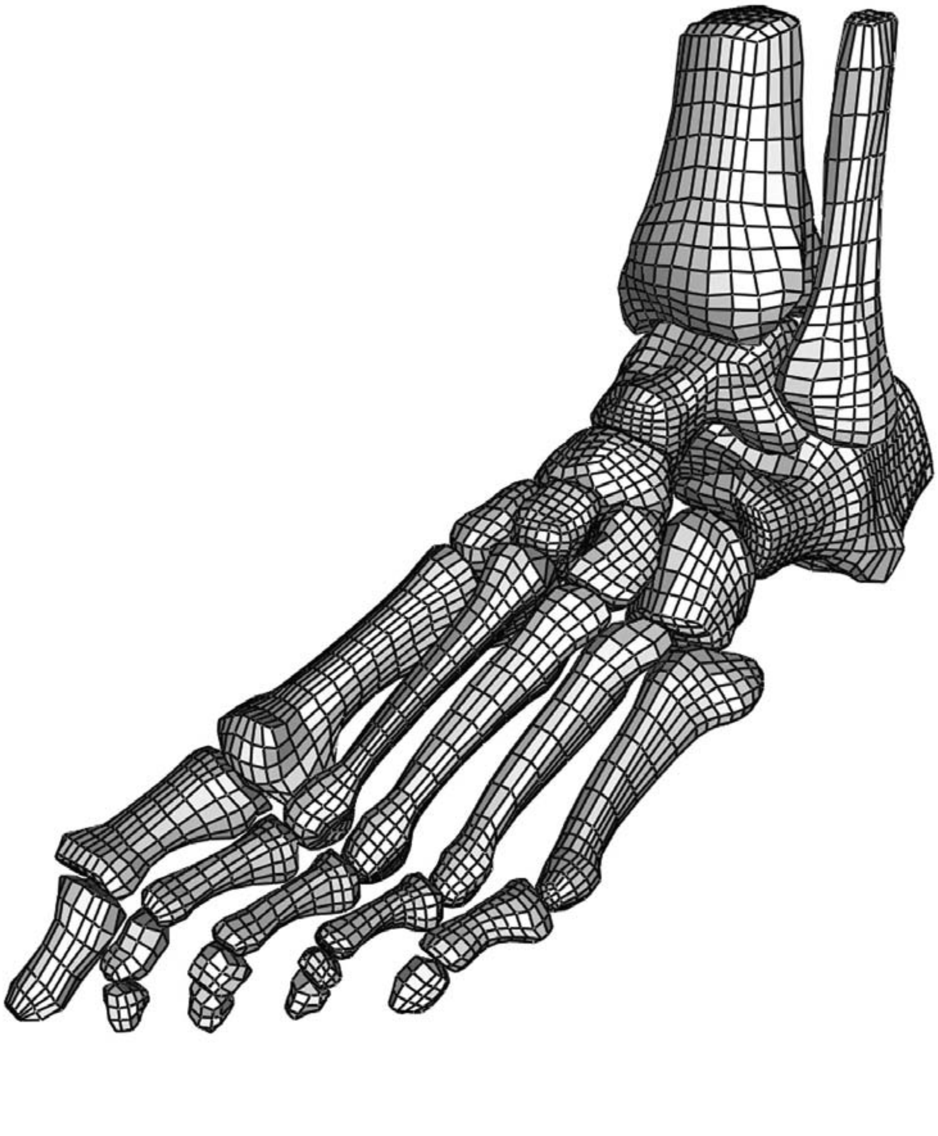
# *Bone Stress Injuries of the Foot and Ankle*

*Markus Sormaala*



*University of Helsinki 2006*

# Bone Stress Injuries of the Foot and Ankle

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**To my family and friends,**

**who mean the world to me**

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# ABSTRACT

Bone stress injuries of the foot have been known for more than 150 years. For a century, their primary diagnostic imaging tool has been radiography. However, currently the golden standard for establishing the diagnosis of stress injuries is magnetic resonance imaging (MRI). Although the injury type has been fairly well documented in the earlier literature, little information is available on the healing of stress injuries located in e.g. the talus and calcaneus.

The current study retrospectively evaluated the stress injuries of the foot and ankle treated at the Central Military Hospital over a period of eight years in patients who underwent MRI for stress injury of the foot. The imaging studies of the patients were reevaluated to determine the exact nature of the stress injury. Moreover, the hospital records of the patients were reviewed to determine the healing of stress injuries of the talus and calcaneus. Patients with a stress fracture in the talus were recalled for a follow-up examination and MRI scan one to six years after the initial injury to determine if the fracture had completely healed, clinically and radiologically.

The bone stress injuries of the foot were found to affect more than one bone in a majority of the cases. The talus and the calcaneus were the bones most commonly affected. In the talus, the most common site for the injuries was the head of the bone, and in the calcaneus, the posterior part of the bone. The injuries in these bones were associated with injuries in the surrounding bones.

Stress injuries in the calcaneus seemed to heal well. No complications were seen in the primary healing process. The patients were, however, sometimes compelled to refrain from physical training for up to months. In the talus, minor degenerative findings of the articular surface were seen in half of the patients who participated in a follow-up MRI scan and radiographs taken one to six years after the initial injury. Half of the patients also reported minor exercise related symptoms in the follow-up. The symptoms were, however, not noticeable in everyday life.

# LIST OF ORIGINAL PUBLICATIONS

This study is based on the following papers, which are referred to in the text by the Roman numerals I-IV.

I) Niva MH, Sormaala MJ, Kiuru MJ, Haataja R, Ahovuo JA, Pihlajamäki HK:
Bone stress injuries of the ankle and foot,
86-Month MRI-based Study of Physically active Young Adults.
American Journal of Sports Medicine, in press

II) Sormaala MJ, Niva MH, Kiuru MJ, Mattila VM, Pihlajamäki HK:
Stress injuries of the calcaneus detected by MRI in military recruits.
Journal of Bone and Joint Surgery [American edition], 2006 Oct; 88 (10):2237-42

III) Sormaala MJ, Niva MH, Kiuru MJ, Mattila VM, Pihlajamäki HK:
Bone stress injuries of the talus in military recruits.
Bone 2006 Jul; 39(1):199–204. Epub 2006 Feb 7.

IV) Sormaala MJ, Niva MH, Kiuru MJ, Mattila VM, Pihlajamäki HK:
Outcomes of stress fractures of the talus.
American Journal of Sports Medicine, 2006 Aug 10; [Epub ahead of print]

The publishers have kindly granted permission to reprint the original articles.

Publication I has also been used in the thesis of Dr. Maria Niva

# ABBREVIATIONS

CT = computed tomography

FOV = field of view

FSE = fast spin echo

MR = magnetic resonance

MRI = magnetic resonance imaging

SE = spin echo

STIR = short tau inversion recovery

T = tesla

T1 = longitudinal relaxation

T2 = transverse relaxation

TE = time to echo

TI = inversion time

TR = repetition time

# 1. INTRODUCTION

Bone stress injuries were first reported in German soldiers over 150 years ago. The painful feet of the soldiers were described by a Prussian military physician, Breithaupt (Breithaupt1855). The pathofysiology remained a mystery until X-rays were invented at the end of the 19th century (Schulte 1897, Stechow 1897).

Bone stress injuries were originally known as march fractures and were associated with the metatarsal bones. Case reports were published of similar injuries in other bones of the lower extremities (Asal 1937 and Scheller 1939) before the Second World War. The term 'stress fracture' was used to describe the injury type.

With the invention of scintigraphy and MRI in the 70´s, the lower grade injuries, presenting only as edema in diverse parts of the bone without a fracture line, were also disclosed (Spitz 2002). Regarding their pathofysiology, the injuries were similar, giving rise to the term fatigue bone stress injuries as the superordinate concept for all the injuries.

Although the developments in warfare and medicine have been remarkable, stress injuries are still common in military recruits. Athletes are also often affected, but outside military and sports medicine, the injury type is more rarely encountered. Bone stress injuries can be divided into fatigue injuries and insufficiency injuries. In fatigue injuries, normal bone is pathologically damaged by excessive exercise. Insufficiency injuries in turn occur in normal everyday activity in bones weakened by pathological processes, such as osteoporosis.

The first line of diagnosis of stress injuries is still radiography. Many stress injuries can, however, not be detected on the radiographs and the golden standard is, therefore, MRI. The otherwise healthy patient typically has a history of exercise induced pain at the beginning of a training period in combination with bone marrow edema seen on MRI. Bone marrow edema has, however, also been documented in healthy, physically active patients (Kiuru 2005).

Stress injuries have mostly been considered as benign, low risk injuries, and they have been treated with reduced exercise and non-weight-bearing. Occurring in, for example, the femoral shaft and neck, the fifth metatarsal and the tarsal navicular, stress injuries can lead to displaced fractures and, in these locations, must be considered high risk injuries (Pihlajamäki 2006, Niva 2005, Burne 2005, Potter 2006, DiGiovanni 2004, Rammelt 2004, Vogler 1995, Fetzer 2006). Regarding the bones in the foot, stress injuries of the talus have also been suggested to have a less than satisfactory outcome (Bradshaw 1996, Travlos 1991).

# 2 REVIEW OF THE LITERATURE

**Bone structure and remodeling**

Bone is a subset of a large and diverse group of tissues referred to as connective tissue. They serve quite varied functions in the body and share certain structural properties. The extensive extracellular matrix of connective tissues enables them to withstand physical stresses far better than any other tissue. Bone tissue represents the extreme in matrix consistency (Turner 2006, Dalle Carbonare 2004).

The gross anatomy of bone varies greatly, influenced by its position and function within the body. The chemical composition of bone consists of both organic and inorganic matrix components. The inorganic component of bone consists mainly of mineral salts known as hydroxyapatites, which are largely made up of calcium phosphates. The organic osteoid, representing about one-third of the matrix, consists of proteoglycans, glycoproteins and collagen fibers secreted by the osteoblasts. These molecules contribute to bone structure and are primarily responsible for the limited flexibility and great tensile strength of bone. Approximately 7 % of bone is water. Bone cells, osteoblasts and osteoclasts represent only a couple of present of the organic matter of bone. (Buckwater 1996, 1995).

There are two distinct tissue compositions, compact or cancellous (spongy) bone, which describe the gross arrangement of bone tissue. Cortical (outer layer) bone is compact; the two terms are often used interchangeably. Although both compact and cancellous tissue compositions have the same basic histological structure, in detailed examination, differences are found. The repeated structural unit of compact bone is the osteon or Haversian system. Through the centre of each osteon is a canal, referred to as the Haversian canal, which contains small blood vessels and nerve fibers. Compact bone makes up a majority of the skeletal mass. In contrast to the apparent internal regularity of compact bone, cancellous bone appears far less organized with an open, meshwork or honeycomb-like structure. Cancellous bone consists of a meshwork of primary (longitudinal) and secondary (transverse) trabeculae separated by fatty or hematopoietic marrow (Cornell 1998).

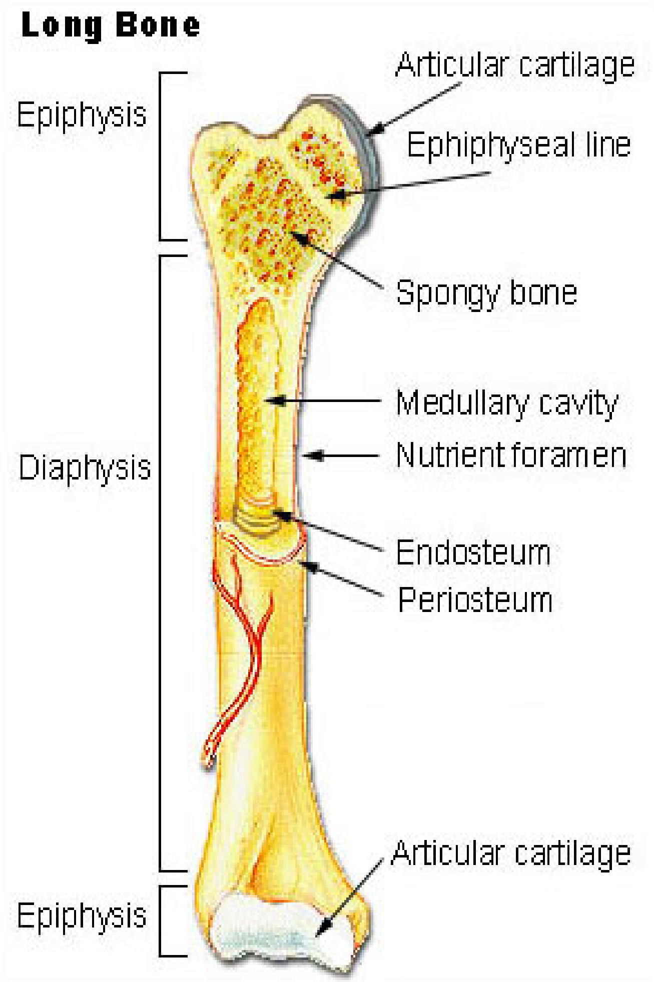
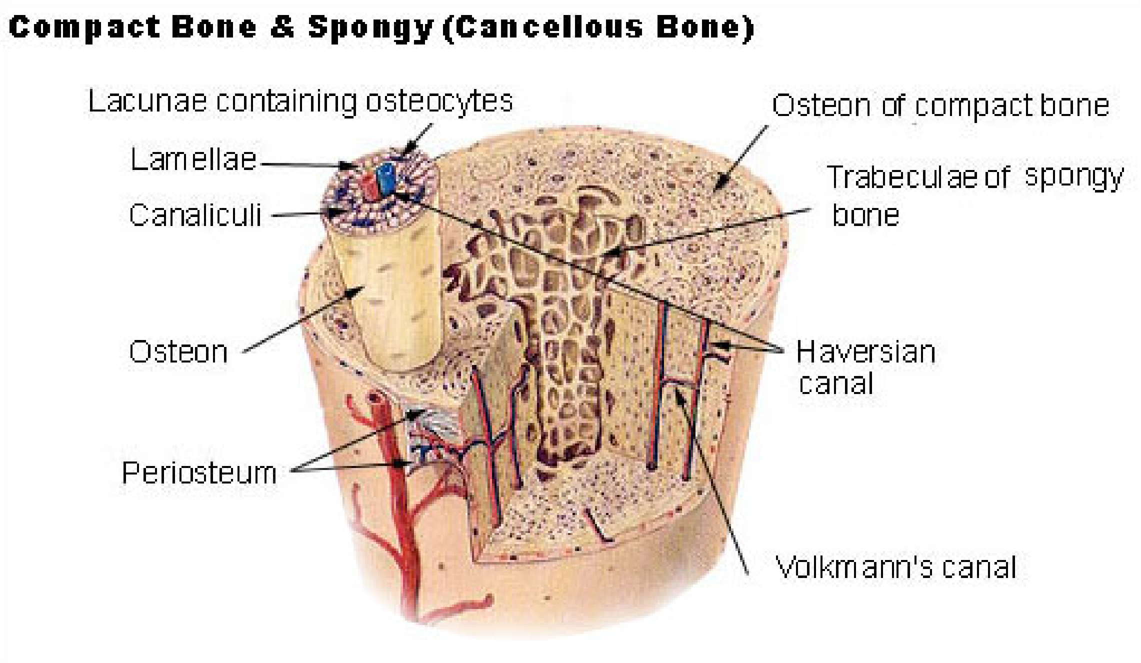



**Figure 1 A and B representing the macroscopic and microscopic structure of bone**



Usually found along the outer casing of long bones, compact bone is characterized by a low surface-to-volume ratio, and two types of surfaces: the lining facing the medullar cavity and the trabeculae of the spongy bone within is known as the endosteum; the outer side facing the surrounding soft tissues is known as the periosteum. Cancellous bone is typically found within the marrow cavities of long and flat bones. The increased vascularity of cancellous bone compared with cortical bone means that it is more prone to drug, endocrine and metabolic related effects. Due to its tremendously high surface-to-volume ratio, cancellous bone has an important role to play in calcium ion homeostasis.

Microscopically, bone is composed of cells and extracellular matrix. Functionally, there are four types of active bone matrix cells: osteoblasts, osteoclasts, and osteocytes and osteoprogenitor cells. The cells of cancellous bone are situated primarily between the lamellae or on the surfaces of the trabeculae, being directly influenced by adjacent bone-marrow cells. The majority of the cell population in cortical bone on the other hand is completely surrounded by bone matrix, these cells are dependant on the narrow Haversian channels for blood supply. The metabolism of bone is regulated by the activity of bone cells and responds to various environmental signals, including stress. Osteoblasts are cells with capacity to synthesize and mineralize bone matrix. They typically operate in groups and functionally are often arranged on the external surface of a segment of cortical or cancellous bone on which they are active. As matrix formation proceeds, some of the osteoblasts become surrounded by the matrix that they have formed. When this occurs, the cells become less metabolically active, assume an inactive appearance and are termed osteocytes. Osteocytes are numerous in mineralized bone matrix of both cancellous and cortical bone. They are assumed to play a role in the mechanical regulation and regeneration of bone (Cowin et al. 1991, Lanyon 1993, Mullender and Huiskes 1995 and 1997). The osteoclast is a large multinucleated cell whose function is to resorb calcified bone matrix. Osteoprogenitor cells are found throughout the bones. Under appropriate stimulation, these cells may differentiate into functional osteoblasts. (Buckwater 1996, 1995)

Bone is a dynamic tissue, continuously formed, resorbed and remodeled, and never metabolically at rest. Remodeling refers to the lifelong renewal process of bone, in which the osteoclasts remove and the osteoblasts replace bone matrix without significantly affecting the shape or density of the bone. Remodeling occurs in all parts of bone. All factors controlling the remodeling are not understood, but healthy bone formation and resorption are usually balanced (Wolff 1892, Parfitt 1984, Frost 1987a, 1987b, 1990a and 1990b). The obvious structural properties of bone tissue, hardness and strength, enable bone to fulfill two of its functions, support and protection. As dynamic tissue, bone supports movement, regulates the mineral composition, and produces the bulk of blood cells (Turner 2006).

**Bone stress injuries**

Bone tissue continuously remodels to match the current stress level applied onto the tissue (Wolff 1892). Moderate stress is, therefore, essential for normal bone to maintain its strength. If bone is left altogether without stress, e.g. during prolonged bed rest or non-weight-bearing, bone strength will be reduced with remodeling, because high bone strength is not required in these situations. When hard stress is applied a stronger than average bone tissue is required to withstand it. It takes, however, up to three months of remodeling for the bone tissue of a normal physically inactive person to strengthen sufficiently to withstand the stress applied during continuous physical exercise (Li 1985, Frost 1991).

Bone stress injuries usually occur in military recruits starting their training programme. Also athletes in the beginning of their training period are often affected, since their bone tissue was remodeled to withstand only the average stress of the rest period and not the stress applied onto the bone tissue during continuous physical activity. These patients first develop microfractures in the bone tissue (Burr 1985, 1993, Fazzalari 1993), not visible on radiographs, but a cause of bone marrow edema visible in magnetic resonance imaging. Consequently, these early stage (I-III) stress injuries can be seen on MRI and scintigraphy. If exercise is reduced, diminishing stress on the bone, no fracture develops. Should, however, the stress continue, the microfractures unite to form a true fracture line. On MRI, this shows as a low signal fracture line, and is graded as a grade VI stress injury (Kiuru 2005, Fredericson 1995). Although this fracture line is often not visible on radiographs due to absent dislocation, a fracture line developing a callus of new bone formation around it will be shown. If excessive exercise is continued, the fracture might dislocate, an event common with the metatarsals (Rammelt 2004, Monteleone 1995).

Histologically, there are different developmental stages in stress injuries. During the first week of physical activity, osteoclasts are activated and osteoclastic resorption occurs in order to replace the old bone with new bone meeting the stress resistance required. Since the new, stronger bone, synthesized by osteoblasts, has no time to organize, a periosteal callus and occasional endosteal callus formation follow in the second and third weeks. This callus remains for the entire healing time of the stress injury, up to 6-8 weeks (Johnson et al. 1963).

Two subtypes of bone stress injuries exist. Fatigue bone stress injuries affect normal bone tissue, which can not withstand the pathological stress applied on to it. The other subtype, insufficiency bone stress injury, is caused by normal everyday activity in weakened bones, and is more commonly seen in the elderly suffering from osteoporosis and in persons with long-term corticosteroid medication (Morrison 2000).

**Incidence of bone stress injuries in the foot**

Stress injuries have been considered a common injury type in all physically active patients, both military recruits and athletes (Almeida 1999, Matheson 1987). The overall incidence of all stress injuries has been estimated as 24 % in Finnish military Israeli recruits starting their training programme (Sahi 1996, Milgrom 1985). The figures from different studies however vary considerably and incidence figures as low as 0.9 % have been presented (Brudvig 1983, Gardner 1988, Jones 1989). The differences are probably attributable to training programmes, methodology of diagnosis, sport and physical fitness level, and footwear. Variation in reports from different military forces and military branches has also been substantial. As most stress injuries are benign self-limiting conditions, they are easily underdiagnosed and, therefore, their true incidence is probably higher then presented in most studies.

There has been considerable variation in the reports from different studies concerning the distribution of stress injuries in the lower extremities, for example, the tibia has been suggested as the most common site for stress injuries (Jones 1989, Milgrom 1985). There is strong evidence, however, that the foot is one of the most common sites for stress injuries anywhere in the skeletal system (Yale 1976), foot injuries representing up to 50 % of all stress injuries.

The metatarsals and the calcaneus have long been considered the bones most frequently affected by stress injuries (Greaney 1983). Stress injuries in the other tarsal bones have been estimated fairly rare until recent years, which might be due to the difficulty of diagnosing stress injuries in these bones. On radiographs, diagnosis of stress injuries is based on the visible callus and sclerosis, but assessing them in the small bones between the calcaneus and the metatarsals is difficult. More recent small case series using MRI as a diagnostic tool have, however, suggested that stress injuries to the navicular and talus might be fairly common (Bennell 1996, Brukner 1996).

**Etiology of bone stress injuries**

A good physical condition has been shown to protect from bone stress injuries (Gilbert 1966). Bone tissue in physically active patients has adapted to stress and is, therefore, less susceptible to stress injuries. The female gender has been found to be predisposed to stress injuries, the likely explanations being the anatomical, biomechanical and hormonal issues in women (Brudvig 1983, Hopson 1975). Moreover, the female athletic triad (inadequate nutrition, amenorrhea, eating disorders) and pregnancy have been considered risk factors for stress injuries in females. Also, such factors as body mass index and training surface have been considered to contribute to susceptibility to stress injuries (Rome 2005).

Bone locations of stress injuries tend to vary according to the type of training the patient undertakes. Distance runners have been reported more likely to sustain stress injuries of the tibia, fibula, femur and pelvis, whereas multi-event athletes, sprinters and jumpers more often sustain injuries of the foot (Snyder 2006, Bennell 1996, Daffner 1978). Moreover, bone stress injuries have been reported in the upper extremities. Tennis players and rowers have been noted to sustain stress injuries to the metacarpal bones, clavicle and ribs (Bespalchuk 2004, Abbot 2001, Brukner 1996). Also, the spine and sacrum can be affected in adolescent athletes (Micheli 2006)

There are conflicting reports on the effects of age on stress injuries (Milgrom 1994, Brudvig 1983, Gardner 1988). No studies have been performed where the amount of exercise has been standardized for different age groups. Therefore, the effect of age as an independent risk factor for stress injuries cannot be determined. The incidence and distribution of the injuries are more likely to be associated with the type, volume and intensity of training than with age (Snyder 2006). Patients with stress injuries are usually young military recruits or athletes, but the injuries can also affect older people e.g. military personnel or gym teachers trying to maintain their fitness for their profession (Matheson 1989).

The etiological risk factors for stress injuries have been divided into extrinsic and intrinsic factors. Examples of extrinsic factors are errors in training technique and excessive training volume. Use of proper footwear might be beneficial in reducing stress injuries of the lower extremities (Rome

2005). Biomechanical factors, such as differences in leg length, a high tarsal arch and excessive forefoot varus, are examples of intrinsic factors and have been shown to predispose to stress injuries (Korpelainen 2001).

**Clinical diagnosis of bone stress injuries**

As in most medicine, patient history is the most important aspect and basis of making a diagnosis (Daffener 1992). To reach the diagnosis of a stress injury, a clinical examination is required including radiological imaging. In most cases, patients with stress injuries to the foot have exercise-induced pain, typically appearing without any associated trauma some 2 to 3 weeks after the beginning of a training period. The onset of pain in stress injuries can be acute or gradual. In the acute form, the patient can identify the exact time when the pain began, and they can describe it to the physician as they would a trauma. Gradual pain usually develops over a period of 1 to 2 weeks. In the early stages of the injury, pain might only occur during exercise. If exercise is not reduced at this point, the injury progresses, and pain might be felt also during weight-bearing or even during rest. Tenderness and edema might be observed at the site of the injury (Brukner 1997).

In the metatarsals, the new bone formation (callus) might be palpable. If the patient continues physical activities regardless of the pain, grade I-III stress injuries can develop into grade IV stress injuries and dislocate. In the foot, this can be seen at least in the metatarsals and the navicular (Burne 2005, Potter 2006 Hulkko 1985, Rammelt 2004, Vogler 1995, Fetzer 2006). At this advanced stage, the diagnosing and treatment of stress injuries does not differ from that of any other acute bone fracture.

Although in many cases of stress injury to the foot there can be a strong suspicion of the diagnosis on the basis of the patient history and clinical diagnosis alone; the diagnosis can also be elusive. The patient may mislead the physician through associating the injury with some recent minor trauma, or with some old trauma which, however, does not cause the current symptoms. At the early stages of a stress injury, the patient may be symptomless on clinical examination. Stress injuries often affect many bones simultaneously, making it difficult for the patient and the physician to pinpoint the symptoms, which again can disturb the diagnosis (Meurman 1980). It is also important to note that, although the patients are usually young, people of all ages can be affected (Matheson 1989). Due to these facts, a clinical evaluation alone is considered unreliable for the diagnosis of stress injuries (Sallis 1991).

## Radiography

Only two years after Wilhelm Röntgen discovered X-rays, they were used to detect stress fractures in the metatarsals (Stechow 1897). Plain film radiography quickly became the cornerstone of stress fracture diagnosis and has remained the first line diagnostic tool owing to its good availability and cost effectiveness. Recently, however, scintigraphy and MRI are fast gaining ground as the golden standard of imaging for bone stress injuries.

If the stress injury is not dislocated, it can be difficult to see on radiographs. The early stages of stress injuries, such as the periosteal and endosteal edema seen on MRI, are usually not detectable on radiographs. Radiographs, nonetheless, show the resorption of the old bone and the new bone formation or callus around the injured site. In the cortical substance of long bones, such as the metatarsals, this phenomenon is called the gray cortex sign, and can be seen as blurring of the cortex (Mulligan 1995). In cancellous bone, such as the calcaneus, the new bone formation is seen as a sclerosis line at the injured site (Savoca 1971, Mulligan 1995). These radiographic findings combined with the typical patient history of exercise-induced pain at the beginning of a training period are considered diagnostic for stress injuries.

Radiographic evidence appears some 2 to 8 weeks after the onset of injury, when the new bone formation has started (Mulligan 1995, Savoca 1971, Sofka 2006, Daffener 1978, Ammann 1991). Therefore, the sensitivity of radiographs is poor especially in the early stages of stress injuries (Prather 1977, Nielsen 1991, Kiuru 2002). In radiography, visibility is also only limited for e.g. the tarsal navicular, the stress fractures of which can have an unsatisfactory outcome (Burne 2005). For these reasons, radiography can not alone be relied upon in the diagnosis of stress injury, and a normal radiographic appearance should never be interpreted to exclude a stress injury. A positive gray cortex sign in cortical bone or a sclerosis band seen in cancellous bone in a patient with a typical patient history, can however be considered diagnostic, and in these cases no further imaging is required.

**Magnetic resonance imaging**

The theoretical basis of nuclear magnetic relaxation to produce magnetic resonance images for detecting pathology in humans was presented in 1971 (Damadian 1971). The Nobel Prize of 2003 was awarded for further developing its use for medical diagnostics (Mansfield 1976, 1977, Lauterbur 1980). MRI was soon also applied for the diagnostics of stress injuries and is currently considered the golden standard of stress injury imaging (Stafford 1986, Spitz 2002, Kiuru 2002). It offers the advantages of a high sensitivity and a mostly high specificity yet without exposing the body to ionizing radiation. The only contraindications for MR imaging are some intra-corporal metal objects, pacemakers, claustrophobia, and early stage pregnancy, which only seldom are issues in patients with suspicion of stress injuries. The only disadvantage of MRI is that it might not always be available for imaging of patients with stress related pain and no visible stress injury on radiographs.

In imaging of stress injuries by MRI, T1-weighted images provide good anatomical detail and are, therefore, useful in the evaluation of the anatomical dimensions of the injury. T2-weighted images, usually with fat suppression, are more sensitive in detecting pathology, allowing even minor bone marrow edema to be seen in these sequences. In imaging the foot, images should be taken in all three planes; sagittal, coronal and axial. In addition to diagnosing stress injuries, many other causes of foot pain can be evaluated from the MR-images. It has been claimed that MRI is considered the best modality for evaluating foot pain (Steinbach 1998, Spitz 2002, Sofka 2006).

Regarding identification of stress injuries, there is evidence that MRI detects them even at their earliest stages, when they are presenting as minor periosteal or endosteal edema. In more advanced stress injuries, a low signal fracture line is seen. Based on MRI, stress injuries have been graded as follows; grade I endosteal marrow edema, grade II periosteal edema and endosteal marrow edema, grade III muscle edema, periosteal edema and endosteal marrow edema, grade IV fracture line, and grade V fracture line with callus (Fredericson 1995, Kiuru 2001, 2005).

The low signal fracture line seen in grade IV-V injuries is considered pathognomonic for stress fractures. The lower grade I-III injuries presenting with edema in different parts of the bone are, however, non-specific, and similar edema can be found in e.g. bone bruises, infections, neoplasia, and transient bone marrow edema. In some cases, a follow-up MRI scan is justified; the bone marrow edema seen in lower grade stress injuries disappears within 2 to 4 weeks after physical exercise is reduced (Sofka 2006).

### Other imaging modalities

In addition to MRI, bone scintigraphy can be used to detect low grade bone stress injuries (Nussbaum 1988, Meurman 1980). The increased metabolic rate related to stress injuries can be seen on scintigraphy in the early stages after injury. Although this imaging modality is known to have excellent sensitivity, it remains inferior to the highly sophisticated MRI technology, which offers superior specificity and also a greater accuracy of anatomical evaluation of stress injuries (Spitz 2002, Sofka 2006). Moreover, scintigraphy has the additional burden of radiation, and is less commonly available than MRI.

Computer tomography (CT) can be used to evaluate stress injuries with fracture lines. CT fails, however, to show the lower grade stress injuries, and it also involves considerable radiation exposure. CT might be useful in evaluating selected cases for which surgery is considered a treatment option. Further, it can offer an alternative imaging method to patients with relative or absolute contraindications to MRI (Sofka 2006). However, CT is not useful in the routine diagnostics of stress injuries.

Ultrasound, or sonography, might in some cases be a useful imaging method for evaluating stress injuries. It enables detection of the hypoechoic callus and buckling of cortical bone around the injury (Sofka 2006). Displaced stress injuries of long bones, such as the metatarsals, can also be visualized on ultrasound. However, the method is not common in clinical use due to the superiority and better availability of radiography.

### Differential diagnosis of bone stress injuries

Diagnosis of stress fracture is usually straightforward. In a majority of cases, the patient’s typical history combined with typical radiographic findings suffices to reach the diagnosis. In unclear cases, MRI is often used to assist in making the diagnosis. In non-typical cases, however, many other conditions must be considered in the differential diagnosis.

The causes for pain in the foot, ankle and heel are numerous. An accessory navicular is present in 4 to 21 % of the population, and may become irritated during exercise causing symptoms resembling stress injuries (Romanowski 1992). The os tibiale externum is another common accessory bone that can cause similar problems (Lepore 1990). Osteochondral fractures and damage to the osteochondral surface can cause foot pain, and are often diagnosed even months after the initial trauma (Steinbach 1998). Sinus tarsi syndrome resulting from inflammation or haemorrhage in the sinus tarsi can cause ankle pain (O'Connor 1958). Bursitis and tendon problems in the Achilles region can be confused with stress injuries. Similar problems can also affect other tendons and bursas in the foot. Plantar fascitis, which can be associated with a radiologically detected calcaneal spur, can clinically be confused with a calcaneal stress injury. Posterior impingement syndrome causes pain into the posterior side of the ankle joint (Hedrick1994). It is an injury resembling a stress fracture and often associated with the accessory os trigonum or the posterior process of the talus. Similar injuries can also occur on the anterior and lateral side of the talus. Morton's neuroma, usually located between the metatarsal bones, is a reactive fibrotic process associated with repetitive trauma of nerve degeneration (Wu 2000). Osteonecrosis of the talus secondary to talar fracture or corticosteroid medication can cause ankle pain (Chiodo 2004, Delanois 1998). In tarsal tunnel syndrome, the posterior tibial nerve is trapped beneath the flexor reticulum and abductor hallucis longus muscle and present as ankle pain. Also the deep fibular nerve, superficial fibular nerve and sural nerve are often subjected to compression (Baxter 1995, Steinbach 1998). Hallux valgus and hallux rigidus affecting the first tarsometatarsal joint are common causes of foot pain (Baxter 1995). Plantar fibromatosis is a proliferative disease of the plantar fibroblasts, often symptomless, but the hyperproliferated fibroblasts can become painful during exercise (Lee 1993). Freiberg disease causes avascular necrosis of the metatarsal head (Binek 1988). Also the navicular is prone to avascular necrosis (Burne 2005, Potter 2006, DiGiovanni 2004). Transient bone marrow edema is a rare condition of unknown etiology known to affect the foot (Radke 2001, Gigena 2002). Other conditions to be considered in the differential diagnosis are infections, such as acute or chronic osteomyelitis, rheumatoid diseases, trauma, metastasis and benign and malign neoplasms such as osteoid osteomas and sarcomas.

Bone marrow edemas seen in the lower grade I-III stress injuries are non-specific findings, which can be undistinguishable from similar bone marrow edemas seen in e.g. some malignities, bone bruises, infections and transient bone marrow edema. In patients with lower grade injuries, the patient history must therefore be carefully taken in addition to the MRI scan to confirm the diagnosis. Should the diagnosis remain obscure, the MRI should be repeated after 2 to 4 weeks of non-weight-bearing. In case of a stress injury, the bone marrow edema will have significantly decreased over this time. If, however, the edema has become larger, a stress fracture can be considered unlikely and other differential diagnosis must be considered. The 2 to 4 weeks' delay in reaching a sarcoma diagnosis has not been shown to increase mortality (Daffner 1992). Biopsies should not be taken of the painful area, because the callus formed around the healing stress fracture can histologically resemble a malignant sarcoma (Daffner 1992, Anderson 1996).

**Treatment of bone stress injuries**

As most stress injuries of the foot are benign, they need only be treated with reduced exercise. In lower grade injuries, reducing the amount of daily physical exercise to a half may suffice to remove the symptoms. This method is often preferred by athletes who refuse to miss their exercise schedules for weeks. In many cases, however, the symptoms prevail, and a complete interruption is necessary for up to 6 weeks. If even walking is painful due to the injury, a short period of non-weight-bearing might be required (Raasch 2006).

The use of cushioned footwear specifically designed for exercise probably decreases stress injuries to the foot (Milgrom 1985, Stacy 1984, Rome 2005). A cushioned running surface compared to asphalt concrete might enable some patients to continue their training. A hard surface has, however, not been proven to increase injuries (Marti 1991, Macera 1992, Hoeberigs 1992).

Stress injuries showing a fracture line and dislocation are those most prone for complication. In the foot, the highest risk of these injuries is found in the fifth metatarsal bone and in the tarsal navicular (Jones 2006, Burne 2005, Fetzer 2006). Dislocated stress injuries in these locations might result in nonunions or avascular osteonecrosis. Therefore, extra care must be taken when injuries in these bones are diagnosed or even suspected. Some cases may require surgical fixation, but in many cases the outcome remains nonetheless unsatisfactory (Burne 2005, Jones 2006).

Ultrasound therapy has been suggested to decrease fracture healing times (Heckman 1994, Rue 2004, Kristiansen 1997), however, the reports have been conflicting. Electromagnetic field therapy has also been proposed as a treatment for stress fractures (Benazzo 1995, Rettig 1988), but these studies were somewhat deficient in their design. To date, neither of these methods have succeeded to reach clinical significance.

## Bone stress injuries of the talus

Stress injuries to the talus are rare, and only few investigations on the subject have been documented. Talar stress injuries were first reported forty years ago by an army physician (McGlone 1966), but later, documented information has been limited to case reports (Gilbert 1980, Bradshaw 1996, Umans 1995, Rossi 2005, Perry 1981, Meurman 1980, Campbell 1983, Black 1994, Motto 1996, Haapasaari 2001). A total of 25 cases have been described in detail in the previous literature. The first cases were diagnosed using radiography as a diagnostic tool, in the later studies also computed tomography, MRI and scintigraphy were used. The patients in these previous studies have been both military recruits and athletes. Apart from the general risk factors for stress injuries, no obvious activity has been identified in the reported cases that would specifically predispose to stress injuries of the talus.

The most common site for the injuries in the case reports has been the head of the talus, but stress injuries to the talar body and to the lateral process have also been reported. Most of the cases have been fatigue-type injuries, but insufficiency-type injuries have also been documented (Umans 1995, Haapasaari 2001).

Due to the rarity of the diagnosis, little is known about the prognosis of the condition. The earlier studies have suggested that all of this kind of injuries heal well (Gilbert 1980, McGlone 1966). It is notable, however, that these studies had little or none follow-up information. Later studies have suggested a more complicated outcome, at least in injuries affecting the body of the talus (Bradshaw 1996). Stress injuries to the talus have even been suggested to cause avascular osteonecrosis (Travlos 1991). This suspicion is corroborated by the frequent cases of osteonecrosis encountered after traumatic talar fractures (Chiodo 2004). All the studies concerning stress injuries to the talus have focused on describing the acute phase of the injuries. These studies have given no emphasis on the longer-term healing and prognosis of the injuries.

## Bone stress injuries of the calcaneus

The calcaneus is one of the most common sites for stress injuries (Yale 1976). Its proportion of all stress injuries varies from 20 % to 43 % in different investigations (Yale 1976, Pester 1992, Darby 1967). After early case reports in the 1930s (Asal 1937, Scheller 1939), an extensive study on calcaneal stress injuries in military recruits was published in the United States in the early 1940s (Hullinger 1944), to be followed by only a handful of larger investigations in later years (Winfield 1959, Leabhart 1959, MacDonald 1966, Hopson 1977). As in all stress injuries, military recruits and athletes are most commonly affected by bone stress injuries of the calcaneus. In addition to the general risk factors for stress injuries, it has been suggested that multi-event athletes, sprinters and jumpers are more susceptible to these stress injuries (Weber 2005, Bennell 1996, Daffner 1978). Bilaterality has been notable, even 73 % of the cases in some studies (Leabhart 1959).

The documented large previously mentioned studies so far reporting calcaneal stress injuries are thus over thirty years old and were conducted using radiographs as the diagnostic tool. The clinical course and healing time of calcaneal stress injuries did not receive much attention in the previous studies, which focused on describing the radiological findings of the acute phase of the injury. Documentation of times of return to physical activity also remains absent from the earlier literature. In the published literature, stress injuries have almost always occurred in the posterior part of the bone, yet the studies have not addressed the more precise anatomical distribution of the injuries with respect to the different parts of the calcaneus.

Stress injuries of the calcaneus have been considered as low risk stress injuries (Boden 1995). In all of the larger studies documented, the patients have healed without complications, such as dislocation or osteonecrosis, and they have been treated conservatively with reduced exercise and non-weight-bearing. Although none of the patients in the major studies were treated with cast immobilization or surgery, a smaller study has suggested that patients who do not respond to conservative treatment might benefit from surgical fixation (Smith 1994).

**Bone stress injuries of the navicular, cuboid, cuneiforms and metatarsals**

Stress injuries to the metatarsals were the first stress injuries reported by Breithaupt in 1855. (Breithaupt1855). The injury type was then called march fractures, and it was also the first type of stress injury to be diagnosed by radiography in 1897 (Schulte 1897, Stechow 1897). The injury type and treatment have remained virtually unchanged for the 150 years since first recognized, and the metatarsals are still, along with the calcaneus, one of the most common anatomical locations for a stress injury. Up to 80 % of metatarsal stress injuries occur in the shafts of the second and third metatarsal bones (Matheson 1987, Sullivan 1984, Orava 1980).

Metatarsal stress injuries have mainly been considered as benign stress injuries. Even injuries with minor dislocation can be treated conservatively, with reduced activity and weight-bearing or with short-term cast immobilization. Dislocated injuries of the first metatarsal and the base of the fifth metatarsal are the most problematic to treat and often require surgical fixation (Rammelt 2004, Vogler 1995, Fetzer 2006). Likewise, a dislocated injury of the base of the second metatarsal, often found in ballet dancers, can be problematic to treat (O'Malley 1996, Harrington 1993, Micheli 1985).

In earlier studies, stress injuries to the tarsal navicular were considered rare, but more recent studies indicate that they are fairly common, representing some 15 % of stress injuries (Hulkko 1985, Orava 1988, Yale 1976, Greaney 1983, Bennell 1996, Brukner 1996). Stress injuries to the tarsal navicular often heal poorly. The bone is susceptible to avascular osteonecrosis, which can cause prolonged foot pain. Surgical treatment has been used for the injury, but has not proven long-term superiority compared with conservative treatment (Burne 2005, Potter 2006).

Very little has been published on stress injuries of the cuboid and cuneiforms. Only a single case report of an insufficiency stress injury to the cuboid has been published (Franco 2005). Likewise, only a small number of case reports concerning stress injuries to the cuneiforms can be found (Meurman 1980, Creighton 1990). No recommendations on the treatment of these injuries have been published.

# 3 AIMS OF THE STUDY

I) To assess the incidence, anatomical distribution and risk factors of bone stress injuries in the foot in general and, specifically, those in the calcaneus and talus based on MRI.

II) To assess the anatomic distribution, severity, and healing of calcaneal stress injuries.

III) To assess the anatomic distribution, severity and risk factors of stress injuries of the talus.

IV) To evaluate the outcome of stress fracture of the talus treated at the Central Military Hospital by reduced exercise and non-weight-bearing.

# 4 MATERIALS AND METHODS

All the studies (I-IV) were performed at the Research Institute of Military Medicine, Central Military Hospital, Helsinki, Finland. The studies were approved by the Medical Ethics Committee of the Central Military Hospital and by the Medical Ethics Committee of the Hospital District of Helsinki and Uusimaa.

**Patients**

All the patients in the study were conscripts performing their military service in the Finnish Defence Forces. All Finnish male citizens are subject to compulsory military service, whereas female citizens can volunteer for the service. The study period was eight years, from 1 April 1997 through 31 March 2005. During this period, 133 patients with 142 feet had 385 stress injuries in different bones. Out of the 133 patients, nine were female and 124 were male, the mean age of the patients was 20 years (range 17 to 27 years). Of the 133 patients, 131 were included in Study I, 30 patients in Study II, 51 patients in Study III, and nine in Study IV.

All the patients in the study were referred to the Central Military Hospital from the primary care units due to exercise-induced pain in the foot region. Their diagnosis was unclear, and a stress injury was not diagnosable from the radiographs taken in the primary health care units. All the patients were treated with reduced exercise; they were given crutches if walking caused pain. The patients were prescribed non steroidal anti inflammatory drugs. None of the patients underwent surgical treatment, nor were they prescribed orthotics or cast treatment. Eight patients were compelled to temporarily discontinue their military service due to their stress injury.

Study I

The patients for Study I were gathered from a time period of 86 months, from March 1997 to April 2004. The inclusion criteria for the patients included an unclear diagnosis at a primary health care centre, an examination by an orthopaedic surgeon, and an MR-image of the foot or ankle due to exercise-related pain in the foot area. Patients with a recent trauma or foot infection were excluded from the study. A total of 268 patients meeting the inclusion criteria were identified from the MRI archives. Of these patients, 131 (9 female, 122 male, age range 17 to 27 years, mean age 20 years) displayed bone stress injuries in the foot and were evaluated in detail.

Study II

Material for Study II was obtained from the MRI archives covering the study period of 96 months, from 1 April 1997 through 31 March 2005. The inclusion criteria for the patients in Study II were a physical examination by an orthopaedic surgeon, exercise-induced ankle and/or heel pain during military service, and a calcaneal stress injury finding on MRI. Patients with a recent trauma or foot infection were excluded from the study. A total of 30 male patients (age range 18 to 26 years, mean age 21 years) met the inclusion criteria and were evaluated in the study.

Study III

Material for Study III was gathered to cover the study period of eight years, from 1 April 1997 through 31 March 2005. The inclusion criteria for the present study were a physical examination by an orthopaedic surgeon, exercise-induced ankle and/or foot pain during military service, and a bone stress injury finding of the talus on MRI. Patients with a recent trauma or foot infection were excluded from the study. Based on MRI, 51 recruits (49 male, 2 female, age range 18 to 27 years, mean age 20) exhibited bone stress injuries in the talus and were evaluated in the study.

Study IV

Material for Study IV was gathered from the patient archives to cover a period of eight years, from the beginning of April 1997 through March 2005. The inclusion criteria for the study were exercise-induced pain in the ankle or foot, a physical examination by an orthopaedic surgeon, and a stress fracture with a low-signal fracture line in the talus confirmed by MRI. Nine patients (7 male, 2 female, age range 19 to 22 years, median age 19 years) met the inclusion criteria and were asked to participate in a follow-up examination.

## Methods

The patients with bone stress injury findings were identified for the study from the MRI archives of the Central Military Hospital. For Studies II and IV, also the original medical records from the primary health care units were obtained and evaluated. For studies II-IV, the original MR-images and radiographs were retrieved from the archives and re-evaluated. The MR-images were interpreted with the aim to determine the anatomical location and the grade of the bone stress injury involved.

All the patients had been examined by an orthopaedic surgeon. The patient histories had been taken to determine the time the pain had started, and its possible relation to a more recent or older trauma. Range of movement of the ankle joints and ligamentous stability had been evaluated to determine the possible laxity of the joints. Based on these examinations, data was collected to estimate the time the patients were suspended from military training and the time until final recovery from the stress injury.

The nine patients in Study IV were invited for a follow-up examination one to six years from the initial injury. Repeated clinical examinations, MR-imaging and radiography were performed to evaluate the long-term healing of the injuries. The follow-up MR-images and radiographs were evaluated to determine if the fracture had healed without leaving radiological findings. Careful patient histories were taken to determine if the patients considered themselves completely healed from the injury.

## Imaging methods

All the patients in the study underwent both radiography and magnetic resonance imaging. The area where the patient displayed the symptoms was first imaged at the primary health care unit by radiography. Once referred to the Central Military Hospital the patients underwent an MRI scan, and in some cases, radiography was repeated.

The patients were imaged on a 1.0 T MR scanner with an extremity coil (Signa Horizon, GE Medical Systems, Milwaukee, USA). MRI images of the ankle or foot were obtained in three different planes. The most common sequences were: sagittal and axial T1-weighted spin-echo (SE) sequence images (repetition time (TR)/echo time (TE = 500-680 msec/10-15 msec), with two signals averaged, and 256 x 192-224 matrix, and the T2-weighted fast spin echo (FSE) sequence images with fat suppression (TR = 4400-6000 msec/TE effective = 80-90 msec) with two signals averaged, echo train length 8-12, and 256 x 224 matrix. The field of view (FOV) was 18-20 x 18-20 cm, and the slice thickness was 3.0-4.0 mm, with a 0.5 to 1.0 mm intersection gap. Additional sequences were also obtained, such as STIR (5400msec/17msec, TI 140msec, with two signals averaged, a 256 x 224 matrix, a FOV of 32-48 x 24-48 cm, a slice thickness of 4.0-5.0 mm, with a 0.5 to 1.0 mm intersection gap). The standard views for radiography were anteroposterior, mortise and lateral for the ankle, and anteroposterior, oblique and lateral for the foot.

The nine patients who were invited for a follow-up examination in Study IV were re-imaged with the following sequences: T1 FSE sagittal view, T2 FSE sagittal view with fat supression, T1 FSE axial view, T2 FSE axial view with fat supression, and T2 FSE coronal view with fat suppression. Anteroposterior and lateral views of the ankle were used in the follow-up radiography.

All the images in the study were evaluated by a radiologist who had experience in musculoskeletal imaging. The grey cortex sign, periosteal callus, endosteal callus and fracture line were accepted as the radiographic signs marking a bone stress injury. Furthermore, in cancellous bone, the accepted signs were subtle blurring in the trabecular margins, a faint sclerotic margin, and a sclerotic band. Based on the original MR-images, the stress injuries were graded on a scale of I to V displaying as edema in the periosteum, endosteum, surrounding muscles, as a low signal fracture line and in some cases as callus formation. Additional findings were also recorded. In Study IV, the follow-up MR-images and radiographs were interpreted to find radiological signs left by the fracture, such as sclerosis, edema, or cystic degeneration at the once injured site.

### Statistical methods

For the purpose of studies I-IV, background information was collected on all conscripts within the hospital catchment area. The available computer database included specified information regarding the age, sex, height, weight, and length of military service for every conscript. This data was used to calculate the body mass index (BMI) of all the patients using the formula of dividing a person's weight in kilograms by height in metres squared (BMI=kg/$m^2$). Information about the conscripts' aerobic and physical fitness level were also taken into account, based on the measurements performed over the first weeks of military service and the obtained physical fitness scores. These scores were based on assessments of aerobic fitness using a 12-min running test, and of muscle strength using a set of five tests: distance of horizontal jump, and the number of sit-ups, push-ups, pull-ups and back-lifts performed within a given time.

Data was collected to determine the time from the entry into military service to the onset of symptoms. The length of time from the onset of symptoms to diagnosis by MRI was recorded. The number of days the patients were suspended from physical training was noted from the medical records. Also the length of time for the patient to become symptomless and return to normal training activity after first seeking medical attention was recorded. This length of time included any failed attempts to resume the training programme as well as leaves from the military base.

The data analyses for the studies I-IV were performed using the SPSS/Win software (version 12.0, SPSS Inc, Chicago, Illinois). In the different studies, data were subjected to statistical analysis using various methods. The Kruskal-Wallis test was used to test differences in the continuous skewed data between the groups (II-IV). The differences in the crosstables were determined using the Pearson chi-square test (II-IV). Statistical significance was assigned at $p$-values $\leq 0.05$.

In addition, In Study I, Pearson chi-square test was used to test the associations between occurrences of bone stress injuries, and the Mann Whitney's u-test to test differences in the skew continuous data between the groups. In Study II, the independent samples T-test was used to test differences in the continuous data between the groups. To obtain the incidence rates for stress injuries, the number of recruits with MRI-identified stress injury was divided by the total exposure time, and the rates were shown per 10 000 recruits per year with 95 % confidence intervals. In Study III, logistic regression was used to study associations between talar stress injuries and the categorical explanatory variables. Odds ratios were calculated with a 95 % confidence interval. Age, sex and serving time were forced into the model and each independent variable was analyzed one at a time. The incidence rates, shown per 10 000 recruits per year (95 % confidence intervals), were obtained by dividing the number of recruits with MRI-identified stress injury by the total exposure time.

# 5 RESULTS

### Incidence of stress injuries of the foot

In Study I, stress injuries were found in all bones of the foot, except for the phalanges of digits II through IV. Of the 268 patients referred to an MRI examination due to exercise-induced foot/ankle pain and an unclear diagnosis, 131 (49 %) displayed bone stress injuries on the MRI. The incidence of these stress injuries, requiring MRI to reach the diagnosis, was 126/100 000 person-years. Study II identified 30 male patients exhibiting stress injuries in the calcaneus. The calculated person-based incidence was 26/100 000 person-years. In study III, with 51 recruits exhibiting bone stress injuries in the talus, the person-based incidence rate was 44/100 000 person-years. In Study II, four, and in Study III, five patients had bilateral injuries. All the aforementioned incidences were stress injuries which could neither be diagnosed by radiographs nor by examination by an orthopaedic surgeon. When taking into account all the patients originally included in Studies I-III, suspicion of a stress injury on the basis of initial radiography was raised concerning six patients, but no finding was suspected in the rest of the patients.

### Anatomical distribution and severity of stress injuries

Study I recorded a total of 378 bone stress injuries which were found in 142 feet and/or ankles. The majority of the injuries were found in the tarsal (58 %) and metatarsal bones (36 %), the rest (6 %), were situated in the upper part of the talocrural joint, the sesamoids and accessory ossicles. Only in 53 (37 %) cases was a single bone affected, in the other 89 (63 %) cases, multiple bones were affected. The most commonly affected bones were the talus with 55 cases, the 2$^{nd}$ metatarsal with 42, the 3$^{rd}$ metatarsal with 37, and the calcaneus and navicular each with 33 cases. Assessing the severity of the bone stress injuries, grade IV or V stress injuries with a fracture line were found in nine % of the cases, most commonly in the calcaneus and in the talus.

In Study II, 19 (56 %) of the stress injuries occurred in the posterior part of the calcaneus, six (18 %) in the middle part, and nine (26 %) in the anterior part. In Study III, we detected stress injuries in the following anatomic regions of the talus: 40 (67 %) in the talar head, 15 (25 %) in the body, and five (8 %) in the posterior part. In a few cases, the injuries affected several areas of the bones. In a clear majority, 27 of 34 cases (79 %), the injury was located in the upper part of the calcaneus.

Also in the talus, the majority of the injuries, 40/56 (71 %), were situated in the upper parts of the bone.

Investigation of the injury grades revealed that, in the calcaneus, 20 of 34 cases (56 %) displayed a low-signal fracture line and were therefore graded as more severe grade IV stress injuries. In the talus, however, a grade IV stress injury was found only in 18 % of all cases, while in 82 % of the cases, the stress injuries were grade I-III exhibiting merely as endosteal edema without a fracture line. The higher grade injuries of the calcaneus were not evenly distributed over the bone, but they were most commonly seen in the anterior and posterior parts of the bone.

The talus and the calcaneus were affected as an only bone in 12 cases, while in a majority of patients with stress injuries, at least one or several other tarsal bones were also simultaneously affected. Stress injuries of the calcaneus and talus located in areas facing the surrounding bones were associated with stress injuries in these bones. For example, when the anterior parts of the talus and calcaneus were affected, stress injuries in the cuboid and navicular were also commonly found. Stress injuries in the upper part of the calcaneus were associated with stress injuries of the talus and vice versa.

According to the hospital records, 13 of the patients in Study II, and 31 of the patients in Study III displayed normal ankle joints at the clinical examination. Palpation pain in different parts of the foot was present in 18 patients in Study II and 20 patients in Study III. Soft tissue edema in the foot or ankle was present in 15 patients in Study II and in eight patients in Study III. Only two of the talar injury patients and two patients with a calcaneal stress injury had minor laxity in the ankle joint at the clinical examination.

With the numbers studied, there were no statistically significant differences between the patients with calcaneal and talar stress injuries and the healthy controls in terms of average height, weight, or body mass index ($p>0.1$). Likewise, age, sex, length of military service, aerobic fitness, or muscle strength did not emerge as statistically significant risk factors for bone stress injuries of the talus or calcaneus in Finnish military recruits.

### Healing of stress injuries of the foot

The median time from the beginning of the military service to the onset of pain in Study I was 30 days (range 2 to 330). In patients with bilateral involvement, the pain occurred earlier compared to those with injury to one foot only (median, 14 days; range 2 to 60 vs. median, 30 days; range 2 to 330 days) ($p$=0.027). Also, the patients in Studies II and III with stress injuries located in the talus and calcaneus displayed symptoms earlier; at sixteen days (range 3 to 250 days) with calcaneal injuries and at 18 days (range 0 to 330) with injuries to the talus. The median duration of the ankle and/or foot pain prior to the diagnosis by MRI in Study I was 65 days. The corresponding time was 55 days (range 20 to 170) for patients with a stress injury to the calcaneus in Study II, and 62 days for the patients with stress injuries to the talus in Study III. In Study III, the grade IV injuries presented with more severe symptoms and were therefore diagnosed earlier than grade I injuries (46 vs. 70 days).

In Studies II and IV, the times that the patients were relieved from the military training programme were evaluated from the medical records. The patients with calcaneal stress injuries were freed from physical training for an average of 24 days (range 3 to 73). They became symptomless and returned to normal training activity within an average of 77 days (range 20 to 223) after first seeking medical attention. In Study IV, the patients with a grade IV stress injury in the talus became symptomless in an average of 64 days (range 12 to 137) after they initially sought medical attention. These lengths of time include leaves and failed attempts to resume the training programme. Five of the patients in Study II and two of the patients in Study IV were forced to interrupt their training programme for an extended period of time due to the injury but were able to return to duty later.

### Outcome of stress fractures of the talus

In the follow-up of Study IV, nine patients with a stress fracture in the talus were identified and evaluated, including one patient with a bilateral stress fracture to the talar bone. One of the nine patients was lost to follow-up MRI and examination due to refusal to participate. His follow-up information was therefore based only on the hospital records, which indicated he still had symptoms 12 months after the initial injury. In the other eight patients, the mean time from the primary MRI diagnosis to the final follow-up examination and MRI was 54 months (range 14 to 74).

Magnetic resonance and radiographic images were obtained of the eight patients participating in the final follow-up of Study IV. MRI disclosed five ankles with minor subchondral changes, and bone marrow edema in the talo-navicular joint close to the original fracture site. Two of these cases involved minor subchondral cysts in the initial injury area, which were also seen on radiographs. Full healing had occurred in four ankles, and was confirmed by MRI and radiography, neither of which showed any abnormalities. Furthermore, an examination by an orthopaedic surgeon was conducted. In the examination, no edema or tenderness was noted, nor was there instability in the ligaments surrounding the ankle joint in any of the nine ankles.

At the follow-up, three of the eight patients had mild symptoms in the ankle, such as minor pain or swelling after exercise, one had moderate symptoms e.g. stinging pain during physical activity. None of these symptoms occurred in normal daily activities, but they were brought on briefly by more straining activities like sports. Patients' symptoms and the subchondral findings by MRI were not, however, significantly associated ($p$=0.4). Four of the patients considered themselves healthy and fully recovered from the injury. According to the information received concerning the one patient who refused to participate in the follow-up, he had reported of some symptoms at 12 months after the initial injury, but there was no further information available to enlighten this case.

# 6 DISCUSSION

**Incidence of bone stress injuries**

Stress injuries to the foot have been considered fairly common (Yale 1976, Greaney 1983). Previous studies with radiography as the diagnostic method of choice implicated that the injuries mainly occur in the metatarsals and calcaneus (Yale 1976, Greaney 1983). More recent studies using MRI have, however, suggested that stress injuries might be more evenly distributed among the bones of the foot (Bennell 1996, Brukner 1996). The total incidence seen in the current study for all stress injuries of the foot was 126 per 100 000 person-years. This incidence is low compared to the previous large studies conducted using radiographs (Yale 1976, Greaney 1983), but, being based on the MRI archives, it is not directly comparable to the incidences presented in the previous studies. In this study, the patients were referred to an MRI scan due to a negative or unclear radiograph. The incidence presented here therefore reflects the amount of patients with stress injuries not diagnosable by means of radiography and clinical examination by an experienced orthopaedic surgeon. As stress injuries were seen in all bones of the foot, the study implies that such injuries might be overlooked.

**Diagnosis of bone stress injuries**

In many cases, the stress injury diagnostics is straightforward, yet this study proves that there are cases when the diagnosis can be elusive to even the most experienced surgeon. If the radiograph shows no abnormalities, the diagnosis of stress injury cannot be made on the basis of the clinical examination. The patients in this study displayed tenderness and edema in different parts of the foot. These findings are extremely non-specific, and many of the patients displayed no clinical signs of injury. Although the surgeon can strongly suspect the diagnosis of stress injury on the basis of the typical patient history and the non-specific findings, the diagnosis can only be affirmed after a positive radiological finding. In most cases, a radiograph is sufficient for the diagnosis, but the current study indicates that in cases where the radiograph displays no abnormalities an MRI scan is often needed.

This study was based on the use of MRI as the diagnostic method of choice, i.e. technology that today should be considered the golden standard for stress injury diagnostics. In the area of the foot, it is the only modality capable of localizing stress injuries of all the small tarsal bones. This capability is especially valuable in the navicular, as its injuries can result in long-term problems (Burne 2005, Potter 2006). MRI offers superior sensitivity and specificity compared to other imaging methods, without subjecting the patient to radiation (Spitz 2002, Sofka 2006). In addition to diagnosing stress injuries, many other conditions such as soft tissue problems and tendonitis can be reliably evaluated from the images. The only disadvantage of MRI is that it might not always be available in the acute phase of the injury.

The current study managed to evaluate the grades and precise anatomic locations of the stress injuries in the foot. Although clues to the anatomic distribution of these stress injuries have been presented in previous smaller studies and case reports, now for the first time the distribution could be confirmed in a larger patient sample. The study also provided the incidence of stress fractures that could not be diagnosed by radiography and clinical examination of an orthopaedic surgeon used to working with military recruits.

Traditionally, a repeated radiograph has been used to diagnose stress injuries. Radiography can be recommended as the first-line modality of imaging due to its good availability.  The injury is usually detectable within 2 to 8 weeks of the onset of the symptoms (Mulligan 1995, Savoca 1971, Sofka 2006, Daffener 1978, Ammann 1991). Especially in the metatarsal bones, which are clearly visible in radiographs, radiography is often sufficient in diagnosing stress injuries.

It is common practice that the patient’s exercise is reduced at the onset of the symptoms. This might be sufficient to prevent the stress injury from developing into a grade IV injury visible on radiographs, but the patient might nonetheless continue to display symptoms. Stress injuries in the tarsal bones cannot be reliably evaluated from radiographs. In many cases, an MRI scan is therefore justified.

An early diagnosis with MRI enables adequate treatment at an early stage. This can be crucial for military recruits and athletes trying to focus on their training programme. The early treatment can also prevent grade IV injuries to the navicular, talus, and the first, second and fifth metatarsals. Injuries to these sites can cause permanent problems in the foot if left untreated (Rammelt 2004, Vogler 1995, Fetzer 2006, O'Malley 1996, Harrington 1993, Micheli 1985, Burne 2005, Potter 2006).

## Stress injuries of the talus

The study established the incidence for stress injuries of the talus. Previously, only case reports have been published, suggesting that the head of the talus would be the most common site for the injuries (Gilbert 1980, Bradshaw 1996, Umans 1995, Rossi 2005, Perry 1981, Meurman 1980, Campbell 1983, Black 1994, Motto 1996, Haapasaari 2001). The current study investigated the anatomical distribution of stress injuries within the talus in a larger recruit population. A clear majority of the injuries were seen in the head of the talus, a finding consistent with those of the earlier reports. In addition, the grades of the stress injuries were evaluated. It was seen that the low grade injuries dominated and represented up to 82 % of all stress injuries in the talus. Though no fracture line was seen in these injuries, they must nevertheless be considered clinically significant as all the patients in the study were symptomatic. The study also concluded that stress injuries to the talus are commonly associated with similar injuries to the surrounding bones, most commonly the navicular and the calcaneus.

The healing of stress injuries of the talus was for the first time evaluated by means of a clinical follow-up including MR imaging and radiography. Previous case reports on stress injuries of the talus have focused on describing the injuries during the primary acute phase. MRI displayed minor degeneration in roughly half of the patients, and degenerative findings were seen in two of the patients in the radiograph. Roughly half of the patients also reported minor symptoms in the once injured foot. The symptoms were not noticeable during everyday life, but affected the patients during occasional recreational sports activities. The symptoms reported by the patients and the degeneration seen in the MR-images and radiographs were minor. However, since some symptoms and degeneration existed, stress injuries to the talus cannot be considered unambiguously benign. The follow-up time of the patients was relatively short, precluding final conclusions to be drawn on the significance of these minor degenerative imaging findings and reported symptoms.

## Stress injuries of the calcaneus

Calcaneal stress injuries have previously been described in detail on the basis of radiographic findings (Hullinger 1944, Winfield 1959, Leabhart 1959, MacDonald 1966, Hopson 1977). These studies concluded that the injuries almost always occur in the posterior part of the bone. In the current study, calcaneal stress injuries were for the first time evaluated on the basis of MRI. The study revealed that, although the posterior part of the calcaneus is the most common location for these injuries, almost half of them can occur in the middle and anterior parts combined. The likely explanation for this finding is the better sensitivity of MRI for injuries located in the anterior and middle parts of the bone. The previous studies using radiography as a diagnostic method had failed to find injuries other than those in the posterior part of the bone. Furthermore, this study also evaluated the severity of the injuries, and the results showed that the lower grade injuries represented over half of all the injuries. Such evaluation was absent from the previous studies, because the low grades (I-III) are not detectable in radiographs.

This study also evaluated the healing time of the patients with calcaneal stress injuries. It was found the all the injuries seemed to eventually heal well with reduced exercise. It seems appropriate that these injuries be considered benign low risk injuries, since no displaced fractures or complications in healing were noted. However, the healing period often lasted from weeks to months, and in some cases interrupted the military service causing considerable hardship for the patients. This possibility should be taken into consideration when treating these patients, who might have benefited from an earlier diagnosis with MRI and adequate treatment at the initial stage of the injury.

**Stress injuries of the navicular, cuboid, cuneiforms and metatarsals**

Stress injuries in the navicular and especially the cuboid and cuneiforms have been considered rare in the previous literature (Franco 2005 Meurman 1980, Creighton 1990). The findings of the current study indicate, however, that albeit rare these injuries are not unseen. The study focused on patients who had an unclear diagnosis at the primary care stage, yet at a later examination, stress injuries were found in these patients in all the bones of the foot. Most importantly, the stress injuries were seldom solitary. On the contrary, in the majority of the cases, the injuries were multiple, affecting several bones of the region. This phenomenon reflects the very nature of stress injuries of the foot; they should not be considered as separate injuries but as part of a single larger injury condition affecting the entire area. The stress injuries of the foot were in other words closely associated with similar injuries in the surrounding bones.

# 7 CONCLUSIONS

All of the original articles highlighted the importance of MRI as the procedure of choice for diagnostic imaging of feet with exercise-induced pain. Among military recruits and athletes, long interruptions in training may be unacceptable and an early diagnosis is vital. A delay in diagnosis or inadequate pain management due to delayed MRI can result in prolonged symptoms lasting up to months, as the patients try to resume their exercise programme too soon. Early diagnosis by MRI and adequate treatment at an early stage may also help to prevent the permanent damage sometimes seen in the talus and navicular after stress fractures to these bones.

I)

MRI frequently reveals stress injuries not seen in radiographs. In a patient sample based on MRI, the talus and calcaneus are the two single bones most commonly affected by stress injuries of the foot. Stress injuries of the foot affect more than one bone in a majority of the cases.

II)

Stress injuries of the calcaneus most commonly affect the posterior third of the bone, where nearly half of these injuries are found, the other half occurring in the middle and anterior thirds of the bone combined. The majority of the injuries are low grade and do not exhibit a fracture line. All the injuries seem to heal well, although sometimes the healing can take up to months.

III)

The most common site for stress injuries in the talus is the head of the bone. Only one-fifth of the stress injuries in the talus are grade IV and display a fracture line on MRI. Although rare, stress injuries of the talus are not unseen in military recruits.

IV)

Treatment of stress fractures of the talus involving reduced exercise and short-term non-weight-bearing is likely to result in fairly satisfactory healing. Minor subchondral irregularities and edema in MRI and radiographs and minor symptoms can, however, be seen in roughly half of the patients in a middle-term follow-up.

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