MAGNETIC RESONANCE IMAGING IN ORTHOPEDIC TRAUMA

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ACADEMIC DISSERTATION

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# CONTENTS

1. LIST OF ORIGINAL ARTICLES 5

2. ABBREVIATIONS 6

3. INTRODUCTION 7

4. REVIEW OF THE LITERATURE 9
   4.1. Bone trauma and imaging 9
      4.1.1. Fractures, occult fractures, and bone bruises 9
      4.1.2. Acute fractures in children 12
      4.1.3. Growth arrest in children 15
      4.1.4. Stress reactions in bone 19
      4.1.5. Biodegradable osteosynthesis 20
   4.2. Soft tissue trauma and imaging 21
      4.2.1. Ligaments and tendons 21
      4.2.1.1. UCL of the thumb 21
      4.2.1.2. Achilles tendon and retrocalcaneal bursa 23
      4.2.2. Joint fluid and tendon sheaths 25
      4.2.3. Muscle injuries 26

5. AIMS OF THE STUDY 28

6. MATERIALS AND METHODS 29
   6.1. Patients and control subjects 29
   6.2. Methods 31
      6.2.1. MRI methods 31
      6.2.2. Image interpretation 33
      6.2.3. Statistical methods 35
7. RESULTS
7.1. Differences between MRI and x-ray in acute wrist trauma 37
7.2. Differences between MRI and x-ray in children’s ankle trauma 39
7.3. MRI compared with plain tomography in growth arrest 42
7.4. MRI in biodegradable osteosynthesis 42
7.5. MRI in chronic ligament rupture of the thumb 43
7.6. MRI findings in asymptomatic, physically active individuals 44

8. DISCUSSION 45
8.1. Bone trauma 45
  8.1.1. Fractures, occult fractures and bone bruise 45
  8.1.2. Acute fractures in children 47
  8.1.3. Growth arrest in children 50
  8.1.4. Stress reactions in bone 51
  8.1.5. Biodegradable osteosynthesis 52
8.2. Soft tissue trauma 53
  8.2.1. Ligaments and tendons 53
  8.2.1.1. UCL of the thumb 53
  8.2.1.2. Achilles tendon and retrocalcaneal bursa 55
  8.2.2. Joint fluid and tendon sheath fluid 56
  8.2.3. Muscles 56

9. CONCLUSIONS 58

10. SUMMARY 60

11. ACKNOWLEDGMENTS 62

12. REFERENCES 64

13. APPENDICES 79
1. LIST OF ORIGINAL ARTICLES

This dissertation is based on the following papers:

   MR imaging in suspected acute trauma of wrist bones.

II. Lohman M, Kivisaari A, Kallio P, Puntila J, Vehmas T, Kivisaari L:
    Acute paediatric ankle trauma - MRI versus plain radiograph.
    Skeletal Radiology (approved).

III. Lohman M, Kivisaari A, Vehmas T, Kallio P, Puntila J, Kivisaari L:
     MRI in the assessment of growth arrest.
     Pediatric Radiology (submitted).

IV. Lohman M, Partio EK, Vehmas T, Kivisaari A, Kivisaari L:
    MR imaging in Biofix-osteosynthesis.

V. Lohman M, Vasenius J, Kivisaari A, Kivisaari L:
   MR imaging in chronic rupture of the ulnar collateral ligament of the thumb.

VI. Lohman M, Kivisaari A, Vehmas T, Kallio P, Malmivaara A, Kivisaari L:
    MRI abnormalities of foot and ankle in asymptomatic, physically active individuals.

The publishers have kindly permitted reprinting of the original articles. The papers are referred to in the text by their roman numerals.
2. ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>2D</td>
<td>2-dimensional imaging</td>
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<tr>
<td>3D</td>
<td>3-dimensional imaging</td>
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<tr>
<td>ax</td>
<td>axial</td>
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<tr>
<td>cor</td>
<td>coronal</td>
</tr>
<tr>
<td>CK</td>
<td>serum creatine kinase</td>
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<tr>
<td>CT</td>
<td>computed tomography</td>
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<tr>
<td>DE</td>
<td>dual echo</td>
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<td>DESS</td>
<td>dual echo in the steady state</td>
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<td>DOMS</td>
<td>delayed onset muscle soreness</td>
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<td>FISP</td>
<td>fast imaging with steady-state precession</td>
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<td>FLASH</td>
<td>fast low angle shot imaging</td>
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<tr>
<td>FOV</td>
<td>field of view</td>
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<td>FTA</td>
<td>anterior fibulotalar</td>
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<td>FS</td>
<td>fat saturation</td>
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<td>FSE</td>
<td>fast spin echo</td>
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<td>GRASS</td>
<td>gradient recalled acquisition in the steady state</td>
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<td>GRE</td>
<td>gradient recalled echo</td>
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<td>IRFSE</td>
<td>fast spin echo inversion recovery</td>
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<tr>
<td>MCP</td>
<td>metacarpophalangeal</td>
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<tr>
<td>MIP</td>
<td>maximal intensity projection</td>
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<td>MPGR</td>
<td>multiplanar gradient recalled imaging</td>
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<tr>
<td>MR</td>
<td>magnetic resonance</td>
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<td>MRI</td>
<td>magnetic resonance imaging</td>
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<tr>
<td>PABAK</td>
<td>prevalence- and bias-adjusted kappa</td>
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<tr>
<td>sag</td>
<td>sagittal</td>
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<tr>
<td>SE</td>
<td>spin echo</td>
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<tr>
<td>SH</td>
<td>Salter-Harris</td>
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<td>SPGR</td>
<td>spoiled gradient recalled echo</td>
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<tr>
<td>SR-PLLA</td>
<td>self-reinforced poly-L-lactic acid</td>
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<tr>
<td>STIR</td>
<td>short TI inversion recovery</td>
</tr>
<tr>
<td>T</td>
<td>tesla</td>
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<tr>
<td>TIRM</td>
<td>turbo inversion recovery magnitude</td>
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<tr>
<td>T1</td>
<td>longitudinal relaxation time</td>
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<td>T2</td>
<td>transverse relaxation time</td>
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<tr>
<td>TE</td>
<td>echo time</td>
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<tr>
<td>TR</td>
<td>repetition time</td>
</tr>
<tr>
<td>TSE</td>
<td>turbo spin echo</td>
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<tr>
<td>TI</td>
<td>inversion time</td>
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<td>UCL</td>
<td>ulnar collateral ligament</td>
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3. INTRODUCTION

The traditional method of verifying and classifying a bone trauma has been clinical examination and plain radiographs. If the clinical findings disagree with the radiological findings, further diagnostic workup may be needed. Computed tomography (CT), nuclear imaging and plain tomography have been used for evaluation of bone trauma, arthrography and ultrasound have been applied mainly in suspected soft tissue trauma. None of these methods can be utilized to demonstrate abnormalities of bone marrow and soft tissues at the same time.

In the last 10 years musculoskeletal diagnostic imaging has has been revolutionized by magnetic resonance imaging (MRI). With MRI, it is possible noninvasively, and without a radiation load, to evaluate both bones and soft tissues at one time. This diminishes the need for different examinations to solve a specific clinical problem. The high price and limited availability of MRI motivate studies of the appropriate utilization of this imaging technique. Although thinner slices can be obtained at high field imaging because of the higher signal-to-noise ratio and improved image resolution, no significant differences in clinical effectiveness was found between high- and mid-field imaging (Rutt and Lee, 1997). The present study is focused on different aspects of high-field MRI in orthopedic trauma to bones and soft tissues in children and adults, comparing the findings with already established diagnostic methods.

Discrepancies have been reported between the findings on MRI and those on radiographs and the clinical status of trauma patients. MRI may show occult fractures and bone bruises (Mink and Deutsch, 1989; Newberg and Wetzner, 1994) that remain undetected on radiographs, although they produce clinical symptoms. On the other hand, abnormal MRI findings have been described in bones and soft tissues of asymptomatic individuals (Schweitzer et al., 1994; Lazzarini et al., 1997).

MRI has proven superior to other imaging modalities in demonstrating occult intraosseous fractures (Escalas and Curell, 1994; Feldman et al., 1994) and bone bruises (Newberg and Wetzner, 1994). Although acute wrist bone trauma is one of the most common traumas, only a few reports are available on the role of MRI in acute wrist trauma of bones other than the scaphoid.

In young children, open physes affect conventional radiographic diagnostics and classification. A nondisplaced fracture passing along the physis may fail to be detected in
radiographs. Furthermore, an open physis may be interpreted as a fracture. Complex physisal fractures may need further radiologic examinations. MRI has been utilized for the verification of fractures, both acute and nonacute, clinically suspected or diagnosed on radiographs (Jaramillo et al., 1990a; Carey et al., 1998; Petit et al., 1996; Iwinska-Zelder et al., 1999).

Physeal fractures may lead to growth arrest which traditionally has been confirmed using conventional tomography. When X-ray tomography was compared with MRI in physeal fracture subgrouping, the two methods were rated equally good (Jaramillo et al., 1990a). During recent years MRI has been used instead of conventional tomography for verifying bone bars across the growth plate (Borsa et al., 1996; Craig et al., 1999). In the diagnosis of growth arrest, these two methods have not been systematically compared.

Breakdown of the biomaterial has been shown histologically and experimentally (Majola et al., 1991; Buchholz et al., 1994; Bersma 1995; Böstman et al., 1995; Matsusue et al., 1995), but it has not been detected with MRI although the biomaterial itself is clearly visible on MR images (Viljanen et al., 1995; Pihlajamäki et al., 1997a+b). Radiological verification of the breakdown of an osteosynthesis could be useful in assessing postoperative healing problems.

MRI has shown to be a reliable method for the primary diagnosis of fresh ulnar collateral ligament (UCL) ruptures in the thumb (Haramati et al., 1995; Hergan et al., 1995; Hinke et al., 1994; Spaeth et al., 1993), but the suitability of MRI in diagnosing chronic UCL ruptures has not been studied.

Bone marrow edema (Lazzarini et al., 1997) and soft tissue changes (von Tosch et al., 1991) have been described in marathon runners after a race. The frequency of pathological MRI findings in physically active individuals without symptoms, and without any preceding unusual physical stress, have not been investigated.
4. REVIEW OF THE LITERATURE

4.1. BONE TRAUMA AND IMAGING

4.1.1. Fractures, occult fractures and bone bruises

In clinically suspected orthopaedic trauma plain radiographs are still essential. Nuclear studies, plain tomography, arthrographies, CT, and ultrasound have been used in selected cases to gain additional information. These methods all have their own limitations. All, except ultrasound, subject the patient to some radiation. In ultrasound, the most performer-dependent of the methods, the visual demonstration of findings to the orthopedic surgeon may also be difficult. None of these methods can be used for demonstrating abnormalities of the bone marrow and soft tissues simultaneously.

Fractures involving the articular surfaces can be divided into two major groups: fractures that also extend through the articular surface, usually more perpendicularly, and osteochondral fracture, which are more or less parallel to the articular surface. Osteochondral fractures can be subdivided further into lesions with intact and with disrupted cartilage. Fractures with an intact chondral surface are either subchondral bone bruises or impaction injuries. In chondral surface and osteochondral lesions, the cartilage is disrupted. According to an experimental study (Vener and al., 1992), fractures due to overloading take place primarily in the zone of calcified cartilage, and also in the subchondral bone. The cartilage is the last to be damaged and it also needs most pressure to break. Although these fractures may not be apparent on radiographs, they may lead later to osteochondral sequelae. On follow-up with MRI 6-12 months later, osteochondral sequelae could be detected in 67% of bone bruises (called occult geographic fractures) situated under the subchondral bone (Vellet and al., 1991).

Patients with clinical suspicion of a fracture, but with negative radiographs, may produce a therapeutic dilemma. Usually, they are treated according to the clinical status,
and follow-up radiographic investigations are scheduled, most commonly control radiographs.

The use of conventional tomography for the exclusion of a fracture has diminished and CT (Saucer et al., 1980; Pretorius et al., 1995; Nunez and Quencer, 1998) has been employed to exclude fractures when radiographs are equivocal. Sagittal and coronal reformatted images facilitate fracture diagnosis with CT. 3D reconstructions may be useful for preoperative planning (Pretorius et al., 1995). If reformatted images are not available, fractures in the imaging plane can be missed with CT.

Occult fractures, not seen on plain radiographs, can occasionally be detected in nuclear scans. However, nuclear scans are unspecific, and various conditions may lead to similar findings (Matin, 1979). Conventional tomography, CT, and nuclear scans cause radiation exposure to the patient and their usefulness for detecting associated soft tissue trauma is negligible.

MRI of an occult intraosseous fracture was first described in 1988 (Yao, 1988). With the use of MR, a new entity has been introduced: the bone contusion or bone bruise (Berger et al., 1989; Mink and Deutsch, 1989; Newberg and Wetzner, 1994). The bone bruise represents a less severe form of trauma to bones, the significance of which has not been fully clarified. In contrast to fractures and occult fractures, no fracture line can be detected in a bone bruise, only a posttraumatic, nonlinear area of signal alteration (Mink and Deutsch, 1989).

Bone bruises have also been divided into three types (Lynch et al., 1989): Type 1 is located in the medullary cavity or metaphysis without cortical interruption, in type 2 the cortex is also disrupted, whereas type 3 is a signal alteration immediately beneath the cortex, which is not disrupted. In 1991, a more complex classification was presented (Vellet and al., 1991), but has not been adopted in other investigations. In histologic sections, subchondral damage has been described in the areas of bone bruises (Donohue et al., 1983; Vener and al., 1992). In one study by Escalas and Curell, bone bruises (verified with MRI) were experimentally produced in 12 rabbit femurs (1994). The animals were investigated with MRI at 1, 3 or 9 weeks after the trauma and some of the animals were killed and biopsied at different times. Eleven human patients with a knee trauma and bone bruises were arthroscoped and biopsied. The histologic findings were negligible: the rabbits showed edema of the bone marrow, but no trabecular microfractures. One rabbit had cartilage disruption. Only one of the human patients (who had a history of severe trauma) showed reparative bone growth over the necrotic trabeculae; all the others had normal bone. In later follow-up studies in rabbits, there were persisting signal alterations on MR images, but the histologic changes were slight; only edema of the bone marrow.
Hemorrhage, edema, and possibly microtrabecular fractures may explain the findings seen with MRI.

Bone bruises in association with lateral ligament disruption of the ankle are relatively common. In a study of 35 adults clinically suspected of having anterior fibulotalar (FTA) ligament rupture, 27 patients had a lateral ligament rupture, also seen on MR images, which in 24 of these, was complete. Of these patients, 14 had a bone bruise in either the talus or the medial malleolus or in both (Nishimura et al., 1996). In another study, 30 patients who had clinically stable ankles and normal radiographs, but persistent ankle pain 6 weeks after the trauma were examined with MRI. Of these patients 57% had injuries at the talar dome, 12 laterally and 5 medially (Magee and Hinson, 1998).

Conventional radiography remains the primary method for evaluating skeletal trauma. MRI has proven useful in both the verification and the exclusion of fractures of the proximal femur (Deutsch et al., 1989). MRI has proven superior to other imaging modalities in demonstrating both occult intraosseous fractures (Deutsch et al., 1989; Escalas and Curell, 1994; Feldman et al., 1994) and bone bruises (Newberg and Wetzner, 1994).

On MRI, a fracture appears as an intraosseous line that extends to the cortex. The line has decreased signal intensity in T1-weighted images and increased signal intensity on T2-weighted images due to hemorrhage and edema. There is often an area of diffuse signal alteration around the fracture. In bone bruises, no fracture line can be detected, only a diffuse area in which the signal is altered. The signal is decreased in T1-weighted sequences, and increased in T2-weighted.

T2-weighted fast spin echo (T2FSE) with spectral fat saturation (FS) is advocated for the diagnosis of bone trauma (Kapelov et al., 1993). In a study comparing fat suppression with no fat suppression, 38% of lesions were missed if fat suppression was not used. Short TR inversion recovery (STIR) images are also useful, but the drawbacks of this sequence are a thicker slice and the longer acquisition time needed (Mirowitz, 1993). On fast STIR imaging (IRFSE), based on fast spin echo sequences, fractures are detected equally well although the imaging times are shorter (Arndt et al., 1994). On IRFSE bone marrow lesions were more conspicuous than on T1SE sequences or T2FSE sequences with fat suppression, although imaging times were comparable. In IRFSE, the problems of inhomogeneous fat suppression were also less pronounced than with T2FSE with spectral fast suppression, although the difference was not statistically significant (Pui and Chang, 1996). Chronic fractures may be of low signal intensity in both T1- and T2-weighted sequences (Lynch et al., 1989).
Several pathologic conditions may result in bone marrow edema and hence should be taken into account in the differential diagnosis: these are tumors (Kroon et al., 1994), infection (Morrison et al., 1993), avascular necrosis (Vande Berg et al., 1993) and transient osteoporosis (Hayes et al., 1993). Even altered biomechanics in the lower legs has been shown to cause bone marrow edema (Schweitzer and White, 1996) not only in the foot but also in the tibia and fibula. Hematopoietic bone marrow hyperplasia (Shellock et al., 1992) is bilateral and usually involves larger areas of the bone marrow than a bruise.

Acute wrist trauma is a common injury, often caused by a fall on an outstretched hand. The diagnosis has been based on radiographs and clinical findings. If a scaphoid fracture is suspected on clinical grounds despite negative primary radiographs, later control radiographs have been advocated. After about 2 weeks, the fracture line should be seen more clearly. MRI has proved useful for the diagnosis and for verification (Imaeda et al., 1992; Lepistö et al., 1995; Hunter et al., 1997) or exclusion of nonunion and posttraumatic avascular necrosis (Imaeda et al., 1992) of scaphoid fractures.

A case report of occult wrist fractures in 3 patients was presented in 1992 by Kettner and Pierre-Jerome (1992), and another study of 5 patients in 1996 by Peh et al. (1996). In 1996, Blease reported of 13 osseous injuries shown by MRI in 52 consecutive patients with an acute wrist injury. Seven of the fractures were situated in the radius, 2 in the scaphoid, 4 in other locations in the wrist. However, the exact number of fractures not detected on plain radiographs was not mentioned.

MRI has been recommended instead of CT if there is a need of additional radiographic data prior to operative fixation of complex distal radius fractures (Spence et al., 1998). In a study of 21 patients with radiographically confirmed radius fracture, two additional fractures (in the capitate and second metacarpal) were discovered with MRI.

4.1.2. Acute fractures in children

Longitudinal growth takes place in the physis, a cartilage structure between the epiphysis and metaphysis (Brighton, 1984). The physis can be divided into different layers: Nearest the epiphysis is the germinal cell zone, in the middle the proliferative zone, and on the metaphyseal side the hypertrophic zone. Between the hypertrophic zone and the metaphysis is the zone of provisional calcification where the forming bone becomes mineralized. This zone of provisional calcification is the weakest point in the bone (Iannotti, 1990). The outermost portion of the physis, called the perichondrial ossification groove of Ranvier, adds some width to the physis via the chondrocyte precursor cells (Shapiro et al., 1977).
On all imaging sequences, the normal perichondrium is thin and hypointense. The periosteum seldom ruptures but it may be stripped from the underlying bone.

The physis does not have a separate blood supply. The blood needed for bone synthesis comes from the metaphyseal region through both the central nutrient artery and the peripheral periosteal vessels. The rest of the physis is supplied from the epiphyseal vessels through several periosteal arteries (Trueta and Sliema, 1960).

With growth, the position of the physis may change. In the ankle, the fibular physis moves more distally in relation to the tibial physis as the child becomes older (Ogden and McCarthy, 1983). In the distal tibia, ossification begins anteromedially in an undulation in the physis known as Polans’s or Kump’s hump (Chung and Jaramillo, 1995). The growth cartilage in the distal fibula ossifies after the distal tibia (Chung and Jaramillo 1995).

The most common classification of physeal fractures is that of Salter-Harris (Salter and Harris, 1963), consisting of five different types (Figure 1).

![Figure 1: Salter-Harris classification of physeal fractures.](image-url)

- **SH1**: Complete separation of the epiphysis along the physeal cartilage.
- **SH2**: The fracture extends along the physis and continues into the metaphysis.
- **SH3**: Fracture along the physis, continuing into the epiphysis and articular cartilage.
- **SH4**: The fracture goes through the epiphysis, physis, and metaphysis.
- **SH5**: Crush injury of the physis.
Rang (Rang, 1983) added one type:

- type 6: Involves the perichondrium around the physis

Ogden (Ogden, 1981) added three types:

- type 7: A pure epiphyseal fracture
- type 8: An injury of the metaphyseal vascularization that disturbs ossification
- type 9: Involves the periosteum and disturbs membranous bone formation

In 1970, the triplane fracture of the distal tibia was defined (Marmor, 1970): this fracture crosses the epiphysis, the physis, and the metadiaphysis in three orthogonal planes. Some fractures (SH 1,2,3) may be associated with crush injuries of the physis and metaphysis, classified as SH5 (Rogers, 1970). Most of the SH5 fractures occur in the distal tibia and may be misdiagnosed as an injury to the ankle ligaments (Salter and Harris, 1963). Isolated SH5-fractures constitute about 1% of physeal fractures (Rogers, 1970; Mizuta et al., 1987). Although they are not detected on ordinary radiographs, they are often associated with growth disturbances. Most physeal fractures occur at the age of 13 in boys and at 11 in girls; they are more common in boys (Mizuta et al., 1987). In young children, physeal fractures of the ankle outnumber ligament injuries, because of the relative weakness of the growth plates.

Radiographic detection of bone trauma has lower sensitivity and specificity in children than in adults, because an open physis may mimic a fracture (a false-positive case) or a nondisplaced fracture line may pass undetected along the growth plate (false-negative case). The disadvantage of plain radiographs is that the growth cartilage itself is not directly depicted. For fractures visualized only on MR images, the term “the pediatric fracture without radiographic abnormality” (Naranja et al., 1997) has been introduced. In a study of 25 children who refused to bear weight or use their leg despite normal radiographs, all were found on MRI to have a fracture. On MR images, a metaphyseal band of lower signal intensity reflects the zone of provisional calcification and is hence a normal finding.

For the visualization of physeal cartilage in MRI, either spin echo (SE), gradient recalled echo (GRE) (Jaramillo and Hoffer, 1992) or spoiled gradient recalled echo (SPGR) sequences (Disler, 1997) have been recommended. Three-dimensional (3D) GRE postimaging reconstructions with exact mapping of the physis have also been made (Borsa et al., 1996). For visualization of the growth plate prior to ossification, proton density SE with fat suppression, or GRE; either gradient recalled acquisition in the steady state (GRASS) or multiplane gradient recalled imaging (MPGR) have been recommended,
before complete ossification of the epiphysis T2-weighted sequences (Chung and Jaramillo, 1995).

The first article about the use of MRI for evaluation of children’s fractures was presented in 1990 (Jaramillo et al., 1990a). The study comprised 26 fractures imaged 4 days to 2 years after the initial trauma. The initial fracture classification according to Salter-Harris (Salter and Harris, 1963) was changed in 6 patients.

In 1994, two papers (White et al., 1994, Smith et al., 1994) were presented, each concerning 4 patients with acute trauma. In both studies, MRI changed the primary classification in three of four ankle fractures. In 1996, in a French study (Petit et al., 1996), MRI changed the fracture classification in only one of 29 fractures of the distal tibia. This study recommended that MRI should be used only in complex fractures if the initial fracture classification was uncertain. Those patients later requiring surgical intervention showed pathologic findings on MR images earlier than on conventional radiographs. In an MRI study in 1998, 14 children were imaged with MRI. The classification was changed in 2 of 9 fractures and five radiographically occult fractures were diagnosed (Carey et al., 1998).

Ten children with a suspected distal tibial fracture were studied with MRI in 1999 and the findings were compared with those from plain radiographs (Iwinska-Zelder et al., 1999). In 7 of the patients, the fracture classification according to Salter-Harris was changed, and in four of these the therapy was also changed. In one patient, a fracture could be excluded.

In a recent experimental study in rabbits, it was been possible to grade the plane of physeal fracture-separation in greater detail as either juxta-metaphyseal, juxta-epiphyseal, or a cleavage plane in the middle of the physis (Jaramillo et al., 2000). Of these three planes, the juxta-epiphyseal showed most complications due to the trauma.

4.1.3. Growth arrest in children

Early diagnosis, treatment, and follow-up of fractures extending to the growth plate are demanding. Physeal fractures may lead to permanent damage to the proliferative layer of the growth plate or a bone bridge across an otherwise viable growth plate. This may result in growth disturbances of variable severity, depending on the extent of physeal damage and the amount of growth remaining.

Injuries to the growth plate may result in progressive joint surface deformities and angular deformities or in length discrepancy of the extremities. About one fracture in five in the distal tibia results in later growth arrest (Bright, 1991). A central growth arrest leads to
shortening of the limb, and a peripheral to angular deformities. These deformities are initially symptom-free and are seen as clinical problems rather late. Physeal fractures are the most common cause of premature physeal arrest, other frequent causes are infections, tumors, and ischemic damage (Jaramillo and Shapiro, 1998).

Extensive experimental studies with MRI have been performed on the visualization of the growth plate and its abnormalities. Experimentally produced physeal fractures in rabbits led to the development of abnormal transphyseal vascularisation, which was demonstrated on MRI (Jaramillo et al., 1990b). Trauma to the rabbit epiphysis resulted in the formation of a bone bridge or focal curving of the growth plate, whereas trauma to the metaphysis resulted in thickening of the growth plate and disturbed ossification of the cartilage; these were best seen on T2-weighted images (Jaramillo et al., 1993). Vascularization of the physis and epiphysis has been demonstrated on contrast-enhanced MRI in children (Barnewolt et al., 1997).

According to Shapiro (1987), growth disorders may be due to two mechanisms: The development of an osseous bridge is dependent on whether the avascular physis is damaged in such a way that the epiphyseal and metaphyseal vessels may conjoin and develop transphyseal vascularity. Another etiology for the growth arrest is destruction of the vascularity in the physis which inhibits physeal growth.

As a sequel of a trauma to the physis the growth plate may be interrupted by either a fibrous or an osseous bar; these are both seen as low signal areas in the physis. When a bar develops, it is at first fibrous and may later be transformed to a bone bar. A medially located bar will lead to a varus deformity, a posterior bar to antecurvatum and a central bar to growth arrest without angular deformity.

If the blood supply to the zone where the cartilage is ossified is damaged, the physis itself is undamaged and open, but areas of nonossified tissue can later be seen in the bone marrow on the metaphyseal side (Jaramillo et al., 1993). If the physis is undamaged, however, these clusters of cartilage in the metaphyseal area do not lead to growth arrest, although the physis maybe widened locally (Laor and Jaramillo, 1993; Laor et al., 1997).

The risk of growth disturbances correlates with certain fracture types, such as fractures crossing the physis and those associated with a crush injury of the metaphysis. In those fractures that cross the physis, the longitudinal fractures, the risk of later bone bridge formation is about 75%, whereas it is only 25% in the transverse fractures, which are parallel to the physis. Several other factors, e.g. the location of the fracture and the age of the patient (Salter and Harris, 1963; Shapiro and Rand, 1992) also affect the risk of a later bone bridge.
Fractures around the ankle and involving the growth plate in children carry a risk of about 30% that growth will later be disturbed (Rogers, 1970). An extensive injury may lead to growth arrest and leg length discrepancy. A partial injury to the growth plate may lead to angular deformity or progressive loss of joint congruence. This may lead to functional impairment and early osteoarthritis (Peterson, 1984; Salter and Harris, 1963).

The risk of later growth disturbances depends on both the type of physeal fracture and its location. In the fibula, growth disturbances are rare. In the tibia, growth disturbances may occur in association with SH2-5 fractures. Fractures caused by an adduction injury, often SH3 or SH4 of the medial malleolus, are especially hazardous (Rogers, 1970). SH4 fractures of the medial malleolus often occur in young children and therefore carry a high risk of growth arrest (Cass and Peterson, 1983). Although 30% of all epiphyseal injuries result in some shortening and angulation, clinically significant functional alterations develop in only 2% (Mizuta et al., 1987).

The size of the growth arrest is important when a decision is made about the necessity of surgical intervention (Peterson, 1984; Peterson, 1993). If the diagnosis is delayed and the deformity becomes obvious on clinical examination, the simple methods of treatment such as removal of the bone bar and interposition of fat, silastic or methyl metacrylate (Langenskiöld, 1981, Österman, 1994, Williamson and Staheli, 1990, Peterson, 1984), may not be sufficiently effective and more demanding methods of treatment must be used. Therefore, there is a need for new methods of early diagnosis and localization of posttraumatic growth problems.

Progressive posttraumatic growth disturbances should be diagnosed as early as possible. Significant physeal injuries should be followed up until maturity as some bone bars become clinically evident only then (Peterson, 1984). In the follow up of these cases, conventional radiographs and clinical examination are of primary value. Until recently, conventional x-ray tomography has been the gold standard in the assessment (Young et al., 1986) and mapping (Carlson and Wenger, 1984) of the extent of posttraumatic growth plate disturbances. If necessary, conventional tomography (Rogers, 1970), and recently, computerized tomography with 3D reconstruction modalities (Loder et al., 1997) have been used. Axial scintigrams (Howman-Giles et al., 1985) have also been recommended, and more recently, MRI (Jaramillo and Shapiro, 1998; Carey et al., 1998).

The only examination of the growth plate in which both x-ray tomography and MRI were utilized was performed in 1990 (Jaramillo et al., 1990a): 7 of 26 patients suffering from fractures of different ages (4 days up to as much as 2 years) were investigated, using both methods: in 5 patients, bone abnormalities were shown equally well on both
modalities. The report does not tell, however, whether these abnormalities were acute
fractures or later complications.

If growth slows down, a line of increased calcification is produced. When growth is re-
established this line is displaced from the physis. If growth is uniform, this calcified line is
parallel to the physis (Figure 2), but if there is growth arrest the line converges with the
physis at the level of an osseous bar (Ogden, 1984; O’Brien et al., 1986). These calcified
lines, also called Park-Harris lines, can be seen on MR images as lines of low signal
intensity with all pulse sequences; however T1SE images show them most clearly (Smith et
al., 1994).

![Diagram](image_url)

Figure 2: Schematic images of growth arrest lines.

a. Normal lines, parallel to the physis.
b. Abnormal lines, converging towards an area of growth arrest.

Tongues of cartilage due to an insult to the zone of provisional calcification may
occasionally be detected in the metaphysis on MRI (Craig et al., 1999). In the epiphyses of
adults, local sclerotic lines may be detected on MRI; these represent growth disturbances
during childhood (Yao and Seeger, 1997).

In 1996, a mapping system showing the location and size of the bar was presented, on
the basis of GRE images (Borsa et al., 1996) using the maximum intensity projection
(MIP) technique, with results comparable to those made by the rendering technique.
3D SPGR was also recommended for mapping bars in the growth plate in a study of 13 children with either suspected or known bone bridging (Craig et al., 1999). SPGR with fat suppression is also recommended in a review (Disler, 1997). For the study of postsurgical results, T1SE with gadolinium enhancement has been recommended (Craig et al., 1999).

### 4.1.4. Stress reactions in bone

Chronic repetitive stress may cause stress injuries to the bone (Jones et al., 1989, Yao et al., 1998). Stress fractures occur in normal bone following abnormal stress, as opposed to insufficiency fractures, which are seen in weakened bone after normal stress. The most common sites for stress fractures in runners are the tibia and fibula (Brukner et al., 1996). In a study of 200 athletes with stress fractures, most of the injuries were found in the tibia; the next most common site was the metatarsals (Orava, 1980). With repetitive overloading, the osteoclastic activity in bone exceeds that of the osteoblastic, the result being bone weakening, microfractures, and eventually a stress fracture (Jones et al., 1989). Usually, the fracture is limited to one side of the cortex, but if the diagnosis is delayed, the fracture may become complete (Orava, 1980). Symptoms of stress fracture usually precede findings on plain radiographs by 2 to 8 weeks (Orava, 1980). Stress fractures are diagnosed by MRI when plain radiographs were still negative (Lee and Yao, 1988).

The differentiation of a bone bruise from a stress fracture on MRI is based on the presence of a low-signal-intensity line extending from the medulla to the cortex in the latter (Lee and Yao, 1988). A grading system for stress reactions, based on MRI of the tibia, has been proposed (Fredericson et al., 1995). A grade I injury exhibits periosteal edema, grades II and III increasing bone marrow edema, and grade IV a fracture line. In another study of stress reactions of the lower extremity (Yao et al., 1998), this classification was not found prognostic for symptom duration. The presence of either a medullary line or a cortical signal intensity abnormality was associated with more prolonged duration of symptoms.

MRI was found to be slightly inferior to CT for the diagnosis of longitudinal tibial stress fractures, but significantly better for showing associated bone marrow edema and soft tissue lesions (Feydy, 1998). The fracture line was seen in 82% of patients on CT and in 73% on MRI. The gold standard in this study was somewhat unclear, however, as the diagnosis is based on clinical and imaging data.

According to Lazzarini et al., (1997), MR images showed bone marrow edema of the ankle and foot in 16/20 marathon runners after a race and in 4/12 nonrunners. Abnormal stress may cause signal alterations on MRI (Schweitzer and White, 1996) and the edema
was proposed possible to represent a stage preceeding a stress fracture (Lazzarini et al., 1997).

Diffuse bone marrow alterations due to reconversion to hematopoietic bone marrow can also be detected without any pathological association, in smokers and obese women (Poulton et al., 1993). Usually, fatty bone marrow remains in the epiphyses and apophyses (Steiner et al., 1990). In a previous MRI study, marathon running was found to be associated with bone marrow hyperplasia, considered to develop as a result of sports anemia (Shellock et al., 1992).

### 4.1.5. Biodegradable osteosynthesis

Biodegradable osteosynthesis has been used as an alternative to fixation using metallic fixation devices (Partio et al., 1992, Rokkanen et al., 1996). A commonly used bioabsorbable material is self-reinforced poly-L-lactic acid (SR-PLLA). Its degradation time is not precisely known: reported resorption times in histologic and experimental studies range from 40 weeks to over 4 years (Majola et al., 1991; Bucholz et al., 1994; Bersma, 1995; Böstman et al., 1995; Matsusue et al., 1995). The strength retention of SR-PLLA osteosynthesis diminishes with time in experimental studies being at the level of cancellous bone after 36 weeks (Majola et al., 1991).

If a fracture of the ankle is associated with a broken syndesmosis between the tibia and the fibula, a transfixation screw is applied. In order to prevent undesirable synostoses between the two bones, this screw is removed within 10 weeks (Kaye, 1989). The use of biodegradable screws for syndesmotic fixation relies on the assumption that the screw will break before any synostosis develops. However, no degradation has been reported in MRI studies.

In conventional radiographs (Viljanen et al., 1995; Pihlajamäki et al., 1997a+b) and computed tomography (CT) (Viljanen et al., 1995) the pin tracks are radiolucent compared to bone and sometimes a sclerotic rim can also be seen. The biomaterial itself is visualized with MRI (Viljanen et al., 1995; Pihlajamäki et al., 1997a+b) but degradation of the biomaterial, reported in histologic studies (Majola et al., 1991; Bucholz et al., 1994; Bergsma et al., 1995; Böstman et al., 1995; Matsusue et al., 1995), has not been documented on MRI - although the postoperative follow-up has ranged from 3 years in the scapula (Pihlajamäki et al., 1997a) and to over 4 years in the ankle (Pihlajamäki et al., 1997b).
4.2. SOFT TISSUE TRAUMA AND IMAGING

4.2.1. Ligaments and Tendons

Tendons are composed of parallel, densely packed collagen fibers. They are surrounded by a peritenon, which consists of an inner epitenon and an outer paratenon. Except for the vascularized tendons of the rotator cuff, most tendons only have a minor intrinsic blood circulation. Tendons in areas of stress are surrounded by a synovial sheath, the tenosynovium, a tubular sac around the tendon. Because of their collagenous structure, normal tendons have low signal intensity on both T1- and T2-weighted MR images. Intact ligaments also have low signal intensity on T1- and T2-weighted images.

4.2.1.1. UCL of the thumb

One of the most frequently occurring ligament injuries in the hand is a rupture of the ulnar collateral ligament (UCL) of the thumb (Diao and Lintecum, 1996; Van Domaelen and Zvirbulis, 1989). If not treated, this injury may lead to loss of pinch grip strength, instability (Boyes, 1970), pain, and later arthrosis. Common causes of this injury are skiing and cycling accidents, and falling on the hand (Campbell et al., 1992; Posner and Retaillaud, 1992). The trauma mechanism is a hyperabduction, and often also hyperextension of the first MCP joint (Stener, 1962).

For treatment of fresh, unstable UCL ruptures, early ligament repair or reinsertion has been advocated, with fixation of the bone avulsion, if present (Dray and Eaton, 1993). Rupture occurs more often from the distal insertion (Resnick and Danzig, 1976; Stener, 1962). An uninjured UCL lies beneath the adductor pollicis aponeurosis (Figure 3). After a total rupture, the proximal part of the dislocated ligament may lie upon the adductor aponeurosis. In these cases, successful healing is not possible, as the torn ends of the ligament are not in close contact with one another. This is the Stener lesion (Stener, 1962), which should be treated operatively. (Stener, 1962; Bowers and Hurst, 1977; Palmer and Louis, 1978; Newland, 1992).
Lesions in the ulnar collateral ligament of the thumb are often primarily missed (Musharafieh et al., 1997). If untreated, both Stener and non-Stener lesions may lead to decreased pinch strength, instability, and osteoarthritis (Watson-Jones, 1943; Boyes, 1970). The longer the time before ligament reconstruction, the worse are the results (Helm, 1987). Several different techniques have been recommended for operative ligament reconstruction, but none has been shown to be superior to the others. Instead of ligament reconstruction in old UCL-ruptures with instability some authors have even recommended a primary arthrodesis (Lamb et al., 1971).

Instability may also be due to chronic repetitive stress on the ulnar collateral ligament. This was first described in Scottish gamekeepers, and was due to their method of killing wounded rabbits by gripping the neck of the animal in the thumb-forefinger cleft in order to stretch and hyperextend the neck (Campbell, 1955). This same type of occupational hazard to the UCL could, according to this author, also affect workers in other occupations such as anesthesiologists who maintain the face mask in position by hand, which stresses the ulnar side of the thumb.
The traditional method of verifying ulnar collateral ligament ruptures of the thumb has been by clinical examination (Stener, 1962), where the limits for a complete tear have a 15- to 45-degree difference in passive movement compared with the opposite side (Newland, 1992). Radiographic stress views (Bowers and Hurst, 1977) have been utilized; the stress may even be applied by the patient himself (Downey and Curtis, 1986). In radiographic stress views an ulnar collateral ligament rupture is diagnosed when there is a difference of 10 degrees or more between sides (Bowers and Hurst, 1977). Verifying of ulnar collateral ligament rupture by ultrasound has not been considered a reliable method (Hergan et al., 1997; Susic et al., 1999). Arthrography (Resnick and Danzig, 1976; Bowers and Hurst, 1977; Stothard and Caird, 1981) and MR arthrography (Harper et al., 1996; Ahn et al., 1998) of the MCP joint are invasive and time-consuming methods. For the differentiation of Stener lesions from non-Stener lesions, arthrography was recommended in an earlier study (Bowers and Hurst, 1977).

MRI has, in several studies, been shown to be a reliable method for the diagnosis of fresh UCL ruptures. The first examinations were performed in cadavers (Spaeth et al., 1993; Haramati et al., 1995; Ahn et al., 1998), and later investigations were also made in normal patients, the findings being correlated with the operative findings (Hinke et al., 1994; Harper et al., 1996; Plancher et al., 1999). For the classification of UCL ruptures into Stener/non-Stener lesions Haramati et al. (1995) found MRI to be inadequate. According to Harper et al. (1996), MRI is more reliable than stress radiographs for the preoperative confirmation and classification of UCL tears. In a cadaver study, MR arthrography was found more reliable than MRI both in the diagnosis and classification of UCL injuries (Ahn et al., 1998).

In these studies as well, SE, FSE and GRE sequences were used, in the axial, sagittal, coronal, and oblique coronal (parallel to the plane of the sesamoid bones) planes. One study was made using a 0.5 Tesla (T) scanner (Hergan et al., 1995), the other examinations were made using high-field MRI. No investigations have been performed to clarify the usefulness of MRI in the diagnosis of old UCL ruptures of the thumb.

4.2.1.2. Achilles tendon and retrocalcaneal bursa

The Achilles tendon has no synovial sheath, but an epitenon, a thick, vascular connective tissue layer, and around that, the paratenon, a thin membranous structure that reduces friction between the tendon and the surrounding tissues (Kvist et al., 1988). The peritenon consist of the inner epitenon and the outer paratenon. In acute peritendinitis the vicinity of the Achilles tendon is edematous showing low signal intensity on T1 weighted sequences
and high signal intensity on T2 and STIR sequences, but the signal and the shape of the tendon itself are not altered. Chronic inflammation may lead to thickening of the paratenon, with fibrotic changes and eventually adhesions (Kvist et al., 1988).

In Achilles tendinitis, the tendon itself shows pathologic alterations. Achilles tendinitis may be divided into two different kinds, depending on the location of the alterations: In insertional tendinitis, there are symptoms of swelling and tenderness at the insertion of the tendon on the calcaneus. In MRI, the tendon is thickened distally and the amount of fluid in the retrocalcaneal bursa there is often increased (Clain, 1995). A prominent posterosuperior calcaneus is often seen in association with insertional tendinitis. Intrasubstance overuse alterations are situated more proximally. Three different stages can be seen (Galloway et al., 1992) with specific MRI alterations. At first, an inflammatory process of the paratenon develops, with thickening and adhesions, followed by tendinosis and tendon degeneration (foci with increased signal intensity in T1-weighted images, but normal on T2-weighted images) and finally by areas of partial tears showing increased signal intensity on both T1- and T2-weighted sequences. According to Movin et al. (1998), intravenous contrast enhancement improves the detection of Achilles tendon signal abnormalities. In chronic tendinitis, there is fusiform thickening and the diameter of the tendon increases. Occasionally, small punctate hyperintensities have been described in the Achilles tendon on T1-weighted sequences (Rollandi et al., 1995; Mantel et al., 1996), on proton-weighted images (Rollandi et al., 1995) and on STIR and FLASH images (Soila et al., 1999). By correlating MRI images with histologic sections, the foci were proposed to be interfascicular septa containing blood vessels (Mantel et al., 1996).

In total ruptures, the tendon is discontinuous and interrupted by a fluid-filled gap. In acute rupture, the signal intensity of the hemorrhage resembles that of fluid with high signal intensity in T2 and STIR sequences and low signal intensity in T1-weighted sequences (Marcus et al., 1989). In due course, scar tissue will replace the rupture site. In partial rupture, there is discontinuity in a part of the tendon fibers. The signal behavior at the rupture site is similar to that in total rupture.

A retrocalcaneal bursitis with an increased amount of fluid in the bursa is often seen in combination with chronic tendinitis (Galloway et al., 1992). Either high-intensity fluid or synovium has been detected in the retrocalcaneal bursa in 100% of asymptomatic individuals, but bursal dimensions exceeding 11x7x1 mm should be considered abnormal (Bottger et al., 1998). In their examination, Soila et al. (1999) found prominent fluid collections in the retrocalcaneal bursa in 15% of asymptomatic cases. With ultrasound, fluid was detected in the retrocalcaneal bursa in 50% of normal volunteers (Nazarian et al., 1995).
4.2.2. Joint fluid and tendon sheaths

Various pathologic conditions, in addition to fractures (Clark et al. 1995) and stress fractures (Shelbourne et al., 1988) may cause an increase in joint fluid in the ankle joint and tendon sheaths (Bluestone, 1988). The amount of tendon and joint fluid varies even among asymptomatic individuals (Schweitzer et al., 1994), and a small amount of joint fluid (Resnick and and Niwayama, 1989; Schweitzer et al., 1994) or tendon fluid (Van Holsbeeck and Introcaso, 1991; Schweitzer et al., 1994) has been considered a normal finding in several anatomic areas. When the amount of joint fluid in the talocrural joint is increased, most of it accumulates in the anterior and posterior synovial recesses (Schweitzer et al., 1994). Distension of the joint capsule, with added anterior and posterior extensions exceeding 13 mm in a lateral projection radiograph of the ankle, has a positive predictive value of 82% for occult ankle fracture (Clark et al., 1995). When different imaging modalities are compared, the most sensitive method for detection of ankle joint fluid is MRI, followed by ultrasound. The least sensitive are radiographs (Jacobson et al., 1998).

Schweitzer et al. (1998) reported increased joint fluid in 77% of the posterior recesses and in 60% of the anterior recesses of the talocrural joints, and in 72% of the subtalar joints as well in normal ankles as in ankles with different pathologic conditions. In another study with ultrasound, joint fluid was found in 33% of patients in the anterior recess but in 0% in the posterior recess of the talocrural joint (Nazarian et al., 1995). In recreational runners, the amount of fluid in the knee joint was increased in 5 of 10 runners (Kursunoglu-Brahme et al., 1990) after 30 minutes of jogging. Another study found that the amount of joint fluid in the knees of trained long-distance runners had not increased after a contest (Shellock and Mink, 1991). This same study, however, showed a slightly increased amount of joint fluid in 2 of 5 runners even before the contest.

In many asymptomatic individuals, an increased amount of fluid has been found in the tendon sheaths of the flexor tendons both with MRI (Schweitzer et al., 1994) and with ultrasound (Nazarian et al., 1995). Schweitzer found fluid in the tendon sheath of the flexor hallucis longus in 31% of subjects. Fluid in the posterior tibial tendon sheath was found in 22% of cases, around the flexor digitorum longus in 24% and around the peroneal tendons in 16-17%. The reason for the increased amount of joint and tendon sheath fluid in asymptomatic individuals is unclear. The effect of training or running on the amount of fluid in the ankle joints or ankle tendons has not been investigated.
4.2.3. **Muscle injuries**

Acute indirect muscle trauma caused by excessive tension can be divided into three groups according to the severity of the lesion (De Smet, 1990; Weatherall and Crues, 1995). In a grade 1 strain, there is minor tearing of the muscle fibers. On T2-weighted- and STIR-sequences, the interstitial hemorrhage, inflammation and edema are bright (Fleckenstein et al., 1989; Tuite and DeSmet, 1994; Kneeland, 1997). In a grade 2 strain or partial tear T2 and STIR sequences show a clearly increased signal. In the muscle, a disruption that does not include all the individual fibers is detected. The areas of high signal intensity on T2-weighted images are due to hemorrhage and edema (Kneeland, 1997). Grade 3 is a complete rupture. Acutely, the signal intensity is clearly increased at the rupture site on T2 and STIR images and a discontinuity of muscle fibers can be seen, often even a retraction of the muscle involved (Kneeland, 1997). The accompanying hematoma is usually larger than in partial ruptures. The signal behavior on MRI reflects the age of the hemorrhage (Ehman and Berquist, 1986; Kneeland, 1997; Dooms et al., 1985; Swensen et al., 1985; Bush, 2000). Direct trauma causes a muscle contusion or a rupture due to compression.

Immediately after exercise, the signal intensities of individual muscles alter (Fleckenstein et al., 1988; Mattila et al., 1993). Fleckenstein found changes in signal intensities in T1, T2 and proton-weighted images (1988). The signal alteration is mainly explained by a change in the extracellular water content of the muscles exercised and it is not dependent on perfusion. Ten minutes after the exercise, the signal intensity of an exercised muscle still remains increased (Fleckenstein et al., 1988) and the signal intensity diminishes with the time elapsed after the exercise (Mattila et al., 1993).

Pain in unaccustomed skeletal muscles after muscular exertion is defined as delayed-onset muscle soreness or DOMS (Fleckenstein et al., 1989; Shellock et al., 1991). The pain starts some hours after the exercise and is worst 1-2 days after the exercise. The levels of serum creatine kinase (CK), reflecting muscle damage, increases, reaching a maximum 24 hours after exertion (Schwane et al., 1983). Signal intensities in MRI correlate with an increase in this enzyme (Evans et al., 1998). Pure eccentric muscle contraction results in more profound alterations (Schwane et al., 1983). A typical MRI change is an increase signal intensity in T2 and STIR sequences (Fleckenstein et al., 1989; Shellock et al., 1991).

In chronic exertional compartment syndrome, the intramuscular pressure within a fascial compartment is increased. This has been described in all four compartments of the leg. It is most common in the anterior and deep posterior compartments (Jones and James, 1987). Occasional cases have also been detected in other locations, such as the quadriceps femoris.
muscle (Orava et al., 1998). The diagnosis may be performed by measurement of compartment pressure (Pedowitz et al., 1990). In chronic exertional overuse syndromes, the intracompartmental pressure is higher than the normal 0 to 8 mm Hg. On MRI, an increased signal intensity can be detected on T2 and STIR sequences (Steinbach et al., 1997).
The general aims of the study were to investigate the usefulness of MRI in certain orthopedic trauma and to compare the findings with established radiographic methods and with the results of the clinical examination. In particular, the goals of the experiments were:

1. To investigate the ability of MRI to detect fractures of the adult wrist not apparent on radiographs.

2. To compare MRI with plain radiographs in the diagnosis and grading of children’s acute physeal fractures.

3. To compare MRI with conventional tomography in the verifying and grading of children’s posttraumatic growth arrest.

4. To demonstrate radiologically the breakdown of the biodegradable screws used in fracture fixation.

5. To evaluate the usefulness of MRI in chronic rupture of the UCL of the thumb.

6. To investigate heavy physical strain as a source of abnormal MRI findings in asymptomatic individuals.
6. MATERIALS AND METHODS

6.1. Patients and control subjects

The material comprises different groups of subjects in the different studies (I-VI). Altogether 192 individuals were studied.

Study I

A total of 67 patients; (38 females, 29 males), mean age 44.6 years (range 15-80), with an acute wrist trauma volunteered for the study. Patients with and without radiographically confirmed fractures were studied by using MRI.

Study II

Sixty children with a suspected physeal fracture or a torn lateral ligament in the ankle, were studied prospectively over a 3-year period (1996-1998). Children under 7 years old were excluded, as were children with prior severe injuries, malformations, or systemic diseases. The examination on admission included manual testing of the stability of the ligaments and a review of the plain radiographs by the surgeon.

The patients were allocated to two groups: The ligament injury group, considered to form the control group, comprised of 29 patients (aged 8 years 0 months to 16 years 0 month, mean 13 years 2 months, 16 boys, 13 girls). They all had a clinical diagnosis of a total lateral ligament tear due to anterior and / or lateral instability and radiographs without a fracture (assessed by the surgeon on call). The children in the ligament group had either operative or conservative treatment. The fracture group consisted of 31 children (aged 8 years 2 months to 15 years 8 months, mean 12 years 6 months, 18 boys, 13 girls) with a recent physeal fracture of the distal tibia or distal fibula.
Study III

a:
Names of patients with a clinical suspicion of growth arrest, who had been examined using plain radiographs, x-ray tomography, and MRI, were collected from the datafiles at the children’s hospital. Eleven children (9 boys, 2 girls, mean age 9 years 11 months), with suspected physeal growth arrest in a total of 13 epiphyses had been examined using all three modalities. The etiology to the growth arrest was a prior trauma in eight patients, osteomyelitis in two, and an operated equinovarus in one. In five of the patients, the growth arrest was later verified operatively.

b:
In the second part of the study 36 children (from study II), without growth arrest clinically, on radiographs or in MRI, who had had an ankle fracture one year earlier, were included in addition to 4 patients with radiologically proven growth arrest in the ankle.

Study IV

Six patients (3 males, 3 females, mean age 40 years (range 14-66)) with displaced malleolar fractures operatively treated with biodegradable SR-PLLA screws were examined 1-2 months postoperatively and after 1-2 years.

A total of 12 screws were applied, 3 medial and 9 lateral, of which 6 were transfixation screws for syndesmotic fixation. The screws had a 3.2 mm inner diameter, and 4.5 mm outer diameter, lengths between 30 to 50 mm and a molecular weight of 50 000 daltons (Bioscience Ltd., Tampere, Finland). To avoid ferromagnetic artefacts in MRI, the drill used for fixation had a vitallium cutting edge. Besides conventional x-ray examinations, the patients were also examined with MRI 1-2 months postoperatively and after 1-2 years. Two patients were also examined once between these two examinations.

Study V

Ten patients (male, 2 female, mean age 41.3 years (range 29-55)) with symptomatic, clinically diagnosed instability of the first metacarpophalangeal joint of over 40-45 degrees were imaged with MRI before the planned operation. In 9 patients, the rupture had occurred more than 1 year before the operation, in one 10 weeks before the operation. The control group consisted of 10 sex- and age-matched (+- 4 years, mean age 41.8 years) volunteers with no history of trauma or symptoms of instability in the thumb.
All 10 patients were operatively treated by the same experienced senior hand surgeon using a specific ligament reconstruction technique, i.e. a ligamentary graft originating from either the musculus palmaris longus or the musculus plantaris. Intraoperatively, the ligament rupture was classified as either a Stener or a non-Stener lesion, or as equivocal.

Study VI

Before an international marathon contest in Helsinki one hundred randomly selected marathon runners were asked to participate in the study. Nineteen healthy, experienced (mean number of 60 previous full length marathons (range 0-224 runs)), non-professional marathon runners (10 males, 9 females, mean age 45.0 years (range 27-58)) were imaged by MRI within 3 hours after finishing the race.

The control group consisted of 19 healthy volunteers (mean age 45.9 years; 10 were males and 9 females). None of the controls were present marathon runners, but they had a regular interest in leisure time physical exercise, mainly jogging and orienteering. In most of the controls, the average running distance was between 15 and 30 kilometers a week. Prior to the MRI they had had no physical activity differing from their normal level of training and they had no history of previous injuries or recent symptoms of overuse of the ankle or foot. All these volunteers were healthy, and they had no history of previous severe injuries or recent overuse symptoms of the ankle or foot.

6.2. Methods

6.2.1. MRI methods

Study I

Conventional radiographs were obtained in at least two projections, with additional specific projections if needed. MR examinations were performed with a 1.5T magnet (Siemens Vision). In the first 6 patients, a knee coil was used, in the remaining 61 a flexible coil. Sixty-two patients were placed prone with the affected arm extended above the head, 5 patients supine with the arm either above or beside the body. In 90% of patients the interval
between the radiograph and MRI was less than 1 week. The sequences used are shown in Appendix 1.

**Study II**

Radiographs on admission were obtained in AP- and lateral projections, with oblique projections or radiographs of the opposite ankle if needed.

MR examinations were performed with a 1.5T magnet (Siemens Vision), using a knee coil. Of the 29 patients in the ligament group 24, and of the 31 patients in the fracture group 26, were examined within 1 week of the trauma, all those remaining within 2 weeks of the trauma, all prior to any operative treatment. MRI:s were performed without knowledge of the type of ankle trauma. The sequences used are shown in Appendix 2.

**Study III**

*a:*
This was a retrospective investigation. Good quality conventional radiographs were available in AP and lateral projections. In all but one patient, conventional tomography had been performed in both the coronal and sagittal planes. MR examinations were made with a 1.5T magnet (Siemens Vision) in 10 patients, and with a 0.1 T magnet (Picker) in 1. In all patients, T1SE images in the sagittal and coronal planes, and frequently also T2SE images with or without fat suppression in the sagittal or coronal direction were available. There was some variability in the imaging parameters obtained. The sequences for individual patients are shown in Appendix 3.

*b:*
The T1SE MR images, in the sagittal and coronal planes were used for the analysis in all patients.

**Study IV**

MR examinations were performed with a 1.5T high field magnet (Siemens Vision) by using a knee coil, with the patient positioned in the supine position. The sequences used are shown in Appendix 4.

**Study V**

Conventional radiographs were obtained in all patients before MRI. All MR examinations were performed with 1.5T magnets (Siemens Vision) using a special commercially
available finger coil that enabled a field of view (FOV) of between 50 and 60 mm. The
patients and controls were imaged with the same sequences and parameters. In order to get
the best signal to noise ratio, both patients and controls were imaged prone with the
affected arm extended above the head. Several scout images were taken before the first
axial sequences. The coronal sequences were obtained parallel to the sesamoid bones,
placed in the axial images; the sagittal sequence was perpendicular to the sesamoids. Slice
thickness varied between 1.5 and 3 mm. The sequences used are shown in Appendix 5.

Study VI
In the study group, MRI examinations were obtained within three hours of completing the
race, with either of two 1.5T magnets. The control group had no preceding physical
exercise prior to the examination. Examinations were made and using a 1.5T high-field
magnet (Siemens Vision) using either a head or a knee coil. The sequences used are shown
in Appendix 6.

6.2.2. Image interpretation

Three senior radiologists familiar with musculoskeletal MRI separately evaluated all
radiographs and MR images, blinded to all patient data and to the results of other
radiographic examinations, as well as to the other analysts’ opinions. A predefined
question form was used in all examinations (Appendices 8-13). If all three radiologists
agreed, their diagnosis was accepted; a consensus diagnosis was the opinion of two
radiologists. If the opinions of the radiologists differed, a consensus opinion was adopted.

Study I
If a distinct fracture line crossed both the cortex and the trabeculae on MR images, the bone
was classified as broken. If there appeared merely a diffuse alteration in signal intensity
without any fracture-line, it was defined as bruised. The findings were classified as
fracture (=3), inconclusive (=2), or no fracture (=1). A bone was considered to be
fractured (=3) or unbroken (=1) only if all three radiologists agreed, and as possibly
fractured or inconclusive (=2), if their opinions did not match. We also compared the
consensus diagnosis on MRI with the primary diagnosis, based on both the reading of the
plain radiographs and the examination of the clinical status by the surgeon on call.
Study II

All radiographs and MRI studies were blindly analyzed by three senior radiologists, all with experience of musculoskeletal MRI. In the analysis of the imaging data, the two groups were mixed. Control MR images and radiographs of the same patients were mixed with the primary examinations during the analysis.

In the analysis of MR images, a diagnosis of fracture was established if there was a distinct fracture line crossing both the cortex and the trabeculae on MRI. A diagnosis of bone bruise was established by a diffuse low signal intensity in the marrow on T1 and increased signal on T2 without any fracture line. A fracture was considered as extending along the growth cartilage if the physis was widened or had an increased signal intensity on T2FS images. Physeal fractures on the radiographs and MRI scans were split into five groups according to the Salter-Harris classification (Salter and Harris, 1963) originally described for plain radiograph reviews. Cortical avulsions and fractures of the fibular diaphysis were noted separately. Fibular diaphyseal fractures were included because of their association with certain types of ankle fractures and ligamental injuries (Weber, 1972). If the three radiologists disagreed, a consensus diagnosis was later adopted. MRI was considered the gold standard for the analyses, except in the case of small avulsion fractures.

The clinical relevance of differences in diagnosis was estimated by a pediatric orthopedist. A difference was considered clinically relevant if it would lead to a difference in the treatment.

Study III

The images were analyzed retrospectively and blindly by three senior radiologists without any knowledge of the patient data, or of the results of previous or other radiographic investigations, or of each others’ opinions. The studies were reviewed for the presence and extent of an osseous growth arrest. The classification system used in the three modalities were 1 = no growth arrest, 2 = growth arrest occupying under 30% of the growth plate area, 3 = growth arrest occupying 30-50% of the growth plate area, 4 = growth arrest occupying over 50% of the growth plate area. The size grouping was based on size limits that are important in the treatment of bridges (Williamson and Staheli, 1990). The presence of pathologic growth arrest lines nonparallel to the physis were also recorded. If discrepancies occurred between the observers, the reported values reflected the consensus
values. Later follow-up information and control radiographs of the patients were available, but were not used in the image estimation.

b:
The MR images were analyzed blindly by three senior radiologists without any knowledge of the patient data, or of the results of previous or other radiographic investigations, or of each others’ opinions. The presence of growth arrest in the patients was recorded.

Study IV
The radiologists estimated not only the healing of the fracture, but also the breakdown of the screws, the migration of the screws into the subcutis, and whether there was an inflammatory reaction around the screws.

Study V
The ulnar collateral ligament was classified as nonruptured if it was continuous and if the thickness was normal. The ligament was considered ruptured if it was discontinuous or if no normal ligament was detected. A ruptured ligament was considered to be a Stener lesion if the ligament lay superficial to the adductor aponeurosis or if the proximal part appeared thickened and folded back on itself. In every individual MRI examination, each radiologist evaluated the most informative sequence for the evaluation of the UCL.

Study VI
Alterations in bone and muscle, fluid in joints and tendon sheaths, the Achilles tendon and the retrocalcaneal bursa were all graded using a 3-graded scale, as shown in Appendix VII. The tendon sheaths primarily estimated were: the tibialis posterior, the flexor hallucis longus, the flexor digitorum longus, the peroneal, the tibialis anterior, and other extensor. The amounts of fluid in the talocrural, talocalcaneal, talotarsal (between the talus, the navicular and cuneiform bones), calcaneocuboidal and tarsometatarsal joints were estimated as normal, slightly elevated, or clearly pathological.

6.2.3. Statistical methods
Rate of agreement was tested using different kappa statistics (Abramson and Gahlinger, 1999, Norman & Streiner, 1994, Altman, 1991). Limits for kappa evaluations: >0.81 very good, 0.61-0.80 good, 0.41-0.6 moderate, less than 0.41 fair. Disagreement between
ratings was tested using McNemar’s test and the Wilcoxon rank sum test (Conover, 1980). P values <0.05 were considered significant.

**Study I**
Disparities between the radiograph and the MRI were compared, using the modified McNemar’s test. We compared the inter-observer agreement on both the MRI readings and the radiograph by using quadratic weighted kappa.

**Study II**
Rates of agreement for consensus fracture diagnosis and for radiographs compared with MR images, were calculated using prevalence- and bias-adjusted kappa (PABAK), separately for the distal tibia and the distal fibula. Inter-observer agreement for fracture diagnosis on radiographs and MRI among the three observers was calculated using average kappa. For the individual radiologists intra-observer agreement between fracture diagnoses on radiographs as compared with MRI was calculated using PABAK, separately for the distal tibia and distal fibula. Sensitivity and specificity of fracture diagnose were calculated separately for the distal tibia and the distal fibula, using MRI as the gold standard.

**Study III**
*a:* The inter-observer agreement for each imaging method was computed by using average weighted kappa, because of the small number of observations. *b:* No statistical analysis was made.

**Study IV and Study V**
Because of the small amount of material, no statistical analysis was made.

**Study VI**
McNemar’s symmetry test with the small sample formula was used to study deviating observations between the index and control groups in findings with a dichotomous outcome (i.e. evaluation of the Achilles tendon and muscle edema). Data between groups with ordinal scale outcome was tested with the Wilcoxon signed rank sum test. The joint fluid and tendon sheath fluid were both treated as sum scores in each individual, where the ordinal scale findings in specified locations were added. The inter-observer agreement on the MRI readings was tested using quadratic weighted kappa.
7. RESULTS

7.1. Differences between MRI and x-ray in acute wrist trauma

The consensus of the three analysts’ opinions and the localization of the fractures are depicted in Table 1. With the analysis methods used one third of the fractures (13 of 37) observed on MRI were missed on the radiographs: six of these involved the scaphoid and/or the capitate, 7 the radius, and 1 the triquetrum. Of the 13 fractures which could be detected on radiographs 9 were also classified as fractured on MRI. The undiagnosed fractures were located in the triquetrum.

Radiographs
According to the radiograph, 13 patients (19%) had a fracture.

MRI
According to MRI, 37 patients (55%) had a fracture and 10 patients (15%) had no bone trauma at all, whereas in 20 patients (30%) the consensus diagnosis was inconclusive. The inconclusive group was due to a difference in classification of the severity of the trauma in 11 of these 20 fractures: some radiologists considered the bone damage a fracture, others merely a bruise. In addition to these bruises, 12 patients also had bruises in other bones.

Diagnosis by the surgeon
The surgeon on call diagnosed 16 fractures (24% of patients), and on MRI, 37 fractures (55% of patients) were detected. In 11 patients, a fracture was suspected primarily on x-rays and later control radiographs were therefore programmed. Five of these patients had a fracture on MRI, although none in the scaphoid which as suspected primarily in 3 of these patients. Four of the fractures were situated in the distal radius and 1 in the triquetrum.
### Table 1: Number and localization of fractures, radiologists’ diagnosis

<table>
<thead>
<tr>
<th>group</th>
<th>%</th>
<th>number</th>
<th>localisation</th>
<th>number</th>
</tr>
</thead>
<tbody>
<tr>
<td>x-ray- / MRI-</td>
<td>13.4</td>
<td>9</td>
<td>radius</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>scaphoid</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>triquetrum</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>lunatum</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ulna</td>
<td>1</td>
</tr>
<tr>
<td>x-ray- / MRI?</td>
<td>22.4</td>
<td>15</td>
<td>radius</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>scaphoid</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>capitate</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>scaphoid+capitate</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>triquetrum</td>
<td>1</td>
</tr>
<tr>
<td>x-ray- / MRI+</td>
<td>19.4</td>
<td>13</td>
<td>radius</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>triquetrum</td>
<td>1</td>
</tr>
<tr>
<td>x-ray? / MRI-</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>x-ray? / MRI?</td>
<td>3.0</td>
<td>2</td>
<td>radius</td>
<td>2</td>
</tr>
<tr>
<td>x-ray? / MRI+</td>
<td>22.3</td>
<td>15</td>
<td>radius</td>
<td>15</td>
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<td>1</td>
</tr>
<tr>
<td>x-ray+ / MRI?</td>
<td>4.5</td>
<td>3</td>
<td>triquetrum</td>
<td>3</td>
</tr>
<tr>
<td>x-ray+ / MRI+</td>
<td>13.4</td>
<td>9</td>
<td>radius</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>triquetrum</td>
<td>1</td>
</tr>
</tbody>
</table>

- x-ray- / MRI- consensus diagnosis of no fracture in x-ray / MRI
- x-ray? / MRI? opinions differ; inconclusive in x-ray / MRI
- x-ray+ / MRI+ consensus diagnosis of fracture in x-ray / MRI

### Statistical results

The modified McNemar’s test indicated significant differences (p=0.0000) in diagnosis between radiographs and MR images. The weighted kappa between the three observers in the evaluation of radiographs was 0.66. For the MR analysis, the interobserver kappa was 0.59.
7.2. *Differences between MRI and x-ray in children’s ankle trauma*

*Sensitivity and specificity of plain radiographs and differences in fracture classification between MRI and plain radiographs*

**Distal tibia**

Two of five fractures diagnosed as SH2 on radiographs had an extension through the epiphysis detected on MRI, converting them into a fracture of SH4 type of fracture. Two of six fractures diagnosed as SH3 on radiographs were found to extend even into the metaphyseal area on MRI, thus converting these fractures also to fractures of SH4 type. One false-positive and one false-negative fracture were found on radiographs in the tibia.

*Figure 4:*

**X-ray and MRI classification compared, distal tibia**

<table>
<thead>
<tr>
<th>MRI:</th>
</tr>
</thead>
<tbody>
<tr>
<td>SH 4</td>
</tr>
<tr>
<td>SH 3</td>
</tr>
<tr>
<td>SH 2</td>
</tr>
<tr>
<td>SH 1</td>
</tr>
<tr>
<td>avulsion</td>
</tr>
<tr>
<td>normal</td>
</tr>
</tbody>
</table>

Fracture classification on X-ray
Distal fibula

In 7 of the SH1 fractures diagnosed on radiographs, MRI indicated ligament disruption alone and no fracture. On MRI, two diaphyseal fractures were not demonstrated because of the small field of view (FOV). On the radiographs, 1 avulsion, 2 SH2 and 1 SH3 fracture were diagnosed as normal. Eleven false-positive and 4 false-negative fractures were found on radiographs of the fibula.

Figure 5:
The incidence of bone bruises

Of the 60 patients, 22 (36.7%) had bone bruises, of which 82.6% occurred in patients with a ligament disruption and without any fracture on MRI. Of the bone bruises, 11 occurred in the talus, 7 in the distal tibia, 5 in the distal fibula. One patient had bone bruises both in the distal tibia and the talus. All the bone bruises in the distal tibia and fibula and 7/11 of the bone bruises in the talus were seen in association with ligament injuries.

Clinical relevance

The false negative fractures on the radiographs consisted of one cortical avulsion in the medial and one cortical avulsion in the lateral malleolus. In the distal fibula, 1 SH3 and 2 SH2 fractures were also missed. All these patients were diagnosed as having ligament disruptions. No complex ankle fractures were missed on the radiographs. Seven false positive SH1 fractures were diagnosed in the distal fibula.

Statistical results

When comparing consensus diagnosis of fracture on radiographs and on MRI in the tibia, prevalence- and bias-adjusted kappa was 0.93 and percentage agreement 97%. Inter-observer agreement for tibial radiographs was 0.78, and for tibial MRI 0.72. Intra-observer kappa values for the 3 individual radiologists when comparing fracture diagnoses on radiographs with MRIs of the tibia were 0.73, 0.77 and 0.70.

When comparing consensus diagnosis of fractures on radiographs and MRI in the fibula, the prevalence- and bias-adjusted kappa was 0.50 and the percentage agreement 75%. Inter-observer agreement for the fibular radiographs was 0.484, and for the fibular MRI 0.531. Intra-observer kappa values for the 3 individual radiologists when comparing fracture diagnoses on radiographs with MRI in the fibula were 0.30, 0.50, and 0.67.

Altogether, when the distal tibia and distal fibula were estimated separately, a difference in classification was found in 21% The overall sensitivity of fracture diagnoses on radiographs as compared with MRI was 23/28=82%, and the specificity was 80/92=87%.
7.3. MRI compared with plain tomography in growth arrest

a:
In the 13 epiphyses, the bone bridge was considered smaller on MRI than on X-ray tomography in 5 cases, equal in 7, and larger only in one (the only one in which the area of growth arrest was estimated to be over 50% of the area of the growth plate).

Diffuse bone marrow edema in the talus, calcaneus and tarsal bones was seen in two patients on MRI. Osteochondritis dissecans was seen in the medial femoral condyle on MRI and only suspected on x-ray tomography in 1 patient. Pathologic, tilted growth arrest lines, indicating abnormalities, were found in two patients and equally were seen both in x-ray tomographies and in MRI. Growth arrest lines were most clearly visible on T1-weighted spin echo sequences: the location of the growth arrest determined the optimal sequence direction.

b:
All the radiologists were able to find the four bone bridges from the images of 40 ankles on MRI.

Statistical results
The inter-observer agreement (weighted kappa) was 0.84 for MRI, 0.76 for X-ray tomography, and 0.60 for radiographs.

7.4. MRI in biodegradable osteosynthesis

In all the sequences, the biodegradable osteosynthetic screws were clearly seen on the MR images because of their lower signal compared with bone marrow. In the primary postoperative MR examination, all the screws were unbroken. Of 6 transfixation screws in the syndesmosis, 5 had broken at the last examination, as was one screw, used for fixation of a SH4 tibial fracture in a 14-year-old boy. Breaking of screws was easy to detect: an unambiguous breakage of the screw shaft.
In three patients, some edema appeared postoperatively in the bone marrow, immediately around the drill hole, but at the final examination only one showed edema in the bone marrow. This was the 14-year-old boy with the SH4 fracture who had edema around the growth cartilage as a sign of epiphyseal damage. At the final MR examination of one patient, the broken outer end of one screw had migrated into the subcutis, causing edema.

Statistical results
Because of the small number of patients no statistical analysis was performed.

7.5. MRI in chronic ligament rupture of the thumb

The consensus diagnosis of an UCL rupture was accurate in all 10 patients, and all controls were classified as having no UCL rupture. In three patients, because of excessive scarring, it was not possible, intraoperatively, to classify the rupture as a Stener or non-Stener lesion. In 5 of the 7 patients with a surgically clearly defined Stener or non-Stener lesion, the consensus diagnosis was the same as the operative diagnosis. (Of the UCL-ruptures 4 were surgically classified as a non-Stener type, three as a Stener type, one of which also had an associated bone avulsion.)

Coronal sequences were regarded as the most informative sequences both in patients and in controls. T2TSE was estimated to be the most useful single sequence (about half of the radiologists’ individual opinions). T1SE with fat suppression was considered the second most useful sequence (about 20% of opinions).

Statistical results
Because of the small number of patients no statistical analysis was performed.
### 7.6. MRI findings in asymptomatic, physically active individuals

Table 2: MR findings in marathon runners and controls:

<table>
<thead>
<tr>
<th></th>
<th>GRADE 0</th>
<th>%</th>
<th>GRADE 1</th>
<th>%</th>
<th>GRADE 2</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>bone marrow</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marathon runners</td>
<td>16</td>
<td>84.2</td>
<td>3</td>
<td>15.7</td>
<td>1</td>
<td>5.3</td>
</tr>
<tr>
<td>controls</td>
<td>16</td>
<td>84.2</td>
<td>3</td>
<td>15.7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>muscle</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marathon runners</td>
<td>18</td>
<td>94.7</td>
<td>1</td>
<td>5.3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>controls</td>
<td>19</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>total joint fluid</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marathon runners total</td>
<td>25</td>
<td>65.8</td>
<td>13</td>
<td>34.2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>controls total</td>
<td>31</td>
<td>81.6</td>
<td>6</td>
<td>15.8</td>
<td>1</td>
<td>2.6</td>
</tr>
<tr>
<td><strong>total tendon sheaths</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marathon runners total</td>
<td>59</td>
<td>77.6</td>
<td>10</td>
<td>13.2</td>
<td>7</td>
<td>9.2</td>
</tr>
<tr>
<td>controls total</td>
<td>59</td>
<td>77.6</td>
<td>13</td>
<td>17.1</td>
<td>4</td>
<td>5.3</td>
</tr>
<tr>
<td><strong>Achilles tendon</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marathon runners</td>
<td>14</td>
<td>73.7</td>
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<td>26.3</td>
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</tr>
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<td>controls</td>
<td>7</td>
<td>36.8</td>
<td>12</td>
<td>63.2</td>
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</tr>
<tr>
<td><strong>retrocalcaneal bursa</strong></td>
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</tr>
<tr>
<td>Marathon runners</td>
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<td>31.6</td>
<td>13</td>
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</tr>
<tr>
<td>controls</td>
<td>8</td>
<td>42.1</td>
<td>10</td>
<td>52.6</td>
<td>1</td>
<td>5.3</td>
</tr>
</tbody>
</table>

In row 1, the same patient had both grade 1 and grade 2 edema in different bones.

**Statistical results**

The only statistically significant difference (p=0.016) between the groups was in the occurrence of small punctuate hyperintensities. The inter-observer kappa was 0.59 for bone marrow edema, 0.18 for muscle alterations, 0.46 for the amount of joint fluid, 0.56 for the amount tendon sheath fluid, 0.57 for signal alterations in the Achilles tendon, and 0.44 for fluid amount in the retrocalcaneal bursa.
8.DISCUSSION

8.1.Bone trauma

The radiologic analysis in studies I, II, and II differed from the optimal situation in everyday work because the radiologists were unaware of the clinical findings in the patients, a fact that may influence the diagnostic performance.

8.1.1. Fractures, occult fractures, and bone bruises

If a bone trauma is suspected, plain radiographs are obtained either to confirm or to rule out a fracture. On MRI, the posttraumatic findings in bone could be divided into five categories: no traumatic alterations, bone bruises, occult fractures, fractures, and stress reactions in the bone (for continuing repetitive stress may lead to stress fractures). Three of these groups are not detected at all on radiographs.

Microfractures of the subchondral plate may be associated with contusion of the articular cartilage even though the chondral surface itself is intact (Donohue et al., 1983). Cartilage dimpling has been reported to occur when arthroscopically probing and applying pressure on chondral areas overlying geographic bone bruises (Coen et al., 1996). Depending on the type of bone bruise, 27% or 70% of subchondral bone bruises showed chondral lesions at arthroscopy (Lynch et al., 1989). Subchondral bone bruises may lead later to osteoarthritis (Vellet and al., 1991; Lahm et al., 1998). In patients with an initially intact cartilage, osteochondral sequelae were noticed on MRI in association with geographic bone bruises in 67% of patients after 6-12 months (Vellet and al., 1991) but in none of the patients with reticular subchondral fractures.

Some authors claim that bone bruises under weight bearing articular surfaces should be noticed and weight bearing avoided to prevent later complications, such as osteonecrosis (Radin et al., 1973; Lynch et al., 1989). Within a relatively short follow up time of 3 months, bone bruises in the ankle did not affect clinical status, physical activity, or return to work (Alanen et al., 1998). According to a study of 47 bone bruises, all the bruises had
resolved at 6 weeks after the trauma (Graf et al., 1993) but even longer resorbtion times have been reported (Lynch et al., 1989).

Prior investigations using MRI for the assessment of acute wrist trauma have mainly focused on the verification or exclusion of scaphoideal fractures in patients who are clinically suspected to have a scaphoid fracture (Imaeda et al., 1992; Lepistö et al., 1995; Bretlau et al., 1999; Thorpe et al., 1996) but whose radiographs have been negative or inconclusive.

We investigated 67 patients with acute trauma of the wrist. One third of the fractures seen on MRI were not detected on radiographs by the radiologists. Even when the clinical findings of the patient had been taken into account in the diagnosis by the surgeon on call, 25% of fractures diagnosed on MRI escaped primary diagnosis. On the plain radiographs, these fractures were totally unsuspected because possible fractures, that were meant to be confirmed by later control radiographs, are not included in this number. In addition to fractures breaking the cortex bone bruises were common. The large group of fractures undiagnosed in plain radiographs can not be explained by unsatisfactory image quality or by misinterpretation.

A capitate fracture, considered uncommon (Rand et al., 1982), was diagnosed in three individuals with MRI; one of these also had a scaphoid fracture. Two additional scaphoid fractures were also found, and three possible fractures (where the radiologists’ opinions were not totally concordant). None of these fractures were seen on radiographs. If primarily untreated, fractures in these bones often lead to later complications such as non-union (Rand et al., 1982; Langhoff and Anderson, 1988). With MRI, we missed several triquetral fractures. One explanation for this is that the gradient sequences we applied for the sagittal plane were not optimal for detecting fractures. In association tests, a great number of ambiguous findings could lead to the false conclusion of good agreement between the methods. This was not true in our material, because the inconclusive groups were small.

In the setting of negative radiographs and a high clinical suspicion of a fracture, the patient is usually treated with a cast, splint or brace. The cost of the MRI should be compared with the expenses of splint treatment for 7 to 10 days, expenses for sick leave and for the costs of repeated examinations and radiographs. The patient selection process may, perhaps, have contributed to the high percentage of undiagnosed fractures: Patients seeking medical care for an acute wrist trauma at the emergency department at Tölö Hospital were asked to participate in an additional MRI study. Patients with and without a diagnosed fracture were given the opportunity to participate. We assume that patients with pronounced symptoms and negative radiographs are more interested in participating in the
study than those with less severe symptoms or those with radiographically proven fractures.

Both radiographs and MR images were analyzed by three senior musculoskeletal radiologists who had no clinical information about the patients. For 54 of the 67 patients (81%), the opinions of the three radiologists regarding the MR images were totally concordant. We did not report the findings in ligaments and other soft tissues, because those findings were not confirmed by other modalities or by surgery. The follow-up of the patients was often performed elsewhere and therefore the long-term outcome of the patients could not be systematically evaluated. The imaging protocol, involving the positioning of the patient, took about 1 hour. This may be impractical for routine use. For fracture screening, one STIR or T2FS sequence would be enough in most cases, accompanied by a T1SE sequence, if necessary. With this approach the total investigation time could be less than 15 minutes. Compared with the expenses of unnecessary casting and follow-up radiographs, this would also be reasonable economically.

8.1.2. Acute fractures in children

All the 60 children in our study had a clinical diagnosis of ankle injury, either a ligament disruption or a fracture. To avoid bias in the interpretations, the images in the two groups were intermingled and control MR images and radiographs of the same patients were mixed with the primary examinations during the analysis. In prior investigations, only patients with either a known or a suspected fracture were examined (Jaramillo et al., 1990a; Smith et al., 1994; Petit et al., 1996; Carey et al., 1998; Iwinska-Zelder et al., 1999).

The classification of physeal fractures on both MRI and plain radiographs was adapted from the classification of Salter-Harris (Salter and Harris, 1963), originally made for plain radiographs. The sequences selected are a compromise between bone and ligament imaging. In accordance with studies by White et al. (1994) and Carey et al. (1998), we found the T2-weighted sequences useful; the contrast between the osseous structures and the cartilage was good. When the signal from normal bone marrow fat was suppressed, contusions and fractures were highlighted. The T1-weighted sequences were obtained with a 512x256 matrix giving a good contrast between the anatomical details of the growth cartilage and bone marrow. The fractures were not subgrouped into juxtaepiphyseal, juxtametaphyseal or middle according to the localization in the physis, because we could not compare that data with any gold standard.

We did not include any 3D gradient echo sequence and reformatting, because we wanted to test time saving protocols suitable for routine screening of both ligaments and bones. At
high field strength, gradient echo sequences are insensitive to alterations in the bone marrow signal (Peterfy et al., 1994). For routine use, we recommend the following protocol depending on the localization of the suspected fracture: a T2FS and a T1SE sequence; one in the sagittal and the other in the coronal plane. An axial T2-weighted sequence is recommended to depict injuries to the lateral ankle ligaments.

Fracture detection and classification on radiographs in comparison with MRI

In the study by Jaramillo (1990a), 50% of fractures were classified as more severe on MRI than on radiographs, in contrast to Petit et al. (1996) who found a discrepancy in the classification of fractures between MR images and plain radiographs in only 1 of 29 fractures in the ankle. Jaramillo et al. also found MRI useful in showing fractures not seen on radiographs (1990a). In that study the time between the initial fracture and the MR varied between 4 days and 3 years. The fracture classification of Salter-Harris was changed in 6 of 26 fractures, which were situated in different locations. In prior studies dealing with physeal fractures of the ankle, only one false-positive fracture on radiographs compared to MR imaging (Iwinska-Zelder et al., 1999) was described. In our study the MRI was performed within 3 days after a radiographically proven fracture, and all patients were examined by MRI within 2 weeks, the majority within 1 week, after the trauma.

Marmor defined triplane fractures of the distal tibia: the fracture crosses the epiphysis, physis, and metaphysis in three orthogonal planes (Marmor, 1970). On frontal radiographs, this fracture looks like an SH3 fracture; on lateral radiographs it resembles an SH2 (Rogers and Poznanski, 1994) even if it actually is an SH4 type fracture. Furthermore, in a study of 36 physeal fractures in the distal tibia, the metaphyseal fragment in SH4 fractures was often missed on standard AP and lateral radiographs and the fracture was therefore incorrectly diagnosed as an SH3 fracture (Cass and Peterson, 1983).

In our study the radiologists suspected an SH1 type of fracture in 6 patients who, in MRI, were seen to have a ligament disruption. In acute ligament disruption, the soft tissue swelling may be extensive and clinical testing is affected by the pain. An extensive soft tissue swelling is a common finding also on x-rays. Distal fibular physeal fractures seem to be more difficult to diagnose on plain radiographs than are distal tibial fractures. No SH4 fractures were totally missed on radiographs, although, in some cases, the extent of the fracture was underestimated.

Fractures adjacent to the ankle may be missed if the FOV is too small. This is unlikely to occur in normal circumstances, when clinical information is available to guide the examinations. Discrepancies in fracture classification between radiographs and MR images
in our study were commonly caused by triplane SH4 fractures, which were initially diagnosed on as either SH2 or SH3. On radiographs, a fissure-like extension of the fracture into either the epiphysis or metaphysis may be missed.

In this study, bone avulsions were graded as fractures. Some of these fractures were missed either on radiographs or on MRI. On MRI, the thin cortical avulsion may be graded as a ligament avulsion because of the low signal intensity of the cortical fragment on all imaging sequences. MRI, although used as the gold standard in our study, proved unsatisfactory for the detection of thin cortical avulsions.

**Bone bruises in the pediatric ankle**

In the adult population, bone bruises in the ankle are reported not to affect the clinical outcome (Zanetti et al., 1997, Alanen et al., 1998). Bone marrow abnormalities in the ankle have been proposed to represent true nondisplaced fractures (Schweitzer, 1993). Bone marrow edema, appearing either as multiple discrete foci or as larger confluent areas, was detected in 63% of symptomatic and 57% of asymptomatic children with no lower limb symptoms for half a year (Pal et al., 1999). Some patients in our study showed several small punctate hyperintensities, too. As these occasional, sharply circumscribed hyperintensities were situated deep in an otherwise healthy-looking bone, we neglected them as unrelated to the present trauma. The bone bruises in our study were situated in the vicinity of chondrous surfaces. The time reported for bone bruises to resolve varies: In one study of 47 bone bruises, all of them had resolved at 6 weeks after the trauma (Graf et al., 1993) but, according to Eustace (Eustace, 1999), most bone bruises begin to resolve at 3 months and disappear within a year. It is plausible to presume that the bone bruises in our study had not resolved before the MR imaging as all examinations in our study were performed within 2 weeks, and most even within 1 week.

Trabecular microfractures, edema and bleeding were detected histologically in the areas of bone bruises in the knee on MRI (Rangger et al., 1998). Subchondral damage, even with primarily intact cartilage, is believed to be associated with later osteoarthritis (Lahm et al., 1998; Vener and al., 1992; Vellet and al., 1991). In a study of 18 children and adolescents with osteochondritis dissecans in the talus, previous traumatic incidents were recorded in 63.1% (Higuera et al., 1998). An association between subchondral bone bruises and later osteochondritis dissecans in children has not, to our knowledge, hitherto been shown.

Bone bruises in the pediatric ankle have not been previously investigated by MRI. Edema around a fracture is common and was not classified as a separate edema. This may explain the low incidence of bone bruises in the distal tibia and fibula in association with
fractures. However, no case of edema in the lateral malleolus was found in cases of medial malleolar fractures and vice versa. Of 11 bone bruises in the talus, only 36% occurred in association with fractures. Half of the patients without any fracture on MRI had bone bruises. In adults, Nishimura et al. (1996) noted contusions associated with lateral ligament injuries in the ankle in 40% of patients.

**Clinical relevance**

Physeal fractures are primarily treated nonoperatively. In cases with a clinically significant dislocation, a closed reduction is undertaken. An operation is undertaken only if a satisfactory result is not achieved with conservative treatment. In cases of extensive physeal damage, the follow-up is important. The treatment of the fracture patients in our study was based on radiographs, as MR images were obtained a few days later in most patients. However, there is no evidence in this study to indicate that MRI significantly altered the primary treatment or prognosis, based on plain radiography, in any case. However, an overdiagnosis of fractures on radiographs may lead to unnecessary bracing in cases where an air ankle brace or other supporting device would suffice.

No SH5 compression injuries were detected in our patients. Neither have any SH5 fractures been described in other studies (Carey et al., 1998; Iwinska-Zelder et al., 1999; Jaramillo et al., 1990a; Petit et al., 1996; White et al., 1994; Smith et al., 1994). About 1% of physeal fractures are isolated SH5 compression injuries (Rogers, 1970; Mizuta et al., 1987), but SH5 injuries may exist in combination with other types of fractures. Although SH5 injuries are not detected on ordinary radiographs, they may lead to growth disturbances. As the physis on T1 and T2FS sequences has a signal intensity similar to that of a fresh contusion, the detection of SH5 injuries may be difficult in cases of nondisplaced fractures.

**8.1.3. Growth arrest in children**

When an osseous bridge developing through the physis becomes large enough, growth is disturbed. This may result in angular and length abnormalities. The assessment of prognosis and the indications for operative treatment depend on the size and location of the growth arrest (Peterson, 1984; Peterson, 1993). Williamson and Staheli (1990) found an inverse correlation between bridge size and the results of resection. Conventional tomograms have been the primary method for confirming a suspected growth arrest in this country. However, MRI is becoming increasingly available and tomograms are being
replaced by either CT or MRI, although there have been no studies comparing these methods for assessing growth arrest.

On account of the radiation load, it is not ethically possible to arrange a prospective investigation comparing plain x-ray tomography, CT, and MRI when only a small percentage (Mizuta et al., 1987) of the children later develop growth arrest. We retrospectively investigated 13 affected epiphyses in 11 children with both plain-film tomography and MRI. The MR images and tomograms in these children had been performed because of suspected growth arrest in plain radiographs. We used a time limit of 70 days between the MRI and x-ray tomography in order to make the findings comparable; however, this strict time limit reduced the number of patients in our study. There was some variation in the sequences used in different patients which is explained by the fact that this was a retrospective study. In about half of the patients the osseous bridges were estimated as larger on x-ray tomography than on MRI. In our examination, the mature bone bridges were clearly seen on T1SE sequences, the high signal intensity of the bone marrow extending through the physis indicating an osseous bridge (Jaramillo et al., 1993). Of the 11 patients, five had indications for operative epiphyseodesolysis (Langenskiöld’s procedure) and the MRI finding of growth arrest was confirmed at surgery in all 5 patients.

In radiographs, estimation of growth arrest is possible only if the beam is parallel to the growth plate. The variation among the three radiologists’ estimations of growth arrest from radiographs was considerable. On x-ray tomography, the interobserver agreement was clearly inferior to MRI. On MRI, the estimation was easiest to make and the agreement was very good. As another part of the study, the usefulness of MRI for detecting growth arrest was tested: images of 40 posttraumatic children’s ankles, four of which had physeal growth arrest, were intermingled. The four subclinical bone bars were detected by all three radiologists.

Growth arrest can probably be suspected earlier from MRI than from tomography, although the time from the initial trauma to the development of the bone bridge was not analysed in this study. Another advantage of MRI, especially where children are concerned, is the absence of radiation exposure. For reasons of economy MRI should be used to confirm a growth arrest suspected from radiographs, not as a primary investigation.

8.1.4. Stress reactions in bone

In the study by Lazzarini et al. (1997), bone marrow edema was found in 80% of marathon runners. Our study showed bone marrow edema in 16% of both marathon runners and controls. All the runners in our investigation were examined within 3 hours, whereas, in
the prior investigation (Lazzarini, 1997), the time interval was up to 3 days. If a reparative process - which could be associated for instance with microfractures of the bone marrow - contributes to the edema seen in MRI, the difference in the timing of MRI could explain the difference in the results. Inversion recovery fast spin-echo sequences, sensitive to bone marrow edema (Pui and Chang, 1996) were performed in both of these studies. In an earlier study (von Tosch et al., 1991) of 25 marathon runners, 12 of whom had subjective symptoms related to running, no bone marrow edema was found on MRI. This investigation was performed using T1, T2, and proton density spin-echo sequences, but without any fat saturation, which may explain the low frequency of bone marrow changes.

The areas of slight bone marrow edema in our study were situated beneath the joint surface. Early osteoarthritic changes may contribute to these subchondral edematous changes. Edema in the bone marrow has been considered to be a nonspecific finding associated with a variety of causes (Pathria and Issacs, 1992; Newberg and Wetzner, 1994). Bone marrow edema in the physically active athlete may, especially if it is painful, represent an earlier stage of stress fracture (Schweitzer and White, 1996). A fracture line in the medulla or an abnormality in cortical signal intensity on MRI is related to a longer duration of symptoms than is the pure edema in the bone marrow (Yao et al., 1998).

Both the marathon runners and the controls in our study were physically active. Bone marrow edema as a response to a sudden physiologic stress may occur more often in less highly trained individuals. Small circumscribed hyperintensities under the joint surface were occasionally seen in both groups. The three perpendicular imaging planes in our study made it easier to differentiate between small areas of diffuse edema and small cyst-like circumscribed hyperintensities. Biomechanical abnormalities of the runners' feet could (Schweitzer and White, 1996) explain why some runners develop the alterations seen in MR. This was not investigated in our study or in the other two studies discussed.

8.1.5. Biodegradable osteosynthesis

The breakdown of self-reinforced poly-L-lactic acid (SR-PLLA) has not been demonstrated in prior MRI investigations (Viljanen et al., 1995; Pihlajamäki et al., 1997a+b). The low-field MRI used in some studies (Pihlajamäki et al., 1997a; Viljanen et al., 1995) has an inferior spatial resolution. Viljanen et al. (1995) investigated the bones of rabbits, which, being small, make interpretation difficult.

Our osteosynthetic device differed to some extent from the one used by Pihlajamäki et al. (1997b); in our examination, the ankles were fixed by screws, whereas in the earlier examination a combination of a pin and an extension plug was used. The six broken screws
in our investigation were either syndesmotic screws or screws through the growth cartilage; areas, where the screw is exposed to heavy tension. Although no-one has investigated the effect of dynamic loading on hydrolysis it is possible that differences in loading may explain the difference between our patients and those in earlier investigations (Pihlajamäki et al., 1997b), where all the SR-PLLA unbroken screws were situated in the medial malleolus. The follow-up time does not explain the differences in the results, for the follow-up time in the former investigation was longer, from 30-51 months, than in our investigation.

To avoid artefacts on MR images, which might have been produced by even very small particles of ferromagnetic material (Alanen et al, 1995), the drill used in the fixation had a vitallium cutting edge. The quality of the MRI images was good, without disturbing metallic artefacts. The edema around the screws in the first postoperative images was probably due to the drilling, because it was not seen in later controls, as would be expected if it had been due to an aseptic inflammation or due to a foreign body inflammation, which usually manifests itself years later (Böstman et al., 1995).

8.2. Soft tissue trauma

8.2.1. Ligaments and tendons

8.2.1.1. UCL of the thumb

Earlier investigations have used stress radiography, arthrography, and ultrasound for the diagnosis of acute UCL ruptures (Bowers and Hurst, 1977) or of a mixed group with mainly acute ruptures (Stothart, 1981). In some studies the time from the injury is not mentioned (Downey and Curtis, 1986; Susic et al., 1999). One arthrographic study (Resnick and Danzig, 1976) deals with acute experimental cadaver injuries. One would expect that stress radiographs would be less reliable in acute UCL ruptures, because of pain. Conventional arthrography and ultrasound are probably easier to interpret in the acute setting, as there is less scarring.

In previous studies using MRI or MR arthrography, the diagnosis of UCL rupture was made either on cadavers or after acute trauma. The sensitivity and specificity of MRI has been shown to be excellent or good in classifying UCL lesions as Stener or non-Stener
lesions (Spaeth et al., 1993; Hergan et al., 1995; Harper et al., 1996; Plancher et al., 1999; Hinke et al., 1994; Ahn et al., 1998). In most studies, however, operative treatment is recommended for all complete ruptures, regardless of type (Newland, 1992).

Our study was concentrated on the MRI diagnosis of old UCL ruptures. As intact ligaments have a typical low signal appearance, it was easy to distinguish ruptured from intact ligaments. The non-ruptured thumb UCL, situated immediately on the ulnar side of the metacarpophalangeal (MCP) joint, is a smooth and homogeneous hypointense structure between the distal metacarpal and the proximal phalanx. Scarring associated with UCL lesion looks like an irregular area of decreased signal intensity on all pulse sequences. Clinically, all the chronic UCL ruptures were unstable; on MRI a subluxation in the MCP joint was seen in only a few patients. In a few patients, the scarred UCL appeared elongated, but in our study it was not measured. An old rupture with extensive scarring was easy to differentiate from an uninjured ligament, but the gap in the ligament could not always be identified. In a recently torn ligament, edema around the ligament and at the rupture site may facilitate the diagnosis (Hergan et al., 1995). In old injuries, surrounding edema was less frequent.

The long interval between rupture and MR imaging explains the scarring that may cause difficulties in both intra-operative and radiographic interpretation. Classification of the rupture as a Stener or non-Stener lesion was not always possible, either with MRI or with surgery. The existence of a Stener lesion does not, however, affect the surgical treatment of chronic instability of the thumb MCP joint. The surgical exposure most used for both acute and chronic ruptures is the same, a Chevron incision on the dorso-ulnar aspect of the MCP-1 joint (Newland, 1992).

None of the patients or controls suffered from arthritis, which may lead to instability and ligament lesions. Any effect of ageing on the findings can be neglected, for the controls were age-matched. All MR images were obtained with the same high-field MRI apparatus, including the same coil, which eliminates any alteration in image quality due to machine-related factors. Because of the dedicated finger coil, the signal to noise ratio was good and the FOV small. The number of sequences used is too great for a clinical practice. The T2TSE FS sequence was the most sensitive to movement. T2TSE without fat suppression, regarded as the most useful single sequence in our study, has previously been estimated to be applicable for acute UCL lesions also (Hergan et al., 1995). Adequate screening of UCL ruptures can be achieved with two sequences; i.e. T2TSE and T1SE with fat suppression, both in the coronal plane, and the total scanning time can be reduced to 20 minutes.
8.2.1.2. Achilles Tendon & retrocalcaneal bursa

Our study showed that the MRI findings in the ankle and foot after marathon races were very similar to those seen in the physically active population. Fluid excess in tendon sheaths, retrocalcaneal bursae or bone marrow are not always related to clinical findings.

None of the marathon runners or controls had suffered any previous severe trauma to the ankle or foot and none made any specific complaints at the time of imaging. The mean age and gender of the two groups were similar. Both the marathon runners and the control population represented a wide range of physical activity levels. We were not able to arrange a premarathon MRI, because the runners came from different parts of the country. The MR investigations were made using four sequences in three perpendicular directions and the sequences were optimized to show edema and fluid both in the bones and in the soft tissues.

Small punctuate hyperintensities were detected in 63% of the controls, but in only 26% of the marathon runners in our study. This finding was the only statistically significant difference between the marathon groups and the control group consisting of physically active persons. The small hyperintense foci were best seen on the T2FS axial perpendicular to the ankle. The reason for including these foci in our questionnaire was that we had noted them in asymptomatic individuals. In correlation with tendon thickening, foci in the Achilles tendon are thought to represent early changes in intratendinous degeneration (Kneeland, 1997). We did not, however, detect any findings consistent with tendinitis of the Achilles tendon. According to an MRI study with histologic correlation (Mantel et al., 1996) these foci represent connective tissue septa with intratendinous vessels. Hyperintense foci have also been detected in earlier studies by Rollandi et al. (1995) and Soila et al. (1999). In the study by Rollandi et al., these hyperintense foci were seen on T1-weighted and proton-weighted sequences; in the study by Soila et al., they were found on fast STIR- and T1-weighted, fast low-angle shot (FLASH) sequences. No T1-weighted axial sequence was included in our protocol. We are not able to provide a plausible explanation for why such foci were more frequently detected in the control group of our study.

Detectable fluid or high-intensity synovium in the retrocalcaneal bursa was a common finding in both groups, in 68% of marathon runners and in 58% of controls. In prior examinations, fluid has been detected in 15% (Soila et al., 1999) and 96% (Bottger et al., 1998) of asymptomatic volunteers. Fat suppression was included in all our sequences, thus excluding the possibility of a misdiagnosis due to fat. Both lack of fluid and some fluid in the retrocalcaneal bursa seem to be normal findings, and heavy physical strain does not increase the amount to a statistically relevant degree.
8.2.2. Joint fluid and tendon sheath fluid

In prior studies, fluid in the talocrural joints has been detected by ultrasound in one third of asymptomatic volunteers (Nazarian et al., 1995), and by MRI in 77% (Schweitzer et al., 1994). In the study by Schweitzer, the amount of joint fluid was calculated using the formula for an ellipse; Nazarian et al. used the maximum AP diameters. However, even these measurements do not give the exact amount of joint fluid. We made an estimate by grading the amount of joint fluid into three classes. The amount of joint fluid that should be considered normal varies. Without other signs of pathology, increased joint fluid seems to be a normal finding. Heavy physical strain does not seem to increase the amount of joint fluid in physically active individuals.

In our study, a slightly increased amount of joint fluid was commonly found both in marathon runners and in asymptomatic controls, but slightly more commonly among marathon runners. MR imaging has been shown to be the most sensitive modality for showing increased joint fluid (Jacobson et al., 1998). Strenuous exercise did not increase the amount of peritendinous fluid; many marathon runners as well as asymptomatic controls showed excess fluid around the flexor tendons and none around the extensor tendons. In most individuals, the amount of fluid in the tendon sheath was only slightly, and locally, increased. In a study of joggers, the amount of joint fluid was increased in 5 of 10 knees (Kursunoglu-Brahme et al., 1990).

During the examination, the ankle was 90 degrees dorsiflexed, which may have caused the fluid in the tendon sheath to accumulate in certain locations. Estimation of the exact amount of tendon sheath fluid is troublesome: the amount may be slightly increased in a long segment or strongly increased more locally, which makes the estimation somewhat subjective, despite classification limits. We used a grading of tendon sheath fluid based on axial images. A similar grading was used by Schweitzer (1994), while Nazarian et al. (1995) also estimated the longitudinal extent of the tendon sheath fluid. An increased amount of fluid around tendons and in joints seems to be within the normal variation among symptom free, physically active persons. The amount does not increase after heavy physical stress. As fluid in the tendon sheaths and joints may be a normal finding, it is not always necessarily in connection with a patient’s symptoms.

8.2.3. Muscles

Only one marathon runner showed an increased signal within the soleus muscle on T2FS and turbo inversion magnitude (TIRM) images, which was consistent with an acute grade I
strain within the soleus muscle. The interval before imaging, up to 3 hours, was long enough for acute post-exercise alterations to disappear (Fleckenstein et al., 1988), while post-marathon myalgia and delayed onset muscle soreness occur later (Fleckenstein, 1999). We found no diffuse post-exercise muscle edema in specific muscle compartments, consistent with exertional compartment syndrome. Muscles accustomed to exercise show a milder post-exercise rise in serum creatine kinase CK (Clarkson et al., 1987), and in well-trained trained individuals, the alterations on MR images are also milder (Fleckenstein et al., 1989). In our investigations, both marathon runners and controls were physically active persons, which may explain the absence of muscle alterations.
9. CONCLUSIONS

Study I

About one third of wrist fractures that are detected with MRI are missed on radiographs, half of these involving the radius. The clinical significance of these occult fractures was not studied in this work. On the other hand, small cortical avulsions, which are seen on plain radiographs, may be missed in MRI.

Study II

The incidence of false-negative ankle fractures in plain radiographs is relatively small, and complex fractures are seldom missed. However, the total extent of complex fractures is not always obvious on radiographs. In these cases, displacement was usually minimal and therefore the underdiagnosis on plain radiography was of minor clinical relevance. In patients actually suffering from a ligament disruption, SH1 fractures of the distal fibula may be overdiagnosed.

Study III

The follow-up of physeal fractures is still based on conventional radiographs. When additional examinations are needed, conventional tomography can be replaced by MRI. Compared to MRI tomography has a tendency to overestimate growth arrest. However, the higher price of MRI may limit its use.
Study IV

The breakdown of biodegradable osteosynthesis can be shown with MRI.

Study V

MRI is an accurate and sensitive method for assessing old ruptures of the ulnar collateral ligament, but typing lesions as Stener- and non-Stener type is not always possible, because of extensive scarring. Coronal SE or FSE sequences are more informative than GRE sequences.

Study VI

Abnormal MRI findings in the ankle and foot of physically active, asymptomatic individuals are common. Heavy physical exercise does not increase the occurrence of such findings. When interpreting such MRI findings, the clinical history should be available, to avoid overdiagnosis.
10. SUMMARY

The relatively high expense of MRI motivates studies comparing this modality with other imaging methods in various fields of orthopedic trauma. The present study concerns the suitability of MRI for assessing musculoskeletal trauma. We studied 192 patients; their ages ranged from 8 to 80 years. The aims of the study were to compare the findings of MRI with those of other radiographic methods and with the clinical status.

**Study I and Study II**

In studies of suspected acute bone trauma, the findings on MR images were compared with those of plain radiographs in 67 adults who had acute wrist trauma and in 60 children who had acute ankle trauma. Both studies included patients with and without a primarily diagnosed fracture.

In radiographs of the adult wrist one third of the fractures seen on MR images were missed; almost half of these were situated in the carpal bones. T1FS was considered good for the visualization of fractures.

In children’s ankles, a difference in the classification was found in 21% when the distal tibia and distal fibula were estimated separately. The total extent of complex ankle fractures was not always, in undisplaced cases, obvious in plain radiographs. Lateral ligament disruption of the ankle may be misdiagnosed as an SH1 fracture of the fibula on radiographs. With T2FS, both the physis and fractures were demonstrated.

**Study III**

The findings on MR images were compared with those on plain tomography in the confirmation and grading of a suspected growth arrest. The selection of treatment depends on the cross-sectional area of growth arrest; in about half of the 11 patients this was estimated smaller in MRI than in tomography.
**Study IV**

In the follow-up examination of ankle fractures operatively treated with biodegradable osteosynthesis, we were able to verify the breakdown of 6/12 biodegradable screws. In prior MRI studies, the breakdown has not been visualized. The breakdown was detected in different sequences and planes.

**Study V**

The sensitivity of MRI for detecting chronic ligament injury was evaluated, with chronic UCL rupture of the thumb as a model. The diagnosis of chronic ligament rupture of the thumb was accurate in all the patients whose MR images were intermingled with images from 10 normal controls. A more exact typing of the rupture was not always possible because of extensive scarring. True coronal T2SE sequences were considered the most informative.

**Study VI**

Incidental MRI findings may lead to a false-positive diagnosis. We studied the effect of heavy physical strain (running a marathon) as a source of abnormal findings by imaging 19 runners and 19 controls. We used STIR and T2FS sequences, which are sensitive to the pathology of bones and soft tissues. The amounts of bone marrow edema, of Achilles tendon and bursal alterations, tendon sheath and joint fluid were not higher after marathon running than in the control group.
I am grateful to Professor Carl-Gustaf Standertskjöld-Nordenstam at Helsinki University Hospital, Department of Radiology for his encouraging support and interest in my work during all the years of this study.

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I owe my profound thanks to all those 192 patients and controls, and, where children are concerned, also to their parents, who participated in the study. The adult patients were treated in the Department of Orthopedics and Traumatology or in the Department of Hand Surgery at Helsinki University Central Hospital. The patients in whom biodegradable osteosynthesis had been performed were treated at Dextra Hospital, Helsinki. All the children were treated at the Hospital for Children and Adolescents at Helsinki University Central Hospital. I wish to thank roentgen technician and marathon runner Salme Peltoniemi and her friends for spending their time in the MRI, some after running a marathon, and some as controls.
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Appendix 1:
**MR imaging parameters; study I**

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Appendix 2:
**MR imaging parameters; study II**

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<th>Parameter</th>
<th>T1ax</th>
<th>T2TSEFSax</th>
<th>T1cor</th>
<th>T2TSEFScor</th>
<th>T1 sag</th>
<th>T2TSEFS sag</th>
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### Appendix 3:

**MR imaging parameters; study III**

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<th>Diagnosis</th>
<th>Location</th>
<th>Sag</th>
<th>Cor</th>
<th>Ax</th>
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<tr>
<td>1</td>
<td>7y 3 mo</td>
<td>M</td>
<td>St.p.fract.SH2</td>
<td>femur dist.</td>
<td>T1, T2, DESS</td>
<td>T1, T2</td>
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</tr>
<tr>
<td>2</td>
<td>14y 7mo</td>
<td>M</td>
<td>St.p.fract.</td>
<td>tibia prox.</td>
<td>T1, T2</td>
<td>T1FS, T2FS</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>12y 8mo</td>
<td>M</td>
<td>St.p.fract. &amp; epiphyseodesisysis</td>
<td>femur</td>
<td>T1</td>
<td>T1, FISP3D</td>
<td>T2</td>
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<tr>
<td>4</td>
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<td>M</td>
<td>St.p.fract. oper.</td>
<td>cond.lat.humeri</td>
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<td>T1</td>
<td>DESS</td>
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<td>T2FS</td>
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<td>T1, T2FS</td>
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<td>T1, T2FS</td>
<td>T1, T2FS</td>
<td></td>
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<td>14y 7mo</td>
<td>M</td>
<td>pes equinovarus l.a oper.</td>
<td>tibia dist.</td>
<td>T1</td>
<td>T1</td>
<td></td>
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<td>12y 6mo</td>
<td>M</td>
<td>st.p.fract. oper.</td>
<td>femur dist.</td>
<td>T1, TIRM</td>
<td>T1, T1FSnat+va</td>
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<td>10</td>
<td>2y 6mo</td>
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<td>humerus prox.</td>
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<td>T1FS, FI2D, DESS</td>
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<td>11</td>
<td>4y 2mo</td>
<td>F</td>
<td>st.p.osteomyelitis</td>
<td>femur dist.</td>
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<td>T1</td>
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**Mean:** 9y 11mo | 9M, 2F

### Appendix 4:

**MR imaging parameters; study IV**

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<td>90</td>
</tr>
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<td>4</td>
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### Appendix 5:

**MR imaging parameters; study V**

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<th>T2TSEFScor</th>
<th>FLASH2Deor</th>
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Appendix 6:

**MR imaging parameters, study VI**

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<td>96</td>
<td>20</td>
</tr>
<tr>
<td>T1 (ms)</td>
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<td>90</td>
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<td>5</td>
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<td>19+19</td>
<td>19+19</td>
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TIRM ax was obtained perpendicular to the distal tibia
T2FS ax and T1FS ax were obtained perpendicular to the metatarsals

Appendix 7:

**Grading system of MR findings in study VI**

Appendix 7:

Grading system used in the evaluation of MR examinations; study VI

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<th>Grade 1</th>
<th>Grade 2</th>
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<td>bone marrow</td>
<td>normal signal</td>
<td>hyperintensities under 10 mm</td>
<td>hyperintensities over 10 mm</td>
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<td>muscle (ref.1)</td>
<td>normal</td>
<td>signal alteration, no fiber disruption</td>
<td>discontinuity</td>
</tr>
<tr>
<td>joint fluid</td>
<td>normal</td>
<td>slightly increased</td>
<td>clearly increased</td>
</tr>
<tr>
<td>tendon sheaths (ref.2)</td>
<td>r.o.f. under 0.25 x diam. of t.</td>
<td>r.o.f. between 0.25 and 1.0 x diam. of t.</td>
<td>r.o.f. over 1.0 x diam. of t.</td>
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<tr>
<td>Achilles tendon</td>
<td>normal signal</td>
<td>punctate hyperintensities</td>
<td>bursal fluid under (11x7x1) mm</td>
</tr>
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<td>retrocalcaneal bursa (ref.3)</td>
<td>no bursal fluid</td>
<td>bursal fluid under (11x7x1) mm</td>
<td>bursal fluid over (11x7x1) mm</td>
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ref.1.=Tuite et deSmet,1994
ref.2.=Schweitzer et al.,1994
r.o.f = radius of fluid
diam. of t. = diameter of tendon

Appendix 8:

**Question form; study I**

<p>| | | |</p>
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<td>patient number:</td>
<td>date:</td>
<td>LK / ML / AK</td>
</tr>
<tr>
<td>fracture:</td>
<td>yes / no</td>
<td>location:</td>
</tr>
<tr>
<td>chondral lesion:</td>
<td>yes / no</td>
<td>location:</td>
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<td>best sequence (only 1)</td>
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### Appendix 9a:

**Question form: study II; x-ray**

<table>
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<th>Patient number:</th>
<th>Date:</th>
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- **Fracture:** yes / no
- **Fissure-like:** yes / no
- **St. p. fracture:** yes / no
- **Triplane:** yes / no

1. **Location:** ______________
   - **Dislocation:** __________
   - **Physiol. closing of growth plates:** yes / no
   - **Bone bridge:** yes / no
   - **Area of growth arrest / area of physis:** under 1/3 1/3-1/2 over 1/2
   - **Type of bone bridge:** central / peripheral
   - **Dislocation:** yes / no
   - **Pathologic Park-Harris lines:** yes / no
   - **Diffuse osteoporosis in bone marrow:** yes / no
   - **Location:** __________
   - **Malalignment:** __________
   - **Osteochondritis dissecans or pathology of the articular cartilage:** yes / no
   - **Location:** __________
   - **Additional to be observed:** __________
   - **Estimation:** fresh / older trauma
Appendix 9b:
*Question form: study II; MRI*

<table>
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<th>LK / ML / AK</th>
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<td>Fracture:</td>
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<tr>
<td>Fissure-like:</td>
<td>yes / no</td>
<td></td>
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<tr>
<td>St. p. fracture:</td>
<td>yes / no</td>
<td></td>
</tr>
<tr>
<td>Triplane:</td>
<td>yes / no</td>
<td></td>
</tr>
</tbody>
</table>

1. Location: ______________ SH: 0 1 2 3 4 5
   Dislocation: ______________

2. Location: ______________ SH: 0 1 2 3 4 5
   Dislocation: ______________

Contusion: yes / no
1. Location: ______________
2. Location: ______________

Physiol. closing of growth plates: yes / no
Bone bridge: yes / no
Area of growth arrest / physis: under 1/3 1/3-1/2 over 1/2
Type of bone bridge: central / peripheral
Malalignment: yes / no
Pathologic Park-Harris lines: yes / no
Diffuse bone marrow edema: location: _______________
Subchondral edema: location: _______________

osteochondritis dissecans or pathology of the articular cartilage: yes / no
location: ___________________

joint fluid: 1.normal 2.slightly increased 3.clearly increased
location: ___________________

additional to be observed: ___________________

quality of images: good / bad

estimation: fresh / older trauma

---

Appendix 10:

Question form: study III

patient number: date: LK / ML / AK

x-ray / conventional tomography / CT / MRI

bone bridge: yes / no
area of bone bridge / area of physis: under 1/3 1/3-1/2 over 1/2
type of bone bridge: central / peripheral
malalignment: yes / no
pathologic Park-Harris lines: yes / no
quality of images: good / bad
**Appendix II:**

**Question form: study IV**

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<th>Option 2</th>
<th>Additional Information</th>
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