LONG-TERM RESULTS AND TREATMENT INJURIES IN PEDIATRIC TIBIAL AND FEMORAL FRACTURES

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ACADEMIC DISSERTATION

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Fractures are common in children. It is estimated that every fourth injured child seeking medical aid has sustained a fracture. Fracture of the tibia is the third most common fracture and femoral fracture one of the most common fractures leading to hospitalization. Data on long-term results in the treatment of these fractures are scant. Injuries related to treatment may lead to evaluation of liability and law suits seeking compensation. In Finland a no-fault compensation system was established in 1987 to provide compensation for treatment injuries. There are no studies evaluating such injuries in pediatric fracture treatment.

In this retrospective study we analysed data on all children treated for tibial and femoral fractures in Aurora Hospital, Helsinki, during the years 1980-89. Only patients treated in the operation room (OR) were included, as emergency department admission data were no longer available. Patient files were scrutinized for injury and treatment details, and in cases with femoral fractures the radiographs obtained during treatment were also evaluated to explore remodelling of fractures. An invitation was sent to all patients to participate in a clinical examination and they were also asked to fill a patients’ assessment form. At the clinical examination gait, possible leg-length discrepancy, alignment and range of motion of lower limb joints were analysed. Radiographs were taken to evaluate axial alignment and possible signs of osteoarthritis.

Treatment injuries were evaluated using patient compensation data from the Finnish Patient Insurance Centre (PIC). We included all claims in connection with children’s tibial and femoral fracture treatment during the years 1997-2004, ten years after the establishment of the insurance system. Claims filed by parents of children, patient files and compensation decisions were analysed in retrospect. Treatment method, possible complications and permanent sequelae were assessed and preventable injuries outlined.

The incidence of tibial and femoral fractures in Finland was calculated. For tibial fractures the incidence was calculated both based on national register data including only hospitalized children and from a prospective one-year population-based follow-up in Helsinki including all children. The incidence of femoral fractures was calculated from the national register data.

A total of 94 children were treated for a tibial fracture in the OR during the study period. Of these, 89 were treated with manipulation under anesthesia and casting, four with skeletal traction, and one with internal fixation. The hospital stay averaged 5 days (1-26). Remanipulation was necessary in 41 cases. Of the 94 patients 58 responded to the study invitation and 45 attended the clinical examination. Patients’ memories of treatment were positive in 32/58 cases, negative in 6. Pain was reported as the only memory by 6/58 patients. The subjective VAS score for function averaged 9.1
and for appearance 9.1. Leg-length discrepancy (5-10 mm) was found clinically in 10/45 patients and rotational deformities exceeding 20° in 4. None of the patients walked with a limp or had axial malalignment exceeding 10°. Osteoarthritis was seen in radiographs in two cases.

Femoral fractures led to hospital treatment for 74 children during the study period. Of these, 52 participated in the clinical examination. The treatment in 44 cases was skeletal traction, 5 internal fixation, and 3 casting. The length of the hospital stay averaged 58 (3–156) days and the median time in traction was 39 (3–77) days. Angular malalignment of more than 10° was seen at the final check-up in 21 of the 52 patients. Limp was detected in 10 patients and leg-length discrepancy of more than 15 mm in 8 of the 52 patients. Knee-joint arthritis was seen in 6 of the 15 patients who were over 10 years of age at the time of injury. A positive correlation between angular deformity and knee-joint arthritis in radiographs was established.

The annual incidence of children’s tibial fractures in Finland was 1.0/1000 children and of femoral fractures 0.27/1000. The risk of treatment injury was 0.6% in tibial fractures and 2.2% in femoral fractures. Compensation claims were filed to PIC in 50 cases involving tibial fracture treatment and 30 cases in femoral fracture treatment. The reasons for filing a claim were pain, insufficient diagnosis or treatment, extra expenses, permanent disability or inappropriate behavior of medical personnel. In tibial fracture treatment compensations were granted due to delay in diagnosis or treatment in 15 cases, inappropriate treatment in 14, and other causes in 3 cases, unsatisfactory standard of treatment and missed diagnosis being the leading causes. In femoral fracture treatment compensation was for delay in treatment in 3 cases, unnecessary operation in 2 cases, inappropriate treatment in 2, and other reasons in 5. Infection-related injuries were compensated in 3 cases in connection with both tibial and femoral fracture treatment. Most of the treatment injuries were regarded in retrospect as avoidable.

Satisfactory treatment results can be achieved with cast-immobilization in tibial fracture treatment: fractures united with a low rate of axial malalignment, although many children required remanipulation to maintain alignment. Rotational deformities should be evaluated more carefully, as spontaneous correction is poor. Malalignment after femoral fracture treatment should not be tolerated, since it may lead to premature knee-joint arthritis. Adequate pain relief is essential in treating children’s fractures. Injury rarely occurs in the treatment of children’s tibial and femoral fractures. However, a majority could be avoided with proper clinical practice. The routine use of radiographs is recommended whenever a tibial fracture is suspected.
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LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following publications:


The publications are referred to in the text by their roman numerals. These articles were reprinted with the permission of the copyright holders. In addition, some previously unpublished data are presented.
ABBREVIATIONS

AP  anteroposterior
BMP bone morphogenetic protein
ED  emergency department
EF  external fixation
FIN flexible intramedullary nailing
GH  growth hormone
ICC intra-class correlation
IGF insulin-like growth factor
OR  operation room
PIC Patient Insurance Center
RCT randomized controlled study
RIM rigid intramedullary nailing
ROM range of motion
VAS visual analog scale
1 INTRODUCTION

Of the 1 million children in the Finnish population one out of six needs medical care due to an injury every year. Fractures are common, comprising up to 25% of pediatric injuries. Tibial and femoral fractures constitute roughly 15% of all pediatric fractures (Mäyränpää et al. 2010).

Treatment of fractures has changed during recent decades. Traditionally fractures have been treated with manipulation and cast-immobilization. Traction was introduced after the First World War, intramedullary nailing in children after the Second World War and external fixation in the 1960s. The choice of treatment of fractures in children depends on the child’s age and skeletal maturity (Slongo 2005a). Methods first utilized in adult treatment are gradually being implemented in children. Despite extensive research, the treatment of pediatric fractures remains controversial even though there is a trend in favor of surgery.

"Fractures in children always heal” is a widespread saying often repeated when discussing the treatment of pediatric fractures. There is little information on the long-term results of tibial and femoral fracture treatment. Results reported earlier have generally been good, but the follow-up times in previous studies on childhood tibial and femoral fractures tend to be rather short.

Complications in the treatment of tibial and femoral fractures vary according to the method used. In conservative treatment complications include malunion, non-union, leg-length discrepancies and various skin problems. In addition, operative treatment may lead to neurovascular injuries and infections (Flynn & Skaggs 2010, Heinrich & Mooney 2010).

Treatment injuries are injuries occurring in connection with medical treatment. In Finland the Patient Insurance Centre (PIC) is responsible for financial compensation in injuries associated with medical treatment. The PIC acts in accordance with the Finnish Patient Injuries Act dated 1987. In addition to Finland, all Nordic countries and New Zealand have a comparable system providing compensation for injuries (Kachalia et al. 2008). There are no previous studies on treatment injuries associated with pediatric tibial or femoral fractures.

The purpose of this study was to assess the long-term results of the treatment of childhood tibial and femoral fractures, to establish the incidence of these fractures, and to evaluate treatment injuries with special focus on avoidable injuries.
2  REVIEW OF THE LITERATURE

2.1  BONE

Bones are calcified living organs formed of connective tissue which act as supportive structures, levers for muscles for movement, blood-producing centers, protective structures for vital organs, and as a repository for calcium and phosphorous. Bones are structurally divided into two types, compact and spongy. Compact bones form the outer, dense core of bones and surround the inner spongy bone, which contains bone marrow. Bones are also classified by their shape into tubular long bones (e.g. tibia or femur), cuboidal short bones (e.g. bones of the wrist), and flat bones (e.g. skull). During embryonic development, bones are formed by intramembranous or endochondral ossification. In intramembranous ossification mesenchymal models transform into bones, whereas in endochondral ossification bones are first formed as cartilaginous models which subsequently ossify. (Ogden 1982, Drake et al. 2010, Xian & Foster 2010)

The long bones are divided into four anatomic regions: epiphysis, physis, metaphysis and diaphysis. Each of these regions has its own unique structure and function. The epiphysis is initially formed of mere cartilage, which is gradually replaced by bone, leaving only the articular cartilage. The physis is the growth plate which rapidly adds bone length and width by endochondral ossification. The metaphysis is the transitional zone between the physis and the diaphysis with more spongy bone and less compact bone than in the diaphysis. The metaphysis is also a major site of bone modeling and remodeling. The diaphysis is the largest part of the long bones whose growth is mediated by the periesteoum from fetal laminar bone towards mature lamellar bone. The diaphysis forms the shaft of long bones. A significant change takes place in the vascularization of bones during growth. (Ogden 1982, Drake et al. 2010, Xian & Foster 2010)

2.1.1  BONE GROWTH

Bone growth occurs by the addition of new bone to existing bone. The growth takes place by the same mechanisms as prevail during embryonic development: endochondral and intramembranous ossification.

Endochondral ossification represents the majority of bone formation and growth in humans. During embryonic development mesenchymal cells initially differentiate to chondrocytes, forming cartilage molds for future bones to build up. (Maes 2013) The function of the physis well describes the processes underlying endochondral bone growth. The physis is responsible for the longitudinal growth of long bones, beginning in the embryonic state and ending at maturity. Bone formation progresses in a sequential manner:
chondrocytes resting in the growth plate proliferate and organize into columns parallel to the axis of growth; chondrocytes grow in size; they mineralize and undergo apoptosis; osteoblasts differentiate to form primary bone and primary bone remodels into secondary bone (Figure 1). (Langenskiöld 1947, Pazzaglia et al. 2011)

The physis receives its vasculature from two functionally and anatomically separate circulatory systems (Figure 1). Epiphyseal circulation originates from cartilage canals and is located close to the resting and dividing cells, facilitating their growth. Metaphyseal circulation is derived from the nutrient artery of the bone mainly responsible for the vascularization of the central parts and the perichondral vessels, bringing blood to the peripheral parts of bone. Disruption of the epiphyseal circulation may lead to growth disturbance, whereas metaphyseal vasculature disruption may cause excess cartilage formation within the bone. (Ogden 1982)

**Figure 1**  Figure showing the endochondral ossification process in the physis. The physis receives its vasculature from both the epiphysis and diaphysis. (Adapted from Xian & Foster 2010.)

Hormones, cell-to-cell signaling, growth factors, transcription factors and vitamins tightly regulate the bone-forming processes in endochondral ossification. The regulation of ossification has been a subject of extensive investigation and lies beyond the scope of this thesis. In general, growth hormone (GH) and numerous growth factors (e.g. IGF-1, bone
morphogenetic proteins BMPs) act together in this complex system. (Schoenwolf et al. 2009, Xian & Foster 2010, Bradley et al. 2011)

Intramembranous ossification is involved in the development of the bones of the skull and sesamoid bones such as the patella. This type of ossification is also essential for fracture healing processes where the periostoeum-derived cells differentiate into bone matrix similarly as in embryonic intramembranous ossification. In this pathway mesenchymal cells differentiate directly to bone-forming cells without a cartilage phase. (Schoenwolf et al. 2009, Xian & Foster 2010) This process of osteogenesis is divided into three phases: induction of the cells into the skeletogenic pathway, formation of condensates, and differentiation into osteoblasts. In the induction phase the differentiation pathway is activated by epithelial-mesenchymal interaction, which continues with an increase in cell numbers in the condensation phase. The cells in the condensations then begin to differentiate to form osteoblasts, the process being regulated by numerous gene products. (Franz-Odendaal 2011)

2.1.2 BONE FRACTURES AND HEALING
Fractures occur due to abnormal stress exceeding the normal tolerance. In the case of an underlying disease weakening the bone (e.g. osteoporosis, osteogenesis imperfecta), fractures may occur even after minimal trauma.

Children have some unique fracture patterns due to their immature and constantly changing skeleton. Children’s bones are at the same time weaker than those of adults but also absorb more energy before breaking, since they are more plastic. A fracture can occur across a growth plate, causing problems in further growth. The periostoeum is thicker in children’s bones and can be separated from the bone without completely disrupting. Furthermore, fractures may also be difficult to see in radiographs and sometimes treatment must be initiated based on clinical findings. (Currey & Butler 1975, Ogden 1982, Irwin 2004, Drake et al. 2010, Xian & Foster 2010)

Some fracture types are found only in children. Torus fractures are caused by a force being applied along the long axis of a bone, resulting in bulging of the cortex typically at the border of the metaphysis and epiphysis. Greenstick fractures occur after a bending force to the bone, with usually a break in the cortex only on the convex side of the bone and plastic deformation on the concave side. A bowing fracture is due to deformation of a bone beyond its recoil capacity, causing permanent deformity. The fracture line reaching the epiphysis describes epiphyseal fractures. (Salter & Harris 1963, Ogden 1982, Irwin 2004)

After bone fracture healing usually proceeds on two different pathways: primary(direct) osteonal bone healing occurs without the formation of callus while non-osteonal healing involves endosteal and periosteal callus formation. Primary osteonal healing takes place in rigid fixation of fractures (e.g. external fixation, plate fixation, rigid intramedullary nailing), whereas
less stable fracture fixation methods (e.g. casting, bracing, elastic intramedullary nailing) lead to non-osteonel fracture healing involving endochondral ossification processes. (Xian & Foster 2010, Zhang et al. 2012)

Fracture healing in the immature skeleton in children usually involves callus formation and occurs in three closely integrated and partly overlapping phases: the inflammatory phase, the reparative phase, and the remodeling phase. At the outset, the rupture of blood vessels initiates the inflammatory phase, when the osseous structures break. The resulting hematoma contains abundant fibrin which rapidly turns into collagen, serving as a building site for the formation of new bone. The hematoma triggers the formation of proteins initiating the differentiation of stem cells into bone-forming cells (fibroblasts, chondroblasts, osteoblasts and angioblasts). (McKibbin 1978, Wilkins 2005, Xian & Foster 2010) The second phase is the reparative phase, where osteogenic cells from the periosteum propagate to the previously formed hematoma to form the initial callus. The callus formed by both the endochondral and the intramembranous ossification pathways is at first rather weak but gradually gains strength through cellular organization. (Wilkins 2005, Xian & Foster 2010) The last phase, remodeling, may last from months to years depending on the fracture site. In this phase the woven bone of the callus is replaced by trabecular/lamellar bone induced by physical stress. The bone formed is first laid without specific orientation but is gradually aligned in accordance with stress patterns. The underlying processes do not differ from the normal maturation processes of the growing child. Growth factors, cytokines and other regulating molecules extensively regulate all the healing phases. (Wilkins 2005, Xian & Foster 2010)

2.1.3 FACTORS AFFECTING SPONTANEOUS CORRECTION
The fact that the skeleton of a child is constantly growing and actively remodeling facilitates the fracture-healing processes. The continuous replacement and repair of the immature skeletal system can benefit the treatment of fractures. Especially in younger children malalignment caused by fractures may be completely corrected during growth.

One of the most important factors in pediatric fracture treatment is the age of the patient. In adults the treatment does not usually change in different age groups. In children, however, the approach accepted for a five-year-old can be totally inappropriate for a teenager. The age affects the fracture type due to changing physical properties, remodeling potential varying with age, and the healing times expected. (Slongo 2005b)

Angular deformities may correct spontaneously up to 85% of the initial fault. Approximately 75% of the correction occurs at the growth plate in the physis and in children younger than 12 as much as 25° angulation can be expected to remodel (Wallace & Hoffman 1992). The rate of correction is affected by the age and gender of the child (years of growth remaining) and
the location of the fracture. The physes grow asymmetrically, correcting angular deformities: the concave side grows more rapidly until the physis is oriented perpendicular to the longitudinal axis of the bone (Ryöppy & Karaharju 1974). The remaining 25% of the remodeling occurs at the fracture site. The bone formation in the healing of the diaphysis is in accordance with Wolff’s law (Wolff 1870), whereby the increased pressure on the concave side stimulates new bone formation. (Wilkins 2005)

Injury involving the physis may cause shortening or angular deformities due to growth disturbance at the growth plate. Anders Langenskiöld studied this upon observing a disturbed growth pattern in two children with Ollier’s disease (Langenskiöld 1948). This pattern was analyzed experimentally by locally radiating the epiphyseal cartilage in rabbits and was established that a bony bridge was formed after the injury to the physis (Langenskiöld & Edgren 1949). He subsequently described growth arrest after trauma in children (Langenskiöld 1967) and the clinical implication of operative correction of this type of growth disturbance (Langenskiöld 1975).

Fractures in long bones often stimulate growth of the injured bone depending on the fracture site and the child’s remaining growth potential. The cause of growth stimulation remains unclear, although increased blood supply after fracture is thought to be one determinant (Herring 2008, Xian & Foster 2010) The growth acceleration has been well established in femoral fractures but to a lesser extent in tibial fractures. This has a clinical implication, since shortening of more than 2 cm has been reported to heal spontaneously. (Greiff & Bergmann 1980, Shapiro 1981, Stephens et al. 1989, Wilkins 2005, Herring 2008)

The periosteum of children’s bones is thicker than that of adults and separates from the bone more easily. This makes it possible for even displaced fractures to have an intact periosteum providing a sleeve for the bone. The bone formation taking place after fractures initiates from the periosteum, quickly forming a bony bridge over the fracture site and stabilizing it. (Beekman & Sullivan 1941, McKibbin 1978, Ogden 1982, Wilkins 2005)

2.2 EPIDEMIOLOGY

An understanding of the treatment of fractures presumes a knowledge of factors affecting injuries in children. It has been estimated that every sixth child sustains an injury every year. Of these, 10 to 25% are fractures. The incidence of fractures varies depending on the age of children, the time of year, and various socioeconomic factors. Landin (1983) analysed all fractures reported in Malmö, Sweden during a 30-year period and found that changes in the fracture patterns had occurred during the study period; the overall risk of a fracture was higher in boys than girls (1.5/1), and there was a different risk of fractures at different ages and different times of year, a peak in
occurrence emerging in May and September reflecting the beginning and ending of summer holidays.

2.2.1 TIBIAL FRACTURES

Tibial fractures are common in children and among the most common lower-limb fractures (Shannak 1988, Cheng & Shen 1993, Gordon & O’Donnell 2012). The pattern of tibial shaft fractures at different ages is three-modal – the incidence increases in the first five years of life, and then decreases within the next couple of years, followed by a second increase at around the age of 10. The third increase occurs at around 15. (Landin 1983) The overall frequency of tibial shaft fractures in children is 5.0-6.2% of all fractures, ranking 6th among all children’s fractures (Landin 1983, Herring 2008, Vitale 2010) with an incidence of 0.91-1.03 per 1000 children (Lyons et.al 1999, Cooper et al. 2004). The reported sex ratio is 2.2/1 with male predominance (Landin 1983).

Most tibial fractures occur in the distal third of the bone, this accounting for up to 70% of fractures. The middle third is the second most common fracture location, the least common fracture site being in the proximal third of the tibia. In children younger than 4 the fracture location is in the middle or distal part of the tibia, whereas in older children a vast majority of the fractures are in the distal third. (Setter & Palomino 2006, Heinrich & Mooney 2010)

Injury mechanisms include a direct force to the lower extremity causing transverse or comminuted fractures, and indirect, usually rotational force in oblique fractures and in isolated tibial fractures without an accompanying fibular fracture (Briggs et al. 1992, Setter & Palomino 2006). The great majority of fractures are isolated (Heinrich & Mooney 2010). The injury pattern changes with age – bicycle spoke injuries and different playground injuries occur in younger children, whereas older children sustain a fracture in different sporting activities. Motor-vehicle accidents are among the most common causes of tibial fractures. (Landin 1983, Shannak 1988, D’Souza et al. 1996, Heinrich & Mooney 2010) Tibial fractures are also associated with child abuse, especially in the youngest patient population (King et al. 1988, Loder & Bookout 1991).

Approximately 10% of pediatric tibial fractures are open (Setter & Palomino 2006). Open fractures are often related to high-energy injuries and are classified according to the Gustilo system (Gustilo & Anderson 1976, Gordon & O’Donnell 2012).

Tibial fractures are usually classified into subgroups by location, configuration and associated injuries. These groups are proximal, middle, or distal third fractures of the tibia with or without fibular fractures, the fracture being transverse, oblique, comminuted, or segmental. (Heinrich & Mooney 2010, Gordon & O’Donnell 2012) Fibular fractures are associated in
approximately 30% of children with tibial fractures and commonly result from high-energy trauma (Mashru et al. 2005).

### 2.2.2 FEMORAL FRACTURES

Femoral fracture occurs typically during play or sports, or in a simple fall in younger children, and in motor-vehicle accidents in older children (Loder et al. 2006, von Heideken et al. 2011). In children under one year the majority of such injuries are caused by child abuse. (Gross & Stranger 1983, Coffey et al. 2005, Flynn & Skaggs 2010, Brousil & Hunter 2013) Newborns may present with femoral fractures resulting from difficult delivery (Flynn & Schwend 2004). The trauma energy resulting in femoral fractures is usually greater than in tibial fractures. The fracture pattern is bimodal with two peaks at around 3-5 years and 15 years, this reflecting physical activity (Landin 1983). The reported frequency of femoral fractures is 1.6-2.3 % of all fractures and the incidence 0.22-0.33 per 1000 children (Landin 1983, Lyons et al. 1999, Bridgman and Wilson 2004, Herring 2008). The incidence has declined in the past decades on average 3% per year (Heideken et al. 2011) There is a male predominance: Landin (1983) reported a sex ratio of 2.3/1 and more recently Loder and associates (2006) calculated that 71% of fractures occur in boys.

Femoral fractures can be classified based on radiographic and clinical evaluation as open or closed, comminuted or non-commminuted, and transverse, spiral or oblique (Flynn & Skaggs 2010). Oblique fractures are often caused by indirect torsional force, whereas and transverse fractures result from direct trauma (Ogden 1982). Open fractures are further classified according to the Gustilo system (Gustilo & Anderson 1976). More than half of all femoral fractures are closed transverse fractures without comminution (Flynn & Skaggs 2010). Open fractures are rare: in a large epidemiological study of nearly 10,000 femoral fractures only 5% were open (Loder et al. 2006).

### 2.3 TREATMENT

Treatment of fractures in children has changed considerably during the last few decades. A shift from non-operative towards operative treatment has been a result of improvements in techniques but also reflects changes in the opinions and values of parents and society. Participation of both parents in work and rising costs of health care have led to minimizing hospitalization times, giving preference to operative treatment. Non-operative treatment has many indirect influences on the child and family. Cast treatment involves extra challenges in schooling and transportation and also the need for nursing increases. (Hughes et al. 1995) The social and psychological effects of
prolonged immobilization in non-operative treatment may be harmful for the child (Reeves et al. 1990, Beaty 2005). Whatever the fracture, there are usually several treatment methods to choose from, including functional bracing, casting, traction and external or internal fixation. The goal of treatment is to stabilize the fractures site, protect surrounding soft tissues, facilitate bone healing, and achieve adequate reduction. Early mobilization and restoration of normal range of motion have been considered important for rehabilitation and rapid return to normal activities. (Sanders et al. 2001, Musgrave & Mendelson 2002, Hedin 2004, Slongo 2005b, Vitale 2010)

Pain management is recognized today as an important part of fracture treatment: there is a chapter dedicated to this issue in the Rockwood and Wilkins’ Fractures in Children textbook (Mencio 2010). This has not always been the situation. Schechter and colleagues (1986) reported that children were likely to receive less analgesic treatment in the 80s than adults. There has since been extensive research on the subject and it has been realized that untreated pain causes significant morbidity. Even today knowledge of the need for pain management and clinical practice are sometimes in conflict. (Howard 2003, Verghese & Hannallah 2010)

2.3.1 TIBIAL FRACTURES
Tibial fractures have traditionally been treated with closed reduction and cast immobilization, which is even today the treatment of choice in most uncomplicated fractures. (Ogden 1982, Heinrich & Mooney 2010) In the “Rockwood and Wilkins’ Fractures in Children” textbook (2010) the authors state that most tibial fractures can be treated by closed reduction and cast immobilization and refer to an article citing 9 pediatric patients treated with skeletal traction or casting (Holderman 1959).

After sufficient reduction casting is usually done in two stages, proceeding from a short-leg cast to a long-leg cast with assessment of alignment in the meantime. Casting is done in bent-knee position to ensure rotation of the fracture. Alignment of the fracture is assessed weekly during the first weeks of cast-treatment and possible angular deformities are corrected (Heinrich & Mooney 2010). Sarmiento (1974) has described a non-operative method of functional bracing, where no immobilization of the upper and lower joints is required, neither strict immobilization of the fracture, and early weight bearing is allowed.

Results, as in most pediatric fractures, are mainly good. Hansen and associates (1976) reported a study of 102 non-operatively treated children, of whom 85 attended their follow-up on average 2 years from injury. It was established that the time of union was related to age, with fractures in older children uniting slower. Subjective pain was reported in 6/85, rotational deformity of 10-20° in 5/85, and 25 patients had 3-19° angulation. The authors concluded that more than 10% correction of malalignment cannot be expected and therefore the initial axial reduction should be accurate. Greiff &
Bergmann (1980) studied remodeling of length a mean 25 months from tibial fracture in 85 patients. They found that with increasing age, the growth stimulation after a fracture decreased, and therefore concluded that in older children residual shortening of more than 2 cm after reduction should not be tolerated. In a study conducted in Jordan, good results were reported after non-operative treatment of 117 children with a mean follow-up of 3.9 years (Shannak 1988). Angular deformity up to 15° and 10 mm shortening corrected in this study, whereas rotational deformities persisted. At their last follow-up, 91 patients had no measurable angular deformity while >10° angulation was found in 6 patients. In another study (Swaan & Oppers 1971), 86 children with a mean follow-up of 6 years were studied to establish the extent to which angular deformities heal and whether or not there is acceleration in longitudinal bone growth after a tibial fracture. The authors concluded that age at time of fracture was the determining factor in remodeling and that angular deformities exceeding 5° and length discrepancies more than a few millimeters should be tolerated only in children younger than 8 (10 years if boys). In 1992 Briggs and associates retrospectively evaluated cast treatment of 61 children who were followed up until fracture union. All fractures united after a mean 46 days from injury. Two patients had angular deformity exceeding 8°. It was also established that isolated transverse tibial fractures did not displace after casting suggesting abandoning follow-up radiography in this type of injury. A group under Gicquel (2005) retrospectively compared 102 fractures treated by casting followed by functional casting with 45 fractures treated by flexible intramedullary nailing (FIN). Overgrowth of more than 5 mm was noted in 3 patients in the non-operative group and 8 patients in the FIN group. Malunion (angulation exceeding 5°) was seen in 8 and 7 patients respectively. The investigators concluded that although FIN may lead to better results in maintaining axial alignment, tibial fracture treatment in children remains mostly non-operative.


Operative treatment of tibial fractures has been reported to yield good results. There is no consensus on the preferred surgical method, since many factors influence the treatment. These include patients’ sex and age, fracture type and location, and economic factors. External fixation has proved to be a good treatment option for severely comminuted fractures and high-grade open fractures, although recent studies have indicated that intramedullary nails may have advantages (Gicquel et al. 2005, Setter & Palomino 2006) Qidwai (2001) reported good clinical and functional results in a retrospective
study of 84 tibial fractures treated with intramedullary Kirschner wiring. The average time to union was 9.5 weeks: all patients presented with full range of motion of knee and ankle joints, 1 patient had non-union due to infection, 1 angulation >10°, and none leg-length discrepancy >1 cm.

Flexible intramedullary nailing (FIN) has recently been extensively studied. A group under O’Brien (2004) reported a 100% union rate with no malunions or leg-length discrepancies in 16 children with unstable tibial fractures. Goodwin and colleagues (2005) retrospectively evaluated the treatment of 19 unstable fractures in children, which all united. Complications were recorded in 5 patients. In a multi-center study treatment of 31 children with either FIN or external fixation (EF) was compared by Kubiak and associates (2005). They found that the union time was shorter and that patients were more satisfied in the FIN group than in the EF group. A group under Gordon (2007) evaluated retrospectively 60 diaphyseal fractures treated with FIN. The average time to union was 8 weeks. Delayed healing was detected in 5 patients and non-union in 2. The mean age of patients suffering from delayed union was higher. Sankar and colleagues (2007) reported a series of 19 patient treated with FIN. Acceptable axial alignment with no malunion was achieved in all patients, but 2 required remanipulation to maintain alignment. All fractures healed completely on average 11 weeks from injury. Srivastava and group (2008) analyzed 24 children with FIN treatment at their institution with a mean 29 months’ follow-up. The average time to union was 20 weeks; one patient had non-union and 2 malunion. Deakin and coworkers (2010) studied FIN treatment in 21 adolescents and found a malunion rate of 38%. FIN treatment in 86 children older than 6 with displaced tibial fractures was studied by a group under Griffet (2011) during the period 2000-2006. The mean age of their patients was 11.8 years and the final follow-up 2 years from injury. All of their fractures healed and the children had normal knee mobility by day 30 from injury. At the final follow-up, 2 patients had angulation (<5°), 15 leg-length discrepancies, and none had refractures; 4/86 had superficial infections necessitating additional surgery.

Intramedullary nailing has gained popularity since it shortens the immobilization time, allows early weight-bearing and easier ambulation, with usually low infection rates, causes little soft-tissue damage, and has relatively straightforward insertion procedures. Treatment results reported are mainly good, although there are potentially substantial complications including compartment syndrome, infections, delayed union, malunion, and long-lasting pain.

2.3.2 FEMORAL FRACTURES
There are multiple factors affecting the choice of treatment in pediatric femoral fractures. Among these are age and size of child, fracture type and location, injury mechanism (multiple trauma, associated injuries), family
situation, and cost of treatment. Child abuse should always be considered especially in the case of children younger than 36 months (Loder & Bookout 1991, Loder et al. 2006, Kocher et al. 2009). The majority of children with femoral fractures require inpatient treatment (Galano et al. 2005). Traditionally these fractures have been treated by traction of variable duration, often followed by casting (Weber 1969, Aronson et al. 1987, Anglen & Choi 2005). Closed reduction and casting has since been described to yield good results (Dameron & Thompson 1959). These last mentioned conducted a retrospective review of 100 children treated by closed reduction and casting with a mean 6.9-year follow-up. No delayed unions, complications or deformities were found. Cast bracing has also been reported to yield favorable results with earlier discharge from hospital than traction and casting (Scott et al. 1981). Stephens and associates (1989) retrospectively evaluated the outcome of 30 childhood femoral fractures treated with traction after skeletal maturity with a mean 9 years’ follow-up. They found that overgrowth after fracture and remodeling of angulation was related to the patient’s age at injury. Two patients had angulation at follow-up and 9 had leg-length discrepancy >1 cm. More recently rising healthcare costs, long hospital stay, and concern for the social and psychological impact of prolonged immobilization on children has popularized surgical treatment in high-income countries. (Reeves et al. 1990, Miettinen 1992, Hughes et al. 1995, Dwyer et al. 2003, Hedin 2004, Hedin et al. 2004, Flynn & Schwend 2004) A vast majority of fractures heal regardless of treatment method (Anglen & Choi 2005).

According to Dameron & Thompson (1959) “the simplest form of satisfactory treatment is best”. A group under Buehler (1995) conducted a prospective study of 50 children treated by early spica casting to find criteria for evaluating the risk of treatment failure. They developed a new clinical test, the telescope test, which was found to correlate significantly with treatment failure. In their study 41 had acceptable outcome as defined by <25 mm shortening of the fractured femur. Many studies have been conducted demonstrating and evaluating different treatment methods, especially surgical. Since operative means have gained popularity and the choice of treatment involves some debate, a study was conducted to evaluate the preferred treatment of pediatric orthopedic surgeons in North America (Sanders et al. 2001). In this study 286 orthopedists’ opinions were evaluated it emerged that operative treatment was increasingly favored with increasing age. Furthermore, the preferred treatment was age-dependent within the operative or non-operative treatment categories. Poolman and colleagues (2006) conducted a systematic review of different treatment options including 33 studies with a total 2422 fractures treated in children younger than 18 years of age. They concluded that a) operative treatment (all types) reduces malunion and total adverse events, b) flexible intramedullary nailing is superior to external fixation, c) dynamic external fixation involves fewer
adverse events than static external fixation. They also suggested that RCTs comparing different operative treatment methods should be performed.

Recommendations by Anglen and associates (2005) suggest that treatment should be chosen according to the age and size of the patient and severity of the fracture as follows: infants (0-18 months) should be treated with Pavlik harness; children 1.5-6 years of age with isolated fractures by spica casting, in multiple trauma by external fixation, and obese children or comminuted fractures by percutaneous plating; children 6-11 years of age with isolated fractures with flexible nails and in multiple trauma by external fixation; children 11-16 years of age according to child’s size: small children flexible nailing or percutaneous plating and larger children locked intramedullary nailing. Flynn & Schwend (2004) suggest similar guidelines, although some differences can be found: they recommend Pavlik harness only for infants up to 6 months of age; traction and casting is mentioned as a successful method with 6-11 year-old children especially with shortening, and they advocate plating only in rare cases when other methods are not available. Hunter (2005), on the other hand, proposes skin traction and/or spica casting for the treatment of infants and Pavlik harness for only the youngest (age 0-3 months). In the case of children aged 18 months to 4 years he suggests hip spica casting with/without skeletal traction, in the age group 4-12 years FIN is his preferred treatment (external fixation in polytrauma), and in adolescents FIN in patients weighing <60kg and plate osteosynthesis or locked intramedullary nailing in heavier patients. The treatment guidelines of the American Academy of Orthopedic Surgeons (Kocher et al. 2009) are similar to those described above. The authors conclude that there is a lack of conclusive evidence in the choice of treatment and that further research is needed to establish more precise guidelines and that controversy still remains.

Traction has been used for decades in the treatment of femoral fractures. Aronson and colleagues (1987) performed a long-term study of femoral shaft fractures treated with skeletal traction in 54 children. After a mean follow-up of 4.3 years they found that all patients had symmetrical range of motion in hips and knees and were back to normal activities. They noted a limb-length discrepancy of >13 mm in 11/54 children and found the alignment of the traction pin to have an effect on residual angular deformities. As a conclusion they recommended traction pin insertion parallel to the knee joint axis. In seeking solutions to rising health-care costs, different treatment options were evaluated to replace skeletal traction, which requires long hospitalization. Non-operative (mostly traction) and operative treatment have been compared in 60 children under 16 years of age with a mean 8.8 years follow-up (Miettinen 1992). No significant differences were found in their clinical or radiographic outcomes. He concluded that operative treatment should thus be considered more often. A group under Boman (1998) studied home traction, using skeletal traction in preschool children with femoral fractures. They included 24 patients (mean age 3.9 years) treated with a specially
designed bed stretcher. All but one patient healed without limb-length discrepancy >10 mm or angulation exceeding 10°. The parents were well satisfied with the treatment. Hedin and associates (2004) compared the costs of external fixation (EF), skeletal traction followed by home traction, and skeletal traction in the hospital. They established that the length of hospital stay was the key determinant in costs and the EF treatment was thus least expensive. Reeves and colleagues (1990) compared rigid internal fixation and traction followed by casting in 90 adolescents with 96 femoral shaft fractures. They found a shorter hospital stay, lower costs of treatment, and fewer complications in the operatively treated patients than in those treated non-operatively. Immediate casting and traction were compared retrospectively in 88 femoral-shaft fractures in children with a mean 8.9 years follow-up (Yandow et al. 1999). Of these patients 55 were treated with traction and delayed casting and 33 with immediate casting. No difference was found in the outcomes, but the hospital stay was significantly shorter in the casting group (2 vs. 17 days). In a study conducted in India (Dwyer et al. 2003) skin vs. skeletal traction methods were compared, noting that in some lower-income countries non-operative treatment methods remain the golden standard. The authors included 28 children with a minimum 12 months’ follow-up and found no advantage to skeletal over skin traction. Good results were reported.

Casting of femoral fractures usually requires anesthesia and is therefore often performed in the operation room (OR). Cassinelli and associates (2005) reported on a series of 145 pediatric femur fractures treated with immediate casting in the emergency department (ED) with an average 20 weeks’ follow-up; 11/145 children required remanipulation in the OR due to loss of reduction and 16/145 had cast-related complications (skin problem, cast softening, cast tightness). They concluded that immediate casting in the ED is safe and effective in children younger than 6 years. A group under Mansour (2010) compared immediate spica casting in the OR or ED in 100 children. Of these, 79 were treated in the OR and 21 in the ED; no differences were reported in their demographic characteristics. The results and complications were similar in both groups: radiographic malunion was seen in 19 (OR) and 7 (ED) patients and cast wedging improved alignment in 7 and 3 patients, respectively. The cost of treatment was 3 times higher in the OR group. Casting and intramedullary nailing of femoral shaft fractures have been compared in a randomized study of 46 children in the age-group 6-12 years (Shemshaki et al. 2011). The treatment groups were similar in demographic characteristics. The authors found that operatively treated children had shorter hospital stay, returned to school earlier and started walking independently earlier, and parent satisfaction was higher. Malunion was reported in 3/23 children after cast treatment, whereas none in the operative group had malunion; 3/23 operatively treated children had postoperative infection.
Plate fixation allows anatomic and length-stable reduction without intraoperative fluoroscopy, prevention of angulation, and early mobilization, is not difficult to apply, and can be fitted to any size of femur. Plate fixation is a good alternative in heavier children. Its disadvantages include various complications and extensive surgical dissection, leading to soft-tissue damage and moderate blood loss, although the submuscular plating technique is possible to perform in a minimally invasive manner. (Gardner et al. 2004, Kuremsky & Frick 2007, Li & Hedequist 2012) Fyodorov and colleagues (1999) evaluated treatment results in 21 children (23 fractured femurs) treated by compression plating with a mean 16 months’ follow-up. All fractures healed with no complications. A group under Mostafa (2001) retrospectively studied plate osteosynthesis in 36 polytraumatized children and 10 old malunited fractures. They concluded that although rarely employed, plate fixation is a reasonable treatment option in children. A retrospective review of 40 children (46 femur fractures) with a mean 6.3-year follow-up was conducted by a group under Eren in 2003. All their fractures united, but one refracture was observed and 1 patient had osteomyelitis. Leg-length discrepancy (0.4-1.8 cm) was noted in an additional 15 patients. A union rate of 100% was observed in another retrospective study (Caird et al. 2003) of 60 children treated with compression plate fixation. This study also reports a low complication rate. Excellent clinical results and 100% union rate were also reported by Kanlic and associates (2004) in the treatment of 51 femoral fractures in children with complex femoral fractures (fractures involving the proximal or distal third, open fractures, multiple trauma, high-energy fractures, segmental fractures). No complications were reported in a study of 27 children with unstable femoral fractures contraindicated for intramedullary nailing (Sink et al. 2006). Angular deformity >10° was found in only one patient and patient had leg-length discrepancy >5 mm.

Before the popularization of flexible intramedullary nailing (FIN) external fixation (EF) was for long the treatment of choice when operative treatment was needed. A fracture can be reduced using minimally invasive pin-insertion and attaching an external frame to stabilize the fracture. EF treatment was widely used in Arkansas Children’s Hospital in the late 80s and early 90s. In one study from this institute Blasier and colleagues (1997) reported results of 132 children (139 fractures) treated with EF during the years 1983-1993. They found this treatment to be successful and cost-effective. In 1999 a report by Skaggs and group with 66 children concluded that the major impediment of EF treatment was the high rate of secondary fractures. Domb and colleagues (2002) performed a randomized prospective study to evaluate the effect of EF dynamization on the rate of refractures. They found that axial dynamization had no effect on the healing or number of complications. In a study from two county hospitals in Sweden, Hedin and associates (2003) reported results of a prospective study of 96 children with 98 femoral fractures treated with EF. They concluded that satisfactory results can be achieved and the advantages compared to non-operative treatment...
override the complications. In 2004 Hedin compared EF and FIN treatment: both methods can be used in almost all kinds of fractures, but in rare grade II or III open fractures (Gustilo & Anderson 1976) EF only. If the fracture is very distal or very proximal, only EF is applicable to avoid growth plate disturbance. The number of complications is similar: FIN involves pin migration and infection, EF infection, and both methods are marked by refractures and malunions, which are usually due to technical errors. Hedin (2004) proposes that traction and casting be abandoned in femoral fracture treatment and presents a protocol where children <3 years of age are treated with skin traction followed by casting and 3-15 years with FIN or EF depending on the fracture type. In children >12 years of age she advises to consider rigid intramedullary nails (RIN). In another study comparing EF and FIN treatment in open femur fractures (Ramseier et al. 2007) the conclusion was that FIN should be used whenever possible. A group under Wright (2005) conducted a multicenter randomized study comparing EF treatment and hip spica casting. They included 108 children from 4 pediatric hospitals, of whom 60 were treated with casting and 48 with EF. Age and sex distributions were similar. Children treated with casting had three times more malunions. On the other hand children treated with EF had longer treatment times (both in hospital and overall) and a 4% risk of refracture.

Flexible intramedullary nails (FIN) form an internal splint holding the length and alignment of the fracture site. It allows rapid mobilization of injured children and has little risk of physeal injury, osteonecrosis and refractures. Furthermore the method is minimally invasive in that nails are inserted percutaneously. These features have made FIN popular (Flynn & Schwend 2004, Gardner et al. 2004). Intramedullary treatment was introduced already in the 19th century in rigid implants and later modified using different materials involving flexible implants, which better suite children’s treatment (Barry & Paterson 2004). The Küntscher nail (Küntscher 1958) was a rigid nail and the Rush nail (Rush 1951) served as a model for modern elastic nails such as the Nancy nails (Ligier et al. 1988). Buechsenschuetz and associates (2002) compared traction and casting with FIN in 71 femoral fractures. They found that the clinical outcomes were similar but the parents of children treated with FIN were more satisfied and this method was also more cost-effective. A group under Ligier (1988) reported on 123 fractures in children aged 5-16 treated with FIN. They reported good results with minimal complications: no delayed unions, 1 bone infection, and minor skin ulcerations in 13 children. In 2006 Ho and colleagues reported that FIN was used routinely for the treatment of femoral fractures in their institution and presented the retrospective results of 91 children with 94 femur fractures. They concluded that the outcome was favorable but complications were relatively common: 16/94 patients had complications including wound or skin problems, hardware-related problems, nonunion, leg-length discrepancy, and 1 nerve palsy. The treatment results of 234 patients treated at different level I trauma centers
were combined in a review by Moroz and associates (2006). They reported excellent (anatomical or near anatomical alignment and no perioperative problems) or satisfactory (acceptable alignment and transient perioperative problems) results in most children, the outcome and complication rate being higher in children older than 11 or heavier than 49 kg. In the following year a group under Bopst (2007) reported the results of FIN treatment in preschool-aged children. They found that the approach was safe and effective but emphasized the significance of long-term follow-up in view of potential overgrowth. Stainless steel flexible intramedullary fixation was described in a study of 81 children divided into two groups according to fracture stability (Rathjen et al. 2007). The authors found this method to be effective in both stable and unstable fractures: all fractures healed and the complication rate was low. In a systematic review of outcomes and complications of FIN treatment in school-aged children, Baldwin and group (2011) found that the rate of union was high but complication rates were also high (>50% in some studies). Complications included malunion (up to 1/3 of patients), leg-length discrepancy, symptomatic hardware, and infections.

Young children with femoral fractures are usually treated with skin traction, Pavlik harness, or by hip-spica cast-immobilization. Irani and associates (1976) reported a mean 5.9 years’ follow-up results of 75 children (age 0-10 years) treated with casting. They divided their study population into subgroups according to fracture type: transverse proximal, transverse mid-shaft, transverse distal, short oblique, long oblique, spiral, and supracondylar. None of their patients had angulation or limitation of motion in the hip or knee joints at the final follow-up. The amount of limb-length discrepancy, not seen in spiral or oblique fractures, was related to the initial overriding. Older children were more likely to have limb-length discrepancies.

2.4 COMPLICATIONS

2.4.1 TIBIAL FRACTURES

Possible complications in the treatment of tibial fractures in children are compartment syndrome, vascular and nerve injury, non-union, premature physeal closure leading to growth arrest, leg-length discrepancy, angular deformity including malrotation, delayed union, and different infections (Mashru et al. 2005, Heinrich & Mooney 2010, Gordon & O'Donnell 2012). The most significant complication, which can follow both non-operative and operative treatment, is compartment syndrome (Setter & Palomino 2006, Gordon & O'Donnell 2012). Compartment syndrome can occur in any of the four muscle compartments of the lower limb due to elevated pressure caused by hemorrhage or soft-tissue edema. The first sign is severe increasing pain.
Review of the literature

The diagnosis is clinical and requires emergency fasciotomy as treatment (Gordon & O’Donnell 2012). Vascular injuries may cause severe consequences but are very rare in children (Heinrich & Mooney 2010). Physeal injuries, again, are unique to children. A growth arrest leading to shortening or angulations may occur if the fracture line reaches the physis (Langenskiöld 1967, Ogden 1982). Leg-length discrepancies may result from shortening of the tibia or the growth stimulation caused by the fracture (Shapiro 1981). Overgrowth is usually seen in younger children (<10 years of age), whereas it is not so evident in older children (Swann & Oppers 1971, Hansen et al. 1976). Angular deformities occur due to malalignment of the fracture site. Deformities may correct spontaneously in growing children (Ryöppy & Karaharju 1974, Wilkins 2005). The remodeling potential, however, decreases with age (Greiff & Bergman 1980) and thus anatomic reduction is essential in older children (Heinrich & Mooney 2010). Malalignment >10° was seen in 6/117 patients after cast-treatment of childhood tibial fracture (Shannak 1988). Rotational deformities can be difficult to evaluate but are important since they do not remodel spontaneously (Hansen et al. 1976). In a study by Shannak (1988) 3/117 patients had persistent rotational deformities at follow-up. Delayed union is not common in children and is mostly seen after operative treatment (Heinrich & Mooney 2010).

Complications of operative treatment are mostly similar to those in non-operative treatment. O’Brien and group (2004) reported a single superficial wound infection after treating 14 children with intramedullary nailing. A complication rate of 26% was reported by Goodwin and colleagues (2005) after intramedullary nailing of 19 children. These included delayed union in 3 children and angular deformity >10° in 2. Kubiak and group (2005) compared retrospectively external fixation and intramedullary nailing. They found 7 complications in 15 children treated with external fixation, including 2 delayed unions, 3 nonunions, and 2 malunions. In their intramedullary nailing group only 1/16 had a complication in bone healing. Gordon and colleagues (2007) reported complications in 9 out of 51 patients treated with flexible intramedullary nailing. These were 5 delayed unions, 1 malunion requiring corrective osteotomy, 1 osteomyelitis, and 2 nail migrations through the skin. In a report by Srivastava and associates (2008) there were 7 complications in 24 children treated with intramedullary nails, including 2 neurovascular injuries, 2 infections, 2 malunions, and 1 leg-length discrepancy. Postoperative pin tract infections were reported in 5/10 children with tibial fracture treated by external fixation (Al-Sayyad 2006). In another study of external fixation in children (Myers et al. 2007) 6/30 had non-union, 11/30 malunion, 3/30 leg-length discrepancy, 13/30 different infections. Percutaneous plating has led to 1 leg-length discrepancy of 15 mm, 1 superficial infection, and 1 skin irritation in a study of 16 children (Yusof et al. 2009).
2.4.2 FEMORAL FRACTURES
Complications often associated with femoral fracture treatment are malunion, non-union, leg-length discrepancy, skin lesions, and nerve injuries. The complication rate in non-operative treatment is 30% (Flynn & Schwend 2004). Angular deformities are tolerated to a certain extent in the treatment of children: in children younger than 10 years up to 15° of varus/valgus angulation, up to 20° anterior/posterior angulation, and up to 30° malrotation is generally accepted (Flynn & Schwend 2004). This is due to the high remodeling potential of growing bones, although rotational deformations remodel poorly (Davids 1994). In 1981 Shapiro noted overgrowth after femoral fractures in children as a universal phenomenon independent of age or fracture type. This finding is the basis of treatment guidelines allowing maximum shortening of 1.5-2 cm in children <10 and 1 cm in older children (Flynn & Schwend 2004). Due to the effect of fracture on bone growth, leg-length discrepancies are often seen in femoral fracture treatment.

According to one systematic review (Wright 2000), traction leads to higher rates of limb-length discrepancy, and higher rates of angulatory and rotational malunion than early or immediate casting. In comparison between casting and internal fixation, the latter led to lower rates of angulatory malunion but higher rates of malrotation and overlengthening. In another systematic review adverse effects were less frequent in early spica casting than in traction, in intramedullary nailing (FIN) than in casting, and in external fixation (EF) than in casting (Poolman et al. 2006). This study also compared all types of operative treatment with non-operative treatment and found a smaller rate of adverse effects in operative treatment. As to operative treatment methods, there were no differences between EF and IN, and static EF had more frequent adverse effects than dynamic EF. Complications reported in relation to intramedullary nailing are fracture shortening and angulation (which may lead to prominent or even exposed nails), limb-length discrepancy, and pain at the site of nail insertion (Li & Hedequist 2012). Sink and associates (2005) retrospectively evaluated the results of 39 children treated with FIN with a special focus on unstable (comminuted or long oblique) fractures. Complications were reported in 12/24 stable fractures and 12/15 unstable fractures. The authors concluded that due to the higher risk of complications, unstable fractures are not amenable to FIN treatment.

According to a systematic review of elastic stable intramedullary nailing in school-aged children (Baldwin et al. 2011) the complication rates were: symptomatic hardware in 23% of patients, malalignment in 15%, infections in 2%, and refractures in 1%. The hardware was removed in 83% of patients.

In a randomized multicenter trial, Wright and colleagues (2005) reported that patients treated with hip spica casting had a 45% overall malunion rate compared to 16% of those treated with external fixation (EF), and limb-length discrepancy of 13% compared to 7%, respectively. There was a 4% risk of refracture in the EF group not associated with the casting group.
Submuscular plating is associated with ingrowth of bone around the plate, refractures and hardware breakage, although complications are rare (Li & Hedequist 2012). A group under Kanlic (2004) studied the use of submuscular plating in the treatment of 51 children with complex femoral fracture. They recorded excellent clinical results with a 100% union rate. There was a complication rate of 7/51: one fracture of implant, one refracture of a pathological fracture, one bent implant, and 4 leg-length discrepancies. In a report by Sink and group (2006) 1/27 patients had angulation >10° and no other complications were reported.

Intramedullary nailing has become popular in treating children’s femur fractures. Luhmann and associates (2003) reported a series of 43 femoral shaft fractures treated with FIN. Of these patients 21 had complications: one septic arthritis, one non-union, one delayed union, 4 nail erosions, and 13 cases of pain at the nail insertion. Complications of this method were also reported by Narayanan and group (2004) after treating 79 fractures over a time period of 5 years. They reported pain/irritation at the insertion site (41), malunions (8), refractures (2), neurologic deficits (2), and wound infections (2). During their study period a change was made in the nail insertion procedure, resulting in a decrease in pain/irritation, which was the most common complication in the beginning. They also hypothesized that the use of two nails of the same diameter could reduce malunions, since different diameters produce asymmetric forces resulting in angulation. A group under Moroz (2006) conducted a review of 234 femoral fractures in children treated at six different level I trauma centers. 80/234 had complications, which included pain at nail insertion, angulation (minor or major), superficial infection, delayed union, and leg-length discrepancies. The outcomes of treatment were excellent or satisfactory in 207 and poor in 23 children. The poor outcome was caused by angulation (17 children), leg-length discrepancy (5 children), and fixation failure (1 child). The complications of operative treatment with flexible intramedullary nails (FIN) or external fixators (EF) were compared in a review by Hedin (2004). FIN treatment was associated with pin migration with skin irritation and infections. EF treatment, on the other hand, was related to infections and inflammations at the pin site. Both treatment methods may lead to refractures.

2.5 TREATMENT INJURIES

Injuries related to medical care are compensated for in different ways in different countries. In most cases, the compensation is based on negligence and some kind of legal proceedings. The increasing number of law suits involving the liability of health care providers has led to dramatically increasing insurance costs. These disadvantages of tort law in compensating medical malpractice have launched processes evaluating no-fault
compensation systems around the world (Dute et al. 2004). In the Nordic countries and in New Zealand there have long been no-fault systems to compensate injuries arising from medical treatment without negligence. (Kachalia et al. 2008)

Improving patient safety is the ultimate goal of the injury compensation systems in the Nordic countries (Denmark, Finland, Iceland, Norway and Sweden) and in New Zealand. The compensation in these systems is based on an avoidability standard: the injury would not occur in the hands of an experienced practitioner. Furthermore, the system does not seek fault or neglect in the treatment.

In Finland the Patient Insurance Act came into force in May 1987. The national treatment injury scheme is designed according to the patient insurance act and compensates pain or suffering, loss of amenities, earnings, or benefits (Brahams 1988). The Patient Insurance Center (PIC) comprises private insurance companies as members and handles the compensation procedures. All health care providers are required to be covered by insurance against liability based on the Patient Insurance Act (Mikkonen 2004).

The Finnish compensation scheme can cover the following types of injuries:

- Bodily injury, illness, or temporary/permanent weakening of health caused by treatment or examination or failure to examine
- Infections caused by micro-organisms obtained in connection to treatment or examination
- Accidental injuries caused during treatment or examination, including patient transportation
- Injury related to faulty equipment or device used during treatment or examination
- Injury caused by damage to the premises where treatment takes place, e.g. fire
- Bodily injuries caused by mistakes in the delivery or instructions of pharmaceutical usage by the chemist
- Unreasonable injury compared to the severity of the illness being treated

If a compensation claim is filed, independent specialists evaluate whether or not the injuries in question could have been avoided if an experienced clinician had conducted the treatment or examination. Unreasonable injuries are compensated if there is disproportion in the consequences of the injury and the severity of the illness, whether or not it could have been avoided. (Mikkonen 2004, Finnish Patient Insurance Center: What is compensated for 2012)

There are no previous studies reporting treatment injuries in pediatric tibial or femoral fracture treatment.
3 AIMS OF THE STUDY

Treatment of tibial and femoral fractures during the last decades has come to favor operative methods. Long-term results in the treatment of these injuries have not been fully assessed. By evaluation of treatment injuries it is possible to attain to safer treatment. The aim of this study was to ascertain the long-term treatment results in pediatric tibial and femoral fracture treatment, what type of treatment injuries occur in these injuries, and whether or not they could be avoided.

The specific aims were:

1. to calculate the incidence of pediatric tibial and femoral fractures in Finland.
2. to determine the long-term treatment outcomes of children with tibial or femoral fractures.
3. to determine changes over time in methods used to treat pediatric femoral fractures.
4. to evaluate treatment injuries related to children’s tibial and femoral fractures and identify those which are avoidable.
4 PATIENTS AND METHODS

4.1 LONG-TERM TREATMENT RESULTS

Long-term results in the treatment of tibial and femoral fractures in children were evaluated retrospectively in Studies I and II.

4.1.1 PATIENTS

Patient information was obtained from operation room (OR) records in Aurora Hospital, Helsinki. All patients treated in the OR for a tibial or femoral fracture during the years 1980-89 were included in the study. A total of 74 children with femoral fractures and 94 with tibial fractures were treated during the study period. Children who received outpatient treatment without anesthesia were not included, since patient admissions data from the emergency department were no longer available. Patient information was available for all patients in Study I and all but three in Study II. Radiographs from the time of treatment and follow-up were available only for the patients in Study I. Due to changes in legislation while conducting the studies, radiographs taken during the time of treatment of patients in Study II were no longer available.

An invitation to attend a clinical and radiographic follow-up examination was sent to the patients together with a written consent form. Altogether 52/74 patients in Study I and 58/94 in Study II responded to the invitation and of these 52 and 45, respectively, attended the follow-up.

4.1.2 METHODS

The patients in Study I and II were sent a study invitation accompanied by a patients' assessment form designed to gather subjective results, including perceived leg-length discrepancy, possible angular deformities, and symptoms. Memories concerning their treatment and possible later treatment for the same injury were inquired after. The patients were also requested to grade the function and appearance of the injured limb using a visual analog (VAS) scale 0-10.

From the patient files, information on patient gender and age, injury mechanism, fracture type and location, method and duration of treatment, and primary complications were recorded. In Study I, the radiographs obtained during the time of treatment were included in this retrospective analysis.

At the clinical examination the patients' gait was evaluated. Possible leg-length discrepancy was measured using a block test. Scars caused by injury or treatment were identified and the circumference of both thighs and calves
Patients and methods

was measured at midpoint. Passive range of motion (ROM) of knees, hips and ankles was registered on both the injured and non-injured side. Stability of knee joint and patellofemoral joints was tested in Study I and both knees and ankles in Study II. Possible rotational deformities were evaluated by measuring the thigh-foot angle and the foot progression angle (Figure 2) on both the injured and contralateral side.

Figure 2  The walking angle (left image) was measured by drawing outlines of patients' feet on paper to measure the angle of deviation of the long axis relative to walking and the line from heel to second toe. The thigh-foot angle (right image) was measured with the patient in prone position and knee flexed 90°, by observing the angle of the foot and thigh. (Adapted from Mosca 2006)

A musculoskeletal radiologist performed the radiographic analysis. In Study I radiographs obtained during treatment were re-analysed in retrospect. For the analysis of remodeling only the last image at close of treatment was included for comparison with those taken in adulthood. For those patients who attended the clinical examination, radiographs were obtained as follows: in Study I a standing, weight-bearing radiograph of both legs separately and a standing lateral view of both femurs; in Study II standing, weight-bearing radiographs of both limbs separately and a lateral view of the injured tibia in prone position with the patient lying on the injured side. Images in Study I were obtained as analogue radiographs in fluoroscopy control at a distance of 1.5m and in Study II as CR radiographs at a distance of 2m (AP view) and 1.15m (lateral view).

Length and angle measurements in Study I were made using a radiopaque ruler and manual goniometer respectively. Measurements in Study II were completed digitally. Lengths of both extremities and femurs separately were measured in Study I and the length of both tibias in Study II. Angular deformities were analyzed (Figure 3) in the coronal plane (varus/valgus, AP-view) and sagittal plane (antecurvatum/recurvatum, lateral view). Drawing a line through the midsection of the diaphysis in both AP and lateral
projections was used in measuring the angulation of the femoral (Study I) or tibial (Study II) diaphysis.

Figure 3  Radiographs of the tibia demonstrating the measurement of angular deformity from the AP (a) and lateral (b) views.

The radiographic mechanical axis of both the injured and non-injured limb was calculated according to Hagstedt and associates (1980). In measuring the mechanical axis (Figure 4), the center of the femoral head was outlined using Mose (1980) circles, the midpoint of the knee was defined by the center of the femoral condyles at the top level of the intercondylar notch, and the midpoint of the ankle as the middle of the superior facet of the talus. The radiographs were analyzed for possible signs of osteoarthritis of the joints according to a 3-point scale (normal = 0; joint space narrowing = grade 1; osteophytes, cysts, or erosions = grade 2).
Patients and methods

**Figure 4** A standing weight-bearing radiograph of the lower limb demonstrating the measurement of the mechanical axis. A line was drawn from the center of the femoral head and from the midpoint of the ankle (middle of superior facet of talus) to the midpoint of the knee (center of the femoral condyles at the top level of the intercondylar notch).
4.2 TREATMENT INJURIES

Treatment injuries were evaluated in Studies III and IV. In both studies, the incidence of fractures was calculated and in Study III the method of treatment was reported. In Study IV, a treatment protocol for children’s tibia fracture treatment was constructed.

4.2.1 PATIENTS

Patient information was obtained from the Patient Insurance Centre (PIC) in Studies III and IV. Demographic data and description of injury were as presented by the parents of children in their compensation claims to PIC (50 cases in Study IV and 30 in Study III). Based on these claims and patients’ medical records, an expert assigned by PIC made the compensation decisions (see Figure 1 in Study IV). We gathered all information concerning treatment injuries in the management of tibial or femoral fractures in children aged 0-16 years during the years 1997-2004 (starting 10 years after the establishment of PIC) from the PIC records.

Information on the child population in Finland and Helsinki was obtained from national register data. This information, together with the data in the hospital discharge registers, was used to calculate the annual incidence of tibial and femoral fractures during the study period. In Study III the method of treating children under 17 years of age was determined using the registers of the National Institute of Health and Welfare.

The total incidence of tibial fractures in Helsinki was estimated during a one-year prospective follow-up starting from February 2005, including all children treated in Helsinki for a tibial fracture. All patients under 16 years of age treated for a fracture were recorded. Children treated during the same period in other regional public clinics dealing with injured children in Helsinki were also recorded to attain population-based data.

4.2.2 METHODS

The data collected from PIC concerning treatment injuries was analyzed by an independent observer, a consultant pediatric orthopedic surgeon not involved in the treatment of patients or the claims-handling process in PIC. The data concerning patient age, sex, fracture type and location, treatment institution and method, complications, and permanent sequelae were recorded from the data provided by PIC. The reason for filing a claim was also recorded. The trauma energy was classified according to the patient information: accidents involving a motor vehicle (e.g. car, motorcycle) or falls from a height (>6m) were considered high, sporting injuries moderate, and falls at ground level low. All compensation claims and PIC compensation decisions were analyzed retrospectively and the number of avoidable injuries was estimated.
4.3 STATISTICS

Incidence is reported per 1,000 children. Differences between two groups were tested for significance using the parametric Student’s t-test or non-parametric Mann-Whitney U test, as appropriate. Poisson distribution was used to calculate the 95% confidence intervals (CI) for incidence figures reported. The correlations were calculated using the Spearman rho test. For reliability of repeated measurements, the intraclass correlation coefficient (ICC) was calculated. The level of significance used in the studies was 5%. The statistical analysis was completed using Microsoft Excel for Mac 2008 and 2011, and SPSS Statistic software (Versions 15.0, 16.0, and 20.0).

4.4 ETHICAL CONSIDERATIONS

The Ethics Board of Helsinki University Central Hospital approved the study protocol (approval identification number 68/E7/2002). The participants were informed that they attended the study on a voluntary basis, and that the information collected was to be used for medical research purposes. Informed written consent to participate was obtained from the patients in Study I and II. Patients were referred to appropriate treatment when further intervention was needed.
5 RESULTS

5.1 LONG-TERM RESULTS

5.1.1 Tibial Fractures (Study II)
A total of 94 children were treated in the operation room (OR) of Aurora Hospital, Helsinki, Finland, during the study period 1980-89. Patient and fracture characteristics and method of treatment are reported in Table 1.

Table 1. Characteristics of the children treated for a tibial (Study II) or femoral (Study I) fracture in the OR of Aurora Hospital, Helsinki, during 1980-89. *of the 52 patients who attended follow-up.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Tibia (n=94)</th>
<th>Femur (n=74)</th>
</tr>
</thead>
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<tr>
<td><strong>Age at time of injury</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
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<td>0-14</td>
</tr>
<tr>
<td><strong>Sex</strong></td>
<td></td>
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</tr>
<tr>
<td>Boys</td>
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<td>51</td>
</tr>
<tr>
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</tr>
<tr>
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<td>Down-hill skiing accident</td>
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<td>9</td>
</tr>
<tr>
<td>Fall on level</td>
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<td>7</td>
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<td>Pathological fracture</td>
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<tr>
<td>Right</td>
<td>43</td>
<td>29*</td>
</tr>
<tr>
<td><strong>Location</strong></td>
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<td></td>
</tr>
<tr>
<td>Proximal</td>
<td>4</td>
<td>13*</td>
</tr>
<tr>
<td>Mid-shaft</td>
<td>22</td>
<td>28*</td>
</tr>
<tr>
<td>Distal</td>
<td>50</td>
<td>11*</td>
</tr>
<tr>
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<tr>
<td><strong>Method of treatment</strong></td>
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</tr>
<tr>
<td>Casting</td>
<td>89</td>
<td>4</td>
</tr>
<tr>
<td>Skeletal traction:</td>
<td>4</td>
<td>62</td>
</tr>
<tr>
<td>-pin in tibia</td>
<td>0</td>
<td>49</td>
</tr>
<tr>
<td>-pin in femur</td>
<td>0</td>
<td>13</td>
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<tr>
<td>-pin in calcaneus</td>
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<td>0</td>
</tr>
<tr>
<td>Internal fixation</td>
<td>1</td>
<td>8</td>
</tr>
</tbody>
</table>
The indication for operative treatment was open fracture in all 5 patients thus treated. The mean hospitalization was 5 (1-26) days. The children were immobilized for a mean 59 (26-149) days and the last check-up in the outpatient clinic was a mean 119 (34-676) days from the date of injury. Remanipulation of the fracture had to be performed in 41 cases. This included wedging of the original cast in the outpatient clinic for 22 children and remanipulation and casting under anesthesia for 19. Primary treatment-related complications were recorded in 4 patients: 2 skin lesions, 1 osteoporosis, and 1 malunion. In addition to these, 1 patient developed a premature closure of the distal growth plate in relation to the injury.

Of the 94 patients eligible for the study 74 were sent an invitation and a self-assessment form; 3/94 had died during follow-up and 58/94 returned the patients’ assessment, one patient responded anonymously; 33/94 could not be reached or did not respond to the invitation. Of these, 5 had a permanent residence abroad.

In the patients’ assessment 32 subjects reported positive memories of treatment, 6 negative, 4 neutral, 2 no memories, and 8 not specified. An additional 6 patients reported intensive pain as their only memory related to the treatment. In one response the patient remembered a staff member telling him “a child does not feel pain”. The injured limb was symptomatic in 43 patients: 17 complained of deformity, 13 of pain, 10 of leg-length discrepancy, and 3 of perceived limping. The mean VAS result for function was 9.1 (range 6-10) and cosmetic appearance of the injured leg 9.3 (range 5-10).

In the clinical examination (n=45/94) at a mean 27 (23-32) years after the injury none of the patients presented with a limp. Leg-length discrepancy of 5 mm was found in 5 patients and 10 mm in 5. Of these patients, aged 7-12 (mean 12) years at the time of injury, the injured limb was shorter in 6. The mean foot progression angle was 10° (0-30°) in both legs. Difficulty in squatting down was observed in 6 patients, with no obvious reason.

Symmetrical passive range of motion was measured in the hip, knee and ankle joints (Table 2). The average thigh-foot angle measured 5° (0-55°) for the injured and 3° (0-17°) for the uninjured limb (p=0.063). Four patients had a thigh-foot angle in the injured limb of 20° or more. No differences were observed in the thigh or calf circumference of the injured and non-injured limb (mean circumference of calves was 37 cm and thighs 52 cm).

The mean radiographic length of the tibia was 38 cm (range 31-45) on both sides. There was length discrepancy exceeding 10 mm in five of these patients, with a median difference of 5 mm (range 1-22 mm). One of these patients had clinically detectable leg-length discrepancy but none was subjectively aware of it.

Angulation measured from radiographs did not exceed 5° in all but 4 patients. Of these, 3 had valgus angular deformity and 1 varus deformity <10°. The mean angulation was 3° (0-10°) on the injured side and 1° (0-5°) on the contralateral side (p=0.001). In the sagittal plane the angulation
averaged 3° (range 0-8°) on the injured side, angulation exceeding 5° in 8 patients.

Degenerative changes in the joints were found in the radiographs of 2/45 patients. One patient had bilateral grade 1 osteoarthritis of the hip joint and 1 bilateral grade 1 osteoarthritis of both the hip and the knee joints. This could not be associated with axial malalignment or leg-length discrepancy.

**Table 2.** The passive range of motion of the hip, knee and ankle joints (*) at check-up as adults. I=injured limb, C=contralateral limb.

<table>
<thead>
<tr>
<th>Joint</th>
<th>Min</th>
<th>Mean</th>
<th>Max</th>
<th>p</th>
</tr>
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<tr>
<td><strong>Hip joint</strong></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Internal rotation, I</td>
<td>19</td>
<td>18</td>
<td>45</td>
<td>0.225</td>
</tr>
<tr>
<td>Internal rotation, C</td>
<td>18</td>
<td>18</td>
<td>45</td>
<td>0.297</td>
</tr>
<tr>
<td>External rotation, I</td>
<td>47</td>
<td>46</td>
<td>70</td>
<td>0.860</td>
</tr>
<tr>
<td>External rotation, C</td>
<td>47</td>
<td>46</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>Abduction, I</td>
<td>47</td>
<td>47</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Abduction, C</td>
<td>47</td>
<td>47</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Extension-flexion, I</td>
<td>138</td>
<td>136</td>
<td>165</td>
<td>0.198</td>
</tr>
<tr>
<td>Extension-flexion, C</td>
<td>136</td>
<td>136</td>
<td>165</td>
<td></td>
</tr>
<tr>
<td><strong>Knee joint</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Flexion, I</td>
<td>167</td>
<td>167</td>
<td>180</td>
<td>1.000</td>
</tr>
<tr>
<td>Flexion, C</td>
<td>167</td>
<td>167</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td>Extension, I</td>
<td>-1</td>
<td>-1</td>
<td>0</td>
<td>0.323</td>
</tr>
<tr>
<td>Extension, C</td>
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<td>-1</td>
<td>0</td>
<td></td>
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<td><strong>Ankle joint, knee in 90° flexion</strong></td>
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<tr>
<td>Extension-flexion, I</td>
<td>75</td>
<td>75</td>
<td>105</td>
<td>0.229</td>
</tr>
<tr>
<td>Extension-flexion, C</td>
<td>75</td>
<td>75</td>
<td>105</td>
<td></td>
</tr>
<tr>
<td><strong>Ankle joint, knee in extension</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extension-flexion, I</td>
<td>66</td>
<td>65</td>
<td>95</td>
<td>0.254</td>
</tr>
<tr>
<td>Extension-flexion, C</td>
<td>65</td>
<td>65</td>
<td>95</td>
<td></td>
</tr>
</tbody>
</table>

**5.1.2 FEMORAL FRACTURES (STUDY I)**

There were altogether 74 children who received treatment in the OR for a femoral fracture in Aurora Hospital, Helsinki during the study period 1980-89. The demographics and the characteristics of injury, fracture and treatment are presented in Table 1. Most of the patients were treated with skeletal traction and they spent 3-156 (mean 58) days in hospital.

Of the 74 patients enrolled for the study, 52 responded to the study invitation and returned the patients’ assessment form. All of these patients attended the clinical examination, with a mean 21 years’ (range 19-38) follow-up. Two patients had died during follow-up, 2 did not wish to participate, and 18 did not respond/could not be reached. The mean age of patients at the follow-up was 28 (19-38) years. The median traction time for the patients attending the final check-up was 39 (3-77) days. Five patients had been treated by internal fixation and 3 with early casting.
The patients' assessment involved 69 subjective complaints: back pain in 20 cases, perceived leg-length discrepancy in 20, pain in the injured limb in 14, deformity in 8, and perceived limp in 7 cases. No correlation was found between leg-length discrepancy and back pain (Spearman's rho 0.22, p=0.1). The memories of treatment were positive in 36, negative in 3, and not specified or no memories in 13 responses.

Limp was seen in 5/52 patients in the clinical examination. A scar from the treatment or injury was found in 48/52 patients. The passive ROM was symmetrical in all but one joint: the mean external rotation of the hip on the injured side was 40° (15-60°) and 45° (5-60°) on the contralateral side (p=0.006). Clinically detectable limb-length discrepancy was noted in 31/52 patients, with an average of 12 (5-30) mm (Figure 5). Eight of these had a discrepancy exceeding 15 mm. The previously injured limb was shorter in 19 patients and longer in 12. Radiographic inequality was found in 6/8 of those patients whose leg-length discrepancy measured ≥ 15 mm in the clinical examination. A positive correlation (Spearman's rho 0.64; p<0.001) was found between the clinical and radiographic leg-length discrepancies. The mean difference of the radiographic leg-length being 11 (0-40) mm. A positive correlation was established between patients' age at injury and ultimate discrepancy.

**Figure 5** A bar diagram showing the clinically detectable leg-length discrepancy in 31/52 patients treated for childhood femoral fracture (Palmu et al., unpublished results).
In the radiographic evaluation remodeling of angulation in the coronal plane was detected from shortly after treatment to the final check (in adulthood), whereas the mean angulation in the sagittal plane remained unchanged. Varus-valgus deformity remodeled from a mean 7° to a mean 5° and antecurvatum-recurvatum deformity was a mean 11°. At the clinical examination angulation exceeding 10° was seen in 21/52 patients in the sagittal plane, two patients also having >10° angulation in the coronal plane. All but 2 patients with this amount of angulation were treated with traction. In a comparison of mean angulation between different treatment modes, there was coronal malalignment of 6° and sagittal malalignment of 12° in the traction group. The respective angulations were 5° and 8° in the operatively treated patients (p=0.2 and p=0.3), see Table 2 in Study III.

The mean antecurvatum angulation at the final check-up was 11° (95% CI: 9–13°) for the injured femur and 8° (95% CI: 8–9°) for the non-injured femur (p = 0.001). Fractures which united in varus malalignment remained unchanged at follow-up in 12 patients, had remodeled into neutral position by the time of follow-up in 10 patients, and had turned towards valgus in 8. Valgus malalignment, on the other hand, remained unchanged in 4 patients and had remodeled into normal alignment in 1. One patient with healing in anatomical alignment had shifted into varus malalignment by the time of the final check-up (Figure 6).

The differences in angular measurements between observers did not exceed 4°. The calculated interobserver rate (intra-class correlation coefficient, ICC) for the measurement of angulations was 0.96 (p<0.001).

Knee-joint arthritis was observed in 7 patients at the final check-up. Of these 6 had grade-I and 1 had grade-II arthritis. In all but 1 patient the degenerative changes were seen in the injured knee. In the age group of 11 years or older at the time of injury, 6/15 patients showed signs of arthritis at the final check, at a mean age of 12 (8-14) years at injury and 34 (32-36) years at follow-up. AP instability of the knee joint was found in 2 patients in the clinical examination. The method of treatment had been skeletal tibial
traction in all patients with arthritis. Four fractures were mid-shaft, 2 proximal, and 1 distal. The patients with signs of osteoarthritis had more angulation in both sagittal and coronal planes (p=0.1 and p<0.001) (Table 3) compared to those with no degeneration. A positive correlation was found between both deformities and knee-joint arthritis (Spearman’s rho 0.57 and 0.44; p<0.01 and p=0.008 respectively). No correlation was found between leg-length discrepancy and knee-joint osteoarthritis (Spearman’s rho =0.12, p=0.4).

The treatment of 5 children in this study was operative. Their results in the clinical examination and radiographic evaluation were essentially similar to those treated with traction or casting.

Table 3. Characteristics of the 6 patients older than 11 years at time of injury with signs of osteoarthritis at follow-up. antec=antecurvatum (Palmu et al., unpublished results)

<table>
<thead>
<tr>
<th>Patient</th>
<th>Coronal</th>
<th>Sagittal</th>
<th>AP instability of knee joint</th>
<th>Grade of osteoarthritis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>varus 4</td>
<td>antec 15</td>
<td>yes</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>varus 10</td>
<td>rec 4</td>
<td>yes</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>varus 4</td>
<td>antec 22</td>
<td>no</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>varus 15</td>
<td>antec 30</td>
<td>no</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>valgus 4</td>
<td>antec 20</td>
<td>no</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>valgus 8</td>
<td>antec 28</td>
<td>no</td>
<td>1</td>
</tr>
</tbody>
</table>

5.2 TREATMENT INJURIES

5.2.1 TIBIAL FRACTURES (STUDY IV)

The incidence of tibial fractures in children necessitating inpatient care was 0.69 per 1,000 (CI: 0.68-0.71) based on register data. The child population (age <17) in Finland varied between 1.04-1.09 million during the study period 1997-2004. The total incidence (inpatient and outpatient treatment) of tibial fractures in the city of Helsinki was 1.0/1,000 according to our prospective 12-month study. Treatment of tibial fractures in Finland was according to hospital discharge registers mostly (78%) in university and central hospitals (Figure 7) during the study period.
A total of 50 compensation claims arising from tibial fracture treatment were filed to PIC during the 8-year study period. Of the patients in question 36 had received inpatient care; 16 in university hospitals, 15 in central hospitals, and 5 in district hospitals. Those treated in an outpatient clinic were treated in health care centers (12 patients), central hospitals (1 patient), and in private institutions (1 patient). The mean age of the patients involved was 11 (0-16) years; 32 of them were boys. The fracture characteristics can be seen in Table 4.

Complications (n=37) were recorded in the treatment of 31 patients. These included infections in 10 cases, skin ulcerations in 8, compartment syndrome in 6, nerve palsy in 6, malunion in 4, non-union in 2 and vascular injury in 1. Of these, 26 were regarded in retrospect as avoidable. The unavoidable complications were 3 infections in operative treatment, 1 malunion, and 1 decubitus ulcer in cast treatment.

One patient had permanent 30% disability caused by treatment according to the graduated disability scale used in Finland. Based on this scale, (0-100%) implemented in units of 5, an additional 2 patients had 10% disability and 1 had 5% disability. Permanent sequelae were recorded in altogether 12 patients: 5 malunions, 3 contractures of the ankle or subtalar joint, 2 peroneal nerve palsies, 1 growth arrest, and 1 skin defect necessitating plastic surgery.
Results

Table 4. Fracture characteristics, accompanying injuries, trauma energy, and treatment method in the case of children filing a compensation claim to PIC after tibial (Study IV) or femoral (Study III) fracture treatment during 1997-2004. FIM=flexible intramedullary nailing, RIM=rigid intramedullary nailing, EF=external fixation.

<table>
<thead>
<tr>
<th>Fracture side</th>
<th>Tibia</th>
<th>Femur</th>
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<tbody>
<tr>
<td>Left</td>
<td>23</td>
<td>15</td>
</tr>
<tr>
<td>Right</td>
<td>26</td>
<td>15</td>
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<tr>
<td>Bilateral</td>
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<tr>
<th>Fracture location</th>
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<tr>
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<td>22</td>
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<tr>
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<tr>
<td>Proximal</td>
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<th>Accompanying injuries</th>
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<tr>
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<td>Compartment syndrome</td>
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<tr>
<th>Trauma energy</th>
<th>Tibia</th>
<th>Femur</th>
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</thead>
<tbody>
<tr>
<td>High</td>
<td>16</td>
<td>6</td>
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<tr>
<td>Moderate</td>
<td>18</td>
<td>14</td>
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<tr>
<td>Low</td>
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<table>
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<tr>
<th>Primary treatment</th>
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<td>Non-operative</td>
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<td>3</td>
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<td>-skin traction</td>
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<td>6</td>
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<td>-skeletal traction</td>
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<tr>
<td>-screw fixation</td>
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<td>3</td>
</tr>
<tr>
<td>-FIM</td>
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<td>-RIM</td>
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<td>-EF</td>
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</tr>
<tr>
<td>-bio-absorbable pinning</td>
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<td>0</td>
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<tr>
<td>No treatment (missed diagnosis)</td>
<td>11</td>
<td>5</td>
</tr>
<tr>
<td>-subsequent casting</td>
<td>6</td>
<td>4</td>
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The most common reason for claims filed by the parents of children treated was pain (n=30). Other claims were insufficient diagnosis or treatment (n=23), permanent disability (n = 24), extra treatment expenses (n = 17), inappropriate behavior of medical personnel (n = 1), and loss of income of the parents (n = 1). There were 4 different claims in 1 case, 3 in 13 cases, 2 in 19 cases and 1 in 19 cases.
Compensation was granted to 35/50 of the patients. In 32 cases compensation was based on inadequate treatment and in 3 cases infection. The compensated inadequacy of treatment included delay in diagnosis or treatment in 15 cases, inadequate surgical procedures in 8 cases (2 iatrogenic peroneal nerve injuries, 2 inadequate implants, 2 incorrect patient positioning during anesthesia, 1 unsatisfactory reduction, and 1 skin necrosis caused by tourniquet), 6 decubitus ulcers due to insufficient padding in casting, 2 malunions in cast treatment, and 1 skin laceration at cast removal. The compensated infections were all related to operative treatment. In 3/6 children suffering from compartment syndrome there was an unnecessary delay in fasciotomy justifying compensation. For detailed characteristics of the compensation claims see Table 3 in Study I. The fracture location did not differ between compensated and non-compensated injuries.

The average compensation for the injuries was 3,900 (200-43,867) EUR. The overall compensations paid by PIC were 51,633 EUR for claims due to permanent disability, 37,849 EUR for pain, and 26,155 EUR for permanent cosmetic harm. The estimate for the total amount of compensations for these patients is approximately 167,000 EUR.

In our retrospective re-evaluation of the compensatable injuries all but one were regarded as avoidable. The one unavoidable injury was an infection related to the treatment of a distal tibial triplane fracture. The treatment was below the standard of an experienced consultant in all but 4 of the compensated injuries. These were 3 infections and 1 decubitus ulcer in casting. Furthermore, national treatment recommendations (Kunnamo et al. 2006) were not followed in 7 cases. In our retrospective evaluation, an independent observer arrived at the same compensation decisions as PIC.

Radiographic assessment was insufficient in 11 cases. Diagnosis was missed because no radiographs were acquired in 8 cases and in three cases the images were misinterpreted.

A treatment protocol (Figure 8) was designed based on the findings of this study to improve treatment and to prevent future patient injuries.
5.2.2 FEMORAL FRACTURES (STUDY III)

The calculated annual incidence of pediatric femoral fractures was 0.27 per 1,000 (CI: 0.10-0.29) during the study period, this according to the mean census population of 1.1 million children. According to national register data the treatment method was operative in 59% of the 1,389 fractures treated during the study period. The operative approaches included internal fixation in 762 fractures (intramedullary nailing, screw fixation, or plate osteosynthesis). The treatment was non-operative (casting or traction) in 563 fractures. According to the incidence and the number of treatment injuries,
the calculated risk of treatment injury was 2.2% in femoral fractures in children <17 years of age.

A total of 30 compensation claims were filed to PIC concerning injuries related to femoral fracture treatment of children during the study period 1997-2004. The characteristics of fracture and treatment are set out in Table 4. Primary treatment was given in a central hospital in 15 cases, university hospital in 8, health care center 6, district hospital in one. Non-operatively treated children were younger than those treated operatively: mean age 4 and 11 years respectively.

Complications were reported in 11/30 cases. These were skin ulcers in 4 patients, infections in 3, pseudo-arthrosis in 2, burn caused by diathermia in 1, and joint-surface damage caused by intramedullary nailing in 1 patient.

Patients claimed for compensation based on the following issues: pain or suffering (n=20), insufficient diagnosis or treatment (n=17), extra treatment expenses (n=9), permanent disability (n=7), and inappropriate medical personnel behaviour (n=2). Seventeen involved more than 1 issue.

A total of 16/30 claimants were granted compensation by PIC. The average compensation was 2,300 EUR. Of the injuries in question, 3 were infection-related and 13 treatment-related. The reason for compensation by PIC was delay in 3 cases (2 in treatment, 1 in diagnosis of non-union), unnecessary operation in 2 cases, inappropriate surgery in 2 cases, and other reasons in 5 cases. The 3 compensated infections were classified as unreasonable injuries. The total amount of compensation was approximately 74,000 EUR (permanent sequelae 14,200, pain 13,700, cosmetic reasons 9,600, other 4,200, still to be paid 32,000).

Of the 16 compensated injuries, 11 were regarded as avoidable in the retrospective evaluation of an independent observer. The non-avoidable injuries were 1 non-union due to implant failure, 1 malunion after cast treatment, and 3 postoperative infections. In all but one case, the investigators’ decision on compensation agreed with that of PIC: one 4-year-old child was granted compensation due to 23° varus malunion (Palmu et al., unpublished results), although in our opinion this would most likely have remodeled.
6 DISCUSSION

Treatment of children’s fractures has undergone a change during the last few decades. Traditionally most pediatric fractures have been treated non-operatively: femoral fractures by traction and cast-immobilization, tibial fractures by manipulation and cast-immobilization. However, treatment of pediatric fractures has gradually become more predominantly operative, not for medical but social and economic reasons. The advantages of operative treatment in femoral and tibial fractures include shorter hospital stay and immobilization time, allowing faster return to normal social activities.

Patients and parents have become increasingly aware of different treatment options in today’s internet era. Choice of treatment method has to be made together with the patient and parents. When complications occur, a question of liability often arises. Concern to guarantee patients’ rights to compensation for malpractice has led to the development of no-fault compensation systems around the world. Since this type of compensation system was established in Finland in the 80s, this study was designed to evaluate compensation claims in tibial and femoral fracture treatment of children.

The aims here were to evaluate the long-term results of non-operative treatment in pediatric femoral and tibial fractures, to determine the current treatment policy in femoral fractures and to evaluate patient injuries and complications occurring in children’s femoral and tibial fractures.

6.1 INCIDENCE

The incidence of children’s fractures seems to have decreased during the past decades (Tiderius et al. 1999, Bridgman & Wilson 2004, Mäyränpää et al. 2010). Studies reporting this decrease suggest that this may reflect changes in lifestyle affecting children’s activities. Tiderius and associates describe the fall-off in children’s participation in physical activities. The effect of this on fracture incidence seems probable, since in the 80s Landin (1983) already noted a seasonal variation in the occurrence of fractures in children this reflecting their activities. In the study in question there was a peak in the incidence of fractures at the beginning and end of summer holidays. Increased use of safety devices and extensive efforts for injury prevention have also been discussed as reason for the decreased incidence.

We calculated the annual incidence of tibial fractures (1.0/1000 children) based on a prospective one-year survey in the city of Helsinki. This figure is similar to that of two population-based studies from the United Kingdom (Lyons et al. 1999, Cooper et al. 2004), where the incidence was 1.03/1000 and 0.91/1000. In our long-term study, the sex ratio of tibial fractures was
2.1/1, which is in accord with that reported by Landin (1983). Our annual incidence of femoral fractures was 0.32/1000 children and the sex ratio 2.2/1. Earlier studies give an incidence of 0.32/1000 (Lyons et al. 1999) and decreasing from 0.33/1000 in 1991 to 0.22/1000 in 2001 (Bridgman and Wilson 2004). Our estimates are in line with earlier reports, although some uncertainty prevails, since our calculations of femoral fracture incidence were based on register data. This uncertainty, however, is probably minimal, since most femoral fractures require inpatient treatment (Galano et al. 2005) and the accuracy of the Finnish Hospital Discharge Register is particularly high (Keskimäki & Aro 1991).

6.2 TREATMENT

Treatment of children’s fractures is variable. The present findings demonstrate that a high union rate and a low complication rate can be achieved with non-operative treatment in both tibial and femoral fractures. In tibial fractures, cast treatment required a mean hospital stay of 5 days. Operative treatment with e.g. intramedullary nailing may shorten the hospital stay, but in most institutions (not in the Helsinki Children’s Hospital) requires additional surgery in connection with implant removal, although the need for routine removal of implants is controversial (Peterson 2005, Kuremsky & Frick 2007, Baldwin et al. 2011). In our study almost one half of the patients required remanipulation of the fracture to maintain axial alignment, this often requiring readmission to hospital. These are issues which must be taken into account when comparing costs of treatment. In addition to cost, it must be remembered that with operative treatment the immobilization is usually shorter and the child returns to normal daily activities earlier than with cast treatment, which reduces the psychological impact of prolonged immobilization on the child (Luhmann et al. 2003). Furthermore a cast often causes extra effort in the mode of transportation, personal hygiene and potential discomfort (Hughes et al. 1995). Operative treatment, on the other hand, has its own complications, including potential refracture not often associated with non-operative treatment (Wright et al. 2005). The choice of optimal treatment in children also depends on age and family conditions. According to our study non-operative treatment is still effective and future RCTs comparing casting and intramedullary nailing in the treatment of tibial fractures are recommended.

Traction has been thought to lead to limitations in range of motion (ROM). Aronson and coworkers (1987), in their long-term study, reported that no such limitations followed. Limb-length discrepancies were found in 11/54 children. The present study supports the finding of the effect on ROM: there was no differences found in ROM. The limb-length discrepancies in this study were frequent: 31/52 of the patients had a clinically detectable discrepancy, although significant (≥15 mm) discrepancies were less frequent.
This reflects the overgrowth phenomenon described by Shapiro in 1981: a fracture in the femur leads to growth acceleration regardless of fracture type or position. A positive correlation was found between age at time of injury and the residual discrepancy, which contradicts the findings of Shapiro (1981) and Stephens’ group (1989). In those studies, the growth-stimulation was independent of age. The limb-length discrepancies in our cohort were asymptomatic. The clinical significance of leg-length discrepancies is probably minimal and only discrepancies of more than 25 mm usually require active intervention (Stanitsky 1999).

Angular deformities were small after cast-treatment of tibial fractures. All patients had angulation <10° in both coronal and sagittal planes. In 4 patients the angulation exceeded 5° in the coronal plane and in 8 in the sagittal plane. Hansen and associates (1976) reported angular deformities after cast-immobilization in 25/85 patients ranging from 3-19°, but they did not report how many of these had angulation >10°. Shannak (1988) reported angulation exceeding 10° in 6 patients after cast treatment. It is not mentioned, however, whether or not remanipulation was performed for any of the 117 patients in his study. At the time of union 2/61 patients have had angulation exceeding 8° (Briggs et al. 1992). These authors did not follow the patients after cast removal at union. Qidwai (2001) reported 1 angulation >10° after Kirschner-wire treatment of 84 tibial fractures. After FIN treatment, O’Brien and group (2004) reported no malunions, Goodwin and group (2005) angulation >10° in 2/14 patients, a group under Gordon (2007) in 1/60 patients, and Srivastava and coworkers (2008) in 1/24. In adolescence, malunion seems to follow FIN treatment more frequently: Deakin and associates (2010) reported a malunion-rate of 38% after the treatment of 21 patients. According to our study, the initial reduction together with casting (and remanipulation) was sufficient to produce good long-term axial alignment. Our results, in terms of axial alignment, are superior to those mentioned above after operative and non-operative treatment. The reports on operative treatment, however, include patients with more severe and often unstable fractures. Moreover, the follow-up times in previous studies have not exceeded 10 years. The follow-up time in the present study was longer, giving more time for remodeling. In a study by Wallace & Hoffman (1992) dealing with femoral fractures the remodeling, however, was reported to happen mostly within 6 years from injury. Unfortunately we were not able to evaluate the extent of remodeling after tibial fractures since, the radiographs obtained during treatment were no longer available.

Significant (>20°) rotational deformity was evident in 4 patients in our study. Hansen and colleagues (1976) noted rotational deformity <20° in 5/85 patients. In their discussion they pinpointed the fact that there is no good means to evaluate rotational deformities after reduction. In a study by Shannak (1988) 3 patients had malrotation, although the extent is not stated. In our study the peak external torsion was 55°, which is very likely to cause
problems in the future. Careful assessment of rotational deformities is to be advocated in tibial fracture treatment.

In femoral fracture treatment a variable amount of angulation is tolerated after reduction. According to Wallace & Hoffman (1992) as much as 25° of angulation in any plane can remodel satisfactorily. On the other hand, Flynn & Schwend (2004) suggest that if malunion does not remodel, coronal plane (i.e. varus-valgus) angulation is more likely to cause problems than malunion in the sagittal plane. According to Flynn & Skaggs (2010) angular deformity in the sagittal plane (i.e. antecurvatum/recurvatum) can be expected to remodel rapidly with little residual deformity. According to Wallace & Hoffman (1992) again, remodeling occurred equally well in both planes. In the present study, angulation in the coronal plane remodelled more than the sagittal plane angulation. Furthermore, the angular deformities especially in the sagittal plane were correlated to knee-joint arthritis; 6/7 patients with knee-joint arthritis were >11 years of age. In this age group Flynn & Skaggs (2010) suggest that angulation >10° in sagittal or >5° in coronal plane should not be tolerated. The results of the present study support these guidelines, since all patients with osteoarthritis had angulation exceeding these values (Table 3). Of these patients 2 had clinical AP instability of the knee joint, which may also have an effect on the degeneration. The mean age of the patients with knee-joint arthritis was 34 years, whereas the prevalence of knee-joint arthritis in this age group in Finland is 0.3-0.4% according to a Finnish health examination survey (Kaila-Kangas 2007). The present findings indicate that a more cautious approach is called for in tolerating angulation after femoral fracture in children older than 10 years of age. In previous studies an association between rotational deformity or leg-length discrepancy and knee-joint arthritis has been suggested (Verbeek et al. 1976, Eckhoff et al. 1994). No such correlation was established in the present cohort.

A majority of our patients were satisfied with their treatment 16-32 years after the injury. According to the patients’ assessment 6/58 patients treated for a tibial fracture mentioned intensive pain as their only memory related to treatment. Schechter and associates (1986) recognized that child patients received less analgesic treatment than adults. Later studies have shown that under-treatment of children’s pain can lead to long-term behavioral changes. The findings in the current study underline the importance of adequate pain management, as so many patients recall pain as their only memory after decades.

Treatment of femoral fractures in Finland during the years 1997-2004 was according to this study mostly operative. This differs markedly from the situation in the 80s, since most of the patients in our long-term study were treated with traction or casting. In 1992 Miettinen concluded that operative treatment should be considered more often based on a study comparing traction and operative treatment. Heideken and colleagues (2011) describe the shift from non-operative to operative treatment in Sweden: the
proportion of children treated with traction or casting has fallen as that of intramedullary nailing and external fixation has increased. This is in line with the recommendation of Hedin (2004), who suggests that non-operative treatment should be abandoned in femoral fractures. In her recommendation only children under the age of 3 should be treated non-operatively. In the light of the present findings, however, good long-term results can be obtained in non-operative treatment, especially in younger children. Of the patients who filed a compensation claim, the operatively treated patients were older (mean 11 years) than those treated non-operatively (mean 4 years). According to the recommendations of Anglen and group (2005), non-operative treatment is suggested in children younger than 6 years of age. In a database study of 84,000 children hospitalized for trauma, Galano and associates (2005) reported that children less than 5 years old were treated primarily with casting, whereas children 11-18 years of age were treated with internal fixation. A marked variation in the method of treatment was described in the age-group 6-10 years old.

In a nationwide study from Sweden describing the incidence and treatment trends in femoral fracture treatment, Heideken and group (2011) reported that the length of hospital stay decreased by 81% from 1987 to 2005. In our study hospitalization times were prolonged: some patients spent almost ½ year in hospital. According to modern standards and cost of hospitalization this would probably be unacceptable. Furthermore, the number of parents willing to leave their child in a hospital for such a long time after a fracture can be questioned.

6.3 TREATMENT INJURIES

The risk of sustaining a treatment injury related to children’s tibial or femoral fracture treatment is relatively low: 0.6% of children with tibial fractures and 2.2% with femoral fractures were granted compensation after a treatment injury. A majority of the injuries, however, were regarded in retrospect as avoidable. In other words, with more careful clinical practice the number of treatment injuries could be even lower. The basis in compensating injuries according to the Finnish Patient Insurance Act is the standard of treatment of an experienced consultant: the question asked is “would this have happened if an experienced consultant had treated the patient?” If a compensatable injury occurs, the standard of treatment has been suboptimal. In most cases, the compensation claims focused on extensive pain or insufficient diagnosis or treatment. These are all issues which could be taken into account in good clinical practice. Injuries regarded as unavoidable were mostly infection-related. Treatment injuries have previously been studied, but in regard to complications of femoral fracture treatment, Hedin (2004) comes to the conclusion that most problems are due to technical error and as such the number of them could be reduced.
One aim in this study was to outline preventable causes of treatment injuries in order to improve treatment in the future. It was noted that the reason for injury was misinterpretation of radiographs or failure to obtain a radiograph of the child in almost 1/3 of the patients with a treatment injury after tibial fracture treatment. This might reflect the fact that physicians treating children are cautious in acquiring radiographs with a view to avoiding radiation. Studies on this issue indicate quite the reverse: according to one report comparing numbers of radiographs taken in the Nordic countries, there were approximately 60% more radiographs obtained in Finland annually than in the other Nordic countries (Piene et al. 1991). The number of radiographs includes all radiographs (both diagnostic and follow-up) and is not therefore directly related to diagnostics. An alternative explanation might be that fractures were not suspected. It was also noted that many skin ulcers occurred due to inadequate casting, in many cases inadequate padding. In order to avoid such injuries, a treatment protocol was designed and published in the Finnish Medical Journal (Palmu et al. 2009) recommending the routine use of radiographs whenever a fracture is possible based on the patient history, and outlining the importance of proper casting technique. In this recommendation we also advocated seeking a second opinion on a radiograph if a fracture is suspected and not seen. Hopefully this would have a positive affect on treatment and help to reduce treatment injuries.

Treatment injuries in femoral fractures were somewhat different from those in tibial fractures, being related to choice of treatment method and procedures. The femur requires greater energy for a fracture than the tibia. This makes femoral fractures more obvious and the chance of missing the diagnosis is smaller. Injuries related to operative treatment were more common in femoral fractures, reflecting the frequency of the operative approach in treatment in general.

The average amount of compensation in femur fracture treatment was lower than in tibial fractures (2,300 EUR vs. 3,900 EUR). The average is not, however, comparable, since 1 single compensation in tibial fracture treatment exceeded the total compensations in femoral fractures. Despite the finding that compensation sums were generally low, this extra cost should be avoided, and avoidance of extra pain and suffering for patients and their families is even more important.

In the claims-handling process in PIC, specialists evaluate the patient files together with the description of injury provided by patients in order to decide on compensation. In our study, an independent observer re-evaluated the same issues to obtain a second opinion. In all claims in tibial fractures and all but one case in femoral fractures, the decisions were congruent. This would imply that the claims-handling process in PIC is coherent and that the compensations are justified. Our evaluation, however, included only a small sample of all compensation claims and these results cannot be generalized to PIC as a whole. The only patient claim in which our conclusion was different
was a 4-year-old with 23° varus deformity after femoral fracture treatment. A child of this age has great remodeling potential and as reported in Study III, varus malunions have a high tendency to remodel.

Although treatment injuries are rare, it is important to recognize them, since according to this study most of them could be avoided. Complications are an essential part of treatment, but the recognition of them should lead to a change in treatment. Not all complications lead to a compensation claim and not all complications are classified as treatment injury. Therefore the complication rate derived from this study is only an estimate. Narayanan and associates (2004) reported complications after their initiation of intramedullary nailing in children’s femoral fractures. They found a high rate of pain/irritation at the nail insertion site and changed their insertion procedure, whereafter they have encountered such complications only seldom. There are no previous reports on treatment injuries in pediatric tibial or femoral fracture treatment and the information presented is therefore novel.

6.4 STRENGTHS AND WEAKNESSES OF THE STUDY

The present undertaking was a retrospective study with a long follow-up. In earlier studies the mean follow-up time has mostly been under 10 years. The long follow-up time is a major strength. The retrospective design affected data collection: patient information was collected from patient files and the information available for each patient thus varied. All but 2 patient files were available, which increases the accuracy of epidemiological data. In the long-term studies we included only patients treated in the operation room. This excludes less severe fractures treated in the outpatient clinic e.g. toddlers’ fractures. The results cannot therefore be generalized to all children’s tibial and femoral fractures.

In Study I we were able to evaluate the radiographs from the time of injury. This made it possible to evaluate the extent of remodeling. Unfortunately due to changes in legislation during the time of data collection, were not able to obtain radiographs of children with tibial fractures. This impairs the value of Study II. Long-term results especially in tibial fracture treatment have not been studied in depth and this paper therefore adds valuable information to the literature.

The follow-up rate in tibial fractures was 62% and 70% in femoral fractures. Such low follow-up rates are due to the long follow-up time and the retrospective nature of the study. Although there are accurate registers in Finland, some patients could not be traced and some had moved abroad and could not be reached. The number of patients studied was relatively small, which is also a weakness.

Treatment injuries in children’s fractures have not previously been studied. The results here have already led to the design of a treatment
protocol applicable to treatment in health care centers, these serving as the primary screening points in pediatric fracture treatment.

The current study presents the long-term results obtained in the treatment of tibial and femoral fractures. No comparison of treatment methods was conducted. Although the findings indicate that good long-term results can be achieved with non-operative treatment, this study could not establish the superiority of any treatment mode.
CONCLUSIONS

The objective in this study was to calculate the incidence of children’s tibial and femoral fractures, analyze long-term results of non-operative treatment in these fractures and evaluate treatment injuries with a view to avoiding them in the future. Based on the results of this study the following conclusions can be drawn:

the annual incidence of tibial fractures in Helsinki, Finland, is 1.0 per 1000 children and of femoral fractures necessitating inpatient treatment 0.27 per 1000 children in Finland.

good long-term results can be achieved in cast immobilization of tibial fractures in children. Remanipulation is often required to maintain axial alignment. Complications are rare, but special attention should be paid to rotational deformities.

traction and/or casting of femoral fractures is a safe treatment method in children younger than 10 years of age and good long-term results can be expected. Residual angular deformity after femoral fracture treatment may lead to premature knee-joint osteoarthritis.

treatment injuries in tibial and femoral fracture management in children are rare, 0.6% and 2.2% respectively. The most common reasons for compensation were delay in diagnosis or treatment and unsatisfactory standard of treatment. The most common reason for treatment injury in tibial fracture treatment was a missed diagnosis, often because no radiographs were taken. A majority of injuries could be avoided with careful clinical practice.

adequate pain management is essential in treating fractures in children.
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Tampere, June 2013
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