Dissertation

Long-term results of Salter Harris III and IV fractures of the lower extremity in children and adolescents

submitted by

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Statutory Declaration

I hereby declare that this is my own original work and that I have fully acknowledged by name all of those individuals and organisations that have contributed to the research for this thesis. Due acknowledgement has been made in the text to all other material used. Throughout this thesis and in all related publications I followed the "Standards of Good Scientific Practice and Ombuds Committee at the Medical University of Graz".

Graz, 10th September 2018

DISCLOSURES

This doctoral thesis was the basis for a manuscript published in the *Journal of Orthopaedic Surgery*. The open access manuscript was written by Dr. med. univ. Thomas Nikolaus Zwetti. Hence, some parts of the doctoral thesis are similar to the manuscript. The manuscript was accepted for publication on August 27th, 2018.

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<u>Title:</u>

Long-term results following intra-articular fractures of the medial malleolus in children and adolescents with special emphasis on MRI

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I hereby confirm that all co-authors have explicitly agreed to the use of their data in this thesis.

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LIST OF ABBREVIATIONS

OMAS	Olerud and Molander Score
ORIF	Open reduction and internal fixation
VAS	Visual analog scale
ROM	Range of motion
CT	Computed tomography
MRI	Magnetic resonance imaging
MRT	Magnetresonanztomographie
M.	Musculus
FLWB	full length weightbearing
mLDTA	mechanical lateral distal tibial angle
aLDTA	anatomical lateral distal tibial angle

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ZUSAMMENFASSUNG

Hintergrund: Hauptziel dieser Studie war es, eine Kohorte von PatientInnen mit Salter-Harris III und IV Frakturen der distalen Tibia, welche an der Abteilung für Kinder- und Jugendchirurgie der Medizinischen Universität Graz konservativ oder operativ behandelt wurden, retrospektiv zu analysieren und ihr klinisches und radiologisches Langzeit Ergebnis zu evaluieren. Als Nebenzielgröße wurde die Korrelation zwischen klinischem und radiologischem Ergebnis, welche durch verschiedene Scores dargestellt werden, definiert. Die Hypothese war, dass mittels MRT diagnostizierte posttraumatische Veränderungen der Gelenksfläche sowohl mit klinischen als auch radiologischen Scores korrelieren.

Patienten & Methoden: Alle PatientInnen mit Salter Harris III oder IV Frakturen der distalen Tibia, welche zwischen 2000 und 2012 behandelt wurden, wurden in die Studie eingeschlossen und zu einer klinischen und radiologischen (Nativröntgen und MRT) Nachuntersuchung eingeladen. Zur Überprüfung des klinischen Ergebnisses wurden der Weber Score und Olerud und Molander Score eingesetzt. Eine mögliche Arthrose wurde im Nativröntgen mittels Kellgren und Lawrence Score erhoben. Die MRT wurde mittels modifizierter Outerbridge Klassifikation analysiert. Korrelationen zwischen klinischen und radiologischen Scores wurden berechnet.

Ergebnisse: 60 PatientInnen mit einem Durchschnittsalter von 11 Jahren (3-15 Jahre) und 61 Frakturen (n=40 Salter Harris III, n=21 Salter Harris IV) wurden in die Studie eingeschlossen. 73,8% (n=45 Frakturen) wurden mittels Gipsruhigstellung behandelt. Bei 3 Frakturen (4,9%) wurde zusätzlich eine geschlossene Reposition durchgeführt. Die restlichen 26,2% (n=16 Frakturen) wurden operativ behandelt. 18 PatientInnen konnten für die Nachuntersuchung rekrutiert werden. Die durchschnittliche Nachuntersuchungszeit lag bei 109 Monaten (48-184 Monate). Der Weber Score ergab ein sehr gutes Ergebnis für 6 (33,3%), ein gutes für 10 (55,6%) und ein schlechtes für 2 (11,1%) PatientInnen. Der Kellgren und Lawrence Score erbrachte Grad 0 bei 16 (88,9%) und Grad 1 bei 2 (11,1%) PatientInnen. Die MRT basierende Outerbridge Klassifikation zeigte Grad 0 bei 13 (76,5%), Grad 1 bei 1 (5,9%), Grad 2 bei 2 (11,7%) und Grad 3 bei 1 (5,9%) PatientInnen. Ein schlechtes Ergebnis im MRT korrelierte mit einem schlechten funktionellen Ergebnis.

Diskussion: Die hier vorliegende Studie liefert vorwiegend gute bis sehr gute Ergebnisse nach Salter Harris III und IV Frakturen der distalen Tibia bei Kindern und Jugendlichen. Weiters konnten wir zeigen, dass ein schlechtes funktionelles Ergebnis mit höhergradigen Veränderungen der Gelenksfläche in der MRT korreliert.

ABSTRACT

Background: The main aim of this doctoral thesis was to retrospectively analyse a cohort of patients with Salter Harris III and IV fractures of the distal tibia treated at the Department of Paediatric and Adolescent Surgery of the Medical University of Graz and to evaluate their clinical and radiological long-term outcome. The secondary aim was to calculate the correlation between the different clinical and radiological scores. The hypothesis was that posttraumatic alterations of the articular cartilage seen on MRI correlate with clinical and radiological scores.

Patients & Methods: All patients with Salter Harris III or IV fractures of the distal tibia treated between 2000 and 2012 were included and invited for a clinical and radiological (plain radiographs and MRI) follow-up examination. To evaluate clinical outcome the Weber score was applied. Osteoarthritis on plain radiographs was assessed using the Kellgren and Lawrence score. MRI were assessed using the modified Outerbridge classification. Correlations between radiological and clinical results were computed.

Results: 60 patients with a mean age of 11 years (range 3-15 years) with 61 fractures (n=40 Salter Harris III, n=21 Salter Harris IV) were included of which 73.8% (n=45 fractures) were treated with cast immobilisation. In 3 (4.9%) of these cases closed reduction was additionally performed. The remaining 26.2% (n=16 fractures) underwent open reduction and internal fixation (ORIF). 18 of the patients were recruited for a radiological and clinical follow-up examination. Mean follow-up time was 109 months (range 48-184 months). The Weber score was very good for 6 (33.3%), good for 10 (55.6%) and poor for 2 patients (11.1%). The Kellgren and Lawrence score yielded grade 0 in 16 patients (88.9%) and grade 1 in 2 patients (11.1%). The modified Outerbridge classification (MRI based) yielded grade 0 for 13 patients (76.5%), grade 1 for 1 patient (5.9%), grade 2 for 2 patients (11.7%), and grade 3 for 1 patient (5.9%) and was associated with worse clinical outcome.

Discussion: The present thesis shows predominantly good to excellent long-term outcome of Salter Harris III and IV fractures of the distal tibia in children and adolescents. We were able to show that a worse clinical result correlates with posttraumatic alterations of the articular surface on MRI.

1 AIMS AND HYPOTHESIS

Fractures are very common in children and adolescents and have a huge impact on the health care system (1). 18% to 30% of the fractures affect the growth plate (2,3). However, fractures of the distal tibia represent only 2.5% of all paediatric fractures (1). Most of them can be treated conservatively by immobilisation with or without previous reduction (4) because of the growth and remodelling potential of the distal physeal plate (5). In contrast, intraarticular fractures need special attention.

In case of an intraarticular fracture with displacement of more than 2 mm left untreated, devastating sequelae can be expected. Hence, in these cases closed reduction and cast immobilisation or open reduction and internal fixation (ORIF) needs to be performed (4,6,7). Despite anatomical reduction and correct fixation long-term complications can still be not completely ruled out (8). Reports evaluating the long-term follow-up of Salter Harris III and IV fractures of the distal tibia are scarce in the literature and based on retrospective analyses (9–11).

Long-term complications of intraarticular medial malleolar fractures i.e. Salter Harris III and IV fractures of the distal tibia, include premature growth arrest, angular deformity, leg length discrepancy and posttraumatic osteoarthritis (4,12). Whereas advanced stages of osteoarthritis can be diagnosed on plain radiographs, MRI (magnetic resonance imaging) is able to detect early alterations of the articular cartilage (13,14). Nevertheless, MRI has not been used to evaluate possible early posttraumatic alterations following medial malleolar fractures (Salter Harris III and IV) in children and adolescents.

The main aim of this doctoral thesis was to analyse the clinical and radiological long-term outcome of Salter Harris III and IV fractures of the medial malleolus treated at the Department of Paediatric and Adolescent Surgery of the Medical University of Graz with special emphasis on MRI. MRI was used to depict potential post-traumatic alterations of the articular cartilage that cannot be seen on native plain radiograms. The secondary aim was to calculate the correlation between the different clinical and radiological scores.

The hypothesis was that posttraumatic alterations of the articular cartilage seen on MRI correlate with clinical and radiological scores.

2 ANATOMY OF THE ANKLE JOINT

In the following chapters the most important topographical and functional anatomical parts of the ankle joint are described.

2.1 Osseous Anatomy (15)

The talocrural joint or ankle joint is a hinge type joint and consists of the following three bones:

- Tibia (lower leg)
- Fibula (lower leg)
- Talus (foot)

The most distal part of the tibia is called medial malleolus. The most distal part of the fibula is called lateral malleolus. Both malleoli together with the tibial plafond build the bony arch of the ankle joint.

Movements performed in the talocrural joint are only possible in one plane. These movements consist of dorsiflexion (about 20° to 30°) and plantarflexion (about 40° to 50°) of the foot.

2.1.1 Ligaments

The talocrural joint is stabilized by three main bundles of ligaments which are located on the medial side, lateral side and at the syndesmosis, respectively (16). The so called syndesmosis is the joint between the distal part of the tibia and the distal part of the fibula (17).

<u>Lateral ligaments (15):</u>
There are three lateral ligaments of the ankle joint. All of them originate from the lateral malleolus.

- *Anterior talofibular ligament*: between the lateral part of the talus and the lateral malleolus

- *Calcaneofibular ligament*: between the calcaneus and the lateral malleolus
- *Posterior talofibular ligament*: between the posterior part of the talus and the lateral malleolus

Medial ligaments (15):

The deltoid ligament or medial ligament of the ankle joint is a flat band consisting of four parts. It expands from the medial malleolus to the talus, calcaneus and navicular bones.

- *Anterior tibiotalar ligament*
- *Tibiocalcaneal ligament*
- *Posterior tibiotalar ligament*
- *Tibionavicular ligament*

Syndesmotic ligaments (16):

The syndesmotic ligaments expand at the anterior and posterior side of the syndesmosis, respectively. It connects the distal part of the fibula with the distal part of the tibia.

- *Anterior tibiofibular ligament*
- *Posterior tibiofibular ligament*

2.2 Muscles

Movements in the talocrural joint are facilitated by several muscles. As it is a hinge type joint, movement is possible in only one plane. The whole ROM (range of motion) lies in between 60° to 80°. The dorsiflexion is limited at 20° to 30°. The plantarflexion is limited at 40° to 50° (15,16).

Dorsiflexion (15):

- *M. tibialis anterior*
- *Assisted by: M. extensor hallucis longus, M. extensor digitorum longus, M. fibularis tertius*

Plantarflexion (15):

- *M. gastrocnemius lateralis and medialis*
- *M. soleus*
- *Assisted by: M. plantaris, M. tibialis posterior, M. flexor hallucis longus, M. flexor digitorum longus, M. fibularis longus*

2.3 Vascular Supply of the Lower Leg

The popliteal artery splits up into the posterior tibial artery and the anterior tibial artery at the distal border of the M. popliteus. The fibular artery branches from the posterior tibial artery about 2.5cm distal to the popliteal muscle. Sometimes it arises with variations more proximally or more distally, in some cases it arises from the popliteal artery directly. Its size depends on the size of the other arteries of the lower leg. The talocrural joint itself is provided by malleolar branches of the anterior and posterior tibial artery and the fibular artery (15).

2.4 Nerves

The talocrural joint is supplied by different nerves. There are so called articular branches from the deep fibular nerve, the saphenous nerve, the sural nerve and the tibial nerve. Incidentally, the superficial fibular nerve also innervates the ankle joint (15).

2.5 The Growing Skeleton

Human long bones are formed indirectly through endochondral osteogenesis. This means that mesenchymal stem cells differentiate into chondrocytes first. These form hyaline cartilage which during development is replaced by bony tissue (16).

2.5.1 The Physeal Plate

The physeal plate also called growth plate or physis is responsible for the gain of length and width of a bone in growing children. Growth is a complicated process and is regulated by interactions between local (e.g. parathyroid hormone-related peptide (PTHrP), transforming growth factor-beta (TGF-ß), Indian hedgehog (Ihh)) and systemic growth factors (e.g. GH, thyroid hormone) (18–20). Histologically, the physeal plate consists of 4 zones (18,21,22):

<u>The reserve zone (also resting or germinal zone):</u>
Chondrocytes are in a relatively inactive state. The extracellular matrix-to-cell ratio is high. This zone is closest to the epiphysis.

<u>The proliferative zone:</u>
It includes proliferating chondrocytes which begin to divide and organise into columns.

<u>The hypertrophic zone (also zone of maturation):</u>
Chondrocytes start differentiating. Due to a low extracellular matrix-to-cell ratio, it is the most fragile zone. For this reason, most physeal plate injuries affect this zone.

<u>The zone of provisional calcification (also zone of vascular invasion):</u>
The hypertrophic chondrocytes release calcium into the extracellular matrix. Capillary loops invade from the metaphysis. Spots of calcified cartilage operate as scaffolds for new bone. This zone is closest to the metaphysis.

Different physeal plates of different bones have different growth potential in the process of growth. For instance, physeal plates near the elbow take considerably less part in length growth (20%) when compared to physeal plates at the distal forearm (80%) or the proximal humerus (80%). The physeal plate at the proximal tibia is involved with 60% and the distal tibia with 40% in length growth of the tibia (4).

The time of synostosis of the distal tibial physeal plate differs between males and females and occurs at the age between 16 and 19 years (16). An increase of oestrogen in both sexes leads to the closure of the physeal plate. That is why patients with genetic disorders which influence these sex hormone are affected by an abnormal bone growth (21,23). A further reason for abnormal bone growth is an injury of the physeal plate (see chapter 3.5). After puberty, the physeal plate is resorbed entirely (21).

3 THE FRACTURE OF THE MEDIAL MALLEOLUS

In children and adolescents fractures are a significant burden on the health care system. However, only 2.5% of all paediatric fractures affect the distal tibia (1). The mechanisms of injury range from simple falls to sports and traffic accidents (11,24). In most studies there is a clear accumulation of injuries in males (9,11,25). Additionally, Zonfrillo and colleagues have found a significant association between overweight and paediatric ankle injuries (26). Intraarticular physeal fractures of the distal tibia in children can be classified as Salter Harris III or IV fractures (see 3.1) (8). During closure of the growth plate special fractures can occur. These fractures depend on the amount of ossification of the growth plate and are classified as transitional fractures (twoplanar or triplanar). This doctoral thesis, however, will only investigate Salter Harris III (see Figure 1) and IV fractures (see Figure 2). Transitional fractures were not included.

Figure 1: Initial a.p. and lateral radiograph of a right ankle joint with a Salter Harris III fracture of a 7-year-old boy who got trapped in a carousel

Figure 2: Initial a.p. radiograph of a left ankle joint with a Salter Harris IV fracture of a 3-year-old boy who got hurt whilst playing in a trampoline

3.1 Classification System

There are a lot of different classification systems for ankle fractures but not all of them are suitable for ankle fractures in children (27). Some depend on anatomic relations others on the mechanism of injury (28–30). Most of them describe fracture patterns in adults.
The Salter Harris classification is suitable for children and adolescents with open physeal plates. It was first described in 1963 by Salter R.B. and Harris W.R. (28) and is still used. The original Salter Harris classification consists of five different types which are described below (28):

Salter Harris Type I:

This kind of injury describes an entire disjunction of the epiphyseal part of the bone from the metaphyseal part without a fracture of the bone.

Salter Harris Type II:

This is the most frequent type of injury. It consists of a partial disjunction of the growth plate and a fracture of the portion of the metaphyseal part of the bone.

Salter Harris Type III:

This type is an intraarticular fracture. It consists of a partial disjunction of the growth plate and a fracture of the portion of the epiphyseal part of the bone.

Salter Harris Type IV:

This type is also an intraarticular fracture. Its fracture line extends from the joint surface through the epiphyseal part of the bone, crossing the growth plate and running out through a part of the metaphyseal section of the bone.

Salter Harris Type V:

This is an infrequent type of injury. It occurs following a severe axial compression force on the growth plate.

3.2 Diagnostics

Every diagnostic examination should start with an appropriate case history. Depending on the patient's age it is sometimes impossible to get suitable answers. If this is the case, a chaperone has to be asked for the case history.
The clinical examination in children is sometimes limited due to pain, anxiety and less cooperation. It consists of an inspection of the injured leg concerning swelling, wounds and obvious malposition plus checking for the vascular, sensory and motor function (31). Rude movements of the injured leg must be avoided in any case (28).
Once the injury is localized an immediate radiographic examination should be performed (4). Radiography in two planes (mortise and lateral view) is the gold standard for ankle fractures (31). In some cases, advanced imaging is necessary to differentiate between physeal fractures and transitional fractures. Nenopoulos and colleagues have suggested that every patient with a displaced Salter Harris III or IV fracture and patients with transitional fractures must undergo a CT scan to make proper diagnosis and choose the right treatment. They found a change in treatment decision (non-surgical/surgical) in 37.5% after performing a CT scan (32).
According to Carey and colleagues, MRI is also important in the evaluation of epiphyseal fractures. They also found a change in patient management, in addition to that they detected some occult fractures missed in plain radiographs (33). A comparative X-ray of the uninjured side is obsolete (8).

3.3 Additional Injuries

Concomitant injuries are common and depend on the mechanism of injury (high or low energy trauma) (31). Below some possible additional injuries of Salter Harris III and IV fractures of the distal tibia are listed:

- Fracture of the fibula
- Ligamentous injuries
- Abrasions
- Lacerations

3.4 Therapy

The choice of an adequate therapy of distal tibia fractures depends on the age of the patient, type of fracture, amount of fracture displacement and additional injuries (8,31).
Most fractures are treated conservatively by cast immobilisation with or without previous reduction (4). However, some fractures require special attention. These include intraarticular fractures (34).

3.4.1 Non-operative Treatment

Non-displaced or slightly displaced Salter Harris III and IV fractures of the distal tibia (< 2 mm) can be treated non-operatively. They are managed by short leg cast immobilisation (see Figure 3) for three to six weeks and radiological surveillance (6,28,31). Patients are mobilized with crutches (6). In some cases (more than 2 mm displacement), closed reduction and cast immobilisation under adequate analgesia may be possible. If closed reduction under appropriate anaesthesia is unsuccessful, ORIF must be considered (28,31). A general thromboembolic prophylaxis is not recommended for children until they reach puberty (35,36).

Figure 3: Short leg cast on the right shank

3.4.2 Operative Treatment

In case of an intraarticular fracture displacement of more than 2 mm that is left untreated, devastating sequelae like early osteoarthritis and persistent pain can be expected (4–7). If

closed reduction is not possible ORIF must be performed (28,31). While there is no scientific proof for the 2 mm threshold, this limit is widely used (4–8).
Operative treatment of paediatric ankle fractures is done under general anaesthesia. There is no consistent use of perioperative antibiotic prophylaxis in children (37). The surgical approach for ORIF is described in chapter 3.4.2.1. Osteosynthesis is either performed with K-wires (see Figure 4), screws (see Figure 5) or a combination of both (6,7,31).

Figure 4: Postoperative a.p. and lateral radiograph of a left ankle joint with a Salter Harris IV fracture of a 3-year-old boy

Lag screws are advantageous in terms of stability (11). Neither K-wires nor screws should cross the physeal plate to avoid additional injuries of the germinative cell layers (4,28). If a concomitant soft tissue injury on the medial side does not allow a full surgical approach a percutaneous screw-osteosynthesis or pin fixation is used (38). The problem with the use of metal implants is the necessity of a second surgery for implant removal.
Podeszwa and colleagues performed a study examining bio-absorbable implants in physeal and epiphyseal distal tibial fractures. They have found no increase in the complication rate compared to metal implants and the advantage of an avoidance of the second surgical procedure (39).
An intermittent external fixator may only be used in very special cases like open fractures or concomitant devastating soft tissue injuries (40).

General thromboembolic prophylaxis is also not recommended for children who undergo a surgery for fractures of the distal tibia. As an exception, patients with previous venous thromboembolism should be treated with low molecular weight heparin (36,41).

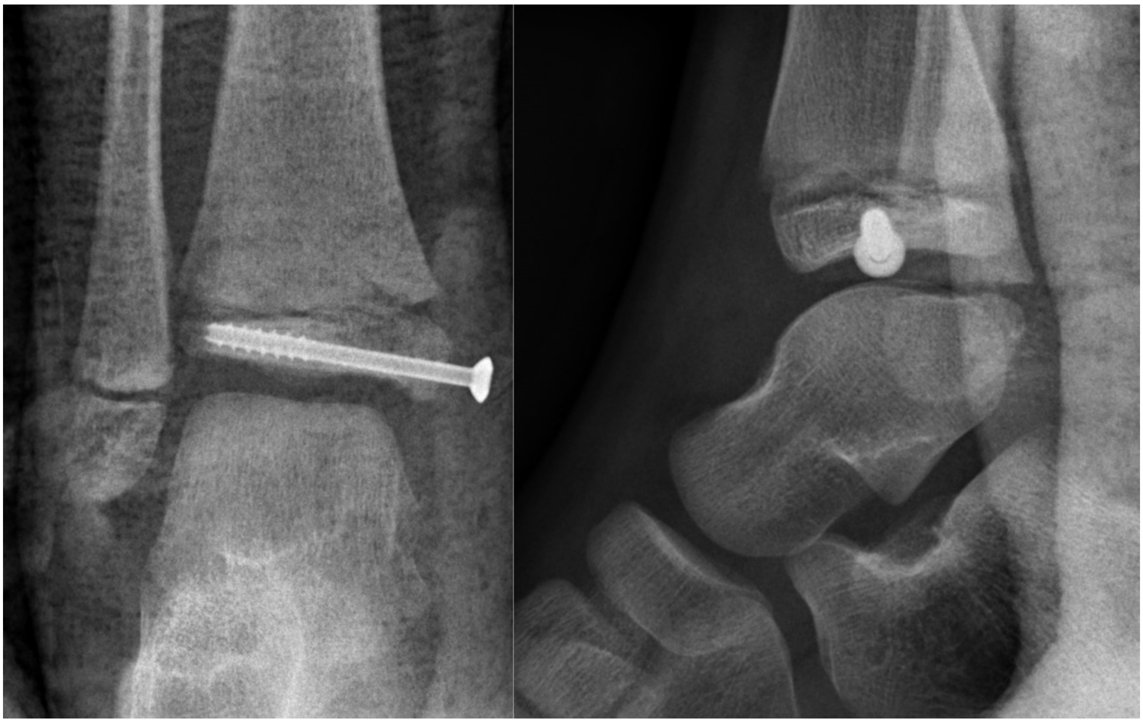

Figure 5: Postoperative a.p. and lateral radiograph of a right ankle joint with a Salter Harris III fracture of a 7-year-old boy

3.4.2.1 Surgical Approach

There are different approaches to the medial malleolus depending on the surgical indication (42). In this chapter only the most widely used approach for ORIF, the posterior approach to the medial malleolus, is described (42):

<u>Position of the patient:</u>

The patient is in supine position on the operating table with slightly externally rotated leg with the surgeon on the end of the operating table. The leg should be exsanguinated with a tourniquet.

Incision:

The incision starts about 5 cm above the tip of the medial malleolus. It follows the posterior border of the tibia, curving downwards and following the posterior border of the medial malleolus. The incision ends about 5cm distal to the tip of the medial malleolus.

Surgical dissection:

Now skin flaps can be mobilised. The saphenous nerve and the long saphenous vein should be preserved. The fracture can be exposed and the ends freed from periosteum. Thereafter, the joint can be inspected and rinsed.

3.4.2.2 Postoperative Treatment

An additional long leg or short leg cast immobilisation for three to eight weeks especially for K-wire osteosynthesis is necessary (6,7,11,40). Non-weight bearing is used for four weeks followed by 2 weeks of weight bearing (7). In a study of Cottalorda and colleagues non-weight bearing was used for 6 weeks (11). K-wires are removed after four to six weeks, screws after two to six months (6,7).

Kling and colleagues recommend radiographic surveillance for at least two years following the fracture (43), Cottalorda and colleagues on the other side suggest follow-up examinations until the end of growth (11) due to the possibility of growth disturbances until that particular time.

3.5 Complications

In this chapter, potential early and late complications accompanied with distal tibial fractures in children are described. The order of complications is not referenced to its frequency.

- Non-union

  In general, fracture non-union is a rare complication in children and adolescents. The risk independent of the anatomical region in those under fifteen years is about 1 in 500 fractures in both sexes (44).

- Surgical site infection

  A surgical site infection is not unique to the ankle joint. Olsen and colleagues have found that obesity is strongly associated with surgical site infections and deep infections following surgery for ankle fractures (45). Additionally, open fractures carry a higher risk for infections than closed fractures (46).

- Compartment syndrome

  The so called extensor retinaculum syndrome is unique to paediatric fractures of the distal tibia (31). Mubarak has described six cases with distal tibial physeal fractures and found pain and swelling of the ankle, weakness of extensor digitorum communis and extensor digitorum longus, anaesthesia or hypesthesia in the first web space and pain on passive flexion of the toes. The pressure was released by an anterior longitudinal incision and fixation was performed within the same surgery (47).

- Reflex sympathetic dystrophy

  It is also called complex regional pain syndrome (CRPS) and is a rare entity in children and adolescents. The lower extremity is more often affected than the upper extremity. Possibilities of treatment are restricted (48).

- Growth disturbances

  Due to open physeal plates a devastating late complication is premature growth arrest. In such cases the cartilaginous tissue in the physeal plate is supplanted by bony tissue. A so-called physeal bar is formed. This could lead to limb-length discrepancy or angular deformity (18,31). Despite a correctly performed osteosynthesis growth arrests still cannot be ruled out (8). For this reason, Lalonde and colleagues suggest frequent radiographic follow-up and early corrective surgery in case of growth disturbances (49). Possible treatment options are bar excision, observation in mild cases, corrective osteotomy and epiphysiodesis (31). Physeal bar excision is mostly performed with an additional interposition of fat, silastic, polymethylmethacrylate (PMMA), fibrin or dura substitute. Different animal studies have shown the possibility of interposition with autologous muscle, autologous chondrocytes or mesenchymal and bone marrow derived stem cells (18).

4 Hypothesis

The main aim of this doctoral thesis was to analyse the clinical and radiological long-term outcome of Salter Harris III and IV fractures of the medial malleolus treated at the Department of Paediatric and Adolescent Surgery of the Medical University of Graz with special emphasis on MRI. MRI was used to depict potential post-traumatic alterations of the articular cartilage that cannot be seen on native plain radiograms. The secondary aim was to calculate the correlation between the different clinical and radiological scores. The hypothesis was that posttraumatic alterations of the articular cartilage seen on MRI correlate with clinical and radiological scores.

5 MATERIAL AND METHODS

This study was approved by the Ethics Committee of the Medical University of Graz (28-127 ex 15/16). Prior to follow-up examination all participants and/or legal guardian signed an informed consent form.

5.1 Patient Selection

Data of all children and adolescents who sustained a Salter Harris III or IV fracture of the medial malleolus between 2000 and 2012 and were treated at the Department of Paediatric and Adolescent Surgery of the Medical University of Graz were analysed retrospectively. In total, data of 60 patients were included.
The 60 included patients were contacted by letter and telephone and invited to a follow-up examination. 16 patients (26.7%) could not be reached due to a wrong address and/or telephone number, 6 patients (10%) claimed to call back but never did and 14 patients (23.3%) did not want to take part. Out of the remaining 24 patients (40%) who assured, 6 did not appear to the examination. All in all, 18 patients (30%) took part in the follow-up examination.

5.2 Data Collection

The retrospective data were collected from the computerised documentation software "openMEDOCS".

The following parameters were analysed:
Sex, age at the time of injury, injured side (left/right), mechanism of injury, type of injury (Salter Harris III/IV; displaced/non-displaced), concomitant injuries, inpatient or outpatient treatment, management (operative/conservative), time to operation, operation technique, operative complications, postoperative management, cast immobilisation (yes/no), total period of immobilisation, intensity of weight bearing (full weight bearing/partial weight

bearing), other kind of imaging before/after operation (CT-scan/MRI), date of implant removal, period of implants in situ (days), complications.

5.3 Follow-up Examination

All these patients were invited to a follow-up examination via mail and/or telephone. Prior to examination all participants and/or legal guardian signed an informed consent form.

5.3.1 Case History

At the beginning every patient was asked about his/her subjective pain at rest, kind of job he/she is doing now and if he/she had to change his/her job due to injury if applicable. If the patient was too young to answer adequately his/her parent or legal guardian gave the answer.

5.3.2 Clinical Examination

The clinical examination consisted of an assessment of ROM of both hip, knee and ankle joints, leg lengths and a photo documentation of both legs. ROM was measured with a goniometer (Figure 6) and leg lengths with a standard measuring tape (Figure 7). All patients had to complete a questionnaire for Olerud and Molander Score (OMAS) (50), Weber score (51) and Visual Analog Scale (VAS). For further information see chapter 5.4.

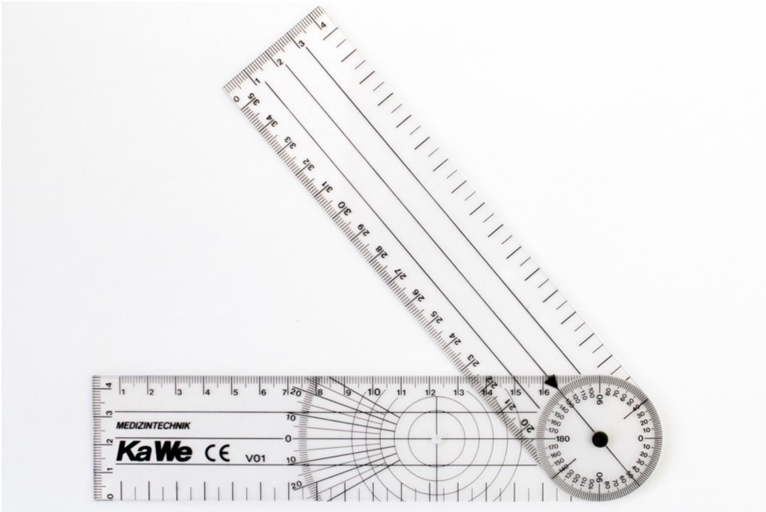

Figure 6: Goniometer to determine the angles

Figure 7: Measuring tape to determine the length of the leg

5.3.3 Photo Documentation

A photo documentation of the front, back and the two sides of all patients was done to get an overview of the axis of the legs. All photos were done with a Canon EOS 7D II camera and a Canon EF-S 18-55mm lens. Representative examples are shown in APPENDIX - Photos.

5.3.4 X-ray

A plain radiograph of the formerly injured ankle joint was done in mortise view and lateral view with a Siemens Aristos x-ray apparatus. The Kellgren and Lawrence classification (52) was used to assess osteoarthritis.

5.3.5 Magnetic Resonance Imaging

Furthermore, every patient was invited for a MRI scan of both ankle joints to assess posttraumatic alterations. The MRI scans were done with a 3 Tesla (T) PRISMA (Siemens Healthineers, Erlangen, Germany) scanner. A dedicated 16-channel ankle coil was used. The scan was performed in supine position. The scanner software automatically adjusted the fields of view, repetition (TR) and echo times (TE) to the particular respective joint. Spin echo proton-density weighted sequences with fat suppression were achieved in sagittal, axial and coronal imaging planes (in-plane resolution ~ 0.4 mm). Furthermore, a sagittal spin echo T1-weighted sequence with an image resolution of about 0.4 mm and a gradient-echo T2-weighted "Double Echo Steady State" sequence (isotropic resolution ~ 0.6 mm) were achieved. The paediatric radiologist was blinded to the clinical results. This adjustments were the same used in the study of Zwetti and colleagues (53).

The following parameters were analysed:
Cartilage thickness, possible steps in the joint (mm) and their localisation and a modified MRI based Outerbridge classification (54).

5.4 Scores

To evaluate the outcome of the included patients the following standard questionnaires and scores were applied. All scores and questionnaires were done in German language for this reason, all scores in APPENDIX are in German too.

5.4.1 Weber Score

The Weber Score is split up in two parts. The first part is completed by the patient and involves pain, walking distance and work/activities of daily life. The rest is completed by the examiner and includes the analysis of an x-ray of the ankle joint to determine signs of osteoarthritis as well as the assessment of the range of motion of the talocrural and subtalar joint (51). A maximum of 4 points for each question is possible. The reached points are summed up. The best possible result is 0 points. In Table 1 the scoring is shown. For the entire score see APPENDIX – Weber Score.

Results	
Very good	0
Good	1-2
Poor	3-4

Table 1: Grading applied for Weber Score

5.4.2 Olerud and Molander Score (OMAS)

The Score of Olerud and Molander (0 to 100 points) has to be filled in on patient's own authority. It includes pain, stiffness, swelling, jumping, supports, work/activities of daily life, running, stair climbing and squatting (50). In Table 2 the scoring is shown. For the entire score see APPENDIX – Olerud and Molander Score.

Results	
Excellent	91-100
Good	61-90
Satisfactory	31-60
Poor	0-30

Table 2: Grading applied for OMAS

5.4.3 Visual Analog Scale (VAS)

The VAS is a score for the subjective wellbeing of patients. The scale ranges from 0 to 10 (0% to 100%). Zero is the worst and 10 the best result. The range for the results from poor to excellent was determined at the author's own discretion. In Table 3 the scoring is shown. For the entire scale see APPENDIX – Visual Analog Scale.

Results	
Excellent	91-100
Good	81-90
Satisfactory	70-80
Poor	<70

Table 3: Grading applied for VAS

5.4.4 Kellgren and Lawrence Osteoarthritis Classification

This classification was established for assessing radiological changes in degenerative joint diseases and is divided in 5 grades (52):

- Grade 0: No osteoarthritis.
- Grade 1: Doubtful osteoarthritis.
- Grade 2: Minimal osteoarthritis.
- Grade 3: Moderate osteoarthritis.
- Grade 4: Severe osteoarthritis.

5.4.5 MRI Based Outerbridge Classification

This grading system is based on the arthroscopic Outerbridge classification (55) and was adapted for MRI by Jin-Suck Suh and colleagues (54):

- Grade 0: Absence of any cartilaginous defects.
- Grade 1: Swelling and softening of the cartilage.

- Grade 2: Fissuring and fragmentation, half an inch or less in diameter and a maximum of one-half in thickness.
- Grade 3: Fissuring and fragmentation, more than half an inch in diameter or more than one-half in thickness.
- Grade 4: Full thickness defect of the cartilage.

5.5 Data Processing and Statistical Analyses

Data are shown as percentages, absolute numbers, and means and standard deviations. Correlations between radiological and clinical scores were computed using Pearson´s correlations. All data was collected and processed with Microsoft® Excel 2016. Statistical analyses were done with IBM® SPSS Statistics 22. P-values of $p<0.05$ were considered as statistically significant. Post hoc power analysis of the Pearson´s correlations were performed with G*Power Version 3.1.9.2.

6 RESULTS

This chapter is split up in two main parts, the retrospective analysis and thereafter the results of the follow-up examination.

6.1 Retrospective Analysis

Overall 60 patients were treated between 2000 and 2012 with 61 Salter Harris III or IV fractures of the medial malleolus. 65% of the patients were male (n=39) and 35% female (n=21) (see Figure 8).

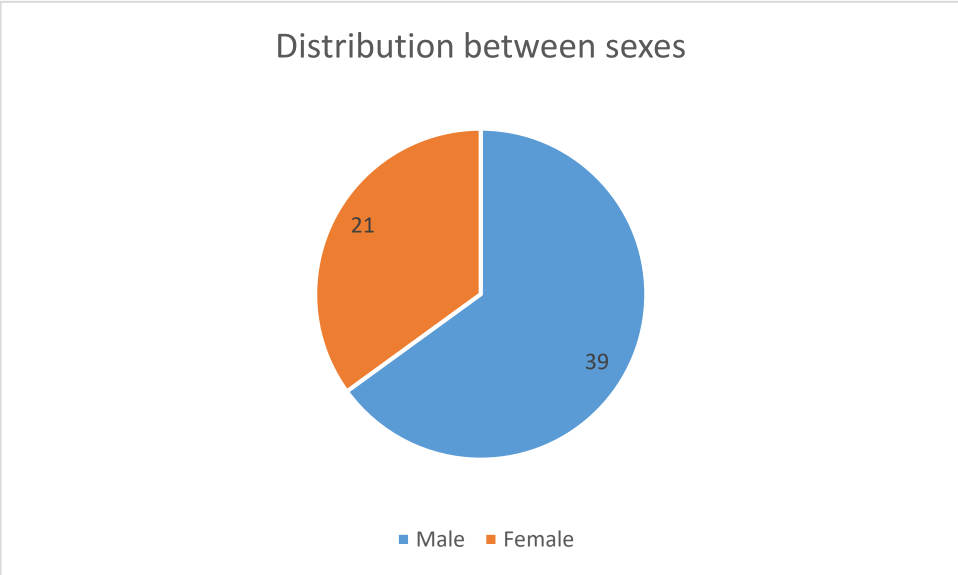

Figure 8: Distribution between sexes of 60 patients

The mean age of the patients at the time of accident was 11 years with a range from 1 to 15 years. In the distribution of frequencies there was a peak at 11 years (see Figure 9).

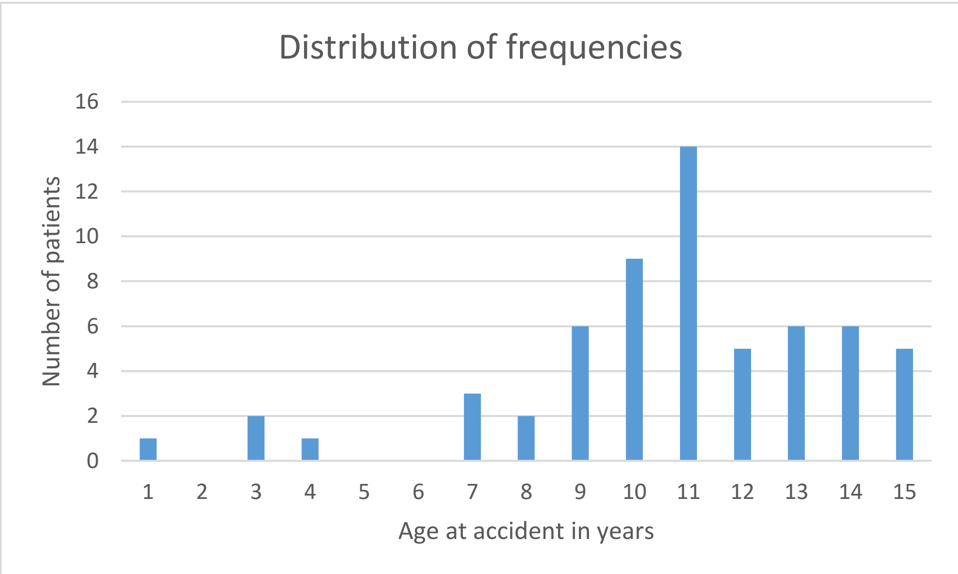

Figure 9: Distribution of frequencies of 60 patients and their age at accident

There was no significant difference in the distribution of affected limbs. The right side was affected in 52.5% of cases (n=32) and the left side in 47.5% (n=29) (see Figure 10).

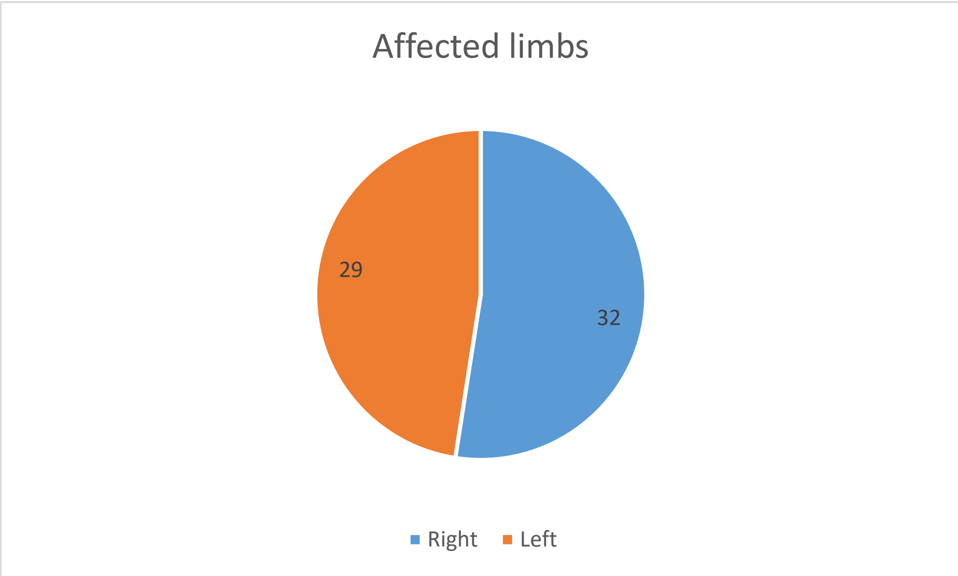

Figure 10: Distribution between affected limbs in 61 cases

Non-displaced Salter Harris III fractures were diagnosed in 33 cases (54.1%), displaced Salter Harris III fractures in 7 cases (11.5%). One male patient presented with a re-fracture of a Salter Harris III fracture approximately two months after the initial injury sustained during a football game. Non-displaced Salter Harris IV fractures were diagnosed in 8 cases (13.1%), displaced Salter Harris IV fractures in 13 cases (21.3%). For the distribution of fractures see Figure 11.

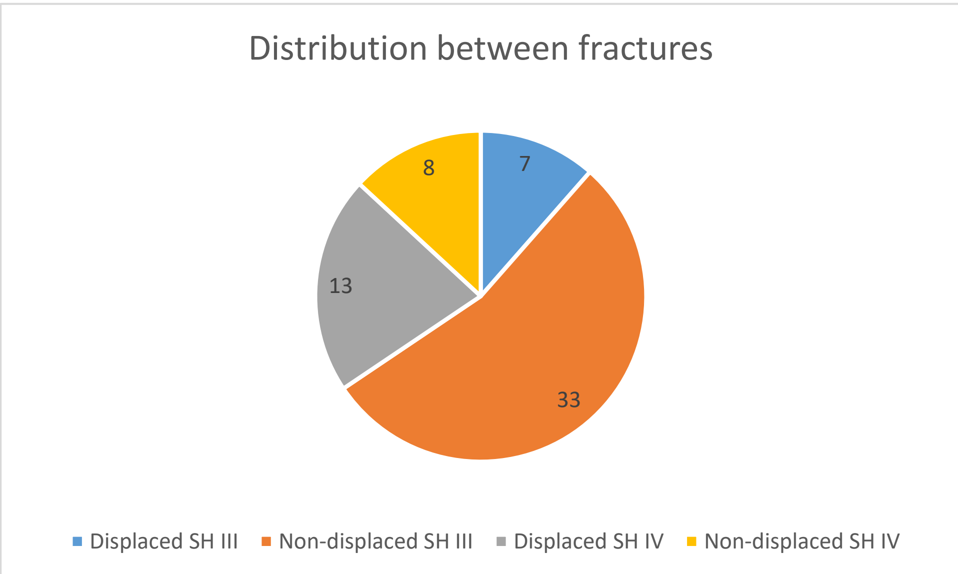

Figure 11: Distribution between displaced and non-displaced Salter Harris III and IV fractures

The mechanisms of injury were sports related in 44.3% (n=27), simple falls in 24.6% (n=15), falls from height (more than 1.5 meters) in 11.5% (n=7), traffic accidents in 6.5% (n=4) and others for the remaining 13.1% (n=8) (see Figure 12).

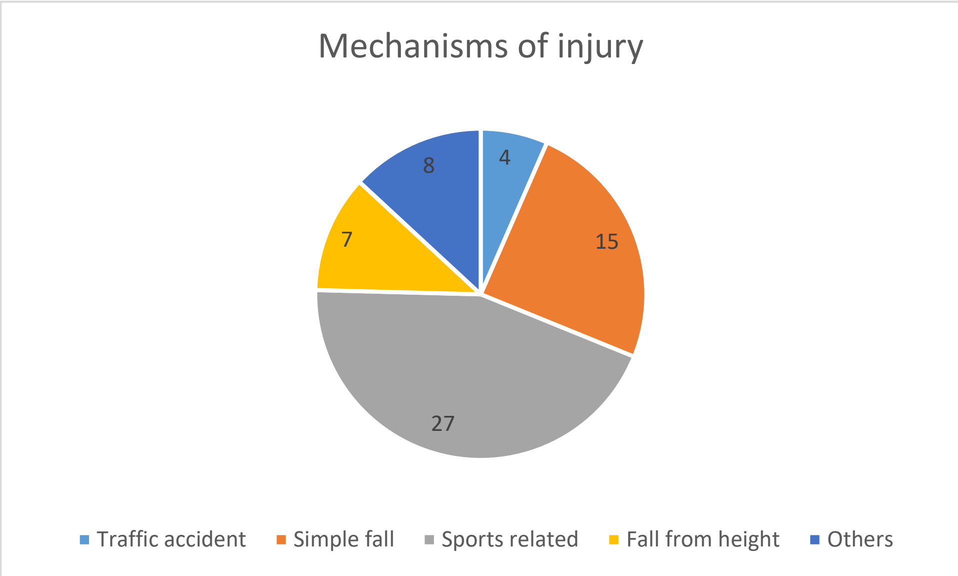

Figure 12: The mechanisms of injury in 61 cases

In more than a half of all cases no additional injuries were diagnosed (55.7%, n=34). The remaining 27 cases sustained between 1 and 5 additional injuries (see Figure 13). The most common additional injury was a fracture or epiphysiolysis of the ipsilateral fibula (n=23) followed by ligament avulsion (n=7) and fractures of other body regions (n=5) (see Figure 14).

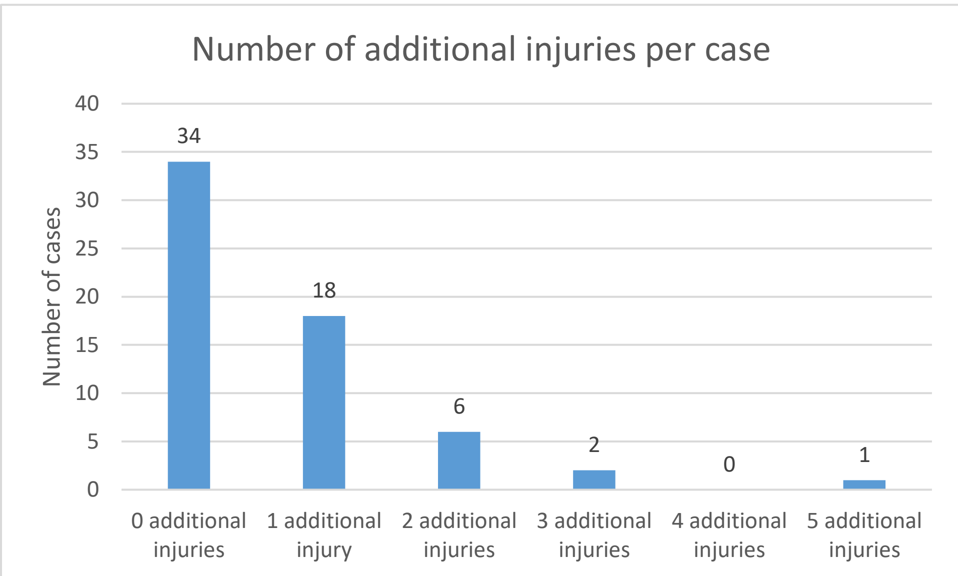

Figure 13: Number of additional injuries per case

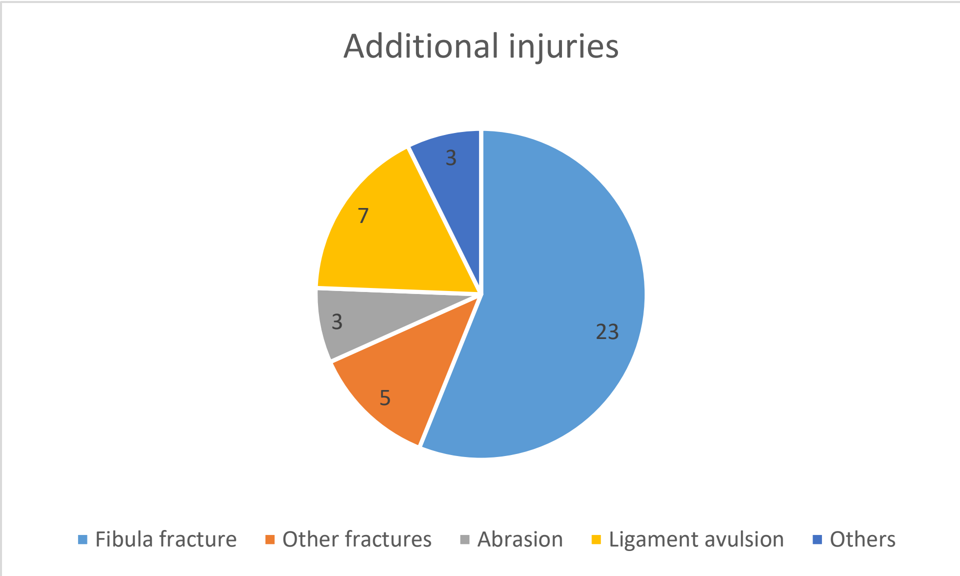

Figure 14: All additional injuries

The distribution of additional injuries according to the types of fractures is shown in Figure 15.

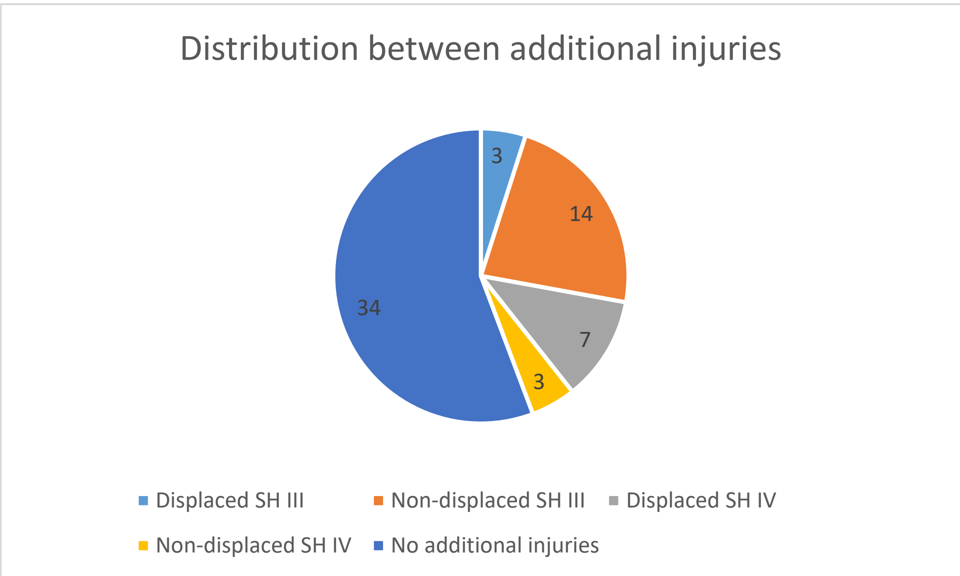

Figure 15: Distribution of additional injuries according to the types of fractures

All patients underwent a plain radiograph to confirm diagnosis, more than a quarter of them received an additional CT (n=17, 27.9%).

In more than half of the cases patients were treated as outpatients (n=37, 60.7%), the remaining 24 (39.3%) as inpatients.

42 (68.9%) fractures were treated with cast immobilisation. In 3 patients (4.9%) closed reduction and cast immobilisation under general anaesthesia was performed. In one case (1.6%), the initial treatment was conservative (treated in another hospital). Because of increasing displacement, however, the patient had been sent to our department. The treatment had been changed to ORIF and excision of a physeal bar. The remaining 15 (24.6%) patients underwent ORIF (for distribution between therapies see Figure 16).

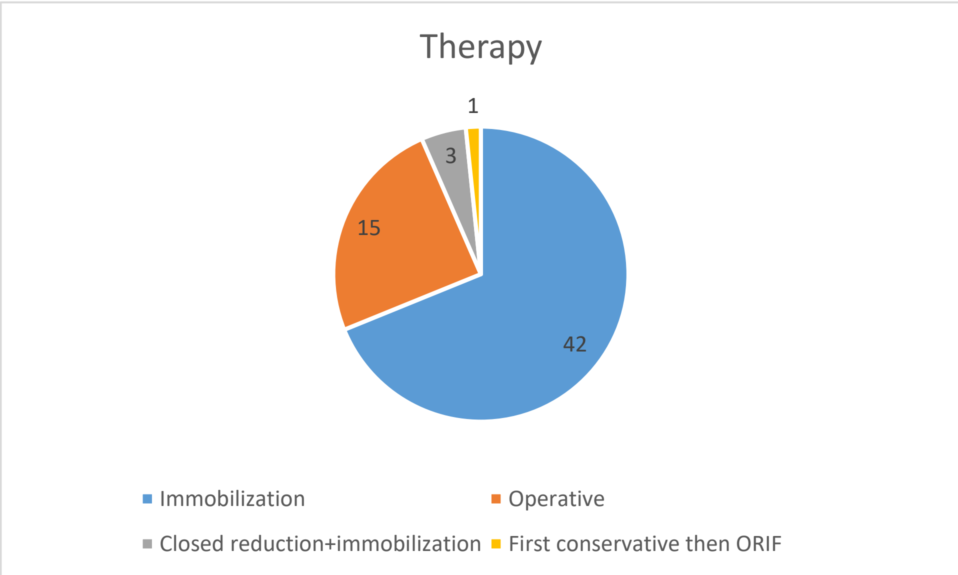

Figure 16: Choice of treatment in 61 cases

Out of all operatively treated patients, 14 (87.5%) underwent open reduction and screw osteosynthesis (n=12, 75%) or closed reduction and percutaneous screw osteosynthesis (n=2, 12.5%). In one (6.3%) case an osteosynthesis via K-wires was done and in another case (6.3%) a combination of screw and K-wire osteosynthesis (see Figure 17) was performed. In one patient the anterior tibial compartment had to be opened up due to an initial compartment syndrome. The screws crossed the physis in one case.

All patients were cast immobilised for a mean of 4.4 weeks (ranging from 1.5 weeks to 6 weeks - depending on the surgeon’s assessment). The duration of immobilisation could not be calculated in 3 patients because of incomplete medical records. The implants were removed after a mean of 149 days (ranging from 60 days to 299 days). The date of implant removal could not be detected in 2 patients because of incomplete medical records.

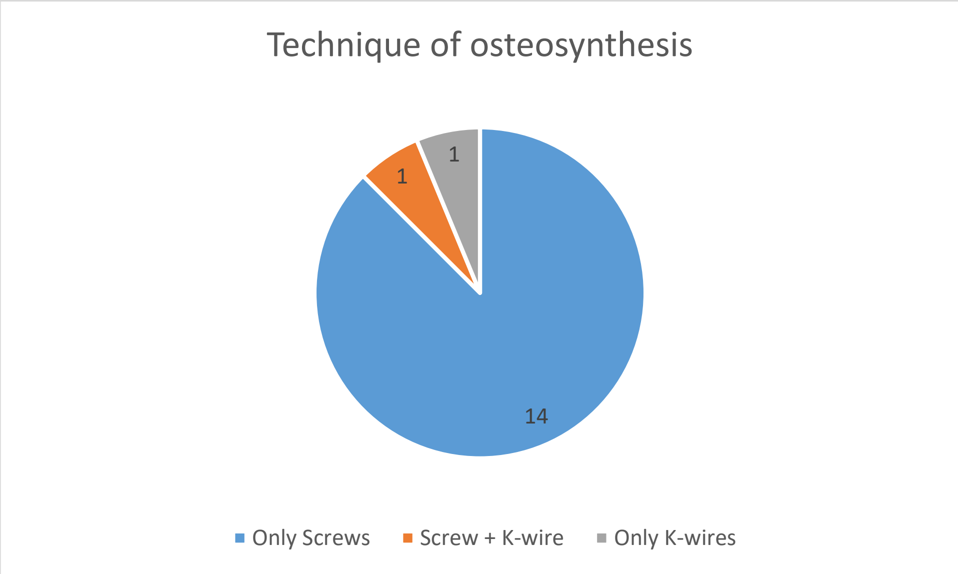

Figure 17: Different techniques of osteosynthesis

Complications:

One conservatively treated patient (1.6%) suffered from a superinfected haematoma at the ankle joint and was treated successfully with antibiotics (2.2% of all conservatively treated patients). 3 (4.9%) operatively treated patients developed complications (18.8% of all operatively treated patients). One patient presented with a tension mark at his heel because of too much pressure from his cast, another suffered from a tension blister at the medial malleolus and the third one developed bigeminy postoperatively (patient has haemophilia A as pre-existing disease). No major complications necessitating a re-operation were registered and no intraoperative complications were detected retrospectively.

6.2 Follow-up

We were able to include 18 (30%) of the 60 patients (n=5 female, n=13 male) (see Figure 18) in the radiological and clinical follow-up with a mean follow-up time of 109 months (range 48 – 184 months). For an overview of the radiological and clinical findings at follow-up see APPENDIX - Follow-up patients.

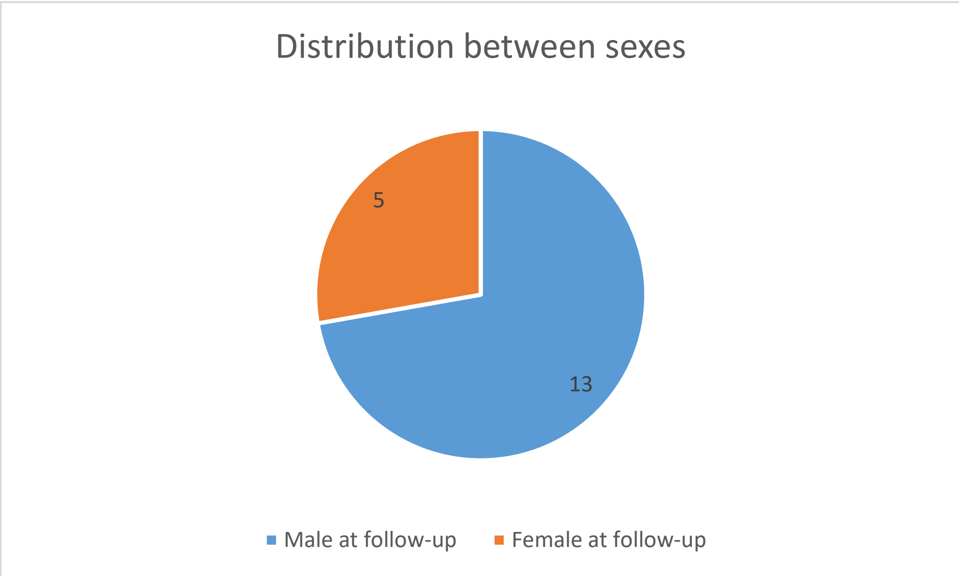

Figure 18: Distribution between sexes at follow-up

The initial injury affected 9 (50%) right and 9 (50%) left legs (see Figure 19).

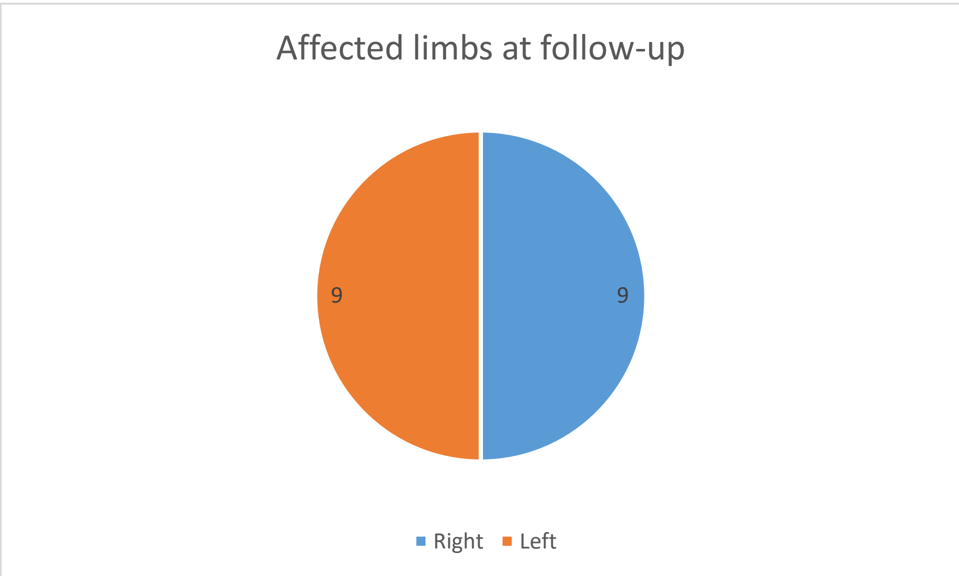

Figure 19: Affected limbs at follow-up

5 (27.8%) of these patients were treated operatively (ORIF) and 13 (72.2%) conservatively (cast immobilisation). For the mechanisms of injury of the follow-up patients see Figure 20.

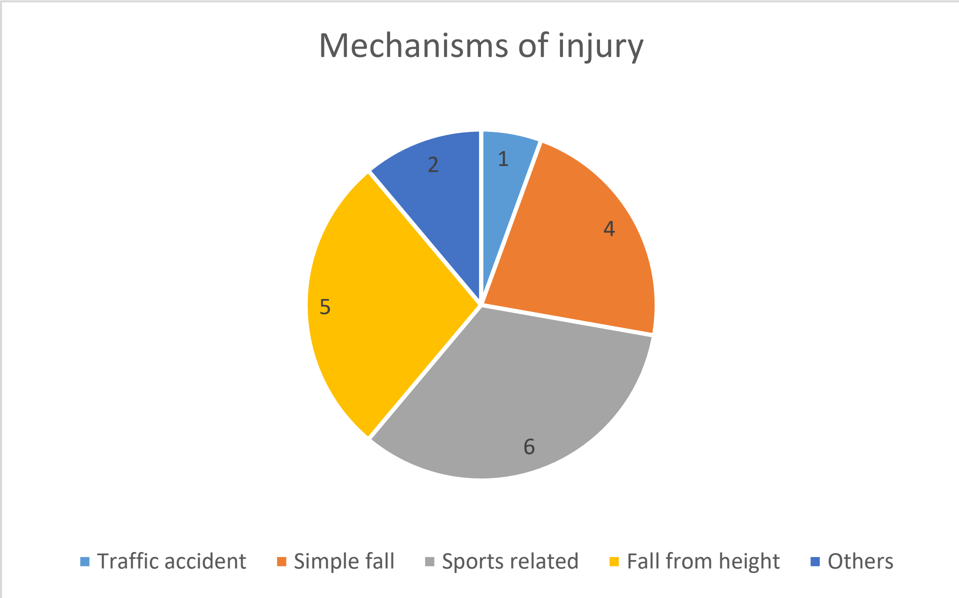

Figure 20: Mechanisms of injury of the 18 follow-up patients

The mean patients' age at the time of injury was 10 years (range 3-14 years) (see Figure 21).

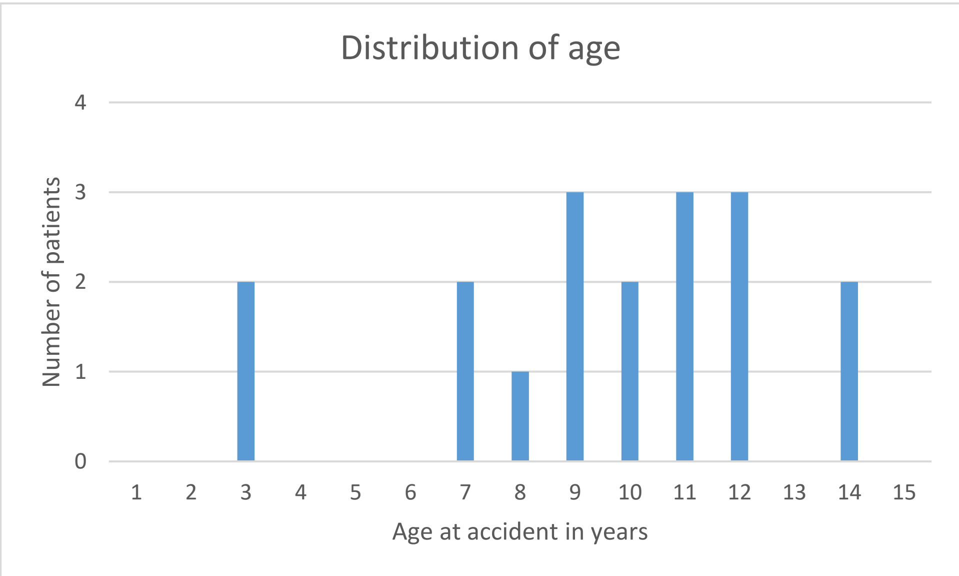

Figure 21: Age distribution of the 18 follow-up patients

Most of the patients had closed growth plates (n=13; 86.7%) at follow-up examination. The average ROM (range of motion) of the talocrural joint was 61° ± 13°. The ROM of the contralateral side was 62° ± 11°. We could not find any significant leg length discrepancies.

The Weber score was considered very good for 6 (33.3%), good for 10 (55.6%) and poor for 2 patients (11.1%) (see Figure 22).

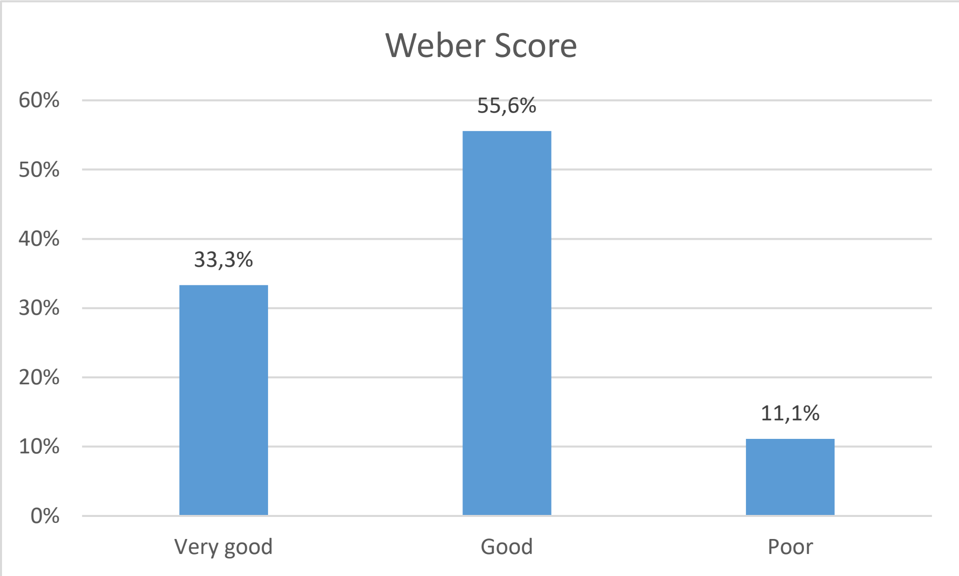

Figure 22: Results of the Weber score for 18 patients

The Olerud and Molander score was excellent for 16 (88.9%) and good for 2 patients (11.1%). No cases with fair or poor outcome were encountered (see Figure 23).

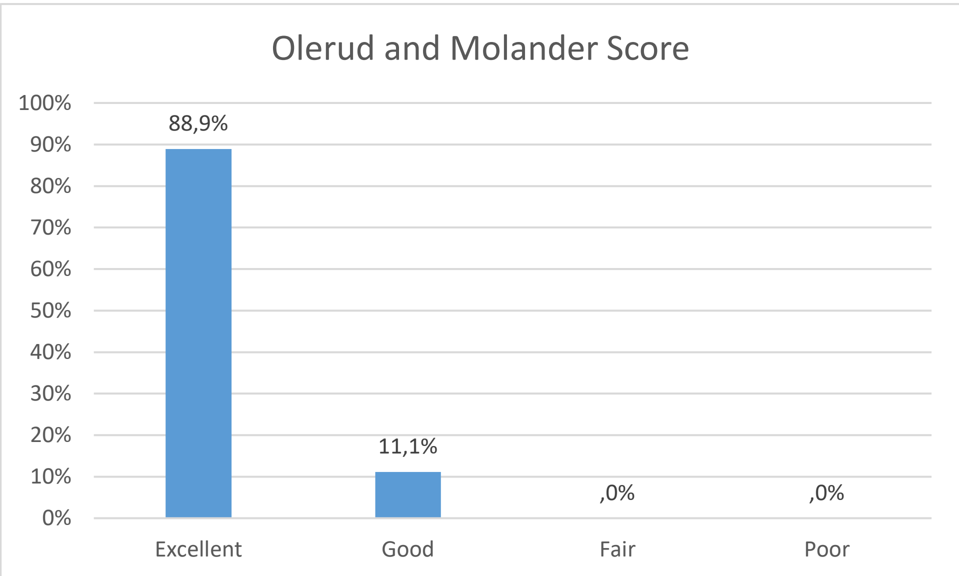

Figure 23: Results of the Olerud and Molander Score for 18 patients

To gather some information about subjective outcome a Visual Analog Scale for patient satisfaction was used (see APPENDIX - Visual Analog Scale). The VAS was ≥ 90% in 16 patients (88.8%), between 80% and 89% in 1 patient (5.6%) and between 70 and 79 in 1 patient (5.6%). No patient quoted a VAS < 70% (see Figure 24).

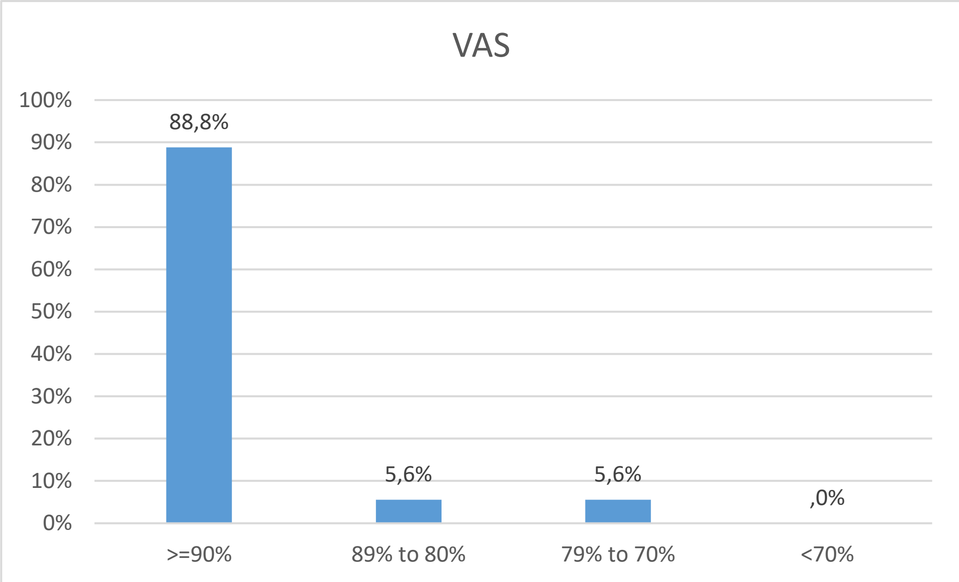

Figure 24: Results of the Visual Analog Scale for 18 patients

The Kellgren and Lawrence score (X-ray based) showed grade 0 in 16 patients (88.9%) and grade 1 in 2 patients (11.1%). Grade 2, 3 or 4 alterations were not detected (see Figure 25).

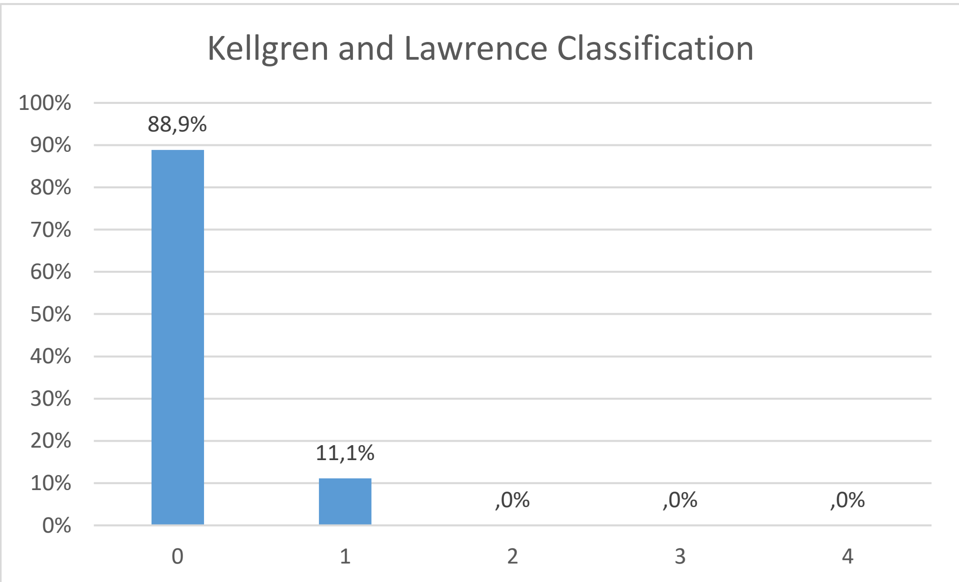

Figure 25: Results of the Kellgren and Lawrence classification for 18 patients

In total, 17 participants underwent MRI examination of both ankle joints. The MRI based Outerbridge classification of the formerly injured ankle joint showed grade 0 for 13 patients

(76.5%), grade 1 for 1 patient (5.9%), grade 2 for 2 patients (11.7%), and grade 3 (see Figure 27 for this kind of lesion in MRI) for 1 patient (5.9%). No grade 4 lesions were detected (see Figure 26). For an Outerbridge grade 0 example see Figure 28 .

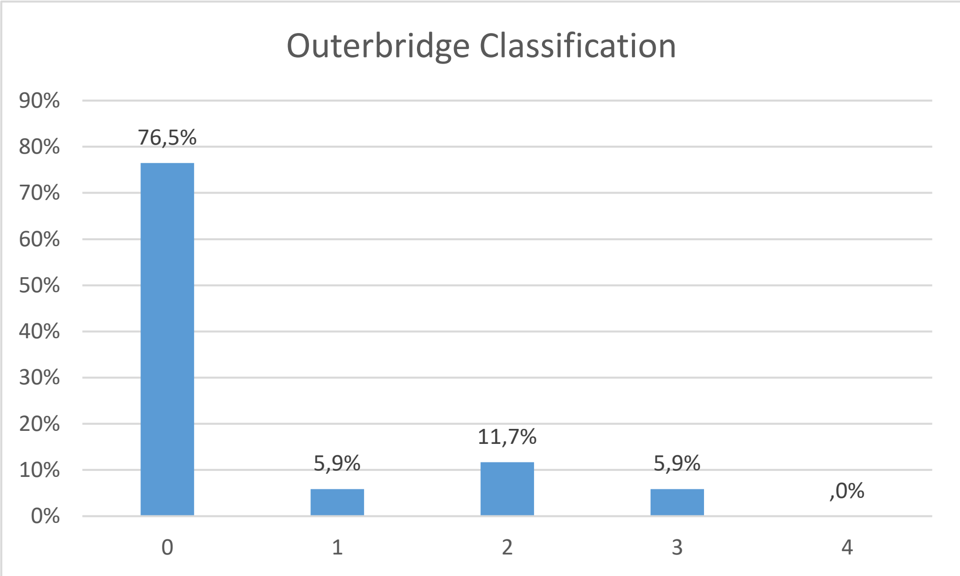

Figure 26: Results of the MRI modified Outerbridge classification for 17 patients

Figure 27: MRI (proton density-weighted with fat suppression (coronal reconstruction)) showing cartilaginous defects (white arrow) 119 months after operative treatment of a Salter Harris IV fracture

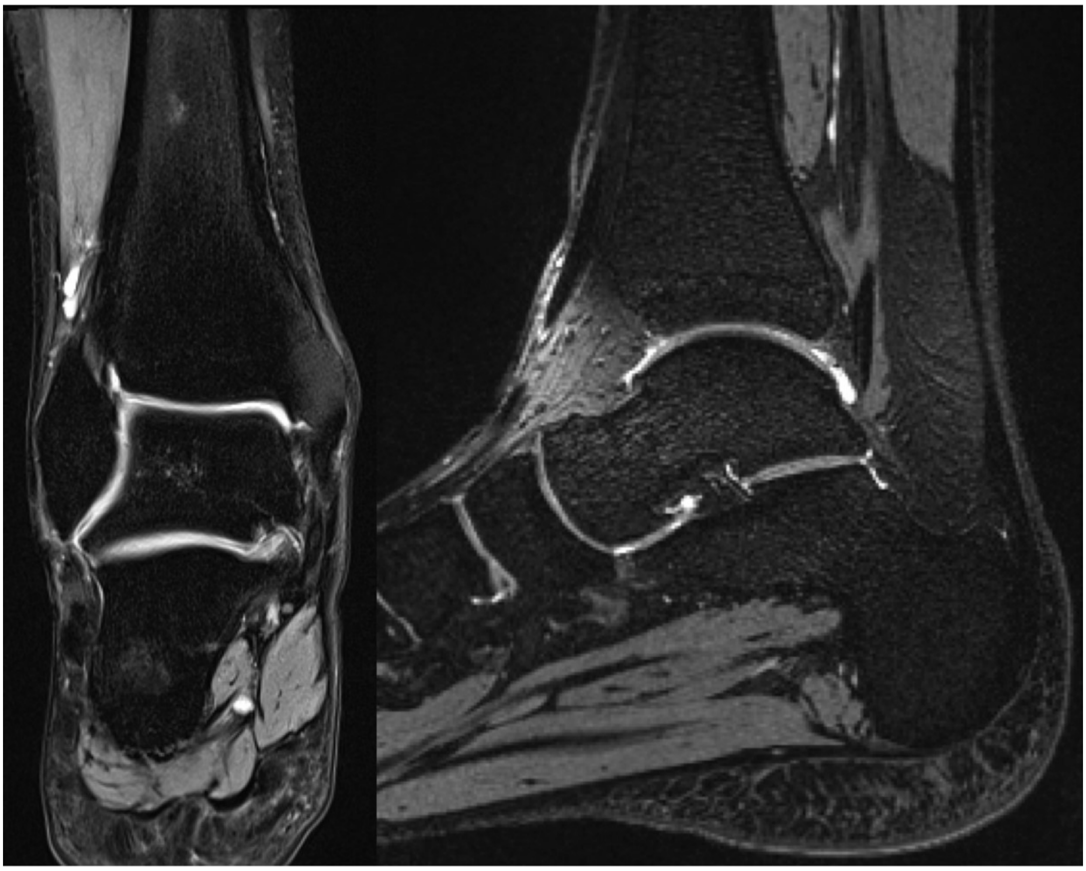

Figure 28: Unremarkable MRI (proton density-weighted with fat saturation (coronal and sagittal reconstruction)) 71 months after closed reduction and conservative treatment of a Salter Harris IV fracture

Figure 29 shows a diagram to compare the two radiological classifications. In both classifications 0 is the best and 4 the worst result.

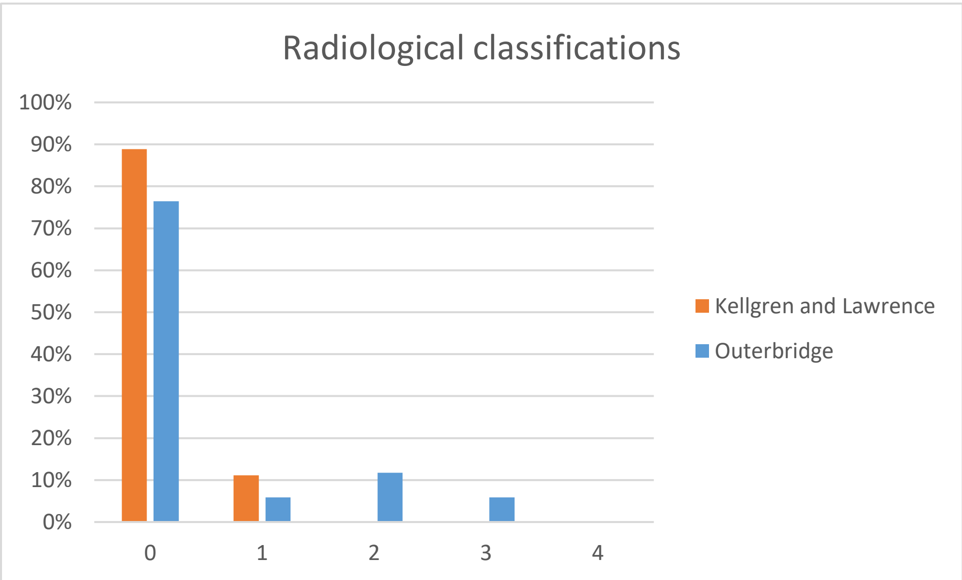

Figure 29: Comparison of the two radiological classifications (Outerbridge & Kellgren and Lawrence)

6.2.1 Correlations

The correlations between radiological and clinical follow-up scores were computed using Pearson's r (see Table 4). The two-tailed significance levels are given below. The Outerbridge classification was associated with a worse clinical result and significantly correlated with the Weber Score (r=0.626) and the Kellgren and Lawrence classification (r=0.810).

	Weber	VAS	Olerud-Molander	Outerbridge	Kellgren-Lawrence
VAS	-0.446	-	0.660**	-0.120	-0.426
Weber	-	-0.446	-0.434	0.626**	0.672**
Olerud-Molander	-0.434	0.660**	-	-0.244	-0.505*
Kellgren-Lawrence	0.672**	-0.426	-0.505*	0.810**	-
Outerbridge	0.626**	-0.120	-0.244	-	0.810**

*Table 4: Correlations between the radiological and clinical scores (*p<0.05 **p<0.01)*

Results of the post hoc power analysis for the correlations given in Table 4 are shown in Table 5.

	Weber	VAS	Olerud-Molander	Outerbridge	Kellgren-Lawrence
VAS	0.50	-	0.49	0.68	0.50
Weber	-	0.50	0.50	0.53	0.47
Olerud-Molander	0.50	0.49	-	0.54	0.52
Kellgren-Lawrence	0.47	0.50	0.52	0.81	-
Outerbridge	0.53	0.68	0.54	-	0.81

Table 5: Results of the post hoc power analysis for the correlations shown in Table 4.

7 DISCUSSION

This doctoral thesis includes a retrospective analysis of 60 patients with Salter Harris III and IV fractures of the distal tibia in children and adolescents and was written on the basis of a study published by Zwetti and colleagues (53). Radiological and clinical follow-up examinations were performed in 18 cases after a mean follow-up time of 109 months. MRI was used to assess alterations of the articular cartilage that may precede alterations seen on conventional radiographs.

Although fractures are very common in children and adolescents only 2.5% of these affect the distal tibia (1). A variety of studies about fractures of the distal tibia include all possible lesions ranging from Salter Harris I fractures to transitional fractures (7,34,49). Transitional fractures occur in older children throughout the closure of the physis. Therefore, the risk for premature physeal closure and its long-term complications is lower (56). For this reason, this study has only included Salter Harris III and IV fractures. Table 6 shows that only a few studies have been published describing the long-term follow-up of Salter Harris III and IV fractures of the distal tibia. However, none of these studies has included MRI to assess alterations in long-term outcome.

Author	Patients	SH III	SH IV	Mean follow-up Time
V. Gleizes et al. (10)	n=24	n=4	n=20	3 years and 2 months
J. Cottalorda et al. (11)	n=48	n=30	n=18	3 years and 3 months
J. Camilleri et al. (9)	n=26	n=17	n=9	2 years and 3 months
D.V. Petratos et al. (57)	n=20	n=8	n=12	8 years and 11 months
C. F. Blumetti et al. (58)	n=11	n=7	n=6	1 year and 6 months

Table 6: Different studies showing outcome of Salter Harris III and IV fractures

Diagnostics: Clinical examination in injured children is difficult and must be done with special attention. Specifically trained staff is advantageous. Plain radiographs are the gold standard diagnostic tool for this kind of injury (31). In the included cohort computed tomography was done in 17 patients (n=8 displaced fractures and n=9 non-displaced fractures) to determine whether the fracture is multiplanar or not. Nenopoulus and colleagues have developed a diagnostic algorithm for children with intraarticular fractures of the distal tibia. The authors have shown that diagnosis and treatment decisions are significantly diverse by executing CT scans as a standard diagnostic tool as compared to plain radiographs (32).

However, higher radiation exposure has to be kept in mind. Furthermore, during data analysis we have seen that there seem to be some difficulties in terming the proper diagnosis. The correct identification and denomination of Salter Harris III or IV and twoplanar or triplanar fractures was not performed in all cases. In our opinion, regular education and training are the only ways to deepen knowledge in this specific field.

Treatment: Paediatric patients show an enormous healing potential. Most authors recommend cast immobilisation (with or without closed reduction) up to a gap of 2 mm (6,7,11,31,53). Others suggest that all intraarticular fractures have to be reduced anatomically independent of patients' age (40). To our knowledge there is no scientific proof for either of these hypotheses. Yet, the 2 mm limit is widely used and was also applied in our patients. Definitely, all displaced intraarticular fractures need an anatomic reduction to avoid long-term complications (31). The precise threshold between operative and conservative treatment, however, still stays inexplicit.

Growth arrest: Premature physeal closure can be a result of injury of the growth plate of the distal tibia and is the most devastating complication leading to growth arrest, angular deformities and leg length discrepancies. With reference to Spiegel and colleagues Salter Harris III and IV fractures are most common to develop growth disturbances (59). Different treatment options ranging from observation, bar excision or epiphysiodesis to corrective osteotomy are used (31). Kling and colleagues have described that younger patients had a higher risk for partial growth arrest (43). Cottalorda and colleagues therefore recommend the surveillance of patients with this kind of fractures until the end of growth since growth disturbances can occur until that point of time (11). In our opinion, clinical and radiological follow-up of a minimum of two years especially in younger children should be maintained whereas monitoring until end of growth would be eligible. Some studies already report the outcome of intraarticular ankle fractures in children but have included various kind of distal tibial fractures like transitional fractures where residual growth is limited (7,34,49). We have decided to include only patients with Salter Harris III and IV fractures to exclude this selection bias. No long-term outcome complications (mean 109 months) associated with a premature closure of the growth plate could be detected in this study. Yet, the low follow-up rate must be considered.

Magnetic Resonance Imaging: Carey and colleagues have described MRI as an important tool for evaluation and preoperative planning in acute paediatric growth plate injury (33). We have used MRI in the present study to evaluate the radiological long-term outcome of intraarticular fractures of the distal tibia of patients with completely open physes for the first time. As already stated, plain radiographs are the gold standard for radiological assessment of intraarticular fractures in children (31) but the articular cartilage cannot be assessed with this technique. Hence, one of the aims of the present study was to assess whether or not long-term posttraumatic changes of the articular cartilage are present in patients with absent alterations on plain radiographs. In 4 patients changes were found on MRI while only two patients showed changes on plain radiographs (see APPENDIX - Follow-up patients). In addition to that, the two patients with an increased Kellgren and Lawrence classification also showed higher grade alterations of the articular cartilage on MRI. Furthermore, both patients had a poor result in the Weber Score which also emphasizes the validity of our MRI results. The correlations between the radiological and clinical scores were computed. We could show a significant correlation between the clinically based Weber score as well as the Kellgren and Lawrence classification and the MRI based Outerbridge classification. If these findings are of clinical significance needs to be investigated in future studies.

Limitations: One limitation of this study is the low follow-up rate. Despite of all efforts via phone and mail we were not able to gather more than 18 patients (30%). 26 patients (43.3%) did not want to take part, because they estimated their constitution adequate. 16 patients (26.7%) could not be reached as a result of wrong telephone numbers and address information in their medical records. An additional weakness of this study is the retrospective design. A prospective study would be the best way to confirm our results. Due to the scarcity of intraarticular distal tibial fractures in children a multi-centre approach would be necessary. A further limitation is the lack of a full length weightbearing (FLWB) X-ray made in standing position. It is considered the gold standard for recording the axes of the whole leg (60). In particular the mechanical lateral distal tibial angle (mLDTA) and the anatomical lateral distal tibial angle (aLDTA) are of importance at the ankle joint (61). However, due to concerns of higher radiation exposure in children a FLWB X-ray was not performed in the present study (62).

7.1 Conclusion

This thesis shows good to excellent long-term results of Salter Harris III and IV fractures of the distal tibia in children and adolescents. The main goal of treatment of these rare injuries is to achieve satisfactory long-term function and to avoid early posttraumatic osteoarthritis. We were able to state that posttraumatic alterations of the articular surface shown on MRI are associated with a worse clinical result. The MRI based Outerbridge classification was associated with a worse clinical result and significantly correlated with the Weber Score and the Kellgren and Lawrence classification. Yet, a well-designed prospective study with a larger cohort and a longer follow-up rate would be necessary to confirm the presented findings. Nonetheless, this is the first study which uses MRI to evaluate long-term outcome of rare Salter Harris III and IV fractures of the medial malleolus in children and adolescents.

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APPENDIX - Follow up table

Pat.Nr.:		Nachname:		Untersuchungsdatum:	
Geb.Dat.:		Vorname:		Fotodokumentation:	
Beruf:		OP (ja/nein):		Berufswechsel (ja/nein):	

	Verletztes Bein:			Kontralaterales Bein:		
Neutral-Null-Methode OSG	Extension	Null	Flexion	Extension	Null	Flexion
Talusvorschub						
lat. Aufklappbarkeit						
Neutral-Null-Methode USG	Pronation	Null	Supination	Pronation	Null	Supination
Beinachse						
Differenz Femur (cm)						
Differenz Tibia (cm)						
Beinlänge gesamt (cm)						
Neutral-Null-Methode Knie	Extension	Null	Flexion	Extension	Null	Flexion
Neutral-Null-Methode Hüfte	Extension	Null	Flexion	Extension	Null	Flexion
	AR	Null	IR	AR	Null	IR
	Abduktion	Null	Adduktion	Abduktion	Null	Adduktion
VAS(0-10)						
Arthrosestadium(1-4)						
Score nach Weber						
Olerud und Molander						
Narbenverhältnisse	bland		hypertroph		keloid	

APPENDIX - Weber Score

Score nach Weber

Vom Teilnehmer auszufüllen			Vom Arzt auszufüllen		
Schmerzen im Gelenk			**Röntgenbild**		
Keine	0		Anatomisch perfekt ohne Arthrose	0	
Bei starker Beanspruchung	1		Spur Verkalkung eines Ligamentes, keine Arthrose	1	
Beim Normalgang	2		Anatomische Unstimmigkeit nur medial	2	
Ohne Belastung bei aktiver Bewegung	3		Anatomische Unstimmigkeit lateral = Arthrose	3	
In Ruhe	4		Hinterkantenstufe = Arthrose, Dystrophie	4	
Gehleistung			**Oberes Sprunggelenk**		
Normal(Gehen, Laufen, Fersen-, Haken-Kantengang, tiefe Hocke)	0		Volle Funktion, Seitengleichheit	0	
Behinderung bei 1 Gangqualität	1		Einbuße von höchstens 10°	1	
Behinderung bei 2 Gangqualitäten	2		Einbuße mehr als 10°, Dorsalflexion bis zu 90°	2	
Deutliches Hinken	3		Nicht fixierter Spitzfuß, Dorsalflexion bis zu 95°	3	
Schweres Hinken, Stockhilfe	4		OSG weitgehend versteift, störender Spitzfuß	4	
Aktivität			**Unteres Sprunggelenk**		
Volle berufliche und außerberufliche Aktivität	0		Volle Funktion, Seitengleichheit	0	
Normale berufliche, aber beschränkte außerberufliche Aktivität	1		Leichte Einbuße, eben knapp erkennbar	1	
Normale berufliche, aber aufgehobene außerberufliche Aktivität	2		Einbuße nicht mehr als die Hälfte	2	
Teilweise verminderte berufliche Aktivität	3		Einbuße mehr als die Hälfte	3	
Sehr gestörte berufliche Aktivität => Berufswechsel	4		Kontraktes unteres Sprunggelenk	4	

Punkte:	
Ergebnis:	
Beurteilungsschlüssel	
Sehr Gut	0
Gut	1-2
Schlecht	3-4

APPENDIX - Olerud and Molander Score

Score nach Olerund und Molander

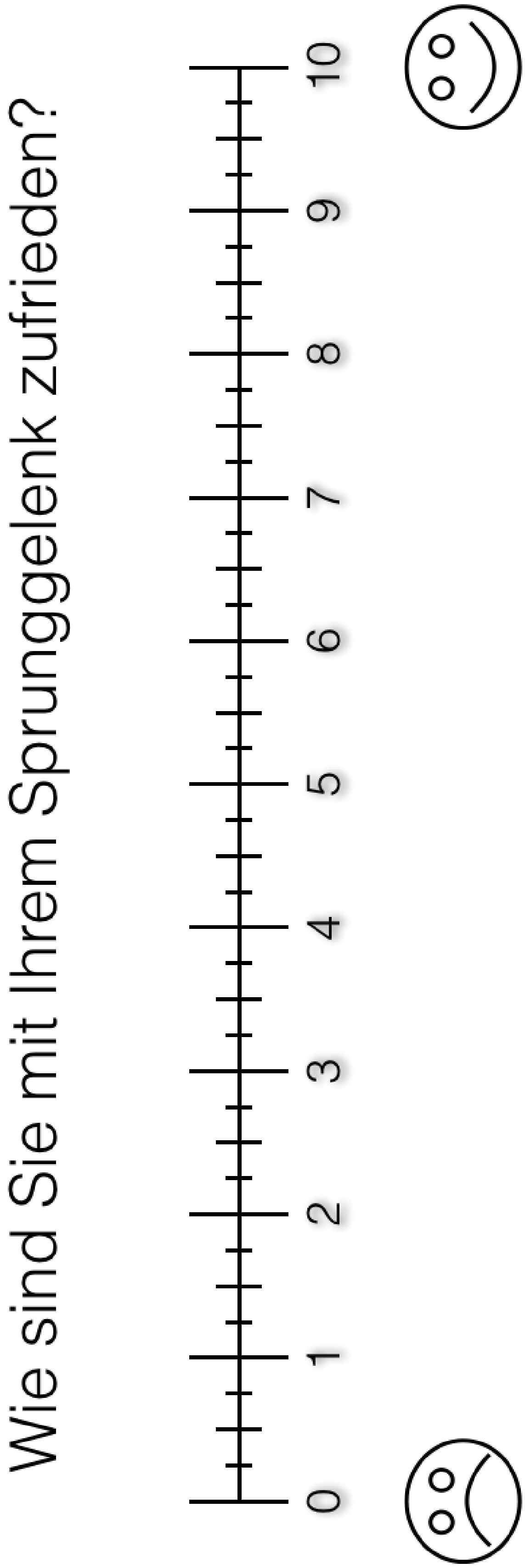
Vom Teilnehmer auszufüllen

Schmerzen im Gelenk		
Keine	25	
Beim Gehen auf unebenen Flächen	20	
Beim Gehen auf ebenen Flächen	10	
Gehen im Haus	5	
Anhaltend	0	
Steifheit im Gelenk		
Nein	10	
Ja	0	
Schwellung am Gelenk		
Keine	10	
Nur abends	5	
Immer	0	
Springen		
Möglich	5	
Unmöglich	0	
Unterstützung		
Keine	10	
Bandage	5	
Gehstock oder Krücken	0	
Arbeit, Aktivitäten des täglichen Lebens		
Keine Änderung	20	
Geschwindigkeitverlust	15	
Jobwechsel, bzw. Teizeitarbeit	10	
Stark eingeschränkte Arbeitsfähigkeit	0	

Laufen		
Möglich	5	
Unmöglich	0	
Stiegensteigen		
Ohne Probleme	10	
Eingeschränkt möglich	5	
Unmöglich	0	
Hocken		
Möglich	5	
Unmöglich	0	

Punkte:	
Ergebnis:	
Beurteilungsschlüssel	
Exzellent	91-100
Gut	61-90
Befriedigend	31-60
Schlecht	0-30

APPENDIX - Visual Analog Scale



APPENDIX - Follow-up patients

Patient	Patient number	Sex female/ male	Age at injury in years	Mechanism of injury	Injured limb	Type of fracture	Therapy	Technique
A	**1**	female	10	Fall from height	right	SH IV non-displaced	Conservative	-
B	**2**	male	14	Simple fall	left	SH IV displaced	Conservative	-
C	**19**	male	3	Fall from height	right	SH IV displaced	First conservative then operative	Screws+excision of physeal bar
D	**20**	female	11	Fall from height	right	SH IV displaced	Operative	Screws
E	**26**	male	14	Sports related	left	SH IV displaced	Closed reduction an immobilisation	-
F	**32**	female	12	Simple fall	right	SH IV displaced	Closed reduction an immobilisation	-
G	**33**	male	10	Traffic accident	left	SH III non-displaced	Conservative	-
H	**37**	female	7	Fall from height	right	SH III non-displaced	Conservative	-
I	**39**	male	11	Simple fall	right	SH III displaced	Conservative	-
J	**40**	male	12	Sports related	left	SH III non-displaced	Conservative	-
K	**41**	male	9	Sports related	right	SH III non-displaced	Conservative	-
L	**42**	male	11	Sports related	left	SH III non-displaced	Conservative	-
M	**43**	male	7	Others	right	SH III displaced	Operative	Screws
N	**45**	male	3	Sports related	left	SH IV displaced	Operative	K-Wires
O	**51**	male	8	Simple fall	left	SH III non-displaced	Conservative	-
P	**53**	female	9	Sports related	left	SH III non-displaced	Conservative	-
Q	**54**	male	9	Fall from height	right	SH III displaced	Operative	Screws
R	**58**	male	12	Simple fall	left	SH III non-displaced	Conservative	-

Patient	Patient number	Days to implant removal	Follow-up in months	VAS (0-100%)	Weber Score	Olerund and Molander Score	Kellgren and Lawrence classification (0-4)	Step in the joint (mm) (MRI verified)	Outerbridge classification (0-4)	Skeletally mature at follow up	Screws crossing physis
A	**1**	-	122	95	Good	Good	0	-	0	Yes	-
B	**2**	-	131	80	Good	Excellent	0	0.8	0	Yes	-
C	**19**	162	184	100	Good	Excellent	0	-	0	Yes	No
D	**20**	n/a	119	100	Good	Excellent	0	-	2	Yes	No
E	**26**	-	104	95	Good	Excellent	0	-	0	Yes	-
F	**32**	-	71	95	Very Good	Excellent	0	-	0	Yes	-
G	**33**	-	82	100	Poor	Excellent	1	-	3	Yes	-
H	**37**	-	70	100	Very Good	Excellent	0	-	0	No	-
I	**39**	-	69	100	Very Good	Excellent	0	-	1	Yes	-
J	**40**	-	68	100	Very Good	Excellent	0	n/a	n/a	Yes	-
K	**41**	-	67	100	Good	Excellent	0	-	0	No	-
L	**42**	-	65	100	Very Good	Excellent	0	-	0	No	-
M	**43**	98	65	90	Good	Excellent	0	-	0	No	No
N	**45**	246	48	100	Very Good	Excellent	0	-	0	No	No
O	**51**	-	181	100	Good	Excellent	0	-	0	Yes	-
P	**53**	-	179	90	Good	Excellent	0	-	0	Yes	-
Q	**54**	87	174	70	Poor	Good	1	-	2	Yes	Yes
R	**58**	-	157	90	Good	Excellent	0	-	0	Yes	-

APPENDIX - Photodocumentation

In the following two exemplary photo documentations are shown.