied under sedation or general anesthesia.

Flynn et al published a study comparing single-leg walking hip spica cast (Figure 7) to traditional hip spica cast, in children 1 to 6 years old, and found similar orthopedic outcomes. A single-leg walking hip spica cast allows the child to be more independent.⁵¹

Figure 6. Hip spica cast



Figure 7. Single-leg walking hip spica cast



Traction

Skin traction is used for children up to 2 years old (≤ 15 kg) (Figure 8) and skeletal traction is used for children over 2 years of age (> 15 kg) up to 5 years of age. In skin (Bryant's) traction, the injured leg (or both legs) is elevated to a vertical position compared with skeletal traction ("90-90 traction"), so that the knee is flexed 90 degrees with a pin placed distally through the femur metaphysis. The child can be placed in skin traction after application of a femoral block for pain relief, while skeletal femoral traction is applied in the operating room under general anesthesia.

Regardless of the type of traction, the patient needs to stay in the hospital for 3-7 days to get accustomed to the treatment and for the acute pain to subside. After that, the patient is treated at home for another three weeks before traction is removed following radiographic control.⁵⁰ An alternative to home traction is to convert traction to a hip spica cast after a couple of weeks.⁵² For various reasons, home traction has not been introduced in many countries; however in Sweden, home traction has been very satisfactory and femur shaft fractures are rarely treated with hip spica casts (Table 4, page 19).^{10,50}

External fixation

In older children, external fixation (Figure 9) is especially useful for damage control in multitrauma patients and patients with open femur shaft fractures and their associated soft tissue concerns.⁵³ The technique is also beneficial for segmental or significantly comminuted fractures.⁵⁴ The external fixator is removed in anesthesia after 2-3 months.^{53,55}

Figure 8. Skin traction



Figure 9. External fixation



Elastic intramedullary nails

Elastic intramedullary nails is a surgical treatment for children starting at four years of age (Figure 10).⁵⁶ An alternative to elastic nails made of titanium (TEN) is less expensive stainless steel nails with a similar design.

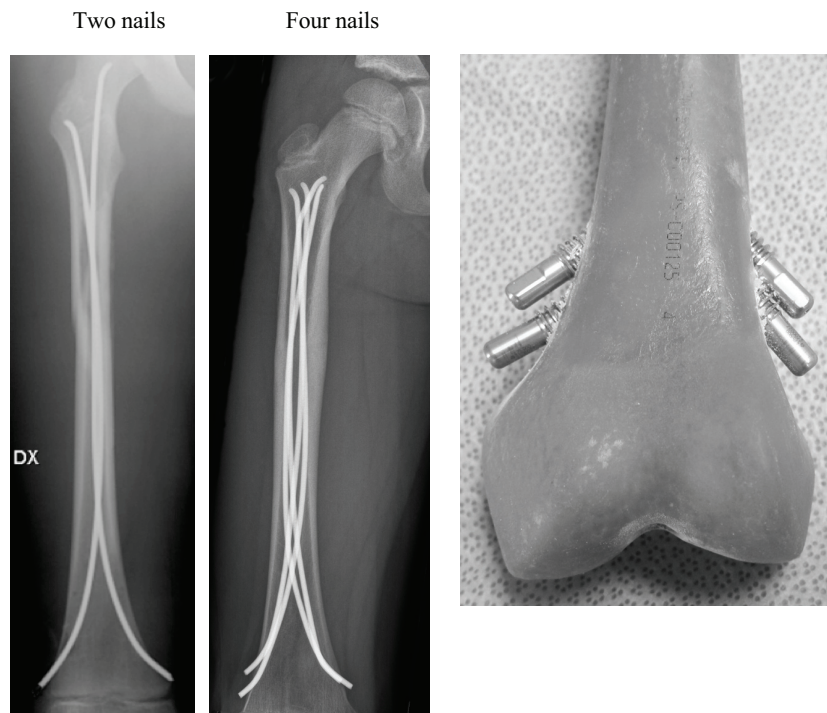
End caps can be used together with TEN to prevent nail migration (Figure 11). This may also prevent soft tissue irritation and loss of reduction (leg shortening).⁵⁷

The nail diameter should be 30-40% of the narrowest part of the medullary canal.⁵⁸ Inappropriate TEN sizes have been associated with femoral malunion⁵⁹⁻⁶¹ and femoral overgrowth resulting in leg-length discrepancy.⁶² To maximize stability, the nails should be pre-contoured with a long gradual bend before retrograde insertion and advance to the proximal metaphysis. Manufacturers of titanium nails recommend two

nails, although stability may be improved with more than two nails for femur shaft fractures. Nails are removed while the child is under general anesthesia 6-12 months after placement.⁶³

Figure 10. Titanium elastic nails

Figure 11. End caps



Semi-rigid pediatric locking nail

Semi-rigid pediatric locking nails (PLN) can be used from the age of 9 and is especially useful in unstable fracture patterns and patients weighing more than 45 kg (Figure 12).^{64,65} To avoid the potential risk of avascular necrosis of the femoral head, a lateral trochanteric entry point is used.⁶⁶

One advantage of this technique is that the patient is allowed to bear weight immediately after surgery. Compared to TEN, removal of the PLN nail requires more time in the operating room.

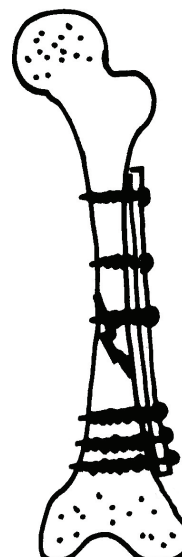
Submuscular plating

For patients over 5 years of age, minimal invasive submuscular plating is suitable for comminuted or long-oblique unstable femur fractures as an alternative to a semi-rigid pediatric locking nail (Figure 13).⁶⁷ The advantage of this approach is that there is no risk of injuring the supply of blood to the femoral head.⁶⁸ A small distal incision is used for plate placement and small incisions are used for screw placement.⁶⁹ The plate is removed under general anesthesia after approximately 6-12 months.⁶⁸

Figure 12. Semi-rigid pediatric locking nail



Figure 13. Submuscular plating



BIOMECHANICAL PROPERTIES OF VARIOUS FIXATION METHODS

Several studies address the biomechanical properties of femur shaft fractures in children using synthetic models beginning in 2001 with Lee et al., who studied the axial compression and rotational stiffness of the fixation of transverse and comminute midshaft femur fractures reduced with two elastic nails (Table 3) (Detailed information, see Table 1, Paper IV).⁷⁰⁻⁸⁴

Subsequent studies cannot be directly compared since they differ regarding the type of implant, fracture, and direction and force applied in the mechanical tests of the specimens. Most studies have investigated various aspects of elastic intramedullary nails. For example two studies concluded that prebending of elastic nails improved the

stability fractures of the femoral shaft.^{81,82} A majority of the biomechanical studies have studied elastic (reversible) deformation while Li et al., who studied TEN, and Porter et al., who compared TEN with locked plating, tested the specimens to plastic (permanent) deformation.^{78,84} Mani et al. concluded that external fixation was biomechanically more stable than flexible nails in a comminuted fracture model regarding prevention of axial shortening.⁷⁵ The mechanical properties of PLN or four TEN have not previously been analyzed.

Table 3. Summary of biomechanical studies of synthetic models of femur shaft fractures.

Author (Year)	Results
Lee et al., 2001 ⁷⁰	In transverse and comminuted fracture models stabilized with flexible intramedullary nail fixation (Ender nails), axial and rotational stability were found to be similar.
Gwyn et al., 2004 ⁷¹	Spiral fracture pattern exhibited the greatest stiffness in external rotation, and the oblique fracture pattern exhibited the greatest torsional stiffness in internal rotation in fracture models stabilized with two 4.0 mm TENs.
Fricka et al., 2004 ⁷²	In both transverse and comminuted fracture patterns, retrograde TEN fixation demonstrated significantly less axial range of motion and greater torsional stiffness than antegrade fixation.
Mahar et al., 2004 ⁷³	In torsion and axial compression TENs were shown to be more stable than similar stainless steel nails.
Green et al., 2005 ⁷⁴	TEN combinations with single nail diameter greater than 40% of the mid-shaft canal width were shown to prevent the fracture from being reduced.
Mani et al., 2006 ⁷⁵	TEN constructs demonstrated higher torsional stability than external fixation constructs.
Mehlman et al., 2006 ⁷⁶	Retrograde insertion of TEN was shown to provide greater stability of pediatric distal-third transverse femoral shaft fractures than antegrade insertion.
Goodwin et al., 2007 ⁷⁷	C- and s-shaped TEN placed in the antegrade position were shown to provide maximum stabilization of a distal femur fracture.
Li et al., 2008 ⁷⁸	Loads of ≥ 600 N lead to coronal and sagittal permanent deformation of 4.0 mm TEN.
Kaiser et al., 2011 ⁷⁹	Steel nails demonstrated greater stiffness than similar titanium nails.

Kaiser et al., 2011 ⁸⁰	The use of end caps was not shown to improve the stability in a spiral femoral fracture model stabilized with retrograde TEN.
Doser et al., 2011 ⁸¹	For transverse fractures of the femoral shaft, prebending of the TEN 0 to 30 degrees was shown to offer greater stability in the coronal and sagittal planes than 45 and 60 degrees.
Kaiser et al., 2012 ⁸²	To reduce varus deformity and shortening and improve stability in spiral fractures, pre-bend of the TEN should exceed 30°.
Volpon et al., 2012 ⁸³	End caps fitted to TEN may contribute to stabilization of fractures.
Porter et al., 2012 ⁸⁴	For unstable femur shaft fractures, locked plating provides a biomechanically more stable construct than TEN.

COMPLICATIONS

Children with femur shaft fractures usually heal with good clinical alignment and without loss of reduction. A complication that can occur after non-operative treatment of femoral shaft fractures in children is leg-length discrepancy.⁸⁵ This can be caused by overgrowth after the fracture has healed or when the fractured femur heals with shortening.^{47,52} Malunion (angulation) often results in varus and flexion of the distal fragment. Spontaneous correction occurs mainly in flexion/extension deformities, as well as, to a lesser extent, for varus/valgus angulation. Rotational malalignment is not remodeled to the same extent and spontaneous correction may take many years.^{86,87} However rotation is rarely symptomatic, Benum and Davids reported that up to 25° of rotational malunion seemed to be well tolerated.^{88,89} In cases where malunion is clinically relevant, osteotomy is performed to correct persistent deformity in older children and limb length discrepancy is managed by epiphysiodesis of the contralateral extremity.

Skin complications related to problems maintaining hygiene may cause hip spica cast adjustment and in some cases early cast removal.⁹⁰ Other complications related to hip spica casting are correlated with loss of reduction, causing malunion and limb length inequality.⁹¹

Compartment syndrome is a rare but devastating complication of skin traction caused by circulation impairment related to hyperextension of the knee and/or too tight application of the traction bandage.⁸³ Other complications related to the bandages are skin problems and peroneal nerve palsy. Pin infections may occur in skeletal traction (Table 4).⁴⁶

Table 4. Advantages and disadvantages/complications of hip spica cast and home traction.

Treatment	Advantages	Disadvantages/complications
Hip spica cast	Hospital stay 2-4 days	General anesthesia
		Risk of pressure sore
		Risk of loss of reduction
		Risk of Volkmann's ischaemia
Home skin traction	Femoral block avoids the need for general anesthesia	Hospital stay 3-7 days
		Risk of Volkmann's ischaemia
	Easy to apply	Risk of skin reaction
		Transportation by ambulance
Home skeletal traction	Easy to apply	Hospital stay 3-7 days
		Risk of pin infection
		Transportation by ambulance

TENs do not always provide optimal stability, and can result in shortening, angulation, and rotation.^{59,92,93} The most commonly reported complication related to TENs, however, involves nail migration, prominence, and irritation at the nail entry site.⁹⁴ The rate of complications on removal of the nails is reported to be low.⁹⁵

A PLN carries a potential risk of avascular necrosis of the femoral head due to the anatomy of the vessels to the femoral head. The nail can injure the apophysis to the greater trochanter which can cause growth disturbance, which can lead to coxa valga or narrowing of the femoral neck.^{96,97} However, these complications are reported in studies of methods using the greater trochanter or piriformis fossa as the entry site for the nail.⁹⁷

Nonunion is rare and seen more often after surgical fixation than conservative treatment.⁹⁸ Refracture is most commonly seen after external fixator and submuscular plate removal. One reason might be delayed union at the original fracture site or fractures through a pin tract or screw hole.^{99,100}

Flynn's criteria provides a summary of both major and minor potential complications after a pediatric femur shaft fracture treated with TEN (Table 5).⁶³ While easy to use

and understand, the score does not take into account the age of the child or the follow-up time after the fracture.

Table 5. Flynn scoring criteria for evaluating the results for femur shaft fractures in children treated with TEN.

	Excellent results	Satisfactory results	Poor results
Leg-length discrepancy	< 1.0 cm	≤ 2.0 cm	> 2.0 cm
Malalignment	< 5 degrees	≤ 10 degrees	> 10 degrees
Pain	None	None	Present
Complication	None	Minor and resolved	Major complication and/or lasting morbidity

PREVENTING FEMUR SHAFT FRACTURES IN CHILDREN

Currently Sweden has the lowest reported incidence of femur shaft fractures in the world (Table 1, page 5).¹⁰ This low rate may be related to broad society-based childhood safety prevention measures designed to reduce all injuries in children.

The most common cause of femur shaft fractures in children younger than 4 years of age is falls of less than 1 meter. Based on this etiology, safety measures should focus on these types of accidents in home and childcare environments. In children 4 to 12 years of age, safety measures should focus on prevention of sports accidents. Among the oldest children, traffic safety improvements are important in order to promote the decreasing trend of femur shaft fractures.

Four studies, including Study II, suggest that specific subgroups of children are at increased risk of femur shaft fractures based on sociodemographic characteristics.^{8,9,34,39} Trying to identify and target subgroups of children based on sociodemographic factors in an attempt to prevent femur shaft fractures is probably not either effective or ethical. Instead, public health campaigns should continue to target families with broad messaging as part of a population-based focus on “safety for all” rather than “targeted safety”.

ASPECTS ON EPIDEMIOLOGY AND STATISTICAL METHODS

Epidemiology can be defined as a field that examines factors affecting health, disease and injuries in a population.⁴⁶ Using national register datasets and applying epidemiological methods is an effective way to examine the incidence and treatment of injuries. This also enables studying the association between different risk factors and a rare injury such as femur shaft fractures in children.

When it comes to epidemiology, there are both descriptive and analytical observational study designs. Descriptive observational studies analyze the occurrence of a disease related to time, place or person. Incidence rate measures the number of new cases per population at risk in a given time period. This is usually measured in person-years and is commonly described as annual incidence and expressed in the form of cases per 100,000.¹⁰¹ Incidence rate can be adjusted to a specific distribution of a year or population. This is especially helpful when studying the change in rate over time, since the age distribution can change. Incidence rate can also be adjusted when comparing differences between populations with varying age distributions. When studying changes over time, linear regression can calculate a trend line. The regression line slope, β , indicates whether the number of new cases per time period is expected to increase or decrease. The relationship between two variables can be measured using correlation coefficients. These coefficients are between -1 and +1 and indicate the strength and direction of the linear relationship between two variables.¹⁰²

Case-control and cohort studies are two types of observational approaches to analyzing associations between diseases and risk factors.

A case-control study can be used to study potential risk factors (exposure). Cases having the disease or injury are compared to controls that are otherwise similar. Odds ratios are commonly calculated in case-control studies. The odds ratio represents the likelihood that an outcome will occur given a particular exposure, compared to the likelihood that the outcome will occur in the absence of exposure. The increase is calculated as the odds ratio minus 1, e.g. odds ratio of 1.16 is equal to a 16% increased risk. By the same token, an odds ratio below 1 implies a decreased risk. Conditional logistic regression provides a way of calculating the odds ratio for a set of risk factors. The model allows adjustment for variables that potentially affect the outcome (confounders) as well as looking at interactions between variables.¹⁰¹

An effective way to study exposure that is uncommon in the general population is a cohort study. This study design can measure the occurrence of a disease or injury within two groups, one of which is exposed and the other unexposed to a risk factor. The calculation of risk needs to take into account the amount of time that each person spends in the study. This can be done using a Cox proportional hazards model with the risk of a defined endpoint (the outcome) expressed as a hazard ratio. The hazard ratio is expressed and interpreted the same way as odds ratios.

There are different types of systematic errors (biases) that can affect the results of observational studies. To avoid selection bias, it is important that the cases chosen represent all cases in the population. In the selection of controls, it is important that they be representative of the population that produces the cases. Information bias occurs when data are collected differently between the two groups. Confounding is when the association between an exposure and an outcome is influenced by a third variable, which may lead to erroneous conclusions. Matching in the study design to minimize differences between the exposed and unexposed groups, such as age and gender, reduces the problem of confounding but does not eliminate it.

RATIONALE FOR THIS THESIS

Prior to Study I there were five studies on the epidemiology of femur shaft fractures.⁵⁻⁹ None of them were nationwide. Moreover, there were no studies that focused on trends over time regarding the occurrence of femur shaft fractures in children or the treatment of this type of fracture.

Three earlier studies demonstrate that femur shaft fractures in children are associated with social deprivation.^{8,9,34} Before Study II, no study has examined sociodemographic data at an individual level for femur fractures, or the relationship between sociodemographic risk factors and a specific fracture type in children.

There is a peak in the annual incidence for femur shaft fractures for both boys and girls around the age of two. In the group of one to three years of age, the incidence is three times as high in boys as in girls.¹⁰ Children who experience their first fracture early in life are especially vulnerable to new fractures.^{4,19} Although all fracture types are more frequent in boys, such a large gender difference in this age group does not occur for other types of fractures.^{4,14} The reasons for the difference are unknown, but studies examining both the behavior of children in this age group and parent-child interactions describe greater risk-taking among boys and higher parental protectiveness toward girls.¹⁰³ The cause might be weaker bone structure, but could also be related to family or personal characteristics of these accident-prone children.¹⁰⁴ The rationale for Study III was that better knowledge of children with femur shaft fractures at a young age regarding subsequent injuries may help identify risk categories.

The rationale for Study IV is based on experience over the last 15 years at Astrid Lindgren Children's Hospital, where, based on the technique described by Ender, four titanium elastic nails are used when two nails have not provided enough stability for femur shaft fractures.¹⁰⁵ The justification for adding two more nails instead of switching to thicker nails is that they are easier to insert. Clinical experience shows that it is easier to achieve optimal fracture reduction with four thin nails than two thick ones. No biomechanical or clinical data have been published comparing TEN and PLN, and there are no previous studies comparing the stability of a fracture using four TENs instead of two for femur shaft fractures.

AIMS

The overall aim of this thesis is to describe trends in epidemiology and treatment, identify risk factors for femur fractures in children and compare the stability of various configurations of intramedullary nails.

Study I: To report the incidence of pediatric femur shaft fractures in Swedish children during the period 1987 to 2005, by age, sex, cause of injury, severity of injury, and seasonal variation. Furthermore to analyze changes in incidence, treatment modalities, and length of hospital stay over time.

Study II: To investigate gender and age differences in sociodemographic risk factors and their relationship with femur shaft fractures and injury mechanisms in children.

Study III: To determine to what extent a previous femur shaft fracture at 1 to 3 years of age increases risk of future hospitalization due to a fracture or soft-tissue injury during childhood and adolescence.

Study IV: To compare the stability of two and four TENs with end caps to a PLN in an oblique femur shaft fracture during physiologic loading in an experimental model.

PATIENTS AND METHODS

This thesis consists of four studies (I-IV). All children with femur shaft fractures included in Study II and III are also included in Study I. The flowchart and an overview of study design are summarized in figures 15, 17, 18 and 20. A detailed description of the patients and methods used can be found in Paper I-IV.

EPIDEMIOLOGICAL STUDIES (I, II, AND III)

Data sources for collecting cases and controls (Study I-III)

Study I-III used a data set created by record linkage between Swedish national registers (Figure 14). The record linkage was possible due to the Swedish personal identification number, which is a unique number assigned to all Swedish residents at birth or immigration.¹⁰⁶

Population-based registers

Since 1987, the *Swedish Inpatient Register* has had national coverage and contained information on all hospitalizations in Sweden.¹⁰⁷ Data include each patient's unique personal identification number, dates of hospitalizations, discharge code and external codes (E-codes) according to the International Classification of Diseases (ICD). ICD-9 was used in 1987 to 1996 and ICD-10 in 1997 to 2005.^{108,109} One county, Skåne, used the ICD-9 through 1997 and ICD-10 afterwards. The register also includes surgical procedures according to the Swedish version of *Classification of Surgical Procedures*.¹¹⁰ The quality of the registry data has been systematically reviewed, and the accuracy of the coding is reported to be high.¹¹¹ Hedlund and Lindgren conducted a validity study of 101 randomly selected cases in their study on femur shaft fractures in adults and concluded that 96% of the diagnostic codes and 98% of the external causes were correct.¹¹² *The Swedish Medical Birth Registry* includes data on the deliveries in Sweden since 1973.¹¹³ The register has mothers' personal identification numbers linked to their children. *The Cause of Death Registry* records data on cause and time of death on all deceased Swedish residents since 1961.¹¹⁴ *The Swedish Multi-generation Register* consists of data on individuals born from 1932 and onwards. The register includes the number of siblings, birth order and parents' personal identification numbers.¹¹⁵ *The Swedish Income and Taxation Register* contains data including family composition, social welfare, income and taxation data for individuals.¹¹⁶ *The Swedish Register of Education* contains information about the highest level of education in addition to the personal identification number for individuals living in Sweden.¹¹⁷

Definition of diagnostic categories

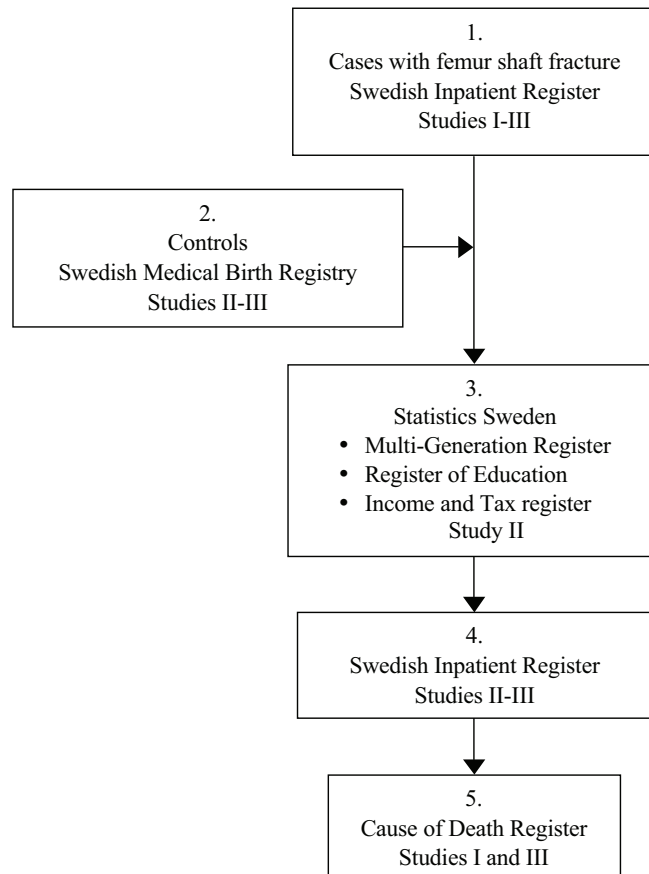
Children with a primary or secondary diagnostic code ICD-9/ICD-10: 821*/S72.3* (femur shaft fracture) were included in Study I-III. The symbol * corresponds to all fourth and fifth position codes in that interval. In ICD-9, fracture of femur, part unspecified, is included under diagnostic code 821*, and therefore we chose to also include children with ICD-10 diagnostic code S72.9 (fracture of femur, part unspecified).

Linkage of Data (Study I-III)

We created a database using five steps (Figure 14).

1. We identified children who suffered a femur shaft fracture between 1987 and 2005 in the Swedish Inpatient Register.
2. From the Swedish Medical Birth Registry, 10 controls were randomly selected for each fracture case. Controls were individually matched by gender, year of birth and county of residence.
3. Information regarding various sociodemographic variables including socio-economic factors was retrieved from Statistics Sweden, the Swedish government agency responsible for producing official statistics.
4. Additional information regarding all hospital admissions since birth, until the age of 14 or until 2005, whichever came first, was identified for exposed and unexposed children from the Swedish Inpatient Register.
5. Data were linked with the Cause of Death Register in order to retrieve dates of death.

Figure 14. Linkage of Data (Study I-III) in five steps.



STUDY I

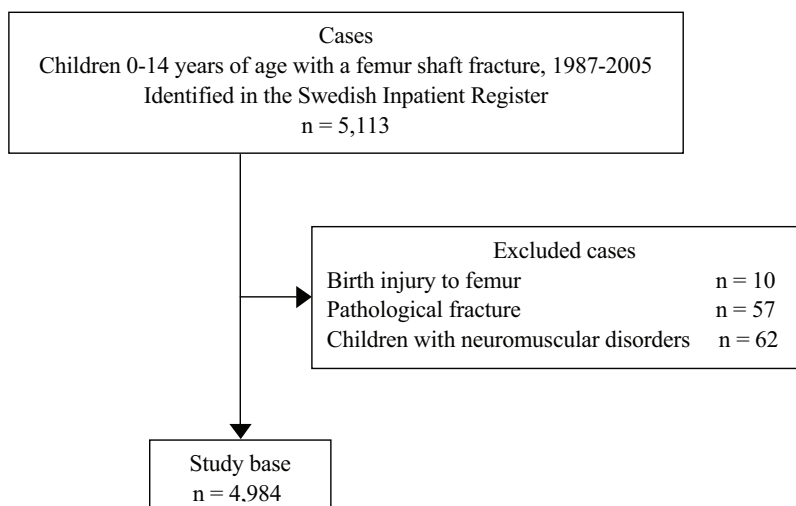
Included patients

Patients included in the study cohort consisted of children age 0 to 14 years admitted with a primary or secondary ICD diagnostic code for fracture of the shaft of the femur. Fifty-two children with an ICD-10 diagnostic code for fracture of an unspecified part of the femur were also included.

Excluded patients

Children with birth injury of the femur were excluded as well as children with pathological fractures and children with neuromuscular disorders.

Figure 15. Flowchart of Study I.



Design: Population-based observational study.

Study period: January 1, 1987 – December 31, 2005.

Exposure: Children 0-14 years of age when hospitalized for a femur shaft fracture.

Covariates: Gender and age group.

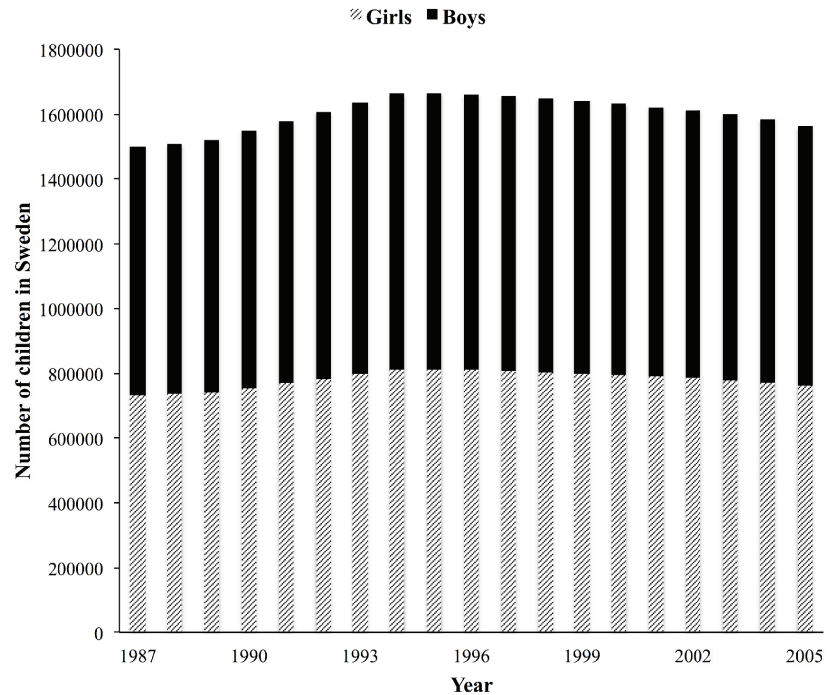
Outcomes: Fracture incidence, cause of injury, treatment, length of hospital stay.

Statistical Analysis: Poisson and Linear regression models and Spearman correlation coefficient.

Methods

Incidence was computed by comparing the number of children with a femur shaft fracture to the total number of children at risk, stratified by year of birth, year of fracture, and gender. The number of children at risk was provided by Statistics Sweden (Figure 16).¹¹⁸ The trend of incidence was adjusted to the age distribution in 2005, using Poisson regression. Descriptive statistics, such as counts, percentage, median with interquartile range (IQR), and cross tabulation were used to analyze data on mechanism of injury, severity of trauma, seasonal variation, treatment, and length of hospital stay. Cause of trauma according to E-codes was analyzed by severity and grouped into slight (fall at ground level and sports injuries), moderate (fall from a height of 0.5 to 3.0 m, fall on stairs, single accident on a bicycle, horse accidents) and severe (fall from a height > 3.0 m, traffic accidents).¹¹⁹ Data for sports accidents as a cause of injury are available only as of 1997, as this variable was not registered in ICD-9. Thus, only children who had ICD-10 E-codes were analyzed by severity. Trends over time were analyzed with linear regression models and the Spearman correlation coefficient.

Figure 16. Number of children, 0-14 years of age, in Sweden, 1987-2005.



STUDY II

Included patients

Children 0-14 years with a primary or secondary diagnostic ICD-10 code for femur shaft fracture between January 1, 1997 and December 31, 2005 identified in the Swedish Inpatient Register were included.

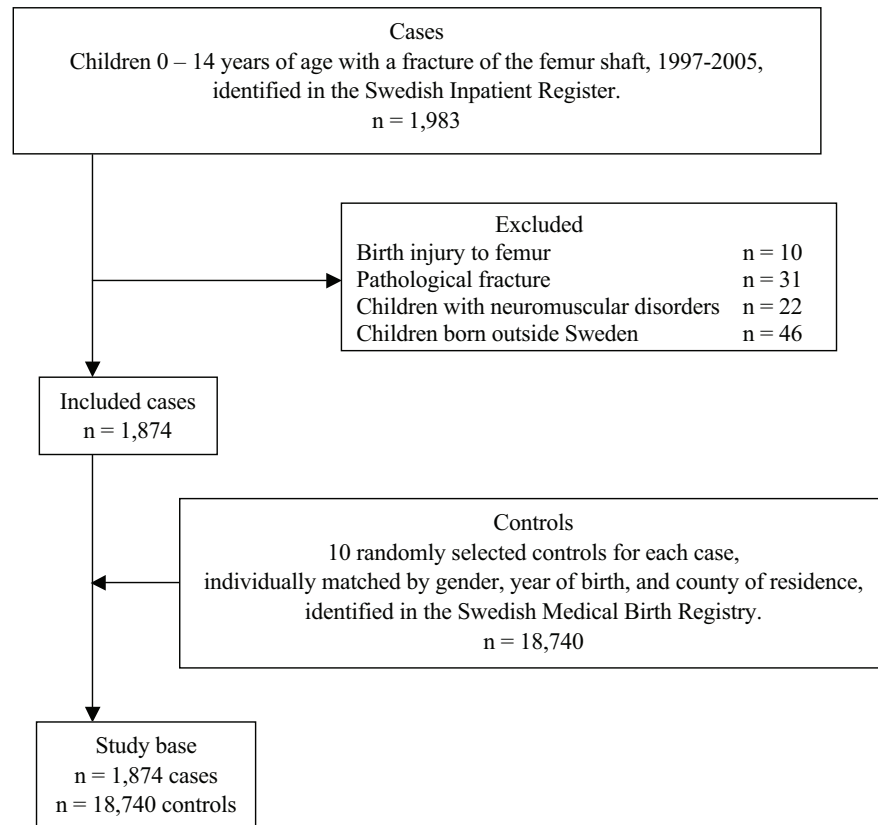
Excluded patients

Cases with a femoral birth fracture, children with pathological fracture and children with neuromuscular disorders were excluded. Since no controls were born outside of Sweden, patients born outside of Sweden were also excluded.

Controls

From the Swedish Medical Birth Registry 10 controls were randomly selected for each case. Controls were individually matched by gender, year of birth and county of residence. The controls had no previous diagnosis of fracture of the shaft of the femur in the Swedish Inpatient Register, and they were not a sibling to a case.

Figure 17. Flowchart of Study II.



Design: Population-based case-control study.

Study period: January 1, 1997 – December 31, 2005.

Exposure: Parents age, family composition, number of siblings, birth order, parents education, social welfare, adjusted total income.

Covariates: Gender, age group (0-6) and (7-14).

Outcomes: Femur shaft fracture and Cause of injury.

Statistical analysis: OR were estimated with Logistic and Conditional logistic regression.

Methods

Through the Swedish Multi-Generation Register, we linked the parents' personal identification numbers. Through this connection, data was retrieved about the parents' highest level of education at the year of fracture from the Swedish Register of Education. From the Swedish Income and Taxation register, data was retrieved on family composition, social welfare and total income after taxation for the families of cases and controls. Also through the Swedish Multi-Generation Register, the number of siblings for the cases and controls was identified, as well as birth order at the time of the fracture. The parents' average age (the sum of the parents' ages, divided by two) at the child's birth was grouped into the categories. Using ICD E-codes from the Swedish Inpatient Register, children were grouped into six categories according to cause of injury: fall of < 1 meter, fall of > 1 meter, unspecified falls, sports accidents, traffic accidents (all road users combined) and miscellaneous.

Descriptive statistics were used to characterize the sample. The median and interquartile ranges, counts and percentages were calculated. Cross-tabulations were used to investigate the relationship between predictor variables and outcomes to ascertain the potential for confounding and/or effect modification. The two primary outcomes for this study were the risk of fracture and the cause of injury. Fracture risk was calculated using logistic regression and expressed as a crude odds ratio (OR). Conditional logistic regression was used to calculate adjusted OR with 95% confidence intervals (CI) for the risk of our two primary outcomes. We stratified by gender and age at the time of fracture (0-6 and 7-14). Given the limited quantity of missing data (cases, 3.9%; controls, 5.0%), we did not impute values for missing data in the adjusted models.

STUDY III

Included patients (exposed)

Patients included in the study cohort consisted of exposed children, and the comparison cohort consisted of unexposed children. Exposed children were defined as one to three years of age with a femur shaft fracture between January 1, 1990 and December 31, 2005 identified in the Swedish Inpatient Register.

Excluded patients

Children with congenital medical conditions affecting bone quality were excluded from the analysis, regardless of time of diagnosis.

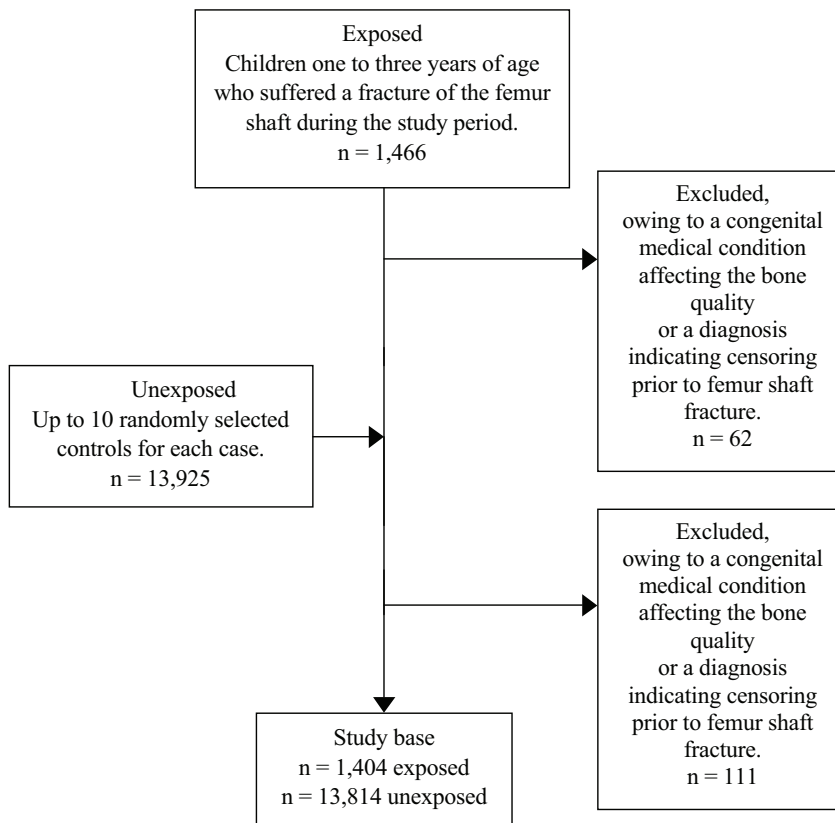
Controls (unexposed)

Up to 10 unexposed children (median 10; range of unexposed per case 7–10) were randomly selected for each exposed child from the Swedish Medical Birth Registry. Unexposed children were individually matched by sex, year of birth, and county of residence. The unexposed children had no diagnosis of femur shaft fracture in the Swedish Inpatient Register, nor were they the sibling of a child with a femur shaft fracture.

Censored patients

Children were censored if they had received a diagnosis that might affect their bone quality or risk of trauma. This means that the child was included in the study until receiving a censoring diagnosis. A child who received a censoring diagnosis before the femur shaft fracture was excluded from the analysis.

Figure 18. Flowchart of Study III.



Design: Population-based cohort study.

Study period: January 1, 1990 - December 31, 2005.

Exposure: Children 0-3 years when hospitalized for a femur shaft fracture.

Covariates: Gender, follow-up time.

Outcomes: Fracture (upper limb and lower leg), soft-tissue injury.

Statistical Analysis: HR were estimated in a Cox proportional hazards model.

Methods

Descriptive statistics employed frequency and percentages. The two primary outcomes for this study were fracture and soft-tissue injury. The risk of having an outcome was calculated using Cox proportional hazards models and expressed as HR with 95% CI. The hazard ratio was adjusted for year of fracture and the corresponding date for unexposed children, year of birth, and sex. The start of the follow-up was defined as the date of the femur shaft fracture for exposed cases and as the corresponding date for the matched controls. The follow-up continued until the patient received an injury diagnosis or a diagnosis that excluded him or her from study, died, or reached age 15, or until December 31, 2005, whichever came first.

A person could have more than one study endpoint (different injuries). Data were stratified by gender, and separate analyses examined fractures and soft-tissue injuries. Furthermore, fractures in the upper and lower extremities (except for femur fractures, regardless of location) were analyzed. The rationale for excluding femur fractures as an endpoint for the exposed children is that unexposed children had no diagnosis of femur shaft fracture in the Swedish Inpatient Register.

In addition, the number of children with the most common type of upper and lower limb fracture, as well as the most common soft tissue injury, were reported. Multiple fractures and multiple soft-tissue injuries, as well as injuries related to non-accidental trauma, were also stated. The assumption of proportional hazard was verified by comparing the difference in HR for follow-up time to injury between children with a follow-up period shorter than three years and children with a follow-up period of more than three years. No signs of insufficient proportionality were detected.

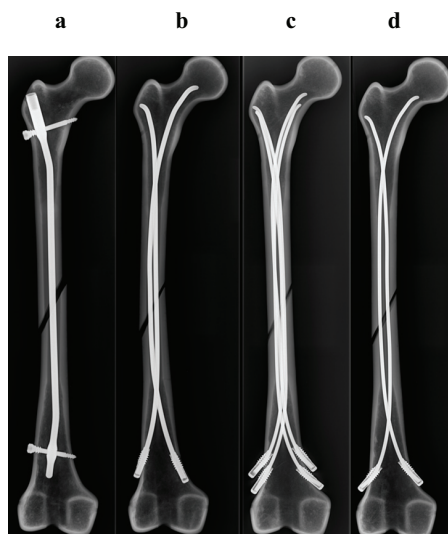
BIOMECHANICAL STUDY (IV)

The hypothesis of the study was that there was no difference between PLN regarding rotational stability, risk of shortening and bending in both the sagittal and coronal plane compared to TEN with end caps in an oblique unstable femur shaft fracture during physiologic loading.

Twenty-four synthetic composite pediatric-sized femur models (fourth generation; Sawbones, Pacific Research Laboratories, Inc., Vashon, WA) were used for mechanical testing. In previous biomechanical studies on femur shaft fractures in children, these pediatric synthetic models have been proven to appropriately represent biomechanical properties of human femurs.⁷⁰⁻⁸⁴

The femur models were 37.5 cm long with an intramedullary canal diameter of 10.0 mm, and they were divided into four groups (a, b, c, d) with six femur models in each group (Figure 19 and 20).

Figure 19. Frontal radiographs of femur models after fixation.



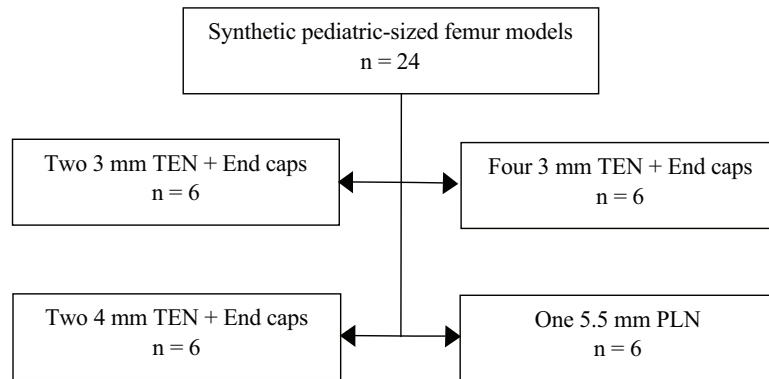
^a One 5.5 mm PLN

^b Two 4.0 mm TEN with end caps

^c Four 3.0 mm TEN with end caps

^d Two 3.0 mm TEN with end caps

Figure 20. Flowchart of Study IV.



Design: Experimental biomechanical study

Exposure: Shortening, Rotation, and Angulation

Outcome: Elastic deformation

Statistical Analysis: Mann-Whitney U test

Methods

The goal of the study was to test elastic deformation of femur models to a point that would be of clinical interest. Therefore, load data from a three-dimensional gait analysis in a group of five typically developed children, with a mean weight of 40 kg was used to test elastic deformation on the femur models (see Paper IV).

Biomechanical testing for axial shortening and axial rotation was performed with a material testing machine (MTS 160kN/1100Nm with Instron 8580+ control unit). The four-point bending test was performed using the testing device MTS 100 kN with Instron 8500 control unit (Figure 21).

The test consisted of a load-displacement cycle. Various strain rates were evaluated in pilot tests, and there were no relevant differences. A strain rate of 0.07mm/s was chosen. The test consisted of a preload of 50 N followed by four load-displacement cycles at 50% and 100% of the load calculated from the gait analysis. If the first specimen tested at 50% or 100% was considered a failure, the following two specimens always failed. Therefore the three final specimens were not tested and the whole group was considered to be a failure and not included in the statistical model. If the first specimen did not fail, none of the following specimens failed.

The groups that failed a mechanical test at 50% for the first three models were not tested at 100%. The groups that failed a mechanical test at 100% for the first three models were considered to be failures and were not included in the statistical analysis.

In each cycle, the predetermined load was reached and immediately unloaded, and the next cycle started as soon the specimen had returned to its original configuration. The fourth cycle was evaluated.

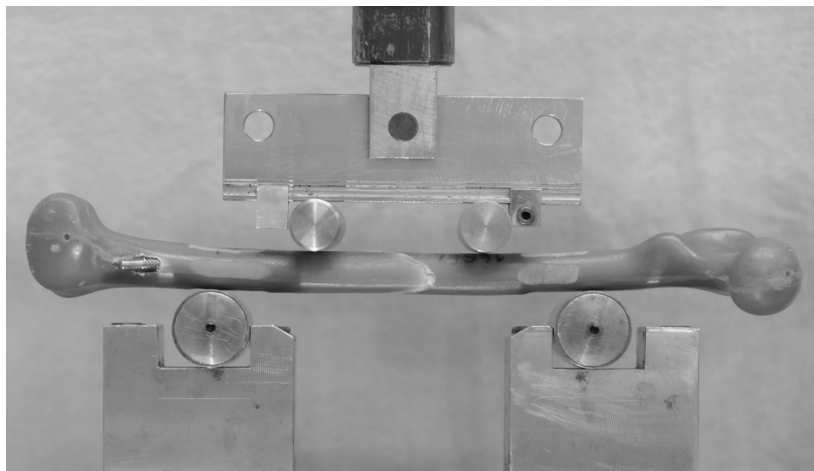
To simulate the normal load line in the femur models, compression force was applied through the mechanical axis, that is, from the center of the femoral head to a centered point between the femoral condyles.

The definition of failure was more than 10.0 mm of shortening during the test, which is in line with the radiological findings after stabilization according to the Flynn score for evaluating shortening after treatment of femur shaft fractures (Table 5, page 17).⁶³ Failure was also considered to be more than 20.0° degrees of rotation or angulation during the tests. Rotation was measured by the testing machine, while angulation was calculated based on the position of the loading and supporting pins of the four-point bending machine. Regardless of failure or not, each specimen always regained its original configuration, i.e. the deformation was considered to be elastic. In view of the fact that the deformation was elastic, it was appropriate to test each specimen in all six directions.

Six stabilized femur models from each group underwent an axial compression test, an axial rotation test, and a four-point bending test in both the sagittal and coronal plane.

Descriptive statistics such as median and range were calculated and presented. The Mann-Whitney U test was used to compare continuous variables between the various TEN-groups compared with the PLN-group.

Figure 21. Four-point bending test in the sagittal plane.



ETHICAL CONSIDERATIONS

Studies I-III were approved by the Stockholm Regional Ethical Review Board (Dnr2006/399-31 and complementary 2006/1442-32). Ethical approval was not necessary for Study IV.

STATISTICS

All statistical analyses in Study I-IV were performed using SAS for Windows (SAS Institute Inc., Cary, NC) and SPSS for Mac (SPSS Inc., Chicago, IL). Statistical significance was defined as $p < 0.05$. An OR or HR were considered significant if the 95% CI did not include 1.00.

RESULTS

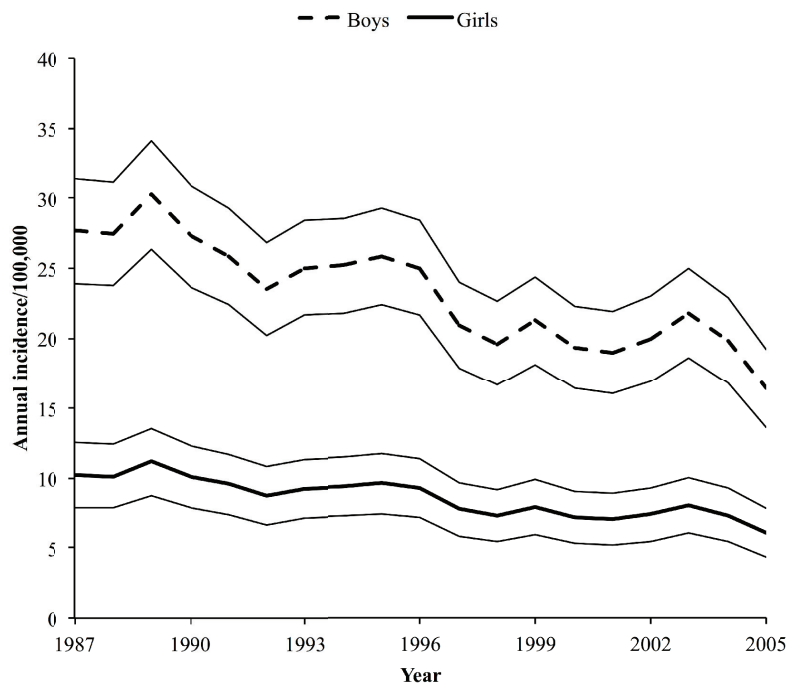
STUDY I

Incidence, Age, and Gender

The overall annual incidence per 100,000 children was 16.4 (95% CI 15.9-16.8), 22.9 (95% CI 22.1-23.6) in boys and 9.5 (95% CI 9.0-10.0) in girls. There was a peak annual incidence at the age of 2 years for boys and girls, 61.0 (95% CI 56.2-65.7) in boys and 17.8 (95% CI 15.1-20.4) in girls. The overall boy/girl incidence ratio was 2.4:1 (95% CI, 2.3-2.6) (Figure 2, page 7).

The annual incidence of femur shaft fractures declined continuously, on average 3% per year, during the study period. In total, the incidence decreased by 42% (42% in boys and 39% in girls), between 1987 and 2005 (Figure 22).

Figure 22. Age adjusted incidence per 100,000 children and year for children with femur shaft fracture as a function of calendar year of occurrence. Thin lines indicate 95% confidence intervals.



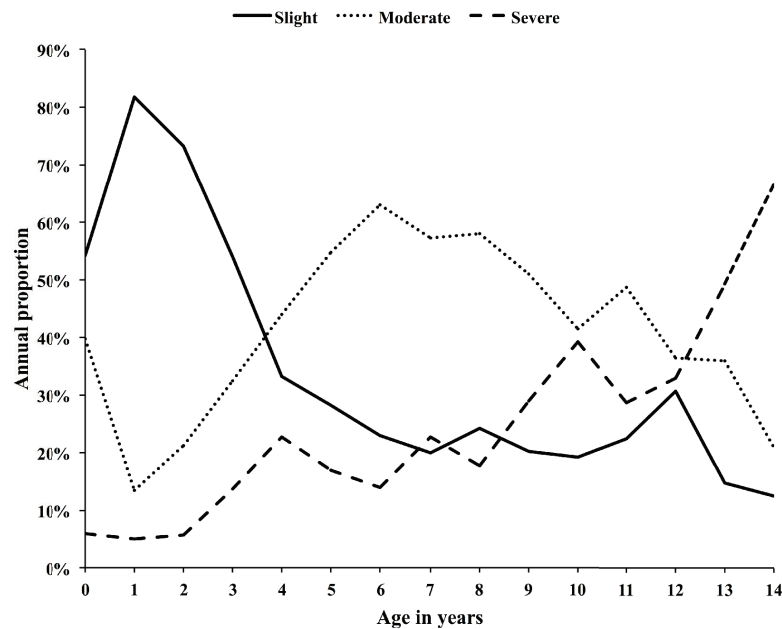
Cause of Injury, Severity of Trauma, and Seasonal Variation

Non-accidental trauma was recorded in 14 cases, 13 of these were among children under one year of age. Another 13 were recorded as undetermined whether accidentally or purposefully inflicted, 9 of these were under one year of age.

Slight trauma was most common among children 1 to 3 years of age, and the severity of trauma increased with age but showed no correlation with gender (Figure 23). The most common cause for accidental trauma for children under four years of age was a fall of less than one meter. For children aged four to twelve years, sports accidents were the most common cause of trauma. Traffic accidents were the most common cause for children aged thirteen to fourteen. During the study period, there was an annual decrease in the number of femur shaft fractures caused by traffic accidents, from 71 fractures in 1987 to 31 fractures in 2005 ($p < 0.001$).

The occurrence of femur shaft fractures varies during the year with peaks in March and August. In March sports accidents are responsible for the increase in incidence and in August the increase is caused by traffic accidents.

FIGURE 23. Annual proportions of severity of injury according to ICD-10 (1997 to 2005) for femur shaft fractures stratified by age and severity of cause of injury.



Treatment and Length of Hospital Stay

The proportion of patients treated with traction decreased from 60% in 1987 to 9% in 2005, and the proportion of patients treated with intramedullary nailing increased from 5% in 1987 to 34% in 2005 (Figure 24). There was a decrease in mean length of hospital stay during the study period, on average 1.2 days per year ($p < 0.001$). The median length of hospital stay decreased continuously, in total by 81%, from 26 days (IQR 11 to 41) in 1987 to 5 days (IQR 3 to 9) in 2005. The length of the hospital stay was reduced by 70% from 1987 to 1998, and the change occurred before a widespread introduction of the new treatment methods (Figure 25).

Figure 24. Annual proportions of treatment modality for children with femur shaft fracture in Sweden 1987 to 2005 by calendar year.

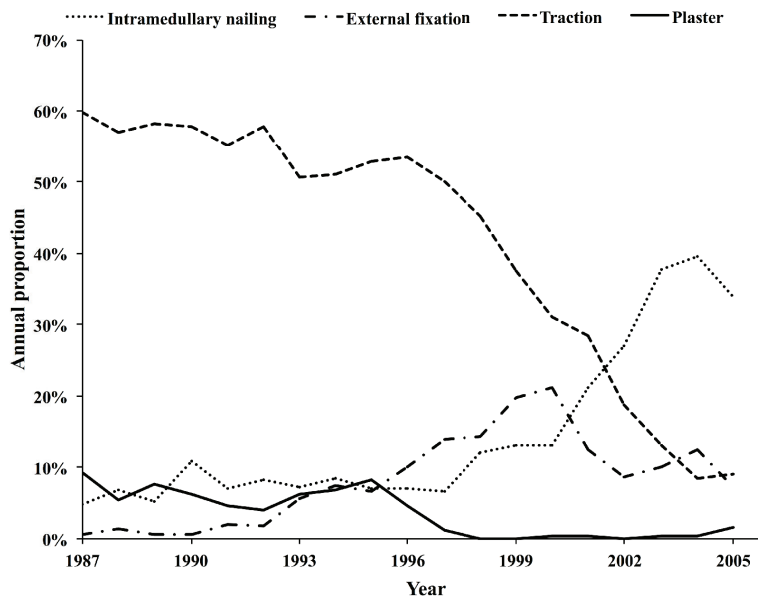
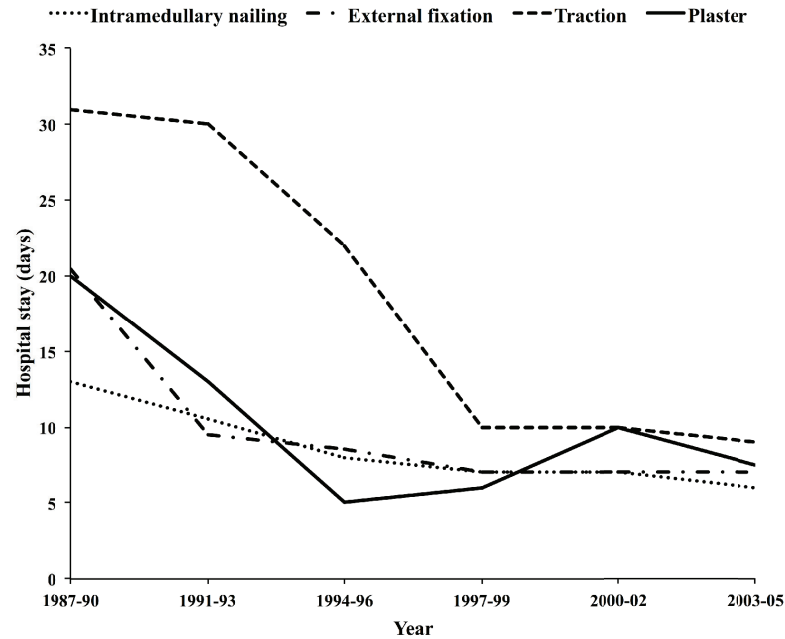


Figure 25. Median length of hospital stay for patients with femur shaft fractures stratified for treatment options in Sweden 1987 to 2005 by periods of 3 years.



STUDY II

The risk of a femur shaft fracture and the cause of injury were compared to the reference group for the different sociodemographic variables. For children with younger parents and those living in low-income households the risk of femur shaft fracture increased. A high level of education, that is, university education, decreased the risk of fracture by 12% (OR = 0.88; 95% CI 0.79-0.98) (n = 729), but this decrease could not be linked to specific gender and age groups. Stratifying for gender and age group, the association between parents' age was evident only for older boys (7-14 years of age) (OR = 1.40; 95% CI 1.11-1.77), and the association between living in low-income households and fracture rate was only seen in older girls (7-14 years) (OR = 1.50; 95% CI 1.01-2.22). Family composition, number of siblings, birth order or receiving social welfare did not influence the fracture risk (Table 5). Regarding the cause of injury, older boys with younger parents had an increased risk by 114% (OR = 2.14; 95% CI 1.06-4.33) (n = 51) for falls < 1 meter. With girls, we observed an increased risk of 268% (OR = 3.68; 95% CI 1.47-9.23) (n = 28) for traffic accidents falls if living in a low-income household.

Table 5. Adjusted OR and 95% CI for femur shaft fracture and association with sociodemographic variables, stratified for gender and age group.

Variable	Adjusted ^a OR (CI) for fracture			
	0–6 years age group		7–14 years age group	
	Boys	Girls	Boys	Girls
	Cases/Controls N=763/7,607	Cases/Controls N=293/2,884	Cases/Controls N=536/5,257	Cases/Controls N=208/2,052
Parents' age (years) ^b				
≤ 24	1.08 (0.85–1.37)	1.27 (0.88–1.83)	1.40 (1.11–1.77)	1.29 (0.87–1.92)
25–37	Reference	Reference	Reference	Reference
≥ 38	0.92 (0.71–1.21)	1.14 (0.76–1.70)	0.97 (0.67–1.41)	0.94 (0.55–1.62)
Family composition				
Two adult households	Reference	Reference	Reference	Reference
One adult households	0.88 (0.67–1.12)	1.09 (0.75–1.58)	1.16 (0.91–1.46)	0.71 (0.48–1.06)
Number of siblings ^c				
≥ 2	0.85 (0.60–1.20)	0.78 (0.43–1.43)	0.95 (0.61–1.48)	0.68 (0.34–1.36)
1	0.86 (0.69–1.06)	0.91 (0.64–1.30)	0.96 (0.63–1.47)	0.80 (0.41–1.53)
0	Reference	Reference	Reference	Reference
Birth order				
1 st child	Reference	Reference	Reference	Reference
2 nd child	1.15 (0.95–1.40)	1.17 (0.84–1.62)	1.13 (0.91–1.40)	0.96 (0.67–1.36)
≥ 3rd child	1.19 (0.84–1.69)	1.59 (0.86–2.93)	1.05 (0.79–1.41)	1.19 (0.74–1.92)
Parents' education ^d				
Elementary school	0.84 (0.58–1.22)	1.32 (0.82–2.10)	1.10 (0.75–1.62)	1.40 (0.79–2.48)
Upper secondary school	Reference	Reference	Reference	Reference
University	0.91 (0.77–1.06)	0.78 (0.60–1.02)	0.93 (0.77–1.12)	0.79 (0.57–1.08)
Social welfare ^e				
No parent	Reference	Reference	Reference	Reference
One or two parents	1.08 (0.83–1.40)	1.25 (0.82–1.89)	0.73 (0.51–1.03)	0.61 (0.32–1.15)
Total income ^f				
Low	1.17 (0.94–1.45)	1.01 (0.70–1.45)	1.19 (0.93–1.51)	1.50 (1.01–2.22)
Middle	Reference	Reference	Reference	Reference
High	1.04 (0.86–1.26)	1.26 (0.92–1.72)	0.92 (0.72–1.16)	1.30 (0.90–1.88)

^a Adjusted for all variables included

^b At infant's birth

^c At time for fracture

^d For the parent with highest level of education

^e The year of fracture

^f The year of fracture, the adjusted total income for parents was grouped into: low (the lowest 25% of the income distribution), middle (26 to 74% of the income distribution), and high (≥ 75% of the income distribution).

Significant values are printed in bold type.

STUDY III

97 children with injuries that required hospital admission among the exposed children during 12,234 person-years of follow-up (mean per child 8.7 years) were compared to 885 injuries that required hospital admission among the unexposed children during 120,849 person-years of follow-up (mean per child 8.7 years). Exposed children exhibited no significantly increased risk of upper-extremity fractures or soft-tissue injuries during childhood, regardless of sex and follow-up time. Boys exhibited a 162% increased risk of suffering a lower leg fracture requiring hospital admission (HR = 2.62; 95% CI: 1.45-4.71), but the refracture risk was not significant for girls (HR = 2.02; 95% CI: 0.58-6.97) (Table 6).

Table 6. Association between femur shaft fractures and injury requiring hospital admission.

	Number of events Exposed	Number of events Unexposed	HR^a (95% CI)
All injuries ^b	97	885	1.08 (0.88–1.33)
Boys	83	717	1.14 (0.91–1.43)
Girls	14	168	0.91 (0.42–1.98)
All fractures	54	388	1.38 (1.04–1.84)
Boys	47	312	1.50 (1.10–2.03)
Girls	7	76	0.91 (0.42–1.98)
Upper-limb fractures ^c	33	297	1.09 (0.76–1.57)
Boys	29	239	1.19 (0.81–1.75)
Girls	4	58	0.68 (0.25–1.86)
Lower-limb fractures ^{c, d}	17	68	2.49 (1.46–4.23)
Boys	14	53	2.62 (1.45–4.71)
Girls	3	15	2.02 (0.58–6.97)
Soft-tissue injury	46	562	0.80 (0.59–1.08)
Boys	38	457	0.81 (0.58–1.13)
Girls	8	105	0.76 (0.37–1.55)

^a Adjusted by matching for year of fracture and corresponding date for unexposed, age, and sex.

^b Injuries resulting in a fracture or soft-tissue injury requiring hospital admission.

^c Some children had experienced both upper- and lower-limb fractures.

^d Except for femur fractures (regardless of localization).

Significant values are printed in bold type.

STUDY IV

In Study IV, the results from 100% of loading during walking (median and range) are presented in table 7. The PLN-group was compared with the TEN-groups. One femur model, stabilized with two TEN with a diameter of 4.0 mm, broke during the test and was therefore excluded from the statistical analysis.

In axial shortening, the PLN was less compressed than the combination with two 4.0 mm TEN, 4.4 mm (3.4-5.4) respectively 5.2 mm (4.8-6.6); $p = 0.030$) (Figure 26). No difference was found in shortening between the PLN and the four 3.0 mm TEN (7.0 mm (3.3-8.4); $p = 0.065$). The two 3.0 mm TEN did not withstand the maximum shortening of 10.0 mm. In external rotation, the PLN rotated 12.0° (7.0-16.4) while the TEN models displaced more than the maximum of 20.0° . No model withstood maximal rotation of 20.0° internal rotation. In the four-point bending test, in the coronal and the sagittal plane, all combinations except two 3.0 mm TEN in extension, withstood the maximum angulation of 20.0° .

Figure 26. Axial compression load (N) versus deformation (mm) for fixation with PLN of the oblique femur shaft fracture during 100% loading calculated from gait analysis during walking (after a preload of 50 N).

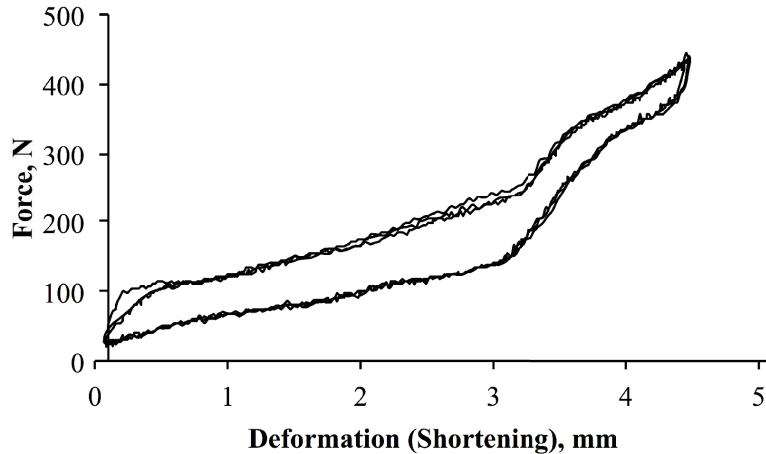


Table 7. Results of the biomechanics test with 100% loading. Comparison of deformation. The pediatric locking nail was set as the reference.

Test	One PLN 5.5 mm (n=6)		Two TEN 4.0 mm (n=5*)		Four TEN 3.0 mm (n=6)		Two TEN 3.0 mm (n=6)	
	Median (range)	p	Median (range)	p	Median (range)	p	Median (range)	p
Axial shortening (mm)	4.5 (3.4-5.4)		5.2 (4.8-6.6)	0.030	7.0 (3.3-8.4)	0.065	Failed	-
External rotation (°)	11.7 (7.0-16.4)		Failed	-	Failed	-	Not tested	-
Internal rotation (°)	Failed		Not tested	-	Not tested	-	Not tested	-
Varus angulation (°)	1.3 (0.9-2.0)		1.5 (1.2-1.9)	0.329	1.5 (1.1-2.1)	0.240	3.7 (2.2-4.9)	0.002
Valgus angulation (°)	1.9 (1.9-2.7)		2.3 (1.4-3.0)	1.000	4.0 (3.2-4.4)	0.002	6.0 (3.8-7.3)	0.002
Flexion (°)	2.3 (2.0-2.5)		2.8 (2.1-3.4)	0.052	3.6 (2.9-4.0)	0.002	6.0 (4.6-7.5)	0.002
Extension (°)	6.1 (4.5-6.4)		6.5 (5.3-8.1)	0.082	8.3 (6.0-9.1)	0.065	Failed	-

Failed = Three models exceeded the preset limits (>10 mm or >20°).

Not tested = Three models exceeded the preset limits (>10 mm or >20°) at 50% force and therefore not tested at 100% force.

* One femur model broke during the test and therefore was excluded from the statistical analysis.

Significant values are printed in bold type.

DISCUSSION

STUDY I

The significant decrease in the incidence of femur shaft fractures in Swedish children between 1987 and 2005 is the main finding of Study I. The decrease was on average 3% per year, rendering a total reduction of 42%. The decrease cannot be explained by the change in ICD in classification 1997. Bridgman and Wilson describe a similar reduction in the United Kingdom between 1991 and 2001.³⁴ A study by Mooney and Forbes from New England shows similar results between 1991 and 2000.¹²⁰ This is in contrast to a previous study from Sweden by Hedlund and Lundgren, where no significant changes in the incidence occurred between 1972 and 1981 and Landin who found an increase in the risk of femur shaft fractures.^{4,5}

Investigating the reasons for this decline falls outside the scope of this study but might to some extent be explained by reduced physical activity in children and increased safety in the traffic environment and on playgrounds during the past few decades.^{121,122} Broad prevention measures including injury prevention research, legislation (car seats for children), safety education and nationwide campaigns aiming to reduce injuries in children have probably also played a role in this reduction. The result is that Sweden has the lowest incidence of child deaths from injuries in the world.¹²²

The length of hospital stay was reduced by 81% from 1987 to 2005, and most of the change occurred before widespread introduction of new surgical treatment methods, such as external fixation or intramedullary nailing. One potential explanation for the decrease in hospital stay is increased pressure on the healthcare system to reduce costs and increase efficiency. For example, various types of home traction methods were introduced in Sweden during the 1990s to reduce hospital stay and thereby save costs.⁵⁰ The use of external fixation and traction showed a dramatic reduction during the last few years of the study period; these methods were replaced by elastic intramedullary nailing.

Although the present study uses a similar definition of non-accidental trauma (NAT) as previous studies examining femur shaft fractures in children, our study disclosed a remarkably low number of cases of NAT.^{8,9,123} There is a possibility that cases of NAT are recorded as an event of undetermined intent instead of NAT. A contributing cause might be the fact that in 1979, Sweden was the first country in the world to prohibit corporal punishment of children. However, the medical literature often stresses that there is always a risk of underestimating the prevalence of non-accidental trauma, and the figures reported in the present study, as well as in other epidemiological studies, are probably too low.^{124,125}

Strengths

- This is the largest epidemiological study regarding included cases and study period of femur shaft fractures in children and the first to examine trends including the change in treatment of femur shaft fractures in a national population.

Limitations

- This study is based on data from patients admitted to a hospital. Patients suffering from femur shaft fractures not treated at hospitals are therefore not part of the data. However, it is clinically unlikely that a patient with a femur shaft fracture would be treated as an outpatient.
- The study is registry-based and there is always the potential for misclassification, especially regarding external causes (e.g. falls < 1 meter).
- Using ICD-codes to identify non-accidental trauma probably resulted in an underestimate of the rate of physical abuse.
- The change in the ICD codes during the study period makes it difficult to study trends over time for the entire period, as sports accidents were probably registered as falls before 1997.
- There are missing data (26%) for the type of surgery and probably regarding non-accidental trauma for some patients. Most of the missing data about type of treatment are found in the age group of 0 to 3, and most of these children were probably treated with skin traction.

STUDY II

The key finding is that the relationship between sociodemographic factors and fracture risk depends on the child's specific subgroup. The difference in femur shaft fracture incidences between gender and age groups is well documented; however, the interactive effect of sociodemographic factors on fracture rate and injury mechanisms has, to our knowledge, not been analyzed separately for boys and girls of various age groups at an individual level.

Three previous studies have described the relationship between deprived residential areas and femur fracture risk.^{8,9,34} Hinton et al. conducted a small-area analysis (zip code level) in the U.S. to determine the association between sociodemographic variables and the rate of femur shaft fracture in 1990-1996. They analyzed data for 1,485 children who were younger than eighteen years of age. The authors stated that adverse socioeconomic conditions were significantly associated with a higher rate of femur shaft fracture. Specifically, there was an eight-fold increase in fracture rate in the lowest income areas compared with the highest income areas.⁸ Revers et al. analyzed data from 1,139 children in Colorado who were 0–17 years of age and suffered a femur fracture between 1998 and 2001. Of the included femur fractures, 62.5% were

shaft fractures. The study, which used census-based socioeconomic characteristics of residential areas, reported higher fracture risk in areas with lower socioeconomic indicators, except for children younger than 4 years of age.⁹ These results correspond to the results from the present study, but are contrary to a study from the West Midlands region of England. In the British study, Bridgman and Wilson used the deprivation score of Townsend for postal code areas and examined data for 3,272 children below the age of 16 with any type of femur fracture in 1991–2001. The incidence of femur fractures was associated with deprivation for both boys and girls age 0–4 and 5–9, but not in the 10–14 age group.³⁴

In the present study, increased fracture risk was found in older boys with younger parents. While the relationship between parental age and fracture risk has not been investigated to date, the relationship between younger parents and childhood injuries has been described in earlier studies.^{32,126-129} Hong et al. found higher risks of fatal injuries in children under five years of age among younger parents (< 20 years of age).¹²⁶ The correlation between younger mothers and the risk of childhood injuries has also been described in analyses of injuries taking place in the home environment.^{128,129}

The results also disclose a relationship between living in low-income households and increased fracture risk in older girls. Even though this association was low, probably due to the relative high degree of equality in Sweden, it is in accordance with previous research stating that childhood injuries are related to socioeconomic characteristics.^{38,128,130} Another conceivable explanation is that lower limb fractures have a weaker connection to socioeconomic factors than fractures of the upper limb, as shown by Menon et al.³⁸

Higher parental education was to some extent protective in our study, but in the stratified analysis concerning gender and age, there was no significant relationship. This lack of association could be due to the reduced size of the subgroups, but the influence of parental level of education is in agreement with several previous studies. It is generally accepted that education may enhance the development of family safety habits and better awareness of injury risks.^{32,128}

A plausible explanation regarding the lack of significant association between sociodemographic variables in younger children may be the use of public health campaigns, as injury prevention research, legislation and safety education campaigns have been successful in reducing injuries in this age group. Previous reports have concluded that pediatric injury prevention focuses on small children and home safety.¹³¹ As Engstrom et al. concluded, there are only negligible socioeconomic differences in injury risk among children age 0–4.¹³⁰ Another Swedish study reported no significant difference in risks for fall injuries between socio-economic groups among pre-school children.³³ Thus, fracture risk may be more heavily influenced by the socioeconomic characteristics of the child's neighborhood, as teenagers gradually become more independent of their parents.^{31,132}

Strengths

- The use of controls minimizes the confounding effect of exposures related to physical characteristics of living environments.
- No previous study has examined data at an individual level and focused on gender and the relationship between sociodemographic risk factors and a specific fracture type in children.
- The study illustrates both fracture rate and cause of injury.

Limitations

- The estimate of total family income may not be correct.
- The study analyzes one sociodemographic variable at a time. Cross-tabulations were performed for some variables but no confounding or effect modifications were found. It is not unlikely that sociodemographic variables interact, even though no such interactions were identified in this study.
- No information about exposure time for various causes of injury.
- No information about children's habitat, for instance whether urban or rural, was available.
- No information regarding ethnic groups was analyzed. Ethnic group may influence income at similar educational level and be correlated with deprived areas.

STUDY III

The main finding in this study was that boys who have suffered a femur shaft fracture at the age of one to three have an increased risk of subsequent lower limb fractures during childhood. Interestingly, there were no significantly increased risks of upper-limb fractures or soft-tissue injuries in boys or girls. The increased risk cannot be explained by simply pointing to higher levels of risk-taking among boys or the fact that children with fractures generally have lower bone mass or slenderer bones than children without fractures. The findings in this study may be explained by factors affecting the bone strength of the lower legs. Immobilization and associated periods of inactivity are known to induce bone mineral loss and muscle atrophy, and they affect the lower limb distal to the fracture site, thus influencing the risk of further fractures.^{133,134} A prospective study by Ceroni et al. examining bone mass in adolescents after a lower-limb fracture shows that full bone recovery can be seen after 18 months.¹³⁵ Study III shows an increased risk of lower leg fracture in boys regardless of whether the incident occurred within three years or more than three years after the original femur shaft fracture. This indicates that the explanation of loss of bone strength above is less probable.

This study provides valuable information regarding the risk of subsequent severe injuries during childhood. However, although repeated accidents contribute little to the overall accident burden, additional studies are needed to better understand the bone health of children, especially boys, who suffer a femur shaft fracture at a young age.

Strengths

- The novel aspect of this study is the prospective analysis that allows us to test the hypothesis that the risk of hospitalization for injuries, both fractures and soft-tissue injuries during childhood, is influenced by a femur shaft fracture at a young age and to determine whether fracture risk differs between boys and girls.
- Previous studies on recurring injuries have not evaluated soft-tissue injuries and fractures separately,¹³⁶⁻¹³⁸ and studies showing that an earlier fracture is associated with increased risk of new fractures during childhood have not included the risk of soft-tissue injuries in their analyses.^{4,19}

Limitations

- This study is based on data from patients admitted to a hospital. Patients suffering from trauma not treated at hospitals are therefore not part of the data.
- Charts or radiographs were not part of the data for this study. It was therefore not possible to confirm the diagnosis or side of each extremity injury.
- Since we did not use information from prescriptions, there may be children in our study with diagnosed or undiagnosed ADHD.
- Using ICD-codes to identify non-accidental trauma probably resulted in an underestimate of the rate of physical abuse.
- This study did not take sociodemographic variables into account.

STUDY IV

The most common surgical treatment for children age 4-14 in our clinic is TENs inserted in the distal femur in a proximal direction. Another treatment option, beside external fixator and submuscular plating,^{53,68} is the more recently introduced PLN.^{64,65} TENs are associated with more complications when used in long oblique or comminuted fracture patterns in older children compared to length-stable femur shaft fractures.^{59,93} Kanthimathi and colleagues compared the number of TENs used for the fracture fixation and found no advantage in using three instead of two nails.¹³⁹ On the other hand, based on clinical experience there is a possibility of enhancing the stability of a fracture using four TENs instead of two for femur shaft fractures, and this is borne out in the present study. There is conflicting evidence on the

value of end caps.^{80,140,57,83} It was not the intent of our study to evaluate whether or not end caps improved stability. We chose to use end caps, since the manufacturer recommends using end caps in length-unstable fractures.¹⁴¹

The main finding of this study is that the PLN results in a biomechanically more stable construct than the TEN when treating length-unstable oblique femur fractures even if the combination with two 4.0 mm intramedullary elastic nails (TEN) and with four 3.0 mm TENs, with end caps, also provided high stability, except for rotation.

From a clinical perspective, the results do not allow any far-reaching conclusions. The differences between the tested configurations that withstood the tests are small, and they probably have limited clinical relevance.

However, the increased stability for the PLN could maybe mean a faster and less painful rehabilitation and thus a potentially better outcome. The increased stability in rotation could also be of importance when performing derotational osteotomies. If the osteosynthesis with two TENs does not provide enough stability during the fixation of a fracture, adding two more nails is an alternative. The rationale for adding two more nails instead of changing to thicker nails is that it might be easier to insert and achieve optimal fracture reduction with 3.0 mm TENs than with the stiffer 4.0 mm TENs.

Strengths

- The mechanical properties of PLN have not been analyzed previously or compared to various configurations of TEN.
- No previous studies have compared the mechanical properties of a fracture using four TENs instead of two.

Limitations

- The use of synthetic bone does not provide the same stabilization, since there are no soft tissues, including the periosteum, as in vivo.
- This study does not report how much load is needed to create a plastic (permanent) deformity of PLN and TEN.
- The sample size is small.

CONCLUSIONS

- The overall annual incidence of femur shaft fractures per 100,000 children was 22.9 in boys and 9.5 in girls. During the study period of 1987 to 2005, there was a reduction of 42% in the incidence of femur shaft fractures, and the annual incidence rate at the end of the study period was 11.3 per 100,000 children. Of the fractures among children under the age of 1, 4.2% were caused by abuse. The severity of trauma increased with age but showed no correlation with gender. The occurrence of femur shaft fractures varies during the year, with peaks in March and August. Treatment modalities shifted toward increased use of operative treatment. The average length of hospital stay was reduced by 81%, and there was no clear correlation with the change in treatment methods.
- Having a parent with a university education indicated a reduced risk of femur shaft fractures. Stratifying for gender and age group, the risk of femur shaft fracture increased for older boys with younger parents. When the cause of injury was assessed in these older boys with younger parents, there was an increased risk of falls < 1 meter compared with parents with an average age of 25–37 years at the child’s birth. Living in low-income households increased the risk of fracture for older girls. When the cause of injury in these older girls was assessed, there was an increased risk of traffic accidents compared with households with a middle income (26% to 74% of the income distribution).
- Repeat accidents contribute little to the overall accident burden for children. An increased risk was found for subsequent fractures in the lower leg that require inpatient care during childhood for boys, but not for girls, who were one to three years of age when they first suffered a femur shaft fracture. Exposed children exhibited no significantly increased risk of upper-extremity fractures or soft-tissue injuries during childhood, regardless of sex and follow-up time.
- The PLN may results in a biomechanically more stable construct than TEN with end caps when treating length-unstable oblique femur fractures but the difference is small and does not, from a clinical perspective, allow for any far reaching conclusions.

SUGGESTIONS FOR FUTURE RESEARCH

Based on the findings of this thesis, future studies on children with femur shaft fractures could focus on the following suggestions.

- Analyzing the hospital discharge code in Sweden probably results in underestimating the prevalence of non-accidental trauma. There are other methods available to study the association between femur shaft fractures in children and physical abuse. One way is to analyze data from cases of assault against children reported to the police or to examine injuries and trauma from child abuse verdicts. Another possibility is to let a multidisciplinary child abuse team evaluate every child younger than 18 months of age with a femur shaft fracture.
- In Study I, we confirmed the unique sex ratio for femur shaft fractures in the age group of one to three. We were not able to find a plausible explanation for this in Study II or III. Further studies are needed to better understand the difference in incidence between boys and girls who suffer a femur shaft fracture at a young age. There is a possibility that the gender difference is related to the properties of the femur.
- For clinical use, it would be of value if biomechanical studies on treatment of femoral shaft fractures in children were complemented by prospective multi center-studies or studies based on national quality registers comparing clinical outcome after treatment of PLN and different numbers of TENs used for fracture fixation.

SAMMANFATTNING PÅ SVENSKA

I den här avhandlingen studeras diafysära femurfrakturer hos barn d v s frakturer på lårbenets mittersta del, en diagnos som kräver slutenvård.

Syfte: Syftet med denna avhandling är att beskriva trender i epidemiologi och behandling, att identifiera riskfaktorer för diafysära femurfrakturer hos barn samt att jämföra stabiliteten av olika märkepikar som används vid behandling av frakturen.

Bakgrund: Sociala skillnader påverkar risken för barn att drabbas av oavsiktliga skador. Ett barn som får en fraktur eller ett mjukdelstrauma har en ökad risk för ytterligare traumarelaterade skador under uppväxten. Instabila sneda diafysära femurfrakturer hos barn i skolåldern behandlas vanligen med flexibla titanspikar alternativt en semi-rigid märkepik.

Metoder: Barn med en diagnostisk kod för diafysär femurfraktur identifierades i det svenska slutenvårdsregistret och jämfördes mot matchade kontroller. Genom att koppla ihop sex olika register erhöles data om slutenvårdstillfällen, socioekonomiska och sociodemografiska faktorer. **Studie I:** Barn (n = 4 984) 0-14 år, diagnostiserade 1987-2005. **Studie II:** Barn (n = 1 874), 0-14 år, diagnostiserade 1997-2005 jämfördes med matchade kontroller (n = 18 740). **Studie III:** Barn (n = 1 412) 1-3 år, diagnostiserade 1990-2005 jämfördes med matchade barn (n = 13 932). **Studie IV:** Tjugofyra plastlårben med en instabil sned diafysär fraktur belastningstestades. Tre grupper med olika kombinationer av flexibla titanspikar med endcaps (TEN) och en grupp med semi-regid märkepik (PLN) testades biomekaniskt.

Resultat: Studie I-III: Den årliga incidensen minskade med 42 %, från 19,4 till 11,8 per 100 000/barn mellan 1987 och 2005. Vårdtiderna minskade med 81 %, från 26 dagar 1987 till 5 dagar 2005. Om barnet hade minst en förälder med universitetsutbildning minskade risken för lårbensskafftfraktur under barndomen. Risken ökade för äldre pojkar med yngre föräldrar och äldre flickor från hushåll med låg inkomst. Familjesammansättning, antal syskon, syskonordning eller socialbidrag påverkade inte risken att drabbas av diafysär femurfraktur. Pojkar med diafysär femurfraktur vid 1-3 års ålder tycks löpa större risk för underbens- och fotfrakturer som kräver slutenvård under barndomen, men inte någon ökad risk för mjukdelstrauma eller frakturer i övre extremiteterna. **Studie IV:** PLN är stabilare i alla plan jämfört TEN med endcaps även om skillnaden mot två 4,0 mm alternativt fyra 3,0 mm TEN är liten.

Slutsatser: Under studieperioden 1987-2005 identifierades en minskning av frakturincidensen, ändrade behandlingsmetoder och kortare vårdtider. Sociodemografiska och socioekonomiska variabler påverkar risken att drabbas av diafysära femurfrakturer. Hos äldre barn skiljer sig riskerna mellan pojkar och flickor. Pojkar som haft en diafysär femurfraktur i åldern 1-3 år verkar ha en ökad risk för frakturer i underbenet och foten. Denna riskökning sågs inte hos flickor. PLN ger en något mer biomekaniskt stabilare konstruktion än TEN av en instabil sned diafysär femurfraktur.

ACKNOWLEDGEMENTS

I would like to thank everyone who has contributed to this thesis. In particular, I would like to express my sincere gratitude to the following persons:

First and foremost, I wish to thank my main supervisor **Per-Mats Janarv**, not only for your curiosity, tireless enthusiasm in supervising me, your patience, and your impressive clinical knowledge of femur shaft fractures in children, but also for being fun to work with.

Associate Professor **Yvonne Haglund-Åkerlind**, former main supervisor and present co-supervisor, for trusting me and giving me the opportunity to start my doctoral studies. Your encouragement and advice during the first years of my Ph.D. influenced me at a great deal.

Associate Professor **Paul Blomqvist**, co-supervisor and a brilliant epidemiologist who unfortunately passed away much too early. His attention to both structure and details was fundamental to Study I-III.

Professor **Anders Ekblom**, co-supervisor, who generously took his friend Paul's place. You added many valuable perspectives and suggestions to this thesis.

Professor **Maura Iversen**, co-supervisor, for sharing your knowledge with me. Thank you for inviting me to Northeastern University where I spent four great months and benefited from a stimulating research environment.

Associate Professor **Lars Rhenberg** my former co-supervisor for encouragement to start my doctoral studies and many friendly discussions.

Tobias Svensson, statistician and co-author, for your patience and vital help with the database and statistical expertise. It has been a pleasure to get to know you and to work with you. You have always been generous with your time and advice and for that I am deeply thankful.

Marianne Flinck, Veronica Wätz and Jacques Riad, co-authors, with whom I had the great pleasure to work on Study IV.

Professor **Lars Weidenhielm**, mentor, for always being available to discuss ideas and answer questions and to inspire me to become an orthopedic surgeon during my medical internship.

Associate Professor **Eva Weidenhielm Broström**, Head of the Department of Musculoskeletal Diseases and Advanced Homecare, for encouragement in many ways, including financial support and providing me with the possibility to combine research with clinical work. I am particularly indebted to you for your guidance and attention.

Associate Professor **Georg Hirsch** for substantial support and for generously sharing your vast knowledge of pediatric orthopedics. I especially want to thank you for your positive comments about my work.

Associate Professor **Lennart Landin** for your inspiring and pioneering work on fracture epidemiology and bone health in children.

Associate Professor **Rüdiger Weiss**, my former college and roommate, for answering innumerable questions about epidemiology and SPSS and being ready to give invaluable advice whenever needed.

Associate Professor **Karin Ekström Smedby**, Director of Doctoral School for clinicians in epidemiology for providing postgraduate courses in an inspiring way.

Colleagues and fellow doctoral-students, **Stefan Gantelius, Marie Askenberger, Eva Bengtsson Moström, Maria Örtqvist, Elin Lööf, Cecilia Lidbeck, Josefine Naili Eriksson** and **Marie Eriksson** for sharing ideas, support and companionship.

Helena Boström-Windhamre, Anders Ekelund, and Anna-Clara Esbjörnsson for interesting projects outside this thesis that have also been an important part of my postgraduate training.

Jonas Bergström, my clinical supervisor during residency, for always searching for ways to improve treatment. Maybe the next paradigm shift in the treatment of femur shaft fractures in children will be based on one of your many ideas.

All my **colleagues at the Departments of Orthopedic Surgery** (Saint Göran Hospital, Karolinska University Hospital and the Astrid Lindgren Children's Hospital), former and present, for being good friends – I could not have completed this thesis without your support.

Astrid Häggblad and **None-Marie Kemp** at the Department of Women's and Children's Health for always being very helpful and providing excellent practical assistance.

Pelle Säfström for being my friend, reading this thesis, and giving constructive criticism.

Fredrik Kjellberg and **Olof Hertting** for being good friends and sharing the discovery that research projects at Karolinska Institutet can take you anywhere in the world. You have been great companions on the long journey towards being a physician.

My father **Carl** for your continuous love and support and for the illustrations in this thesis. Your lust for life is an inspiration.

My final thanks go to my brave and wonderful wife **Virginia** for your persistent love and strength, and our adorable children **Isabella** and **Alex**. The three of you have brought the happiest moments of my life, and I am sending you my gratitude for the strength you gave me to write this thesis.

Funding for this thesis was provided by the following research foundations: Department of Women's and Children's Health (Karolinska Institutet), Karolinska University Hospital (R&D), Capio Forskningsstiftelse, Stiftelsen Samariten, Stiftelsen för Barnavård and Stiftelsen Konung Oscar II:s and Drottning Sophias Guldbrylllopsminne.

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