PHYSICAL ACTIVITY AND OVERUSE INJURIES

FACTORS ASSOCIATED WITH THE AETIOLOGY AND MANAGEMENT OF OVERUSE INJURIES THAT OCCUR DURING PHYSICAL ACTIVITY WITH SPECIFIC REFERENCE TO BONE STRESS INJURIES AND THE ILIOTIBIAL BAND FRICTION SYNDROME

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for

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by

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DEDICATION

This thesis is firstly dedicated to the Lord Jesus Christ who is the author and sustainer of life, and whom I have accepted as my personal Lord and Saviour.

I would also like to dedicate this work to my loving wife Riana, my adorable son Peter, and my parents Immo and Lotte.

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DECLARATION

This thesis is the original work of the author, both in its conception and execution. The results of the work and ideas of others mentioned in the text are fully referenced. Where data, collected with the help of others in collaborative studies, has been reproduced, this has been with their full permission and I have fully acknowledged the source of such data.

Portions of the work described in this thesis have already been published or are in review:

1. Schwellnus M P, Jordaan G: Prevention of common overuse injuries by the use of shock absorbing insoles. A prospective study. Am J Sports Med, 1990; 18(6): 636-641.

2. Schwellnus M P, Theunissen L, Noakes T D, Reinach S G: Anti-inflammatory and combined anti-inflammatory/analgesic medication in the early management of iliotibial band friction syndrome. S Afr Med J, 1991; 79: 602-606.

3. Schwellnus M P, Jordaan G: Does calcium supplementation prevent bone stress injuries? A clinical trial. Int J Sports Nut, 1992; 2(2): 165-174.

4. Schwellnus M P, Mackintosh L, Mee J: Deep transverse frictions in the treatment of iliotibial band friction syndrome in athletes: A clinical trial. Physiotherapy (in press).

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ABSTRACT

Regular physical activity is an important component in the prevention and rehabilitation of chronic disease. Physical training also forms an integral part of the basic military training programme of recruits. The development of injuries, in particular overuse injuries, can negate the health benefits effects of regular physical activity or interfere with the basic training of military recruits. The aim of the research described in this thesis was to investigate specific factors in the aetiology, prevention and management of two common overuse injuries. The two injuries that were chosen were bone stress overuse injuries and the iliotibial band friction syndrome (ITBFS).

The first series of studies focussed on bone stress injuries and the following investigations were undertaken: i) to describe the epidemiology of overuse injuries in military recruits undergoing basic military training, ii) to document whether shock absorbing inner soles decrease the incidence of overuse injuries, in particular bone stress injuries during basic military training, and iii) to document whether calcium supplementation decreases the incidence of bone stress injuries during basic military training.

The studies on bone stress injuries were undertaken in a group of 1635 new military recruits that underwent 9 weeks of basic military training in the South African Defence Force. The recruits were randomly allocated to one of three groups: a control group (n=1151), a group receiving shock absorbing inner soles (n=237), and a group receiving 500mg of supplemental calcium daily (n=247). All injuries were monitored during the 9 weeks of training and all the recruits performed the same training.

The overall incidence of injuries sustained by recruits (n=1151) during 9 weeks of basic military training was 31.9% and most of the injuries were of the overuse type (86.4%). Over 80% of the injuries occurred in the knee, lower leg, foot and ankle. The single most common injury was the tibial bone stress reaction (0.33 injuries/1000 training hours), followed by the patellofemoral pain syndrome (0.22 injuries/1000 training hours) and the ITBFS (0.08 injuries/1000 training hours). The incidence of stress fractures was 0.07 injuries/1000 training hours. Bone stress injuries, including stress fractures, accounted for the greatest number of lost training days.

In the group of recruits that wore the shock absorbing inner soles there was a significant ($p<0.05$) reduction in the overall incidence (injuries/1000 recruits/week) of overuse injuries (Control, 36.3; Inner sole, 25.8), and tibial bone stress reactions (Control, 7.6; Inner sole, 2.8). There was also a tendency ($p<0.1$) for the incidence of stress

fractures to be lower in the inner sole group (Control, 1.4; Inner sole, 0.0). However, calcium supplementation did not decrease the incidence of bone stress injuries (injuries/1000 recruits/week) in recruits who were already consuming 800mg of dietary calcium per day (Control, 7.6; Calcium, 7.1). These studies therefore show that the high incidence of bone stress injuries is a major cause of morbidity and loss of training days during basic military training, but that it can be reduced by the wearing of shock absorbing footwear.

The second series of studies focussed on the ITBFS because it is a common injury that has not been well studied. The following specific investigations were undertaken: i) to determine whether there is an association between lower limb biomechanical abnormalities and the ITBFS, and ii) to study which are most effective modalities of treatment in the primary phase treatment of the ITBFS.

In the first study, lower limb biomechanical parameters were measured in 52 male and 8 female athletes with the ITBFS and 41 non-injured control athletes (males, 24; females, 17). In males there was a significantly ($p<0.05$) greater mean leg length difference (mm) (ITB, 5; Control, 1), prevalence of tibial varus (%) (ITB, 46; Control, 9) and mean Q angle (^{o}) (ITB, 14.5; Control, 11.3) in injured compared to control athletes. In female athletes, there was a significantly

($p<0.05$) greater mean forefoot varus (°) in the right (ITB, 6.6, Control, 3.1) and left (ITB, 6.6; Control, 2.4) limbs of the injured compared to the control athletes. These findings are novel and support the hypothesis that lower limb biomechanical abnormalities are associated with the ITBFS. The correction of these abnormalities by appropriate orthotics would be particularly important in the secondary phase of treatment of the ITBFS.

Two clinical trials were undertaken to study different treatment modalities in the primary phase treatment of ITBFS. A novel method of assessing the outcome of treatment in overuse injuries was developed for this purpose. In the first trial, physiotherapy (ultrasound and deep transverse frictions) alone ($n=13$) and combined with either an anti-inflammatory agent (diclophenac 50mg) ($n=14$) or an analgesic/anti-inflammatory agent (Myprodol) ($n=16$) was used in the first 7 days of treatment of the ITBFS. This trial demonstrated that physiotherapy combined with analgesic/anti-inflammatory medication was the most effective therapy to increase the ability of athletes to run further and longer with less pain after treatment. However, from this study it was not clear which of the two physiotherapeutic modalities (ultrasound or deep transverse frictions) was primarily responsible for the improvement.

A second clinical trial was therefore undertaken to compare the value of ultrasound treatment with (n=9) and without (n=8) deep transverse frictions in the primary phase treatment of ITBFS. There was a significant improvement ($p<0.05$) in the pain experienced during running in both treatment groups. No significant differences ($p>0.05$) were observed between the two groups. The results of these two clinical trials therefore show that physiotherapy (ultrasound) combined with analgesic/anti-inflammatory medication is the most effective primary phase treatment for ITBFS.

ABBREVIATIONS

AMP	Adenosine 5′ monophosphate
ARF	Activation/Resorption/Formation
ATP	Adenosine 5′ triphosphate
BGP	Bone GLA protein
BMU	Basic Multicellular Unit
BSU	Basic Structural Unit
cm	centimeter
CT	Computed Tomography
CSA	Cross Sectional Area
DB/BMU	Delta Bone turnover per BMU
DNA	Deoxyribonucleic acid
DTF	Deep Transverse Frictions
g	gram
GLA	Gamma-carboxyglutamic acid
GnRH	Gonadotrophin releasing hormone
hrs	hours
ITB	Iliotibial band
ITBFS	Iliotibial band friction syndrome

kg	kilogram
km	kilometers
MES	Minimum Effective Strain
mg	milligram
MRI	Magnetic Resonance Imaging
N/m^2	Newton per square meter
NSAIDS	Non-steroidal anti-inflammatory drugs
Pa	Pascal
PGE_2	Prostaglandin E_2
PTH	Parathyroid hormone
Q angle	Quadriceps angle
RDA	Recommended Dietary Allowances
TPBS	Triple Phase Bone Scan
uE	microstrain
USA	United States of America
W/cm^2	Watts per square centimeter

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CHAPTER 1

INTRODUCTION AND SCOPE OF THE THESIS

1.1. General background

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1.1. General background

Regular physical training is the cornerstone of preparation for any athlete for competition. It is also a major component of the training that military recruits undergo in preparation for military tasks (Brudwig et al, 1983; Giladi et al, 1985b; Gordon et al, 1986b; Greaney et al, 1983; Jones et al, 1989; Milgrom et al, 1985a; Stacy et al, 1984; Volpin et al, 1989). However, from a medical perspective, participation in regular physical exercise has in recent years been identified as a major component in the prevention and treatment of a variety of diseases (Aldrich, 1985; Belman et al, 1980; Blair et al, 1989; Bundgaard, 1985; Kohl et al, 1988; Leon et al, 1987; Paffenbarger et al, 1984; Poole, 1984; Richter et al, 1986; Shephard, 1986). It has been well documented that regular physical exercise is of particular value in the primary and secondary prevention of coronary artery disease - the major cause of mortality in Western populations (Derry et al, 1987; Oldridge et al, 1988; Paffenbarger et al, 1984; Thompson, 1988). Exercise prescription has therefore become an important therapeutic option available to medical practitioners in the management of disease. As a result there has been a dramatic increase in the number of individuals participating in regular physical activity over the last two decades.

Regular physical activity is however also associated with a substantial risk of musculoskeletal injury, in particular overuse injuries (Belkin, 1980; Clement et al, 1981; Herring et al, 1987; James et al, 1978; Macintyre et al, 1991; McKeag et al, 1989; Newell et al, 1984; Sheehan, 1977). Overuse injuries are particularly common in sedentary individuals who embark on a regular physical training programme such as running or basic military training. The development of injuries can often interfere with such a programme and therefore negate the potential benefit of regular training.

Although the epidemiology, clinical diagnosis, management and rehabilitation of overuse injuries have been the subject of many studies in Sports Medicine, there are still areas where scientific information is not available or is controversial. This thesis concentrates on some of these areas.

It has been well documented that overuse injuries are common in distance runners but they also occur in military recruits undergoing basic military training (Clement et al, 1981; Gordon et al, 1986b; Jones et al, 1989; Volpin et al, 1989). The incidence and nature of overuse injuries has recently been described in distance runners, but the epidemiology of overuse injuries during basic military training has not been well documented. This area therefore requires attention.

One of the most common and certainly the most debilitating overuse injury in distance runners as well as military recruits is the bone stress overuse injury. The clinical features, diagnosis, and management of bone stress overuse injuries are well described (Amman et al, 1991; Jones et al, 1989; Detmer, 1986). However, the challenge to the sports physician is to identify specific risk factors for this injury and to institute appropriate measures to prevent this injury.

It is well accepted that the mechanism of bone stress injury is repetitive force transmission through bone resulting in microdamage. Bone stress injuries occur when the rate of microdamage exceeds the rate of repair in the bone. Risk factors for this injury are therefore related to either increased rate of damage to bone or the inability of bone to repair the damage. The following specific risk factors for this injury have been identified; structural biomechanical abnormalities (James et al, 1978; Friberg, 1982) training errors (James et al, 1978; Myburgh et al, 1988; Richie et al, 1985; Sullivan et al, 1984), inappropriate or worn athletic footwear (James et al, 1978; Myburgh et al, 1988) and hard running surfaces (James et al, 1978; Sullivan et al, 1984).

Recently, it has been documented that there is an association between a low dietary intake of calcium and an increased risk of developing bone stress injuries in athletes (Myburgh et al, 1988). Furthermore, it has been suggested that increased dietary calcium intake may decrease the risk of developing bone stress injuries (Myburgh et al, 1990). However, the hypothesis that prophylactic calcium supplementation reduces the risk of bone stress injuries has not been tested in a well conducted clinical trial.

The rate of microdamage to bone can be decreased by wearing footwear with good shock absorbing properties. Although this has always been suggested as a specific measure to prevent bone stress injuries, it has not been well documented. In one clinical trial no significant reduction in the incidence of bone stress injuries could be demonstrated by wearing a sorbothane insole (Gardner et al, 1988). Although sorbothane is commonly used as a "shock absorbing insole" recent laboratory studies indicate that neoprene insoles (Spenco) reduce shock better than sorbothane (Brodsky et al, 1988). The choice of a better shock absorbing insole may therefore result in a significant reduction of bone stress injuries. This may be an important method of reducing the risk of bone stress injuries and requires investigation.

Iliotibial band friction syndrome (ITBFS) is also a common overuse syndrome that affects distance runners and military recruits (Orava, 1978; Sutker et al, 1985). The pathology of the injury is thought to be inflammation between the lateral femoral condyle and the iliotibial band as a result of repetitive friction between these two structures during walking or running (Noble, 1980; Orava, 1978). The risk factors for ITBFS have been studied and include i) extrinsic factors (training errors such as rapid increases in training frequency (Noble, 1980), distance and speed, hill training, running on one side of a cambered road and wearing incorrect shoes), and ii) intrinsic factors (Krissof et al, 1979; Lindenberg et al, 1984). Although specific intrinsic risk factors (biomechanical abnormalities) such as leg length discrepancy, cavus foot and rearfoot abnormalities have been identified, none of these have not been well studied. Reports that identify these abnormalities as risk factors did not include appropriate control groups (Lindenberg et al, 1984; Pinshaw et al, 1984). The precise identification of biomechanical abnormalities remains an important component of the clinical assessment of these patients because correction of these underlying abnormalities is a cornerstone of the secondary phase management of this condition.

The traditional management of ITBFS is twofold: i) treatment of the symptoms (primary phase treatment) and ii) identification and correction of underlying intrinsic (biomechanical) and extrinsic (training, footwear) abnormalities (secondary phase treatment) (Noble, 1980; Noble et al, 1982). The desire of the athlete is to return to sports activity as soon as possible. At present a wide variety of modalities are used in the primary phase treatment of the patient. These therapeutic options include the administration of anti-inflammatory medication or combined analgesic/anti-inflammatory medication. A number of different physiotherapy modalities such as ultrasound and deep transverse frictions are also used commonly. Despite the widespread use of these modalities in the primary phase management of ITBFS, no clinical trials have been conducted to evaluate their effectiveness. It is therefore important to obtain precise information on the clinical effectiveness of each of these treatment modalities.

1.2. Aims of the research

The aim of this thesis was to study specific aspects of overuse injuries that occur during physical activities such as distance running and basic military training.

The first study was conducted to describe the epidemiology of all overuse injuries that occur in military recruits during basic military training. This has not been well documented by previous research.

The remainder of the studies focussed on the aetiology and management of two common overuse injuries that occur as a result of participation in regular physical activity. The two overuse injuries that were studied were bone stress injuries and the iliotibial band friction syndrome (ITBFS).

Bone stress injuries were chosen because i) they are the most serious and debilitating overuse injuries for athletes and military recruits, and ii) very few studies have been conducted to investigate measures to prevent these injuries.

The aims of the research on bone stress injuries were therefore to investigate the effectiveness of preventing these injuries by i) reducing the rate of microdamage to bone by the use of shock absorbing insoles and ii) to improve the rate of microdamage repair by prophylactic calcium supplementation.

The iliotibial band friction syndrome was chosen because i) it is an overuse injury that appears to occur more and more frequently in distance runners and military recruits, ii) it is a condition where the intrinsic biomechanical risk factors associated with the injury have never been well documented, and iii) the modalities used in the primary phase of treatment of the condition have never been studied in well conducted clinical trials.

The aims of the research on ITBFS was therefore i) to identify specific intrinsic biomechanical risk factors in the aetiology of ITBFS and ii) to evaluate existing treatment modalities (anti-inflammatory medication, combined analgesic/anti-inflammatory medication and deep transverse frictions) that are currently used in the early phase management of ITBFS.

1.3. General format of the thesis

The thesis is divided into thirteen chapters. Chapter 2 serves as a general introduction to overuse injuries that occur during physical activity. Particular emphasis is however placed on overuse injuries in military recruits during training and distance runners because these were the populations that were studied in this research.

Chapter 3 describes research findings on the epidemiology of overuse injuries sustained by recruits during basic military training.

Chapters 4 and 5 deal with the current literature on the normal structure and function of bone and bone stress injuries respectively. The reports of two scientific investigations on the prevention of bone stress overuse injuries in military recruits are discussed in chapters 6 and 7.

Chapter 8 reviews the current literature on the iliotibial band friction syndrome (ITBFS). Chapter 9 describes research findings documenting lower limb biomechanical abnormalities that are associated with the iliotibial band friction syndrome. Chapter 10 describes a novel method that was designed to assess the outcome of clinical trials in lower limb overuse injuries more accurately. In chapters 11 and 12 the research findings from two clinical trials on the primary phase treatment of the ITBFS are described.

In chapter 13 the research findings and recommendations of the thesis are summarized.

Finally, the main findings of each chapter are summarized in point form at the end of the chapter for easy cross reference.

CHAPTER 2

EPIDEMIOLOGY OF OVERUSE INJURIES

2.1. Introduction

Injuries sustained during physical activity can be classified according to the anatomical site involved, the severity of the injury or the mechanism by which the injury occurred. However, the most common classification is either as acute (traumatic) or overuse (stress) injuries (Taimela et al, 1990). Acute injuries are associated with a sudden precipitating traumatic event which results in substantial tissue damage. The symptoms and physical signs of acute injuries are therefore most evident in the period immediately after the injury has occurred and there is progressive healing of tissues with appropriate treatment.

In contrast, overuse injuries develop gradually over a variable time period which can range from days to months.

The symptoms and physical signs of overuse injuries may not be evident immediately but become progressively more apparent with continued activity. These injuries are associated with repetitive force application to a tissue. This eventually results in significant tissue damage with the appearance of symptoms and physical signs (Herring et al, 1987; Stanish, 1984). The principles of management of overuse injuries are firstly to alleviate the symptoms and secondly, and more importantly, to identify and manage underlying aetiological factors. Failure to adequately do the latter results in recurrence of the injury. The focus of this thesis is on overuse injuries sustained during physical activity. Acute injuries will therefore not be discussed further.

Overuse injuries can occur in all forms of physical activity. The incidence, anatomical distribution, aetiological factors, mechanism, and management of overuse injuries differs between sports. This thesis focuses on bone stress injuries and the iliotibial band friction syndrome (ITBFS) which are two overuse injuries that commonly occur during military training and distance running. In order to place these two overuse injuries in perspective, the general epidemiology of overuse injuries in distance runners and military recruits will be discussed in this chapter. The epidemiology of the two specific injuries will be discussed in chapters 5.4. and 8.5. respectively.

Epidemiology can be defined as the scientific study of the frequency and determinants of disease or injury in a population (Noyes et al, 1988; Walter et al, 1990). Prior to World War II, epidemiological research focussed mainly on the control and the elimination of infectious and communicable diseases in populations (Wallace, 1988). In the late 1940's epidemiologists began to apply the concepts and methods of epidemiological research to the identification and prevention of accidents and injury patterns in populations (Gordon, 1949; McFarland, 1955). At that stage, the application of these principles had not yet been applied to the study of injuries related to physical activity. It was only in the late 1960's that data regarding injuries sustained during physical activity, in particular distance running and military training, started to appear in the medical literature. Unfortunately, these early reports were often characterized by methodological errors that are commonly encountered in epidemiological research of this nature (Table 2.1.). The most common errors were (Powell et al, 1986):

- failure to express the true incidence (new injuries that occur in the population over a specific time) or prevalence (number of injuries in a population at a specific time) in the population that was studied
- failure to define the injury adequately

Table 2.1.

Common methodological errors in sports injury epidemiological research

1. Injuries are not well defined
2. Definitions of incidence, prevalence and frequency of injuries are not described
3. Selection bias is introduced
4. Uniform observation techniques are not applied
5. The population at risk is not well defined
6. There is no well stated hypothesis
7. Bias is introduced by including or excluding dropouts
8. Recall bias is introduced

- failure to define the population that was studied adequately

The data obtained from these early studies can therefore often not be compared to those obtained from more recent reports.

Epidemiological research techniques, if correctly applied, form a very important component of the scientific study of injuries sustained during different forms of physical activity. In particular, the trends of injury patterns in different activities or in the same activity at different times can be identified, aetiological factors for injuries can be identified, and the effects of therapeutic intervention can be studied.

The epidemiology of overuse injuries in distance running and military training will now be reviewed. The discussion will be confined to the incidence of injuries in these populations, the anatomical sites affected by overuse injuries and general aetiological factors for overuse injuries. The specific aetiology of bone stress injuries and the iliotibial band friction syndrome will be reviewed in detail in chapters 5.6. and 8.7. respectively.

2.2. Epidemiology of overuse injuries in distance runners

2.2.1. Introduction

Distance running is a very common recreational and competitive sport worldwide. It is also a form of physical activity that is the basis of many preventative and rehabilitative exercise programs. However, distance running is also associated with a significant risk of developing an overuse injury. The incidence, anatomical distribution and general aetiological factors of overuse injuries in distance runners will now be discussed.

2.2.2. Incidence

Despite the popularity of distance running, precise scientific data pertaining to the incidence of injuries in this sport have only been obtained recently. Indeed, in a review of the literature in 1986, only three studies had at that stage been published from which the incidence of injuries in runners could be estimated (Powell et al, 1986). In that report, the importance of applying correct epidemiological research methods to obtain accurate data on the incidence of injuries in sport was emphasized. Prior to 1986 most studies on running injuries were in the form of case series (Clement et al, 1981; James et al, 1978; Orava, 1978; Pinshaw et al, 1984). These case series provided valuable insight into the nature and the anatomical distribution of injuries, but were of no value in estimating the incidence of injuries in a population of runners.

The incidence of overuse injuries in runners can be defined as the number of runners that develop new overuse injuries in a specified time period divided by the total population of at risk runners (Powell et al, 1986). Studies where such a definition of incidence has been applied vary with respect to, i) the definition of an overuse injury, ii) the population of runners studied, iii) the time period over which the study was conducted and, iv) whether the data was collected in a prospective or a retrospective manner. These differences in study methodology do not allow for comparison of incidence rates between all the different studies.

Furthermore, in most of the studies the method of data collection was by self-completed questionnaire. This method relies on, i) an adequate response rate to the questionnaire, ii) runners to interpret the definition of an injury correctly and iii) runners to provide the anatomical site of the injury accurately. These factors can all introduce bias in the estimation of true incidence rates. In most studies no clear distinction has been made between acute and overuse injuries. In a number of studies, the incidence of injuries in runners therefore refers to all injuries rather than overuse injuries alone.

Studies in which the incidence of injuries has been documented can also be classified as either prospective (Lysholm et al, 1987; Macera et al, 1989; Pollock et al, 1977; Walter et al, 1989) or retrospective (Jacobs et al, 1986; Koplan et al, 1982; Marti et al, 1988; Walter et al, 1988).

2.2.2.1. Prospective studies

Although some researchers have reported the incidence of running injuries during a single event such as a marathon (Kretsch et al, 1984; Maughan et al, 1983; Nicholl et al 1983), most investigators have chosen to study the incidence of running injuries in a population of runners over a period of one year to calculate the annual incidence. However, the incidence of running injuries can also be documented as the incidence per running exposure (number of running hours) (Bovens et al, 1989). The expression of incidence in this format takes into account the exposure to the "harmful" stimulus and therefore has particular advantages. It allows for an accurate comparison of incidence data between i) different populations of runners, ii) a variety of aetiological factors and iii) different sports. The disadvantage of this method of expressing the incidence is that it does not allow the documentation of exposure as a particular risk factor for injury. Very few studies have however documented the incidence of running injuries in this format.

One of the earliest prospective studies documenting the incidence of injuries during walking/jogging was reported in 1977 (Pollock et al, 1977). In this study 70 young men (ages 20-35) followed a walk/jog program for 20 weeks at 85-90% of their maximal heart rate. Subjects were assigned to one of six groups which differed with respect to frequency (30 min for 1, 3 or 5 times per week) or duration (3 times/week for 15, 30 or 45 min) of exercise. The 3 frequency study groups exercised on an asphalt track whereas the 3 duration study groups exercised on a motor driven treadmill. Injuries were recorded over the study period. The incidence of injury over the 20 week study period was 22%, 24%, and 54% in the 15-, 30-, and 45- minute groups respectively; and 0%, 12%, and 39% in the 1, 3, and 5 times a week groups respectively (Pollock et al, 1977). This study was the first show an association between an increased frequency and duration of exercise and an increased incidence of injury.

This study also documented accurate data on the hours spent on walking/jogging for each group. The incidence of injury per 1000 hours of participation can therefore be calculated. An analysis of the data in this manner reveals that the incidence of injuries during walking/jogging in this population was 0.11/1000 hours of walking/jogging. It is interesting to note that this injury rate is slightly higher than that reported for runners (0.07/1000 hours) that were studied as part of a large survey of sports injuries in a rural Swedish municipality (de Loes et al, 1988), but markedly lower than that documented for distance runners that were followed prospectively for one year or longer: 2.5/1000 hours (Lysholm et al, 1987); 7-12/1000 hours (Bovens et al, 1989). However, a true comparison between injury rates in these populations is not strictly valid because of differences in i) the definition of injury, and ii) the populations studied.

In three recent prospective studies the annual incidence of injuries in distance runners has been documented. In the first of these studies, 60 runners were followed for 1 year and all injuries were documented (Lysholm et al, 1987). An injury was defined as any injury that "hampered" training or competition for at least 1 week. The limitations of this study were i) a poor definition of injury, ii) a small sample size of male long distance runners (n=28) - the other runners were male and female sprinters and middle distance runners - and, iii) no clear distinction was made between acute and overuse injuries. In this group of male long distance runners the annual incidence of all injuries was 57%.

The annual incidence of injuries was also recently reported in a group (n=583) of habitual runners (Macera et al, 1989). This group, which consisted of runners that responded to an initial questionnaire by indicating their willingness to participate in the study, was followed prospectively for one year. All the injuries were documented. The definition of an injury was "a musculoskeletal ailment attributed to running that caused the runner to reduce the weekly mileage, take medicine, or visit a health professional". This definition was the same as that originally described by Koplan et al (1982) and subsequently used in other studies (Walter et al, 1988; Walter et al, 1989). This makes a comparison between the injury rates in these studies possible. The limitations of the study by Macera et al (1989) were i) the low response rate to questionnaires (60%), and ii) the failure to clearly distinguish between acute and overuse injuries. The annual incidence of all injuries in this population was similar for males (52%) and females (49%).

The largest prospective study to document the annual incidence of injuries in runners was conducted on a cohort of 1680 runners who were enrolled from a group of 2524 eligible runners participating in four different community running events (4km, 16km, 22,4km and a 5.6km relay) (Walter et al, 1989). Both males and females were included in the study. The definition of an injury was the same as that used in previous studies (Koplan et al, 1982, Macera et al, 1989, Walter et al, 1988). Furthermore, in this study it was possible to distinguish acute from overuse injuries. Overuse injuries accounted for 94% of injuries.

The annual incidence of injuries was 48.4% for the overall population (49.3% in males and 45.5% in females). It was interesting to note that at the onset of this study, the annual incidence of injury in this population was also determined retrospectively. The result of this determination of the annual incidence of injuries was 50.4%; which is very similar to the incidence documented in a prospective manner (48.4%). In this study, recall bias therefore did not appear to alter the determination of the annual incidence of injury, indicating that runners can reliably recall information regarding their running injuries.

In summary, only a few prospective studies have been conducted to document the annual incidence of injuries in runners. Despite differences in study design, the annual incidence of all running injuries appears to be remarkably consistent (approximately 50%) provided the same definition of injury is used and similar populations are studied. Little data are available on the incidence of overuse injuries in runners when it is expressed as injuries per number of running hours. This method of expressing the incidence has specific advantages when comparing incidences of injury in different populations of runners or between different sports.

2.2.2.2. Retrospective studies

The first retrospective study documenting the annual incidence of running injuries was reported in the medical literature in 1982 (Koplan et al, 1982). In this study 1250 males and 1250 females were randomly selected from over 25,000 entrants in a popular 10km road race. All the injuries that runners experienced in the preceding year were documented by means of a questionnaire. In this study the most frequently used definition of a running injury was first described. The limitations of this study were i) a low response rate to the questionnaire (55% for males and 58% for females), and ii) failure to distinguish between acute and overuse injuries. The annual incidence of all running injuries in this population was similar in males (37%) and females (38%).

The annual incidence of running injuries was also documented in Danish marathon runners (Holmich et al, 1989). In this study the definition of injury was not well documented but it was reported that 31% of all the marathon runners (n=1426) reported an injury that "prevented training" in the last year. The response rate to the questionnaire was only 68%.

In the largest survey on running injuries, the incidence of running injuries in the last year was documented in 4358 male joggers entering a 16km road race (Marti et al, 1988). The response rate to a questionnaire was 83.6%. The definition of injury was "any jogging injury that resulted in involuntary complete interruption of running of at least two weeks duration". No clear distinction was made between acute and overuse injuries. The annual incidence of injury in this population of male runners was 45.8%.

The annual incidence of injuries in a group of 688 runners who entered for a 16km road race was documented (Walter et al, 1988). The response rate to a questionnaire detailing injuries sustained during the last year was 69%. In this study injuries were defined in a similar fashion to that previously described (Koplan et al, 1982). No clear distinction was made between acute and overuse injuries. The annual incidence of injuries in this population was 57% with and no difference was noted between the incidence of injuries in male and female runners.

Finally, in a survey of a sample of 550 entrants to a popular 10km road race, the incidence of injuries over two years was documented as 46.6% (Jacobs et al, 1986). The data from this study can however not be compared to that of the previously mentioned studies because of the difference in the time period of the study.

In summary, data from retrospective studies show a wide variation (ranging from 31% to 57%) in the annual incidences of running injuries. It is likely that differences in study methodology, in particular differences in injury definition, the population of runners studied and recall bias could account for this variation. Finally, from prospective studies, it appears that the annual incidence of running injuries is high (approximately 50%). This is a fairly consistent finding despite some differences in study design and methodology. It is clear that the most consistent results were recorded in prospective study designs that have used the same definition of injury.

2.2.3. Anatomical distribution of injuries

Numerous studies have reported the frequency of injuries in different anatomical sites in distance runners. In general, these studies can be categorized as either case series or cohort studies (retrospective or prospective). Case series generally provide more accurate data on the precise diagnosis of the injuries, but are not representative of the injuries in the general distance running population. Furthermore, the anatomical distribution of injuries from different series or cohorts can not always be compared because of the way in which injuries have been categorized into various anatomical sites.

However, if injuries are categorized into seven broad anatomical regions, the data from thirteen studies can be summarized (Table 2.2.). The data from four of these studies is either incorrect (all the injuries not adding up to 100%) or incomplete and can therefore not be compared to the other nine studies. Most researchers have combined the injuries in male and female runners but in three studies separate data are available. The mean frequency of injuries (expressed as a percentage of all running injuries) in these anatomical regions, as obtained from all the available studies, is summarized in Table 2.3. The injuries to the knee, lower leg, ankle and foot account for approximately 75% of all the injuries in runners. The knee is the single most common area to be injured in all runners (26.6%), male runners (37.9%) and female runners (40.5%). The frequency of injuries in the lower leg and foot/ankle areas are similar and account for 20 to 25% of all running injuries respectively (Table 2.3.). In general, the anatomical distribution of running injuries does not differ between male and female runners (Table 2.3.).

In only a few studies have the relative frequencies of specific injuries in each anatomical region been documented (Clement et al, 1981; James et al, 1978; Newell et al, 1984;

Table 2.2.

The anatomical distribution of injuries (as a % of all injuries) in distance runners.

Authors	Study	Sex	Lower back	Hip/ pelvis	Upper leg	Knee	Lower leg	Foot/ ankle	Other	Comments
Clement et al, 1981	Case series	All	3.7	5.0	3.6	41.7	27.9	18.1		
		Males	3.3	4.2	3.5	42.2	27.2	19.6		
		Females	4.3	6.1	3.8	40.9	28.8	16.1		
James et al, 1978	Case series	All				34.0	24.0	7.0	6.0	Not complete data
Pinshaw et al, 1984	Case series	All			6.0	40.0	23.0	4.0	5.0	Not complete data
Kretsch et al, 1984	Case series	All	5.4	9.1	12.2	21.7	19.1	20.8	11.7	
Maughan et al, 1983	Case series	All	3.0	5.0	9.0	32.0	23.0	25.0	3.0	
Koplan et al, 1982	Retro-spective survey	All								
		Males	9.1	4.5	6.8	31.8	20.4	27.3		
		Females	6.3	6.3	6.3	29.2	18.8	33.3		
Marti et al, 1988	Retro-spective survey	All	2.2	6.1	5.0	27.9	29.2	28.5	1.1	
Walter et al, 1988	Retro-spective survey	All	6.0	13.0	9.0	23.0	22.0	22.0	5.0	

Table 2.2. (continued)

The anatomical distribution of injuries (as a % of all injuries) in distance runners.

Authors	Study	Sex	Lower back	Hip/ pelvis	Upper leg	Knee	Lower leg	Foot/ ankle	Other	Comments
Jacobs et al, 1986	Retro-spective survey	All			9.9	31.7	32.4	26.1		Not complete data
Lysholm et al, 1987	Prospec-tive survey	All	5.4	7.3	18.2	12.7	32.7	23.6		
Walter et al, 1989	Prospec-tive survey	All	11.0	9.0	7.0	27.0	12.0	31.0	4.0	
Krissof et al, 1979	Case series	All		7.0	6.0	25.0	40.0	35.0		Incorrect data
Macintyre et al, 1991	Case series	Male	4.4	9.9	7.7	39.8	21.9	16.4		
		Female	5.2	11.3	5.2	51.5	11.3	15.5		

Table 2.3.

The anatomical distribution of injuries (as a % of all injuries) in distance runners: A summary

Anatomical area	All runners *	Male runners #	Female runners #
Lower back	5.2	5.6	5.3
Hip/pelvis	7.8	6.2	6.9
Upper leg	9.1	6.0	5.1
Knee	26.6	37.9	40.5
Lower leg	23.7	23.2	21.6
Foot/ankle	24.1	21.1	20.6
Other	3.5	-	-

*: Mean frequency of injuries derived from studies 1, 4, 5, 7, 8, 10 and 11 (Table 2.2)

#: Mean frequency of injuries derived from studies 1, 6 and 13 (Table 2.2.)

Macintyre et al, 1991). A detailed discussion of the frequencies of specific injuries in each region is beyond the scope of this thesis but the relative frequency of occurrence of bone stress injuries and the iliotibial band friction syndrome in distance runners will be discussed in chapters 5.4. and 8.5. respectively.

2.2.4. General aetiological factors for injuries in runners

2.2.4.1. Introduction

There are multiple aetiological factors for injuries in distance runners. These can be divided into general factors for all injuries and specific factors for individual injuries. In this section the discussion will be confined to general aetiological factors for all injuries. The specific aetiological factors associated with bone stress injuries and the iliotibial band friction syndrome will be discussed in detail in chapters 5.6. and 8.7. respectively.

It is common for the aetiological factors associated with running injuries to be classified as extrinsic or intrinsic (Herring et al, 1987; Renstrom et al, 1985; Stanish, 1984; Taimela et al, 1990). Extrinsic aetiological factors refer to factors that are independent of the runner and are related to training, equipment and/or the environment. Intrinsic factors refer to abnormalities inherent to the runner and are usually genetically determined. These include age, gender, race and biomechanical abnormalities of the runner. Common extrinsic and intrinsic aetiological factors associated with running injuries are listed in Table 2.4.

Many researchers have attempted to relate aetiological factors to the development of running injuries in case series (Clement et al, 1981; James et al, 1978; Kretsch et al, 1984; Krissof et al, 1979; Pinshaw et al, 1984). The limitations of case series to determine aetiological factors has already been discussed (Section 2.2.2.). In recent years a few researchers have reported the association between specific risk factors and the development of all running injuries in well conducted epidemiological studies (Powell et al, 1986). The current evidence derived from epidemiological studies that documented the association between extrinsic and intrinsic aetiological factors and running injuries will now be reviewed briefly. A detailed discussion on the complex interaction that may exist between these different aetiological factors (Powell et al, 1986) is however beyond the scope of this thesis.

Table 2.4.

General risk factors for running injuries

Extrinsic:

- Training errors
  - excessive training volume (distance, frequency)
  - excessive training intensity
  - incorrect technique (warm-up, stretching)
  - excessive hill training

- Training surfaces

- Environmental conditions

- Footwear and equipment

Intrinsic:

- Age

- Sex

- Abnormal alignment of the lower limb

- Muscular abnormalities
  - muscle weakness
  - muscle imbalances

2.2.4.2. Extrinsic aetiological factors and running injuries

2.2.4.2.1. Training errors

The most consistent documented aetiological factor in the development of injuries in runners is an increase in training volume (Macera, 1992). An increase in training volume can be defined as an increase in the duration and/or the frequency of training. It is commonly measured as training distance per week or the number of training sessions per week.

The association between training duration (min), training frequency (number of times per week) and the development of injuries in jogging was first documented in 1977 (Pollock et al, 1977). The association between increased training volume the risk for the development of a running injury has now been documented in numerous studies (Macera, 1992). This has been a fairly consistent finding despite differences in the expression of training volume between studies. Training volume has been described as increased weekly mileage (Jacobs et al, 1986; Koplan et al, 1982; Marti et al, 1988; Samet et al, 1982; Walter et al, 1989), number of days run per week (Jacobs et al, 1986), or running > 64km/week (Macera et al, 1989).

The association between training speed and injury risk has also been investigated. In most studies no association between training speed and injury risk could be documented (Koplan et al, 1982; Marti et al, 1988; Walter et al, 1989). In only two reports a faster running speed was reported as a risk factor for injury (Jacobs et al, 1986; Samet et al, 1982).

Other training errors such as excessive hill training, inadequate warm-up and poor stretching technique have not been associated with an increased risk of injury in runners (Jacobs et al, 1986; Walter et al 1989).

2.2.4.2.2. Training surfaces

In general, there is little epidemiological evidence to support the association between the type of training surface and the risk for injuries (Jacobs et al, 1986; Macera, 1992; Marti et al, 1988). However, there are two reports where training surface has been associated with the risk for injury.

In the first study, the calculated incidence of injury per 100 hours for joggers training on a treadmill was 0.16/1000 hours compared to the incidence when training on an asphalt track (0.06/1000 hours) (Pollock et al, 1977). This indicates the importance of training surface as a possible aetiological factor in jogging injuries. However, it must be emphasized that these calculations are not derived from the original data but only from published data (Pollock et al, 1977) and must therefore be interpreted with caution.

In the second study, it has been documented that running on concrete surfaces was associated with increased risk of injury in female runners (Macera et al, 1989).

2.2.4.2.3. Environmental conditions

The association between different environmental conditions and running injuries has not been well documented. However, in one report, injuries were more common in spring and summer compared to winter and autumn (Lysholm et al, 1987). However, in this study the possibility that an increase in training volume, which usually occurs in spring and summer, could account for this finding was not excluded.

2.2.4.2.4. Footwear and equipment

There is a lack of epidemiological evidence to support the possible association between footwear and running injuries. Indeed, no association between the physical characteristics of running shoes (varus wedge, waffle sole, sole wear pattern, personal shoe repairs) and injuries could be documented (Marti et al, 1988; Walter et al, 1989).

2.2.4.3. Intrinsic aetiological factors and running injuries

2.2.4.3.1. Age

There is no epidemiological evidence to support the hypothesis that running injuries are more common in older age groups (Jacobs et al, 1986; Koplan et al, 1982; Macera et al, 1989; Macera, 1992; Marti et al, 1988; Walter et al, 1989; Walter et al, 1988). In two reports a significantly lower risk of injury was documented in older runners (Marti et al, 1988; Samet et al, 1982). In this study, possible selection bias was eliminated by an age-adjusted analysis of the risk of injuries in runners (Marti et al, 1988).

2.2.4.3.2. Gender

There is no epidemiological evidence to support the hypothesis that the risk of injuries differs between male and female runners (Jacobs et al, 1986; Koplan et al, 1982; Macera et al, 1989; Macera, 1992; Samet et al, 1982; Walter et al, 1989; Walter et al, 1988). Differences in the training habits of males and females have however been reported (Jacobs et al, 1986).

2.2.4.3.3. Abnormal alignment of the lower limb

The hypothesis that abnormal lower limb alignment is associated with an increased risk of injuries in runners is generally accepted. This stems from observations reported in case series of running injuries and generally lacks scientific support. The postulated abnormalities of lower limb alignment in injured runners are, excessive and prolonged subtalar joint pronation, forefoot varus or valgus, rearfoot varus or valgus, tibial varus or valgus, genu varus or valgus, large quadriceps angle, femoral anteversion, and leg-length discrepancy (Clement et al, 1981; James et al, 1978; Krissof et al, 1979; Newell et al, 1984; Pinshaw et al, 1984). Although there is evidence that some of these abnormalities are associated with specific running injuries, there is no epidemiological study to date that has adequately investigated the association of these abnormalities and the risk of all running injuries.

2.2.4.3.4. Muscle abnormalities

Although it has been postulated that muscle weakness, muscle imbalances and muscle fatigue are associated with the development of injuries in distance runners, there is no epidemiological evidence to support this.

2.2.4.3.5. Other factors

A previously injured runner may be more likely to develop a recurrent injury because i) the original cause may still be present, ii) the repair tissue may not function as well or be less protective that non-injured tissue or, iii) the injury may not have healed adequately (Powell et al, 1986). The association between a previous running injury and the increased risk of developing a new running injury has recently been confirmed (Macera et al, 1989; Macera, 1992; Marti et al, 1988; Walter et al, 1989).

It has been postulated that inexperienced runner are more prone to injury because of poor adaptation of the tissues or because of improper running techniques (Clement et al, 1981). Recent epidemiological data has shown either no association between injury risk and years of running experience (Jacobs et al, 1986; Koplan et al, 1982; Walter et al, 1989) or an increased risk of injury in less experienced runners (Macera et al, 1989; Marti et al, 1988).

Individual psychological susceptibility has also been postulated as a risk factor for running injuries. In two recent studies, the competitive nature in runners has been associated with an increased risk for injury (Marti et al, 1988; Walter et al, 1989). The association between body size and the risk for developing running injuries has also been investigated. In one study either a low or a high body mass index was associated with an increased risk for injury (Marti et al, 1988), whereas in two other reports no such association was documented (Koplan et al, 1982; Walter et al, 1989). Finally, the association between the risk of developing a running injury and the participation in other sports has also been investigated. Runners who also participate in other sports have been shown to have a lower risk for the development of a running injury in one study (Jacobs et al, 1986), but not in others (Marti et al, 1988; Walter et al, 1989).

2.2.5. Summary: Epidemiology of overuse injuries in runners

The epidemiology of overuse injuries in distance runners was first studied by means of case series. More recently, retrospective and prospective studies have been conducted. An annual incidence of injuries in distance runners of 50% has been fairly consistently reported in well conducted prospective studies provided the same definition of injury was used, and similar populations were studied. In case series, the anatomical distribution of injuries in distance runners has been documented. The knee, lower leg, ankle and foot account for over 75% of all injuries in distance runners. The single most common area to be affected is the knee (27%). The most consistent general aetiological factors associated with overuse injuries in distance runners is increased training volume. Other aetiological factors are training surface, previous injury and body size. Factors such as footwear, lower limb biomechanics and muscle strength have not been well investigated, while age and gender do not appear to affect the risk for injury.

2.3. Epidemiology of overuse injuries in military recruits

2.3.1. Introduction

Physical training is an integral part of basic military training and serves to prepare the soldier for the physical demands placed on him/her during combat. Basic military training incorporates a variety of strenuous exercises including marching, running and calisthenics. These are conducted regularly (usually 5 days per week) by new recruits over a period of usually 8-10 weeks (Giladi et al, 1985b; Gordon et al, 1986a; Kowal, 1980; Stacy et al, 1984). During this period, recruits are injured frequently. The most common injuries sustained by recruits are overuse injuries (Gordon et al, 1986b). The incidence and anatomical distribution of overuse injuries in military recruits undergoing basic military training will now be reviewed briefly.

2.3.2. Incidence

There is little accurate scientific data on the true incidence of overuse injuries in military recruits undergoing basic training. Most of the studies on injuries in this population have only reported the incidence of stress fractures (Brudvig et al, 1983; Giladi et al, 1985a; Giladi et al, 1985b; Jones et al, 1989; Milgrom et al, 1985a; Milgrom et al, 1985b; Reinker et al, 1979; Scully et al 1982; Volpin et al, 1989) or sprain/strain injuries (Marcinik, 1986; Marcinik et al, 1987) and have ignored the occurrence of other overuse injuries. Indeed, only four published studies and one recently presented abstract (Jones et al, 1991) have reported the incidence of all overuse injuries in military recruits undergoing training. Unfortunately, the data obtained from these studies can not be compared because i) different definitions of injury were used, ii) the exposure to training was variable, and iii) the diagnostic criteria that were used for the injuries were not reported accurately.

The most comprehensive study documenting the incidence of all overuse injuries in basic military training was conducted in the South African Defence Force from July 1982 to July 1983 (Gordon et al, 1986b). In this study, the incidence of overuse injuries (defined as an injury sustained during training and preventing return to normal duties for at least one day after medical consultation) was documented as 3.24/1000 recruits over a 10 week training period (Gordon et al, 1986b).

In an abstract presented at the 1991 American College of Sports Medicine Meeting, the incidence of injuries (not defined) sustained by 124 male military recruits during 8 weeks of basic military training was 27.4% (Jones et al, 1991). In another report, the incidence of "work related injuries" (not well defined) during a 10 week basic military training period was 8.55/1000 recruits (Stacy et al, 1984). The incidence of overuse injuries sustained during basic military training has also been reported as 75/1000 and 260/1000 in two studies where the training periods were 16 and 8 weeks respectively (Reinker et al, 1979; Kowal, 1980). In the latter two studies the definition of injury also differed from the previously mentioned reports. The value of the data from all these studies would have been greatly enhanced if i) a similar definition of injury was used and ii) the exposure to training (hours of training) was recorded more accurately.

In only two of these studies data were available on the hours spent on vigorous physical training over the study period. It was therefore possible to calculate the incidence of injury per 1000 training hours. In the first study, the data on physical training hours per week (excluding marching and field exercises) for the same study population was reported elsewhere (Gordon et al, 1986a). The incidence of overuse injury for this population could then be calculated as 8.1/1000 training hours. In the second study, the injury rate (injuries per 1000 training hours) could also be estimated provided training hours that have been classified as "mild training hours" were excluded. In this study "mild training" was defined as classroom activities or training where little physical stress was applied to the recruit and is therefore unlikely to contribute to injury risk (Stacy et al, 1984). The calculated incidence of overuse injuries in this study was 10.1/1000 training hours which is comparable to that calculated for the first study. It is important to note that these rates are very similar despite the substantial difference in incidence rates when these are expressed as injuries/1000 recruits over a 10 week period. This emphasizes that the time of exposure to the training is an important factor to consider in calculating incidence rates.

In summary, the incidence of overuse injuries expressed as injuries/1000 training hours has not been well documented in military recruits. The reasons are that studies differ with respect to injury definitions, diagnostic criteria for injuries and the expression of true incidence rates per exposure time. However, it can be estimated that the incidence of overuse injuries in military recruits is between 8-10/1000 training hours when these rates are calculated from published data.

2.3.3. Anatomical distribution of injuries

A number of studies have reported overuse injuries that occur during basic military training. However, most of these have concentrated only on a single injury or on one anatomical region and have not considered all overuse injuries (Brudvig et al, 1983; Carlson, 1944; Fleming, 1988; Gardner et al, 1988; Giladi et al, 1985a; Giladi et al, 1985b; Hullinger, 1944; Kujala et al, 1986; Milgrom et al, 1985a; Milgrom et al, 1985b; Scully et al, 1982; Stacy et al, 1984; Tomlinson et al, 1987; Volpin et al, 1989).

In the only published study to date, 330 overuse injuries were recorded in different anatomical regions over a period of 10 weeks basic military training in the South African Defence Force (Gordon et al, 1986b). The frequency of overuse injuries (% of all overuse injuries) recorded in this study are summarized in Table 2.5. In this study the most common anatomical site for an overuse injury was the knee (34%), followed by the lower leg (24%) and the Achilles tendon (12%). Injuries in other anatomical sites were less common.

In two other published studies and one published abstract (Linenger et al, 1991) overuse injuries in different anatomical sites were also recorded. The data from the published studies can not be compared to that of Gordon et al (1986b) because i) the one study was conducted on female recruits (Kowal, 1980), and ii) only severe injuries requiring specialist evaluation were reported in the other study (Reinker et al, 1979). Furthermore, in both these reports, injuries were not always clearly documented for all the anatomical regions and a large proportion were collectively grouped as "other" injuries.

In the published abstract, soft tissue and musculoskeletal injuries sustained by military recruits undergoing basic training were reported (Linenger et al, 1991). In this report, the lower limb was involved in 86% of all injuries, with the most frequent anatomical site being the knee (50% of injuries). The incidences of specific injuries in this study were iliotibial band syndrome (22.4%), patellar tendonitis (15%) and mechanical back pain (11.4%).

It is clear from all these reports that, with the exception of stress fractures, there is little data available on the incidence of specific overuse injuries in each anatomical area. There is therefore a need to obtain data on the specific overuse injuries that occur in military recruits undergoing basic military training.

Table 2.5.

Anatomical distribution of overuse injuries in military recruits undergoing basic military training

Anatomical area	Frequency of injury (% of all overuse injuries)
Lower back	11
Hip/pelvis	2
Upper leg	2
Knee	34
Lower leg	36
Foot/ankle	14
Other	1

Adapted from: Gordon et al, 1986b

In summary, there are few accurate data available on the anatomical areas affected by overuse injuries in military recruits undergoing basic military training. It appears that the knee, lower leg and Achilles tendon are commonly affected. However, with the exception of stress fractures, the frequency of specific overuse injuries in these anatomical areas is not well documented.

2.3.4. General aetiological factors for overuse injuries in military recruits

2.3.4.1. Introduction

The general aetiological factors for overuse injuries in military recruits can also be classified as either extrinsic or intrinsic. The terms extrinsic and intrinsic have already been defined (section 2.2.4.1.). In general, most studies in military recruits have been conducted to document the causes of bone stress injuries only, and have largely ignored the aetiological factors associated with overuse injuries in general. The aetiological factors associated with bone stress injuries will be discussed in detail in Chapter 5.6.

2.3.4.2. Extrinsic factors associated with overuse injuries in military recruits

It has been postulated that the extrinsic factors associated with injuries in distance runners such as training errors, training surfaces, footwear and equipment are also causes of injuries in military recruits (Jones, 1983; Gordon et al, 1986b).

The effects of training errors, training surfaces and footwear on the incidence of overuse injuries in military recruits has not been well documented. The reasons for this are that military training in a particular unit or camp, where most studies are conducted, is standardized and military officials are usually reluctant to alter training programs. It is also not possible to compare the incidences of overuse injuries between different units or camps because i) precise details on the frequency, intensity and duration of training are mostly not described, ii) all overuse injuries have mostly not been documented, and iii) the incidences have not been expressed as weekly or monthly incidences so that these can be compared. A number of studies have been conducted to study the effects of training errors and footwear on the incidence of bone stress injuries in military recruits. These studies will be discussed in detail in Chapter 5.6.

In has been reported in one study that the introduction of a variety of measures to decrease extrinsic risk factors reduced the incidence of lower limb musculoskeletal injuries in female military recruits by 50% (Reinker et al, 1979). These measures included i) eliminating running and marching on concrete surfaces, ii) a change in the type of military boot, and iii) spreading the physical training over the entire cycle with a gradual introduction of stressful activities. This study provides indirect evidence that a combined alteration in training, surfaces and footwear (extrinsic factors) can decrease the incidence of all overuse injuries. However, this study does not identify which of the factors was primarily responsible for the reduction of injuries.

The results from two recent studies, which were presented at the 1991 American College of Sports Medicine meeting, provide some evidence that i) more frequent weight-bearing training (more times per week) (Reynolds et al, 1991), and ii) increased exposure to running (running miles per week) (Cowan et al, 1991) increase the risk for injury during military training.

The specific effect of changes in the footwear on the incidence of overuse injuries during basic military training has been studied in the New Zealand Army (Stacy et al, 1984). In this study the following measures were introduced during basic military training: i) the elimination of training in boots for the first five weeks of training, ii) the gradual introduction of boots thereafter, and iii) the use of approved running shoes during organized physical training. These measures reduced the incidence of overuse injuries from 86% to 53% over the 10 week training period. This study provides evidence to indicate that footwear is associated with the aetiology of overuse injuries in military recruits.

2.3.4.3. Intrinsic factors associated with overuse injuries in military recruits

It has been documented that intrinsic factors such as age, gender, race, lower limb biomechanics, pre-training fitness and previous injury are associated with specific overuse injuries such as bone stress injuries (Chapter 5.6.). However, very few studies have been conducted to document the association between specific intrinsic factors and the incidence of overuse injuries in general.

In one prospective study the incidence of all injuries sustained during 16 weeks of basic military training was significantly higher in female (16.3%) compared to male (7.5%) recruits (Reinker et al, 1979). This higher incidence in female recruits could not be attributed to differences in height, weight or age. However, 50% of the female recruits wore an inferior boot compared to that used by male recruits and the authors acknowledged that this may have contributed to the increased incidence of injuries in female recruits. The data were not unfortunately not analyzed separately for the female recruits with the two types of boots. The results from this study, at best, can only suggest that the female gender may be associated with an increased risk of overuse injuries.

In an abstract that was presented at the 1991 American College of Sports Medicine meeting, the incidence of injuries sustained during 8 weeks of military training was reported as 44.6% and 20.9% in female (n=186) and male (n=124) military recruits respectively. However, when the incidences were corrected for "aerobic fitness", no differences in the incidences between male and female recruits were observed. The authors suggested that gender is not an independent risk factor for injury during military training.

It has been reported that an increased body weight and body fat, decreased leg strength and poor physical conditioning were associated with an increased risk of injury during 8 weeks of basic military training in female recruits (Kowal, 1980). However, in this study the differences between injured and non-injured recruits were only significant ($p<0.05$) for percent body fat (injured, 28.4 ± 4.9%; non-injured, 27.7 ± 4.4%) and static muscle strength of the leg extensors (injured, 91.2 ± 32kg; non-injured, 95.7 ± 28kg). Furthermore, it must be noted that although these differences were statistically significant, the absolute differences are very small. However, in a recent report, the association between poor physical fitness in military recruits (slow 2-mile running time and low number of sit-ups in 2 minutes) and an increased risk for injury was documented (Knapik et al, 1991).

In one well conducted prospective study a variety of intrinsic factors were documented in 505 male trainees prior to the first 8 weeks of training at the Basic Underwater Demolition/SEAL School at the U.S. Naval Special Warfare Center in Coronado, California (Montgomery et al, 1989). An orthopaedic history was taken and a lower limb examination was performed before the onset of training. In this study no association was found between all overuse injuries sustained during training and lower limb flexibility, knee alignment (varus, valgus, normal), foot type (cavus, normal, planus) or previous training. However, lack of previous training was associated with the risk of bone stress injuries.

The association between overuse injuries during military training and specific intrinsic risk factors has not been well documented. Although there is some evidence to suggest that there is an association between the risk of overuse injuries and gender, percent body fat, muscle strength, poor physical conditioning and previous training, this requires further investigation.

2.3.5. Summary: Epidemiology of overuse injuries in military recruits

Overuse injuries frequently occur in military recruits undergoing basic military training. Despite this, there is very little scientific data on the true incidence of all overuse injuries in this population. The comparison of injury rates between different studies is not possible because of differences in methodology and poor application of epidemiological research principles. Most researchers have concentrated on stress fractures and little data is available on the incidence, anatomical distribution and specific diagnosis of overuse injuries other than stress fractures in military recruits. The general aetiological factors associated with overuse injuries in military recruits have also not been well documented. Extrinsic factors (footwear and training errors) as well as intrinsic factors (gender, percent body fat, poor muscle strength and lack of physical conditioning) have all been identified as possible aetiological factors associated with overuse injuries in military recruits.

2.4. Summary: Chapter 2

- In this chapter the epidemiology of overuse injuries in distance runners and military recruits was reviewed.
- The annual incidence of injuries in distance runners is approximately 50%.
- Over 75% of injuries in distance runners occur in the knee, lower leg, ankle and foot.
- The most common anatomical area to be injured in distance runners is the knee (27%).
- The most consistently documented general aetiological factors associated with injuries in distance runners are increased training volume and previous injury.
- There are major methodological differences between studies that have documented injuries during military training.
- The precise incidence of injuries in military recruits during military training has not been well documented.
- Over 80% of injuries in military recruits occur in the knee, lower leg, ankle and foot.
- The most common anatomical area to be injured in military recruits is the lower leg (36%).
- The general aetiological factors associated with injuries in military recruits have not been well studied.

CHAPTER 3

AN INVESTIGATION OF THE EPIDEMIOLOGY OF OVERUSE INJURIES IN MILITARY RECRUITS DURING BASIC MILITARY TRAINING

3.1. Introduction
3.2. Aims of the investigation
3.3. Methods
3.4. Statistical analysis
3.5. Results
3.6. Discussion
3.7. Summary

3.1. Introduction:

The epidemiology of overuse injuries in distance runners, in particular the incidence of overuse injuries, has recently been well documented (Chapter 2.2.). However, there are few accurate data on the epidemiology of overuse injuries in military recruits undergoing basic military training (Chapter 2.3.). Most researchers have only investigated the incidence of stress fractures in this population, and have largely ignored the occurrence of other overuse injuries (Chapter 2.3.).

The incidence of all injuries sustained during basic military training has only been reported in four studies to date (Gordon et al, 1986b; Kowal, 1980; Reinker et al, 1979; Stacy et al, 1984). The details of these studies have already been discussed (Chapter 2.3.2.). It is important to note that the incidence of injuries recorded in these studies can not be compared because i) the definition of an injury was not always well described and differed between studies, ii) the training periods varied, iii) incidences were not expressed as injuries per week or per hours of training, and iv) the type of training (formal physical training, marching or field training) was not accurately defined.

The expression of the incidence of injuries as a mean weekly incidence would allow for comparison of data from different training periods. Furthermore, the expression of the incidence of injuries as injuries/1000 training hours would make comparisons between different types of training programmes and other sporting activities possible.

The anatomical distribution of overuse injuries in military recruits undergoing basic military training has only been reported in one study (Gordon et al, 1986b). However, in that study data on the incidence of specific overuse injuries were not presented. A variety of specific overuse injuries have been described in both civilian and military populations (Clement et al, 1981; Detmer, 1986; James et al, 1978; Jones et al, 1989; Jones et al, 1987; Kowal, 1980). These injuries include the patellofemoral pain syndrome, tibial bone stress injuries, Achilles tendonitis, patellar tendonitis and the iliotibial band friction syndrome (Clement et al, 1981; James et al, 1978; McKeag et al, 1989; Taunton et al, 1988). However, the incidence of these injuries in military recruits during basic military training has not been documented.

3.2. Aims of this investigation

The main aim of this study was to investigate the epidemiology of all overuse injuries in military recruits undergoing basic military training. This study differs from previous studies in that the incidence of overuse injuries is not only expressed as a percentage of all the recruits that were injured over the training period but also as i) a mean weekly incidence of injuries, and ii) the number of injuries per 1000 hours of formal training. A secondary aim was to document the incidence of the specific common overuse injuries during basic military training.

3.3. Materials and methods

3.3.1. Subjects

One thousand two hundred and sixty-one (1261) new military recruits acted as subjects. These recruits were selected from 1761 Caucasian male recruits that reported for basic military training at the Potchefstroom Military Base (South Africa) in February 1989. Transfers to other units during the study period resulted in the loss of 110 recruits from the original study population (8.7% dropout rate). The final number of recruits studied was therefore 1151.

Prior to entering the study all the recruits were examined by medical staff of the South African Defence Force and declared medically fit for duty. In particular those with one or more gross biomechanical abnormality or a history of previous major injury or illness were not included as subjects. The height and body weight was determined in a random sample (n=129) of the group using standard measurement techniques.

3.3.2. Training

All the recruits performed basic military training during February 1989 to April 1989 for a period of 9 weeks. All underwent physical training according to a specific predetermined programme. There were three main categories of physical training: i) formal physical training sessions 3-5 times a week, ii) marching, and iii) field training consisting of route marches and battle tactics training. The number of hours that recruits spent on training in each category was carefully documented every week during the study period. The formal training programme consisted of organized 60-90 minute group training sessions under the guidance of trained instructors. The recruits started with a warm-up which was then followed by group training activities that included jogging, sprinting, and calisthenics. The details of the field training is classified information and can therefore not be discussed in this thesis.

3.3.3. Footwear

All the recruits wore standard military footwear (Boot with leather upper and rubber sole) during march and field training; standard running shoes were worn during formal physical training sessions. Care was taken to ensure that the footwear fitted well.

3.3.4. Injuries

For the purposes of this study an injury was defined as an occurrence resulting from physical conditioning during basic training that was severe enough to prevent return to normal activities for at least one day after medical consultation. This definition was chosen because it was the one used in the only other study that documented the anatomical distribution of overuse injuries in this population (Gordon et al, 1986b). Severe injuries were classified as those that prevented return to normal activities for 4 days or longer; less severe injuries prevented return to normal activities for 3 days or less. Injuries were classified as overuse if they were not associated with a sudden precipitating event; the latter were regarded as acute traumatic injuries (Greaney et al, 1983).

All the injuries during the 9 weeks were monitored by the author. All the injured recruits reported to the Base Hospital where the diagnosis was established and treatment instituted by a panel of eight doctors. Before the experimental period, uniform diagnostic criteria were established for six common overuse injuries (stress fractures, tibial bone stress reactions (syndrome), patellofemoral pain, iliotibial band friction syndrome, patellar tendonitis, Achilles tendonitis). The criteria that were used to diagnose injuries are described in Appendix A.

Due to financial constraints it was not possible to perform bone scans on all the recruits presenting with bone pain. Bone stress reactions (stress syndromes) were therefore diagnosed on the basis of clinical criteria. Stress fractures were diagnosed on the basis of symptoms and clinical signs and confirmed by repeated X-Ray studies (at the time of the injury and repeated at least 14 days after the injury) (Murray et al, 1971; Weissman et al, 1986).

All the injuries were recorded by the examining doctors on specific injury report forms (Appendix B). The injury report forms were collected weekly by the author and the data were analyzed on completion of the study. The incidence of injury was calculated as i) the overall injury rate over the study period (% of recruits injured) for comparison with previous studies, ii) a weekly injury rate (% of recruits injured per week), and iii) an injury rate per hours of exposure to physical training (injuries/1000 training hours).

Data were also collected on the number of training days lost as a result of each injury. These data were expressed as i) the total number of days lost for each anatomical area injured, and ii) the training days lost per injury or anatomical area that was injured. The latter calculation provides an estimate of the impact that specific injuries have on the training time of a recruit.

3.4. Statistical analysis

All the data were analyzed on a personal computer using STATGRAPHICS software (Version 4.0) (STSC, Inc, Maryland, USA). Standard descriptive statistics were performed on the data.

3.5. Results

3.5.1. Physical characteristics

The age (mean ± SD) of the recruits was 18.5 ± 1.2 years (range: 17-25). The heights and body weights of the subsample of recruits were 178.6 ± 6.9 cm and 70.1 ± 11.4 kg respectively (mean ± SD).

3.5.2. Training

The total hours of physical training per week as well as the proportion (%) of training time devoted to the three categories of physical training (formal physical training, marching and field training) are depicted in Table 3.1. In the nine week period the 1151 recruits performed a total of 203 670 hours of physical training. The total number of training hours in each category of physical training was: formal physical training (16 620 hours; 8.2%), marching (43 410 hours; 21.3%) and field training (143 640 hours; 70.5%).

The physical training in weeks 1 to 5 and week 9 was mostly marching (77-100% of the total training time) with little formal physical training (7-23 % of the total training

Table 3.1.

The physical training programme during basic military training: The total hours of training per week and the proportion (%) of training time devoted to categories of training (physical training, marching, field training)

Week	Physical training	Marching	Field training	Total
1	1493 (23%)	4975 (77%)	-	6468
2	2725 (23%)	9082 (77%)	-	11807
3	1814 (11%)	14911 (89%)	-	16725
4	1818 (23%)	6060 (77%)	-	7878
5	-	6040 (100%)	-	6040
6	-	-	48000 (100%)	48000
7	4470 (9%)	-	47680 (91%)	52150
8	3597 (7%)	-	47960 (93%)	51557
9	703 (23%)	2342 (77%)	-	3045

time). The training in weeks 6 to 8 was mostly field training (90-100% of the total training time) (Table 3.1.).

3.5.3. The overall incidence of injuries

The overall incidence of all injuries in the study population over the 9 week training period was 31.9% (367 injuries). The mean weekly incidence of injuries during basic military training was 3.63/100 recruits/week and the incidence of all injuries expressed as injuries per 1000 training hours was 1.8/1000 training hours.

3.5.4. The type of injuries

Of all the injuries, 317 injuries (86.4%) were classified as overuse injuries and only 50 injuries (13.6%) were classified as acute traumatic injuries.

3.5.5. The severity of injuries

Two hundred and sixty eight (73%) of the injuries sustained by the recruits prevented them from returning to their normal activities within 4 days and were therefore classified as severe injuries. Less severe injuries (99) accounted for only 27% of all the injuries.

3.5.6. The weekly incidence of overuse injuries

The weekly incidence of overuse injuries sustained by military recruits over the 9 week study period is depicted i) as the percentage of recruits injured per week (Fig 3.1.), and ii) as the injuries/1000 training hours in each week (Fig 3.2.). When expressed as the percentage of recruits injured each week the highest incidence of injuries was recorded in week 1 and 2, followed by weeks 9 and 3. However, incidences expressed in this manner do not take the hours of exposure to training into account.

When the incidence of injury was expressed as injuries/1000 training hours for each week, the highest incidence of injuries was recorded in the 9th week of training followed by the 1st and 2nd weeks. In general, high incidences of injury were documented in weeks 1, 2, 3, 4, 5 and 9, whereas low incidences were recorded during weeks 6, 7 and 8. It should be noted that in the weeks where high incidences were recorded, the training was predominantly marching (>77% of the total training time) (Table 3.1.).

3.5.7. The incidence of specific overuse injuries

The incidences (injuries/1000 training hours) for the six overuse injuries that were investigated in this study are documented in Fig 3.3. The highest incidence for a single

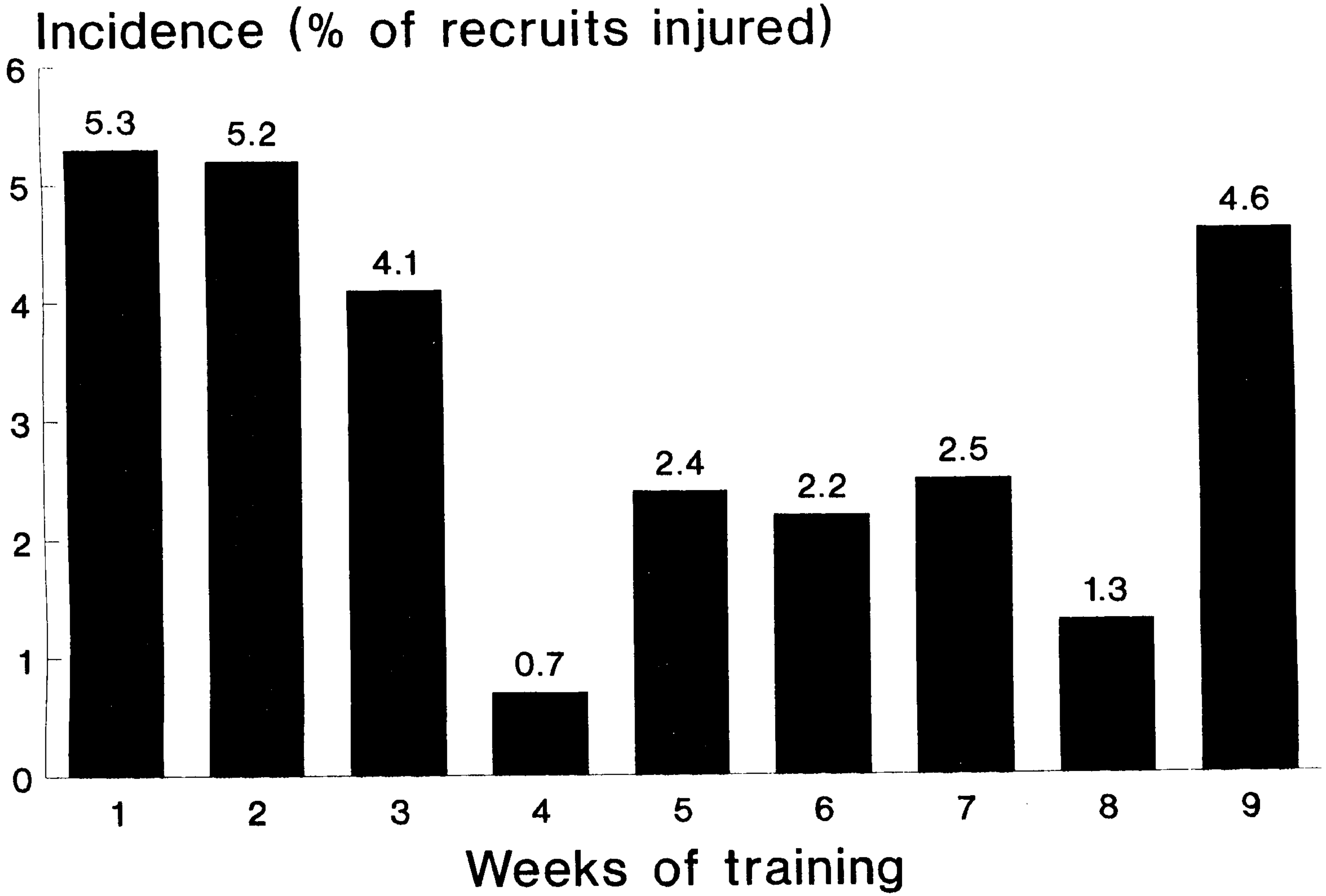

Fig 3.1. The weekly incidence of overuse injuries during basic military training (expressed as a percentage of recruits injured per week)

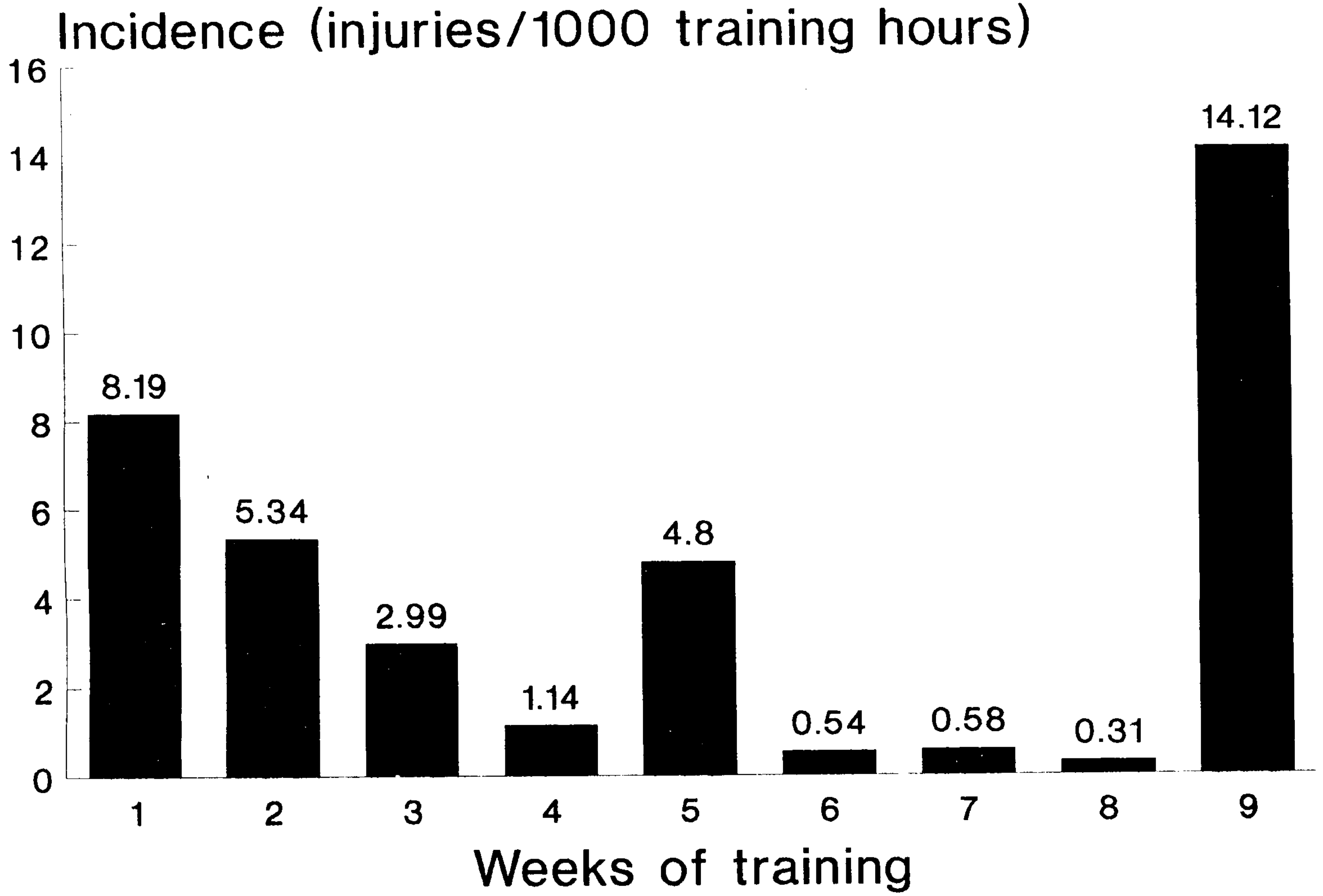

Fig 3.2. The weekly incidence of overuse injuries during basic military training (expressed as injuries per 1000 training hours per week)

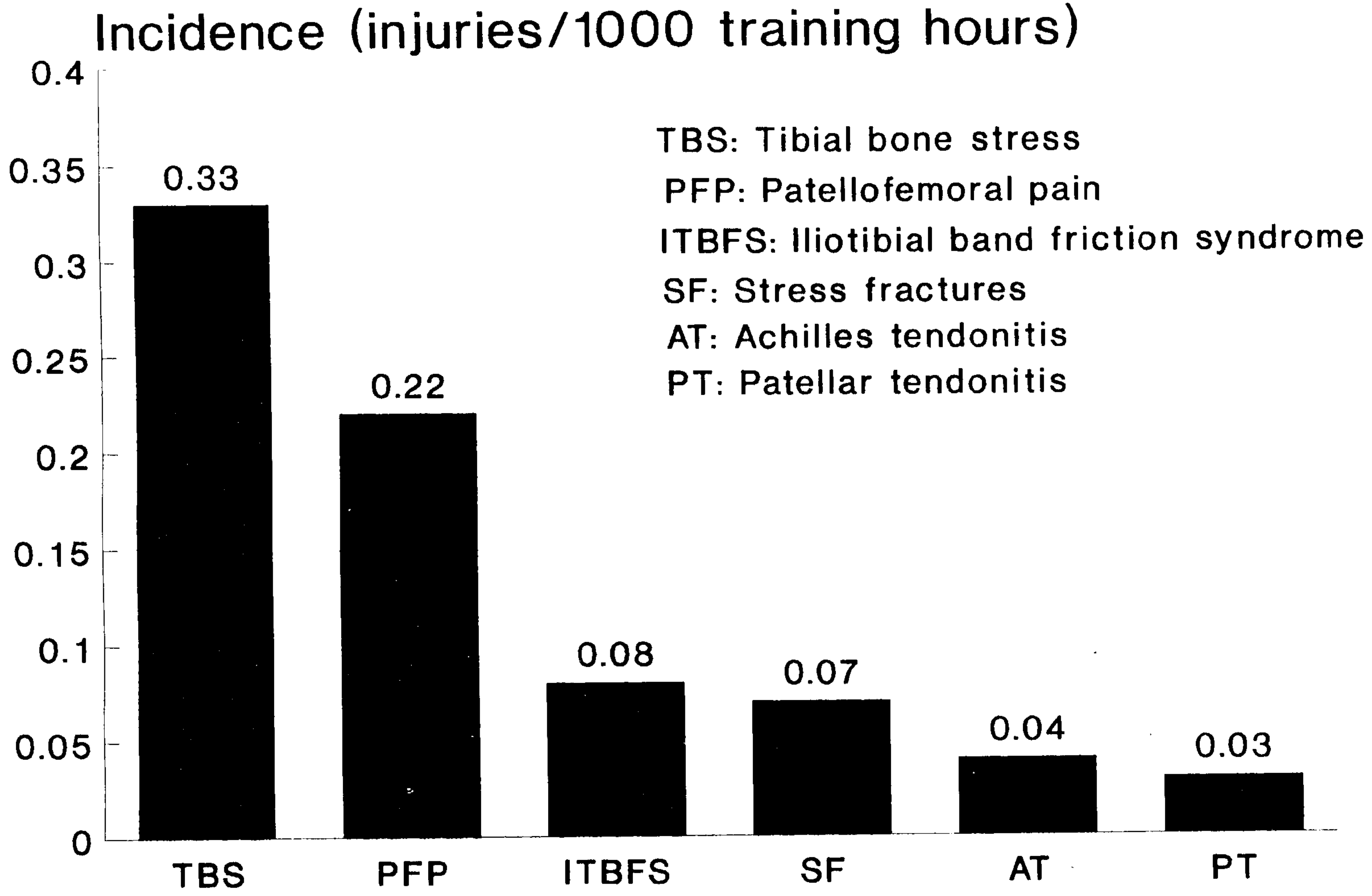

Fig 3.3. The incidence of six specific overuse injuries (injuries per 1000 training hours) during basic military training

injury was tibial bone stress reaction (0.33/1000 training hours), followed by patellofemoral pain (0.22/1000 hours training) and the iliotibial band friction syndrome (0.08/1000 training hours).

In this study population a total of 14 stress fractures (overall incidence of 1.2% over the 9 weeks of training) was recorded. The anatomical distribution of the stress fractures was as follows: Femoral shaft (1), Tibial shaft (10), Metatarsals (3).

3.5.8. The anatomical distribution of overuse injuries

The anatomical distribution of the overuse injuries sustained by recruits during basic military training is depicted in Table 3.2. For comparison, the anatomical distribution of overuse injuries recorded in the only other study conducted in a similar population over a similar training period is also indicated (Gordon et al, 1986b). The injury patterns in the two studies are similar and the most common anatomical sites to be injured are the knee (34-40%), lower leg (26-36%) and the ankle/foot region (14-15%).

3.5.9. The loss of training days as a result of injuries

During the 9 week training period injuries were responsible for the loss of 2631 training days (3.6% of all the training

Table 3.2.

The anatomical distribution of overuse injuries in military recruits undergoing basic military training. A comparison with a similar population previously studied (Gordon et al, 1986b). The frequency of injuries are expressed as a percentage (%) of all overuse injuries.

Anatomical site	Present study	Gordon et al, 1986b
Lower back	8	11
Hip/pelvis	1	2
Upper leg	3	2
Knee	40	34
Lower leg	26	36
Foot/ankle	15	14
Other	7	1

days). Overuse injuries were responsible for the loss of 2301 training days (2 training days per recruit) and acute injuries were responsible for the loss of 330 training days (0.29 training days per recruit).

The loss of training days (total days lost and days lost per injury) for injuries sustained in various anatomical sites is depicted in Table 3.3. Knee injuries were responsible for most lost training days (747 training days lost). However, the single injury responsible for most lost training days was tibial bone stress reaction (577 training days lost).

The training days lost as a result of an injury was highest for a stress fracture (21.6 days lost per stress fracture). The femoral shaft stress fracture was responsible for the most lost training days (49 days lost per femoral stress fracture). After stress fractures, tibial bone stress reactions were responsible for the most significant loss of training days per injury (8.7 days lost per tibial bone stress reaction).

Table 3.3.

The total number of training days lost and the training days lost per injury for specific overuse injuries and overuse injuries in major anatomical sites sustained during basic military training.

Anatomical site or injury	Total days lost	Days lost per injury
Upper limb	159	7.95
Back	150	6.00
Hip	10	3.33
Thigh	68	7.56
Knee (total)	747	5.66
Patellofemoral pain	299	6.80
Iliotibial band friction	82	5.13
Patellar tendonitis	7	1.40
Other	359	5.34
Tibial bone stress	577	8.74
Calf	57	6.33
Achilles tendonitis	52	7.43
Ankle/foot	230	5.11
Stress fractures (total)	303	21.64
Femur	49	49.00
Tibia	182	18.20
Foot	72	24.00

3.6. Discussion

This is one of the few studies documenting the incidence of all overuse injuries in military recruits during basic military training. It is the only study to record the incidence of injuries sustained during basic military training as injuries per 1000 hours of physical training. Furthermore, it is the only study documenting the incidence of six specific overuse injuries during basic military training.

The incidences of all injuries (31.9%) and overuse injuries (27.5%) recorded in this study are very similar compared to those reported in a similar population over 10 weeks of training (all injuries, 37.9%; overuse injuries, 32.4%) (Gordon et al, 1986b). In these two studies the same definition of injury was also used, and a similar training programme was followed (South African Defence Force Basic Training Programme). The incidence of all injuries sustained during basic military training that were recorded in these two studies do however differ substantially from those previously reported by others: 85.5% (Stacy et al, 1984), 7.5% (Reinker et al, 1979), and 26% (Kowal, 1980). The discrepancies in the findings between these studies is probably as a result of differences in the duration of the training periods and the definitions of injury that were used by researchers.

In two previously reported studies the incidence of overuse injuries sustained during basic military training could be calculated from the published data and expressed as injuries/1000 training hours (8.1/1000 hours, Gordon et al, 1986b; 10.1/1000 hours, Stacy et al, 1984). In the present study the incidence/1000 training hours was recorded as 1.8/1000 hours, which is substantially lower than that calculated from the previously reported studies.

The reasons for these differences are not clear but are probably related to the failure by other researchers to include the hours spent on field training as part of physical training (Gordon et al, 1986a). Differences in the type of training could also account for the discrepancy between the incidences of injury in these studies. Finally, it must be emphasized that, in the case of the two mentioned studies (Gordon et al, 1986b; Stacy et al, 1984) the incidences were calculated from published and not original data and may therefore not be absolutely reliable.

The proportion of overuse injuries in the present study (86.4%) is similar to that reported previously for a similar population and training period (81.7%) (Gordon et al, 1986b).

This is the first study to record the weekly incidence of overuse injuries in military recruits undergoing basic military training. In this study the weekly incidence of overuse injuries was expressed firstly as the percentage (%) of recruits injured each week (Fig 3.1.), and secondly as the injuries per 1000 training hours (Fig 3.2.). Irrespective of the method of expressing the incidence, it is clear that the highest incidence of injury was documented in the first 3 weeks, and the last week of training. The lowest incidence of injuries/1000 training hours was clearly documented in weeks 6 to 8 of training. This finding is however not immediately evident when the injury incidence is expressed purely as a percentage of recruits injured per week. The reason for the low incidence recorded during weeks 6 to 8 is that during this period a large number of hours were spent on field training. Despite the large number of training hours (Table 3.1.), few injuries were reported. This provides some evidence that the type of training does affect the risk for injury. In particular, this study indicates that marching, which was the predominant form of training in weeks 1 to 5 and week 9, is associated with a high risk of injury, and that field training is associated with a low risk of injury.

This study is also one of the first to document the incidences of specific overuse injuries during basic military training. It is clear that tibial bone stress reaction is the most common injury followed by patellofemoral pain and the iliotibial band friction syndrome. These data can not be compared to that of other activities or sports because there are no accurate data available on the incidence (expressed as injuries/1000 hours) of these injuries in other activities or sports. In one study of runners, the incidence of tibial bone stress injuries can be calculated as 0.58/1000 running hours (Chapter 5.4). This incidence is similar to that recorded for tibial bone stress injuries in this study (0.33/1000 hours).

The incidence of stress fractures recorded in the present study (1.2%) is similar to that reported for military recruits in the United States (0.9-4.1%) (Brudvig et al, 1983; Gardner et al, 1988; Gordon et al, 1986b; Jones et al, 1989; Protzman et al, 1977; Reinker et al, 1979; Scully et al, 1982). The epidemiology of stress fractures in military recruits is discussed in detail in Chapter 5.4.

The anatomical distribution of overuse injuries recorded in the present study is similar to that previously reported in a similar population (Gordon et al, 1986b). Injuries to the knee, lower leg, ankle and foot accounted for over 80% of all overuse injuries sustained by military recruits during basic military training.

Injuries can have a detrimental effect on the effectiveness of a military training program as well as on the cost of training soldiers. These effects can be measured by the number of training days that are lost as a result of injuries (Gordon et al, 1986b). In the present study it was documented that a substantial number of training days were lost as a result of injuries, in particular overuse injuries. Stress fractures, tibial bone stress injuries and knee injuries were responsible for the largest number of lost training days. Stress fractures caused the largest number of lost training days per injury. Bone stress injuries, including stress fractures, therefore remain the injuries causing the greatest degree of morbidity to the recruit, and are the most detrimental to the training programme. Attention must therefore be focussed on the prevention of bone stress injuries in military recruits during basic military training.

3.7. Summary: Chapter 3

- This chapter presents research findings on the epidemiology of injuries, in particular overuse injuries, during basic military training.
- The overall incidence of injuries during 9 weeks of basic military training was 31.9% or 1.8 injuries/1000 training hours.

- Most of the injuries were overuse injuries (86.4%) and most were classified as severe (73%).
- The highest weekly incidences of injuries were recorded in weeks 1 to 3 and week 9 of the training period, which were weeks characterized by marching (>77% of the training time).
- The highest incidences of specific overuse injuries were recorded for tibial bone stress reactions (0.33/1000 training hours), patellofemoral pain (0.22/1000 training hours), and the iliotibial band friction syndrome (0.08/1000 training hours).
- The overall incidence of stress fractures during 9 weeks of basic military training in this population was 1.2%.
- Injuries to the knee, lower leg, ankle and foot accounted for over 80% of all overuse injuries in this population.
- A total of 2631 training days (3.6% of all the training days) were lost due to injury over the 9 weeks training period in this population.
- Bone stress injuries, including stress fractures, are responsible for the largest number of lost training days.
- Attention must be focussed on the prevention of bone stress injuries in military recruits during basic military training.

CHAPTER 4

A REVIEW OF THE NORMAL STRUCTURE AND FUNCTION OF BONE

4.1. Introduction
4.2. Histology of bone
4.3. Normal skeletal organization
4.4. Normal bone turnover
4.5. Factors affecting bone turnover
4.6. Summary

4.1. Introduction

Bone stress injuries are the most debilitating overuse injuries that occur during physical activity. In this chapter the normal structure and function of bone will be reviewed with emphasis on the normal response of bone to mechanical loading. A review of this response of bone is essential for the understanding of the pathogenesis, aetiology, management and prevention of bone stress injuries which will be discussed in Chapter 5. In particular, the following aspects of bone structure and function will be reviewed; the basic histology of bone, normal skeletal organization, normal bone turnover and the factors affecting normal bone turnover.

4.2. Histology of bone

Bone is a rigid type of connective tissue that constitutes most of the skeleton of higher vertebrates (Leeson et al, 1976). As in all connective tissue, bone is made up of cells, fibres and ground substance (Leeson et al, 1976). In bony tissue the fibres and ground substance are known as the bone matrix (Leeson et al, 1976).

4.2.1. Cellular components

The three main cellular components of bone are osteoclasts, osteoblasts and osteocytes (Revell, 1986). Recently, a layer of thin flattened lining cells which cover the bone surface has been identified (Parfitt, 1984). Fibroblasts have also been shown to occur in relation to the surface of bone (Bell et al, 1980). The origin, structure and functions of the cellular components of bone will be discussed briefly.

4.2.1.1. Osteoclasts

Osteoclasts are responsible for bone resorption. The precise mechanism by which resorption takes place is not well understood (Revell, 1986) but will be discussed in more detail in section 4.4.5.2.3. Osteoclasts are morphologically characterized by their i) large size, ii) multinucleated appearance, iii) characteristic vacuoles in the cytoplasm, iv) many folds in the cytoplasm, and v) close association to the surface of bone where they are found in shallow excavations known as Howship's lacunae in trabecular bone and cutting cones in cortical bone (Leeson et al, 1976; Parfitt, 1984; Revell, 1986). Osteoclasts are thought to originate from the fusion of precursor cells of the circulating mononuclear phagocyte system which includes monocytes and macrophages (Parfitt, 1984). They therefore ultimately arise from a haemopoetic stem cell (Revell, 1986). The precise mechanism/s of activation of the precursor cells is not known but appears to occur partly at random and partly in response to focal structural or biomechanical requirements in bone (Parfitt, 1984).

4.2.1.2. Osteoblasts

Osteoblasts are responsible for formation of a variety of substances in the bone matrix (Parfitt, 1984). These include i) Type I collagen molecules, ii) matrix vesicles (that play a role in mineralization) (section 4.4.5.2.4.), iii) osteocalcin (an extracellular protein that binds calcium), and iv) osteonectin (a phosphoprotein that binds both collagen and calcium) (Raisz et al, 1983a). Osteoblasts are characterized morphologically by i) a variable shape, ii) cytoplasmic basophilia, iii) a large nucleus with a prominent nucleolus, iv) abundant endoplasmic reticulum, v) large numbers of free ribosomes and polyribosomes and vi) containing the enzyme alkaline phosphatase (Leeson et al, 1976; Revell, 1986). These features are characteristic of a cell involved with active protein synthesis (Revell, 1986). Osteoblasts are therefore closely associated with bony surfaces where bony matrix is being deposited. The presence of the enzyme alkaline phosphatase indicates that this cell may also be involved in the mineralization of osteoid (Leeson et al, 1976).

Osteoblasts are derived from mesenchymal osteoprogenitor cells, also known as preosteoblasts (Raisz et al, 1983a). Preosteoblasts are derived from local precursor cells and originate from the bone marrow stromal stem cell (Parfitt, 1984). The precise mechanism/s that are responsible for osteoblast recruitment is/are not known but may be mechanical or biomechanical stimuli (Parfitt, 1984). In addition, other factors have been shown to stimulate osteoblast proliferation (Wallach et al, 1989). These are human skeletal growth factors I and II (Raisz et al, 1983b). Their origin is not known. Osteoblast function is also under the influence of hormonal control. This will be discussed in section 4.5.3.3.

4.2.1.3. Osteocytes

Osteocytes are small darkly stained cells that are completely surrounded by mineralized bone matrix. These cells are characterized by i) small nuclei with sparse cytoplasm, ii) few mitochondria, and iii) several long cytoplasmic processes that pass through the surrounding bone matrix (Leeson et al, 1976; Revell, 1986). These cells originate from osteoblasts that are incorporated into the bony matrix (Revell, 1986). It has been suggested that osteocytes may also play a role in bone resorption (osteocytic osteolysis), bone deposition (osteoplasis) (Revell, 1986) and assessment of "strain history" in bone (Lanyon, 1987). However, these mechanisms have not been well documented and a detailed discussion of these mechanisms is beyond the scope of this thesis.

4.2.1.4. Other cells

It has been documented that the bone surface is covered by a layer of very thin, flattened lining cells. These cells apparently arise from the terminal transformation of osteoblasts and therefore retain some of the functions of the osteoblast (Parfitt, 1984). The precise functions of these cells has not been well documented but they may play a role in the regulation of plasma calcium and/or osteoclast activation (Parfitt, 1984).

Fibroblasts are also found on the surface of bone outside the layer of osteoblasts and are largely inactive. They may play a role in fracture healing (Bell et al, 1980).

4.2.2. Bone matrix

The matrix of bone consists of an organic and an inorganic component (Leeson et al, 1976).

4.2.2.1. Organic component

The organic component which comprises 35% of the matrix is made up of mainly Type I collagenous fibres, calcium binding proteins (osteocalcin and osteonectin), and to a lesser extent sulfated polysaccharides (chondroitin sulfate), glycoproteins, lipids and peptides (Bell et al, 1980; Raisz et al, 1983a; Revell, 1986).

Collagen molecules are synthesized by osteoblasts and are secreted as procollagen into the extracellular space. They are then assembled into fibrils prior to impregnation with minerals (inorganic component) (Revell, 1986). The mechanism of bone formation is discussed in more detail in section 4.4.5.2.4.

Two recently described matrix proteins deserve brief discussion. Osteocalcin or bone GLA protein (BGP) is a single-chain polypeptide (49 amino acids) which has three residues of the Vitamin K dependent amino acid gamma-carboxyglutamic acid (GLA) at positions 17, 21 and 24. These GLA residues enable BGP to bind to hydroxyapatite which is the principle constituent of the mineral phase of bone. The serum concentration of BGP is thought to represent a specific index of bone turnover (Azria, 1989).

Osteonectin is a glycoprotein which is not only produced by osteoblasts but also by a variety of noncalcified tissues including platelets. Its function has not been well defined and its value as a biomarker has therefore not been identified (Azria, 1989).

4.2.2.2. Inorganic component

The inorganic component comprises 65% of the matrix and is located in the cement between the collagen fibres (Leeson et al, 1976). About 60% of the bone mineral is in the form of calcium phosphate crystals which have a characteristic hydroxyapatite pattern on X-Ray diffraction. The remainder (40%) of the bone mineral is not crystalline but rather is an amorphous tricalcium phosphate which has a distinctive "doughnut" appearance on electron microscopy (Bell et al, 1980). Other ions besides calcium and phosphate that are also present within the bone matrix are carbonate, magnesium, chloride, fluoride and citrate (Warwick et al, 1973). The mineral components are deposited in close relationship to the collagenous fibres by the process of mineralization. The process of mineralization will be discussed in more detail in section 4.4.5.2.4.

4.2.3. Summary: Histology of bone

In summary, bone consists of a cellular component and a matrix. The cellular components of bone are responsible for the normal dynamic alteration of bony tissue in response to mechanical stress or damage. The bony matrix consists of an organic and an inorganic component.

4.3. Normal skeletal organization

4.3.1. General organization

The skeleton can be divided into a central and a peripheral compartment (Snow-Harter et al, 1991). The central or axial skeleton represents the skull bones, vertebrae, sternum, ribs and pelvic bones. The peripheral or appendicular skeleton is made up of all the bones of the upper and lower limbs (Warwick et al, 1973). The central and peripheral skeletal compartments differ with respect to the type of bony tissue that predominates in each compartment. The central compartment consists mostly of trabecular or cancellous bone (70% by volume) and the peripheral compartment consists mainly of cortical or lamellar bone.

4.3.2. Cortical bone

Cortical bone is characterized by the organization of plates or lamallae around a central nutrient canal (Revell, 1986). It is therefore also known as lamellar bone. Concentrically arranged lamellae that surround a central canal are classically seen in the shafts of long bones and are known as Haversian systems (Leeson et al, 1976). The nutrient canals in these systems are known as Haversian canals. In the Haversian system, the osteocytes are arranged circumferentially around the central canal in parallel with the lamellae. The central canals of adjacent Haversian systems can interconnect. Irregular areas of lamellar bone between Haversian systems are remnants of previously formed systems which have been altered by remodelling and are known as interstitial lamellae. The lamellae on the endosteal and periosteal surfaces of the shaft of long bones are known as circumferential lamellae (Revell, 1986).

4.3.3. Trabecular bone

Trabecular bone is made up of a series of interconnecting bony plates or trabeculae which are surrounded by bone marrow and fat (Leeson et al, 1976; Revell, 1986). The trabecular structure provides a large surface area for the metabolic activities of bone but also provide mechanical strength without the disadvantage of undue weight (Revell, 1986). The thickest and strongest trabeculae are typically arranged in the direction of the greatest mechanical forces. Although trabecular bone forms the majority of the bone in the central bone compartment, it is also present in the metaphysis of long bones of the peripheral compartment. Changes in the bone mass are earlier and more impressive in trabecular compared to cortical bone because of the large surface area of trabecular bone (Snow-Harter et al, 1991). This has important implications with respect to the measurement of changes in bone density in different regions of the skeleton.

Both cortical and trabecular bone play an important role in maintaining the mechanical integrity of the skeleton when forces are applied such as during physical activity. The study of the effects of force application to bone (biomechanics) and the study of the response of bone to these forces is important when considering the pathogenesis of bone stress injuries.

4.4. Normal bone turnover

4.4.1. Introduction

Bone is a dynamic tissue that undergoes constant change throughout life, particularly in response to mechanical loading. This phenomenon was first recognized in the 17th century when Galileo observed that body weight and level of activity were related to bone size (Treharne, 1981). In the 19th century there was considerable interest by several scientists to express the relationship between bone form and its function. One of the most prominent researchers of that time, J Wolff, published a monograph in 1882 in which he described a law governing bone turnover (Wolff, 1882). Wolffs law states that "every change in the form and function of bones, or of their function alone, is followed by certain definite changes in their internal architecture and equally definite secondary alteration in their external conformation, in accordance with mathematical laws". Although the basic principle that mechanical loads influence the bone architecture, as derived from Wolffs law, still holds today, it is now recognized that bone turnover is a complex biological process which is dependent on genetic, hormonal, metabolic, age-related as well as mechanical load influences (Hart et al, 1984).

It has only recently been recognized that several distinct processes, each governed by their own responses to mechanical and non-mechanical challenges, are responsible for bone turnover (Frost, 1990a). According to this new skeletal paradigm, changes in bone can occur as a result of five fundamental tissue-level activities: growth, modeling, remodeling, repair and inflammation (Frost, 1991a; Frost, 1991b). Each of these activities has its own functions, mediator mechanisms and responses to drugs, hormones, mechanical loads and other agents (Frost, 1991a; Frost, 1991b).

Because this review focuses mainly on the response of bone to mechanical loading, the processes of bone repair, excluding repair from microdamage, and inflammation will not be discussed further. Only the processes of growth, modeling and remodeling will be reviewed in some detail as these processes are responsible for the changes that occur in bone in response to mechanical loading. The discussion of these three processes will be preceded by a brief review of basic biomechanical principles as they pertain to mechanical loading of bone.

4.4.2. Basic mechanics of bone

4.4.2.1. Basic principles

If a force of sufficient magnitude (load) is applied to any material it will result in the alteration of the shape and/or size of the material (deformation) (Black et al, 1981; Sumner-Smith, 1982). Upon removal of the force the material may return to its original shape or size (in which case the deformation was temporary) or it may have changed its size or shape permanently. Temporary deformation is known as elastic deformation whereas permanent deformation is known as plastic or viscous deformation (Cochran, 1982). Most biological tissues, including bone, exhibit both viscous and elastic properties and are therefore known as viscoelastic tissues. Furthermore, these properties of materials can be studied scientifically in biological materials such as bone.

Although bone appears homogeneous to the naked eye, histological examination reveals a trabecular pattern which varies in its orientation within a bone and between bones. If the mechanical properties of materials with such a variation in structure are measured, they will differ depending on the direction of force application. This is a characteristic of bone known as anisotropy (Cochran, 1982) and is important to consider when evaluating scientific studies that compare the mechanical properties of bone. Furthermore, bone can be regarded as a two-phase composite material that is composed of a strong brittle material (inorganic matrix) and a flexible, resilient material (organic matrix) each of which impart specific mechanical properties to the bone (Nordin et al, 1989).

If loads of increasing magnitude are applied to bone they will result in deformation of that bone. The principles of mechanical testing on bone have been recently been reviewed (Black et al, 1981; Cochran, 1982; Nordin et al, 1989; Sumner-Smith, 1982). Under experimental conditions both the load and the deformation can be measured and the results can be depicted graphically. Loads are usually measured as force per unit area of bone (stress) and deformation is usually measured as the change in length divided by the original length (strain). The units of stress are N/m^2 (Newton per square meter) which is Pascal (Pa) in the SI system. Strain can be expressed as percentage change in length (%) or more conventionally as microstrain (uE). This is because the changes that are observed in bone are very small. One microstrain indicates a 10^{-6} change in the original length (Cochran, 1982).

A hypothetical example of a typical stress/strain curve for bone is depicted in Fig 4.1. A number of important observations can be made and specific biomechanical

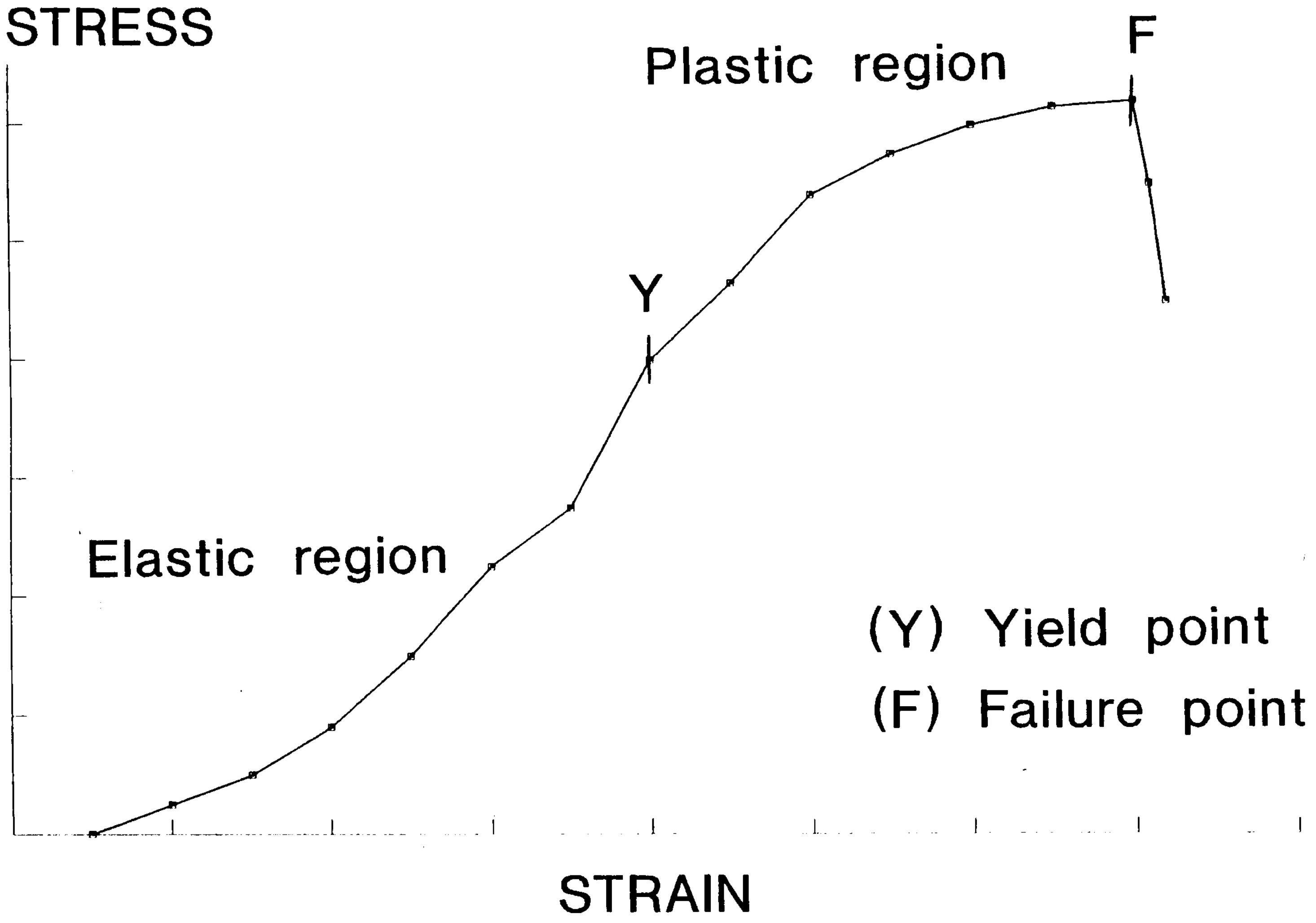

Fig 4.1. A hypothetical stress/strain curve for bone

parameters can be derived from the stress/strain curve (Black et al, 1981; Cochran, 1982; Nordin et al, 1989; Sumner-Smith, 1982):

- Elastic region: This region reveals the elasticity of the bone and the bone will return to its original length upon removal of the stress when loaded in this region.

- Plastic region: This region is characterized by permanent (plastic) deformation in the bone. Upon removal of the stress, the bone will not return to its original length.

- Yield point: The yield point signals the elastic limit of the bone and is identified by the maximum stress (yield stress) and strain (yield strain) that can be applied before plastic deformation will occur in the bone.

- Failure point: The failure point indicates the point where the bone fails and is identified by the maximum stress (stress to failure) and strain (strain to failure) that can be applied before the bone breaks.

- Modulus of elasticity (Youngs modulus): This is the slope of the stress/strain curve in the elastic region and is an indication of the stiffness of the bone.

- Total energy stored before failure: The area under the stress/strain curve is indicative of the energy absorbed by the bone prior to failure.

These parameters form the basis of most of the experimental procedures that have analyzed the effects of force application on bone. The experimental procedures used in the mechanical testing of bone will now be reviewed briefly.

4.4.2.2. Mechanical testing of bone: experimental procedures

Forces and moments can be applied to bone in various directions (Fig 4.2.). The following are common forces that are applied to bone in vivo: tensile forces (forces that are directed away from the bone surface), compressive forces (forces applied towards the surface of the bone), shear forces (forces applied parallel to the surface of the bone), bending forces (forces applied in a manner to bend the axis of the bone), torsional forces (forces applied in a manner to twist the bone about its axis) and combined forces (forces that are various combinations of those described above) (Nordin et al, 1989).

Forces that are applied to a particular bone during daily activity and sports activities such as running are complex (Lanyon et al, 1975) and vary with respect to type, magnitude, rate of application, frequency, duration and

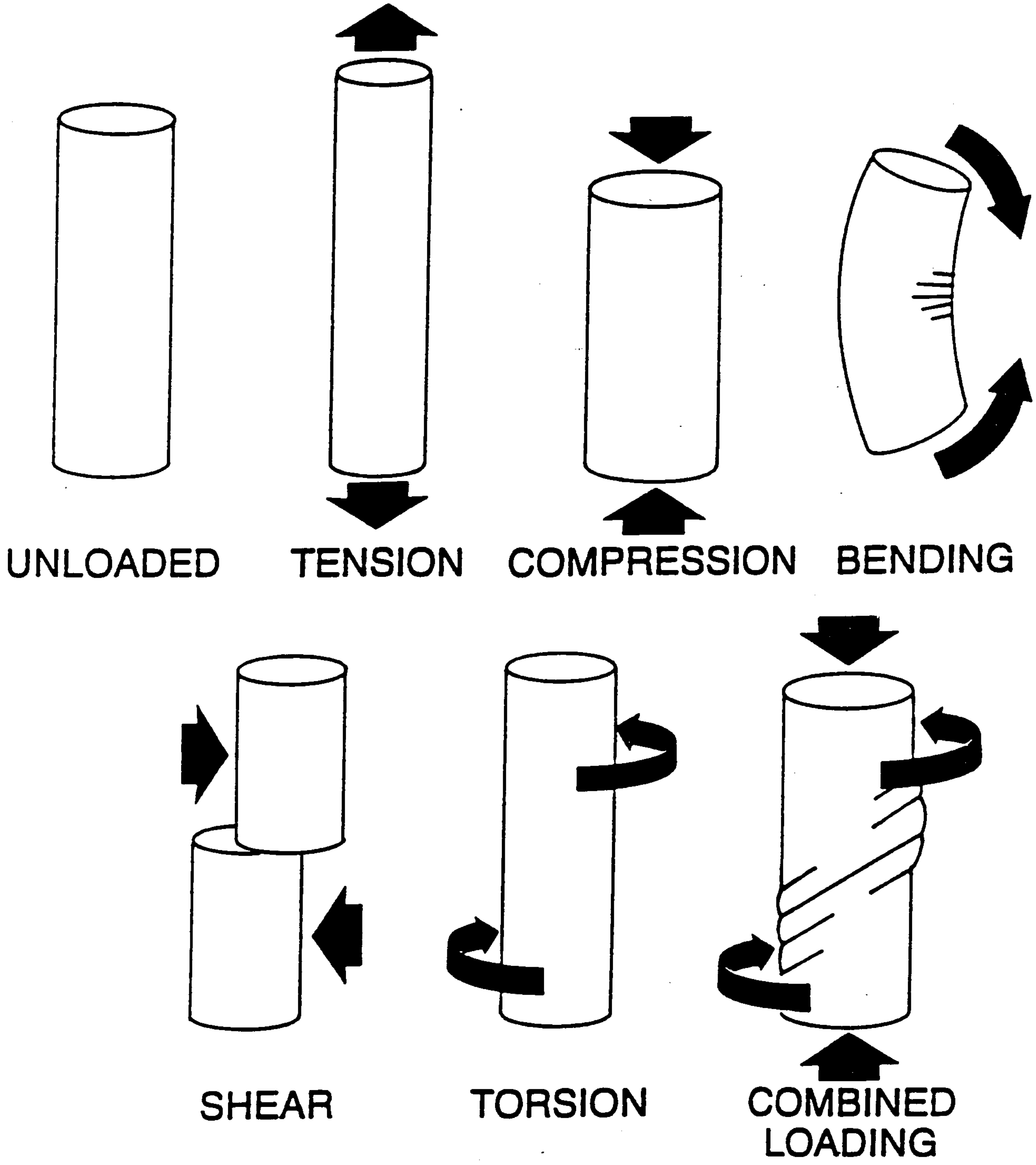

Fig 4.2. Forces and moments applied to bone
Nordin et al, 1990

distribution. The precise measurement of such forces is difficult and it is therefore not surprising that very little information is available on the nature of these forces during sports activities. Most of the published research has been confined to firstly the study of stress application to bone specimens in vitro, and secondly to the study of strains in bone during activity (in vivo). These procedures will now be discussed.

4.4.2.2.1. In vitro mechanical testing of bone specimens

In this type of experimental model, bone specimens are subjected to forces under controlled laboratory conditions. The force application can be varied with respect to the direction, magnitude (Carter et al, 1976; Carter et al, 1981a), rate of application (Sammarco et al, 1971), frequency (Carter et al, 1977b) and type of force (Caler et al, 1989; Carter et al, 1981a; Carter et al, 1981b; Forwood et al, 1989). The stresses and strains are measured using standard mechanical testing systems. Data are then calculated from the stress/strain curves and compared between different experimental conditions. Fatigue testing (the effect of repeated application of forces on the mechanical properties of bone) can also be performed by using a technique of repetitive force application (Caler et al, 1989; Carter et al, 1976; Carter et al, 1977a; Carter et al, 1977b; Carter et al, 1981a; Carter et al, 1981b; Evans et al, 1957; Evans et al, 1970; Forwood et al, 1989; Keller et al, 1985). This technique has been of particular value in studying the pathogenesis of bone stress injuries and the results of these studies will be discussed in Chapter 5.5.

4.4.2.2.2. In vivo assessment of bone strain

The technique of in vivo assessment of bone strain during physical activity was first described in the 1940's. However, these early studies were plagued by the inability to attach strain gauges to the bony surface with suitable bonding material. The results of this early work was therefore never published (Lanyon, 1987). The first successful use of the technique was described in 1970 and was made only possible through the introduction of fast polimerising cyanoacrylate adhesives (Lanyon et al, 1970).

Essentially, this technique requires the attachment of strain gauges, that measure strain in different directions, to the bone at different locations (Rubin et al, 1985). The animal or human subject is then tested during a variety of activities, and the output from the strain gauges is recorded (Burr et al, 1985; Lanyon, 1987; Rubin et al, 1984; Rubin et al, 1985). Comparisons can then be made between i) strains in different bones during the same activity, ii) strains at different sites within the same bone during one activity and, iii) strains in the same bone in response to different activities. This information has been particularly useful in documenting the response of bone to different mechanical strain environments (Burr et al, 1985; Churches et al, 1979; Cowin et al, 1985; Lanyon, 1987; Rubin et al, 1984; Rubin et al, 1985). The findings of studies that have examined the response of bone to different strain applications on will be discussed in section 4.5.2.2.

4.4.2.3. Summary: Basic mechanics of bone

In summary bone is a biological tissue that has specific mechanical properties when subjected to materials-testing procedures. These properties include viscoelasticity and anisotropy. Specific mechanical properties of bone can be quantified by studying the stress/strain curve of bone in response to force applications which can vary with respect to direction, magnitude, rate of application, frequency and type. In vitro and in vivo laboratory techniques can be used.

Finally, this brief review on the principles of mechanical loading of bone serves as an introduction to discuss the effects of mechanical loading on processes that are involved with bone turnover namely bone growth, modeling and remodeling.

4.4.3. Bone growth

4.4.3.1. Definition of growth

Bone growth refers to the normal increase in the number of bone cells and intercellular material that occurs between conception and maturity. This process includes embryological development, the normal increases in the size of the bone and the ossification process (membranous or endochondral) (Revell 1986).

4.4.3.2. Mediator of bone growth

The mediator mechanism for bone growth in long bones is the well described growth plate with its different zones (Leeson et al, 1976; Revell, 1986). The activities of the growth plate cease at skeletal maturity. Although the precise time of growth plate closure differs from region to region in the skeleton, it is usually at around 18 years of age.

4.4.3.3. Factors controlling bone growth

The control of bone growth is complex and involves genetic control (which controls general bone growth), local factor control (which controls local growth) and systemic control which includes nutritional and endocrine control (Frost, 1991a; Frost, 1991b). Abnormalities of normal bone growth can arise from derangements in any of these groups of control factors. Abnormalities include osteogenesis imperfecta (genetic), achondroplasia (genetic), cretinism (hormonal), acromegaly (hormonal) and rickets (nutritional) (Moore, 1977).

In addition to the above mentioned general control factors, normal bone growth also appears to be impeded by lack of mechanical load application during the growth process. This is most evident in patients that have been paralyzed since birth. In these patients it has been documented that their bones have a i) decreased length, ii) decreased outside diameter, iii) decreased cortical thickness and iv) abnormal shapes (Chantraine et al, 1979; Frost, 1990a). The two main mechanism by which mechanical loading affects bony architecture during the skeletal growth period are modeling and remodeling.

Further detailed discussion of all the factors that control bone growth are beyond the scope of this thesis. However, the effects of modeling and remodeling will be discussed in more detail.

4.4.4. Modeling

4.4.4.1. Definition of modeling

Modeling can be defined as the process by which a bone achieves and maintains its shape during the skeletal growth period in response to increased mechanical loads (Marcus, 1987a). It also refers to the alteration of the tissue content, tissue distribution and the size of bones in response to increased mechanical loads (Frost, 1988).

4.4.4.2. Mediators of modeling

It has been proposed that two "mediator mechanisms" are responsible for the modeling process in bone (Frost, 1990a) and that these "mediator mechanisms" differ from the "mediator mechanisms" responsible for remodeling (section 4.4.5.2.). The "mediator mechanisms" responsible for modeling are called "drifts" (Frost, 1991a; Frost, 1991b). Formation drifts add circumferential lamellae of bone on to the periosteal surface of bony surfaces through the action of osteoblasts (Frost, 1990a) and resorption drifts remove bone from the endosteal surface of the bone (Frost, 1990a). This means that resorption and formation drifts do not occur at the same site although they are coupled (Parfitt, 1984). In modeling the volume of bone formation always exceeds that of bone resorption so the nett effect is that of a positive bone balance (Parfitt, 1984). Modeling therefore, always adds bony tissue to an existing bony surface (periosteum or endosteum) and has also been termed surface adaptation (Cowin, 1984).

The combined effects of formation and resorption drifts are also responsible for alterations in bone architecture (Parfitt, 1984). The classic experiment which has shown this alteration in response to moderate increases in mechanical loading was performed in dogs. In this study the radius of one limb was resected so that all weightbearing was transferred to the ulna. Normal physical activity resulted in a substantial hypertrophy of the loaded ulna, indicating a nett gain in bone mass in response to moderate mechanical loading (Chamay et al, 1972). A further example of the combined effect of formation and resorption drifts is seen during axial compression of a curved long bone. In this case formation drifts are activated on the concave surfaces while resorption drifts are activated on the convex surfaces. The nett effect is that of "drift" of the curved shape to that of a straightened long bone (Frost, 1990a; Parfitt, 1984). A final important characteristic of modeling is that it is seen predominantly during skeletal growth, decreases after skeletal maturity has been reached and is virtually absent after the age of 25-30 years (Frost, 1991b; Parfitt, 1984).

4.4.4.3. Factors controlling modeling

Modeling can be influenced by mechanical and non-mechanical factors. These factors will be discussed in sections 4.5.2. and 4.5.3. respectively.

4.4.5. Remodeling

4.4.5.1. Definition of remodeling

Remodeling is one of the processes responsible for bone turnover. It refers to the continuous dynamic process which constantly alters the structure of the bone throughout life (Marcus, 1987a). Remodeling is responsible for bone resorption and formation but usually the volume of bone resorption exceeds that of formation resulting in a negative bone balance.

Increased remodeling i) removes bone from the spongiosa and cortico-endosteal surface, ii) enlarges the marrow cavity, iii) causes thinning of the cortex, iv) makes the spongiosa and cortex less stiff and strong, and v) causes slight expansion of the outer bone diameter (Frost, 1988).

Decreased bone remodeling i) decreases removal of bone and thus conserves spongiosa and cortico-endosteal bone, ii) retards marrow cavity expansion, and iii) retards cortical thinning (Frost, 1988).

One of the more specific functions of remodeling is to repair microdamage in the bone. This involves the recognition of areas of microdamage, resorption of the damaged areas and replacement of the damaged areas with new bone (Frost, 1988; Frost, 1989b). Microdamage repair will be discussed in more detail in Chapter 5.5.

4.4.5.2. Mediator of remodeling

The mediator by which bone structure is altered through remodeling is the basic multicellular unit (BMU). This was first identified in 1969 through the use of tetracycline labeling of bone (Frost, 1969).

4.4.5.2.1. Definition of a BMU

A basic multicellular unit (BMU) in bone can be defined as a group of bone cells that undergo a sequence of events starting with activation of the BMU (A), followed by a phase of bone resorption (R) and finally a phase of bone formation (F). This is known as the ARF sequence (Frost, 1989a; Frost, 1991a). Once the BMU has completed this sequence it continues with a maintenance stage. This basic multicellular unit (BMU) is the mediator mechanism which is responsible for bone turnover in remodeling. The sequence of BMU function deserves further discussion.

4.4.5.2.2. Activation (A)

The activation phase of BMU function has the following components: i) the recruitment of new osteoclasts from precursor cells of the mononuclear phagocyte system, ii) the penetration of the cellular and connective tissue barrier by precursor cells to gain access to the bone mineral, and iii) attraction and binding of these cells to the bone matrix (Parfitt, 1984). The precise details of each of these components of the activation process are beyond the scope of this thesis but have recently been reviewed (Parfitt, 1984). The mechanical and non-mechanical factors controlling the activation process will however be discussed further in sections 4.5.2. and 4.5.3. respectively.

4.4.5.2.3. Resorption (R)

The resorption phase follows immediately after BMU activation. This phase is characterized by osteoclastic activity and typically lasts for about 1 month (Frost, 1989a). Resorption is the term that is used to describe the removal of both mineral and organic matrix of bone (Revell, 1986). The precise mechanism by which osteoclasts resorb mineral and organic matrix are poorly understood (Revell, 1986). The main reason for this is that the techniques to study osteoclastic function are not well developed. However, it appears that the mineral component of the matrix is resorbed by increased local hydrogen ion production and that citrate acts as a calcium chelating agent (Revell, 1986). The unmineralized bone matrix appears to be degraded by extracellular proteinases and by lysosomal acid hydrolases (Revell, 1986). The precise mechanisms are not well described. Further detailed discussion of the resorption phase of BMU activity is beyond the scope of this thesis. The process has however been reviewed recently (Parfitt, 1984).

4.4.5.2.4. Formation (F)

The bone formation phase follows the resorption phase. This phase is characterized by osteoblastic activity and typically lasts 2-3 months (Frost, 1989a). This time span is variable and depends on factors controlling osteoblastic activity. These factors will be discussed in more detail in section 4.5.

Bone formation involves two processes that occur simultaneously. These are i) the secretion of bone collagen by osteoblasts, and ii) the deposition of calcium-phosphate onto the collagen. The latter process is known as mineralization.

Collagen molecules or polymers of these molecules are secreted into the extracellular space by osteoblasts. They are then assembled into collagen fibrils. The collagen fibrils of bone and dentine are unique in that individual molecules are arranged so that spaces exist between molecules. These spaces are known as "holes" and "pores" and function to accommodate other substances such as calcium and phosphate (Revell, 1986). Almost all the mineral (90-95%) of lamellar bone is therefore located within the collagen fibrils.

The precise mechanism of mineralization is not well understood. Initially it was proposed that alkaline phosphatase hydrolyzed phosphate esters to produce excess free organic phosphate. This would cause an increased calcium and phosphate ion product and result in precipitation of mineral. However, it is now clear that a number of other mechanisms are involved in this process. These include i) the local elevation of calcium and phosphate ion concentrations, ii) the presence of substances that provide sites for nucleation of mineral and iii) the removal or deactivation of substances that prevent mineral formation (Parfitt, 1984; Revell, 1986).

In the early 1970's small extracellular vesicles, later known as matrix vesicles, were first documented in relation to sites of mineralization. These vesicles are formed either as buds from the plasma membrane or are derived from cell organelles. The membranes of matrix vesicles are rich in phospholipid, which serves as a trap for calcium ions, and also contain enzymes such as alkaline phosphatase, pyrophosphatase and ATPase. These enzymes serve a dual purpose; i) they hydrolyse phosphate esters to provide phosphate ions and ii) they hydrolyse inhibitors of mineral crystal formation such as pyrophosphate and ATP. The matrix vesicle therefore provides the optimal environment for mineral to be deposited and acts as a nucleating agent (Revell, 1986).

In addition, it has been recognized that calcium and phosphate accumulates in the form of electron-dense granules in mitochondria of chondrocytes in the growth region of bones. It is therefore possible that the mitochondria of chondrocytes concentrate calcium and phosphate, then export these ions to the extracellular space so that hydroxyapatite crystals can grow on matrix vesicles. The matrix vesicles then deposit the mineral in relation to the collagen fibril "holes" and "pores". However, the relationship between the calcium deposition and the mineralization of collagen fibrils is not well understood (Revell, 1986).

Mineralization starts about 1 week after osteoblasts deposit the lamellar bone matrix and is rapid at first but then progresses more slowly. It is however only fully completed by 7-8 months (Frost, 1989b). The mineralization process imparts "stiffness" to the bone. The stiffness of the BMU is therefore only maximal about 1 year after its initial activation.

Once mineralization is completed, the BMU is known as a basic structural unit (BSU) (Frost, 1989b). It has been documented that each BMU is responsible for about $0.05mm^3$ bone turnover per completed cycle. The maintenance stage is characterized by the formation of an osteocyte. In cortical bone this is the well described secondary osteon of the Haversian system (section 4.3.2). The maintenance stage can last from 2-20 years (Frost, 1989a). During this phase the BSU carries some of the physical loads of the bone it lies in, and likely has other functions such as homeostasis and mechanical microdamage detection (Frost, 1989a).

4.4.5.2.5. Summary of BMU function

In summary, the BMU is a group of bone cells that undergo a sequence of activation, resorption and formation in response to a variety of stimuli. It is the proposed mediator for the process of bone turnover (remodeling). Finally, as has already been mentioned, the time spans that have been given for each of the phases of the ARF sequence are variable and can be influenced by a number of factors. These factors are discussed in section 4.5.

4.4.5.3. DB/BMU (Delta B per BMU)

Remodeling BMUs at different sites and in response to different stimuli need not resorb and form equal amounts of bone. It has been documented that at the marrow surface (cortico-endosteal) BMUs form less than they resorb resulting in nett bone loss. Conversely, BMUs at the periosteal surface form more bone than is resorbed resulting in nett bone gain. This bone balance (positive or negative) for each BMU is known as the DB/BMU or delta bone volume per BMU (Frost, 1989a). The DB/BMU can therefore be +ve, -ve or 0. The DB/BMU for a particular BMU can only be measured once the formation phase is completed, however long that takes.

Remodeling is generally responsible for nett bone loss because BMUs on the cortico-endosteal surface (with -ve DB/BMU) are activated. Once bone growth ceases (when peak bone mass is achieved in the 3rd-4th decade of life) continuous remodeling is responsible for the continued loss of bone mass. Adult annual bone loss (normally 0.75% of the previous bone mass) is related to the product of the -ve DB/BMU of remodeling times the number of BMUs completed in that year (Frost, 1989a).

4.4.5.4. Factors controlling remodeling

The factors that control remodeling can also be classified as either mechanical or non-mechanical . These factors will be discussed in sections 4.5.2. and 4.5.3. respectively.

4.5. Factors affecting bone turnover

4.5.1. Introduction

The control of bone turnover is a complex process and is under the control of a variety of factors. The factors affecting bone turnover can be classified as mechanical and non-mechanical. These will now be reviewed.

4.5.2. Mechanical factors affecting bone turnover

4.5.2.1. Introduction

The basic mechanics of force application to bone, as well as the laboratory techniques that are used to study the mechanical properties of bone have already been described (section 4.4.2.).

It has been observed for centuries that components of the musculoskeletal system adapt to their mechanical strain environment. The mechanical loads that are applied to the skeleton can be external (for example ground reaction forces during weight bearing) or internal (for example muscle contraction). The evidence that the mechanical strain environment influences bone turnover comes from two types of scientific studies: i) the investigation of the effect of controlled mechanical loads on bone in the laboratory setting, and ii) the investigation of mechanical load application through physical activity on bone in the clinical setting.

4.5.2.2. Controlled mechanical strain application and bone turnover: Laboratory based studies

4.5.2.2.1. Introduction

The adaptation of bone to mechanical loading implies that the skeletal system somehow monitors its "loading history" and then adapts to that mechanical strain environment (Frost, 1988). The process of monitoring the "loading history" is not well understood. However, this process would have to involve i) monitoring the mechanical strain environment (loading history), ii) translating the mechanical strain into a biological stimulus, and iii) activating the formation and/or resorption of bone.

In this section the current understanding of i) what constitutes the "mechanical environment", ii) how this environment is monitored by bone, and iii) how the mechanical stimulus is translated into a biological stimulus will be reviewed.

4.5.2.2.2. The mechanical strain environment

The application of mechanical strain (external or internal) to a bone can vary with respect to i) the magnitude of the strain, ii) the rate of strain application, iii) the number of strain cycles (frequency of strain application), and iv) the distribution of the strain within a bone (Lanyon, 1984). It follows that the mechanical strain environment that a bone must monitor will also differ with respect to these parameters. It is not clear which of these parameters is the most important determinant of the "loading history". The apparent role that each of these parameters play in bone turnover will be discussed briefly.

4.5.2.2.3. Magnitude of the strain

It has been well established that the magnitude of the strain applied to the bone is an important determinant of the bones' response to the strain. Direct evidence for this has been provided by studies in which controlled strains of different magnitudes were applied daily to the ulnas of turkeys for 8 weeks (Rubin et al, 1985). A linear regression analysis revealed that increases in cross-sectional areas (CSA) of the loaded ulnar bones correlated well (r=0.83) with increases in strain magnitude between 1500uE and 3000uE (Rubin et al, 1985). Furthermore, for strains below 100uE there was a decrease in the CSA of bone. It therefore appears that a specific minimum magnitude of strain is required to i) activate nett bone formation (modeling), or ii) deactivate nett bone resorption (remodeling). This minimum microstrain has been termed the minimum effective strain (MES) and the MES has been determined for modeling and remodeling. For modeling, strains below the MES (1500-3000uE) result in inhibition of modeling whereas strains above this range activate modeling (Frost, 1988; Frost, 1990a). In contrast, remodeling is deactivated by strains above the MES for remodeling (50-100uE) and activated by strains below the MES (Frost, 1990b). The magnitude of mechanical strain therefore is an important determinant of the response of bone to mechanical loading. In general, high strain magnitudes will cause nett bone formation whereas low strain magnitudes cause nett bone loss.

It must however be noted that excessively high strain magnitudes can result in a fracture of the bone. In vivo strain studies have documented that the fracture strain (the strain which will result in a fracture after one strain application) of cortical bone is 25 000uE in longitudinal tension or compression (Frost, 1988). This is approximately 10 times higher than documented peak strains during the most vigorous physical activity (Rubin, 1984). However, repeated applications of strains in the range between 3000uE and 25 000uE can also result in "fatigue" damage. This forms the basis of the pathogenesis of bone stress injuries and will be discussed in detail in Chapter 5.5.

In summary, mechanical strain that is applied to the bone can activate or inhibit modeling or remodeling depending on the magnitude of the strain.

4.5.2.2.4. Rate of strain application

The loading "history" of a bone can also vary with respect to the rate of force application. A force can be applied to bone gradually (low strain rate) or rapidly (high strain rate). At this stage there is no clear evidence to indicate how important different strain rates are in stimulating bone turnover. However, from animal experimentation the effects of different strain rates on bone have been investigated. It has been suggested that high strain rates result in increased bone formation whereas low strain rates do not increase bone formation (Hert et al, 1971; Lanyon, 1984; O'Connor et al, 1982). High strain rates would therefore appear activate the modeling process or induce remodeling of BMU's with a positive DB/BMU.

4.5.2.2.5. Number of strain cycles (frequency of strain application)

The effect of frequency of strain application (defined as the number of cycles over a specific time period that are required to affect bone turnover) on bone turnover has been investigated in the animal model (Rubin et al, 1985). In this study mechanical strains (2000 uE) were applied to functionally isolated avian ulnae at daily frequencies varying from zero to 1800 cycles. The bone mineral content of the ulna loaded by 36 or more cycles per day was increased by 33%. No additional bone formation occurred after the number of daily load cycles were increased from 36 to 1800. It therefore appears that a certain minimum number of load cycles (threshold frequency) is sufficient to activate nett bone formation and further increases in load frequency do not increase this activation.

This may be one of the mechanisms of monitoring the mechanical strain environment of the bone. A single or a small number of load applications to the bone will not result in an immediate modeling response and only if the load is repeated (above the threshold frequency) will modeling be activated. This would prevent an "over-reaction" of the bone to any sudden load.

4.5.2.2.6. Distribution of the strain

The effects of altered distribution of the strain application on bone formation has not been investigated well. However, in a single animal experiment the importance of altered strain distribution has been suggested. In this study, the effects of resection of the ulna on bone formation in the radius was investigated in sheep (Lanyon et al, 1982). In this study only a slight increase (maximum of 20%) in strain magnitude in the radius was observed during walking after ulnar resection. This small increase in strain magnitude could not alone account for the observed increased bone formation in the radius. The authors concluded that the peak strain levels were less responsible for stimulating the adaptive response than the concurrent change in strain distribution. It therefore appears that alterations in strain distribution may also be an important factor in the loading "history" of bone.

4.5.2.2.7. Monitoring the mechanical environment

Mechanical strains that are applied to bone must monitored constantly so that changes in the strain environment can be detected. The mechanisms for monitoring the mechanical environment are not well understood but a number of theories have been proposed.

It has been postulated that changes in interstitial fluid flow occur in response to mechanical loading (Frost, 1988). These changes resemble the flow in fluids of a wet sponge when it is compressed, stretched or bent. The postulate is that changes in pressure gradients and their magnitude are translated into a biological stimulus.

Other postulated mechanisms by which the mechanical environment may be monitored are i) mechanically induced changes in local blood flow (Frost, 1988), ii) mechanically induced deformation of the bone matrix (Frost, 1988), in particular strain induced alterations in proteoglycans (Lanyon, 1987; Skerry et al, 1988; Skerry et al, 1990), iii) alterations of ion flow across cell membranes in response to mechanical loading (Binderman et al, 1984), and iv) and mechanically induced deformation of receptor sites (Binderman et al, 1984).

In summary a number of mechanisms to monitor the mechanical environment have been postulated. However, further investigation is required to identify the precise mechanism/s. Detailed discussion of each of these possible mechanisms is beyond the scope of this thesis.

4.5.2.2.8. Translating the mechanical strain into a biological stimulus

The mechanical strain applied to the bone must be translated into a biological stimulus so that the appropriate response to the strain can be initiated. The precise stimulus is not known. It has been hypothesized that changes in electrical potentials within the tissue are the link between the mechanical strain and biological responses. Evidence for this is i) changes in interstitial fluid flow are associated with the generation of electric potentials (known as zeta or streaming potentials) (Frost, 1988), ii) the application of an external electric field to bone has been shown to mimic the effects of mechanical loading on bone (Binderman et al, 1984), and iii) it has also been shown that when different voltages are used in the application of an electric field to bone, different cells are activated or inhibited (Binderman et al, 1984).

In addition to electrical field stimulation of bone cells, mechanical strain has also been shown to activate phospholipase A_2 (Binderman et al, 1988). Phospholipase A_2 in turn increases the formation of arachidonic acid which stimulates prostaglandin E_2 (PGE_2) synthesis. It has been shown that mechanical strain application increases prostaglandin E_2 (PGE_2) synthesis in specific bone cells. PGE_2 has been shown to increase cyclic AMP (cAMP) production with resultant increased DNA synthesis (Binderman et al, 1984). These effects can be inhibited by the administration of indomethacin (Pead et al, 1989).

It therefore appears that two mechanisms may be responsible for translating mechanical strain into a biological stimulus. These are i) induced electric potentials which, depending on the type of potential, affects the function of specific cells, and ii) activation of phospholipase A_2 resulting in increased PGE_2 production in specific cells causing increased DNA synthesis via cAMP production.

4.5.2.3. Mechanical strain application through physical activity and bone turnover: clinically based studies

4.5.2.3.1. Introduction

There is considerable evidence from clinical studies that mechanical strain application through regular physical activity affects bone turnover. In particular, there is evidence that decreased physical activity is associated with bone loss and that increased physical activity is associated with bone formation. The evidence for these associations will be reviewed briefly.

4.5.2.3.2. Decreased physical activity

The effects of decreased physical activity on bone have been studied in both animal and human models.

4.5.2.3.2.1. Animal studies

In animal experiments different methods of reducing the physical activity and therefore mechanical strain have been used. These include i) restraint, ii) denervation, iii) casting of limbs, and iv) immobilization of bone segments. Furthermore, different species of animals have also been studied. In general, the results of these studies showed that decreased mechanical loads result in decreases in bone mass, bone mineral content, and cortical cross-sectional area (Mosekilde et al, 1985; Young et al, 1981; Young et al, 1983). In some studies reversal of these detrimental effects do occur to some extent with resumption of activity (Young et al, 1981; Young et al, 1983).

The effect of decreased mechanical loading on bone can also be influenced by other non-mechanical factors that affect bone turnover (section 4.5.3.). In a recent study, the interaction between dietary calcium insufficiency and immobilization was demonstrated. In this study calcium deficiency increased the bone loss induced by immobilization in rats (Weinreb et al, 1991).

4.5.2.3.2.2. Human studies

Epidemiological data on the effects of reduced physical activity on bone have been obtained mainly from studies of bed rest, immobilization and exposure to the weightless environment during space travel.

It has been well documented that prolonged bed rest and immobilization in healthy persons results in rapid loss of trabecular bone from the calcaneus (Donaldson et al, 1970; Hulley et al, 1971; Schneider et al, 1984), iliac crest (Minaire et al, 1974) and lumbar spine (Hansson et al, 1975; Krolner et al, 1983) at a rate of about 1% per week. The loss of compact bone occurs at a slower rate (1% per month) - except compact bone at areas of muscle insertions which is lost at a higher rate (Krolner et al, 1983; Schneider et al, 1984).

In studies on astronauts that were exposed to a weightless environment similar changes were observed in bone. Calcaneal bone loss occurred at a rate of about 2% per month and there was a negative calcium balance (Vogel et al, 1976; Whedon et al, 1976). After restoration of weightbearing activity, hypercalciuria persisted for about 3 weeks and trabecular bone was restored either partially or completely at a rate of about 1% per month. This appeared to depend on the extent of the initial bone loss (Schoutens et al, 1989).

4.5.2.3.3. Increased physical activity

There is substantial evidence, from clinical studies, that increased physical activity influences bone turnover. These studies have recently been reviewed (Sandler, 1988; Schoutens et al, 1989; Smith et al, 1987; Smith et al, 1991; Snow-Harter et al, 1991). It is important to note that studies differ substantially with respect to study design and the results are therefore difficult to compare. Furthermore, in most clinical studies the exact nature of the mechanical loads (magnitude, rate of application, frequency and distribution) have not been documented. The measurement of changes in bone have, in some studies, been also performed at sites not related to the anatomical area that was subjected to the mechanical load.

Bearing in mind these general limitations of clinical studies, it is convenient to classify them into four categories (Snow-Harter et al, 1991): i) cross-sectional studies in athletes, ii) exercise intervention studies, iii) studies documenting the association between muscle mass, muscle strength and bone mineral density, and iv) studies documenting the association between cardiorespiratory fitness and bone mineral density.

4.5.2.3.3.1. Cross-sectional studies in athletes

There have been a number of cross-sectional studies in the literature that have examined the relationship between bone turnover in active compared to sedentary individuals. A detailed discussion of each of these studies is beyond the scope of this thesis. However, the main findings of each of these studies are summarized in Table 4.1. The populations that were studied differed with respect to age, sex, type of activity, the selection of control groups and menstrual status (female athletes). Furthermore, the anatomical area as well as the method of assessing the effect of activity on bone differed between studies.

In general, the studies support the hypothesis that increased physical activity is associated with increased bone deposition whether this is assessed as cortical thickness, bone density, bone width or total body calcium. Increased bone deposition also appears to occur to some degree in the specific sites that are loaded by the activity. In particular, i) the dominant arm of tennis players has an increased bone mineral content (Huddlestone et al, 1980; Montoye et al, 1980) or cortical thickness (Jones et al, 1977) compared to the non-dominant arm, ii) the bone mineral content of the radius was higher in tennis players and swimmers compared to sedentary controls

Table 4.1.

The effects of mechanical loading on bone turnover: Cross-sectional studies in athletes

Subject groups Sex and number	Mean age (yrs)	Bone studied (Technique)	Results	Reference
Controls (M15) Exercising controls (M24) Athletes (M55) Top rank athletes (M9)	22	Distal femur(SPA)	Bone density: Top rank athletes > Athletes > Exercising controls > Controls	Nilsson et al, 1971
Professional tennis players (M44) (F23)	27 24	Midshaft radius (X Rays)	Cortical thickness > on playing side (M=34.9%, F=28.4%)	Jones et al, 1977
Controls (M16) Marathon runners (M30)	42	Distal radius (SPA) Total body calcium (NAA)	Total body calcium 11% greater in runners Distal radius: no difference	Aloia et al, 1978a
Senior tennis players (M61)	64	Hand-wrist and hand (X-ray) radius ulna, humerus (SPA)	Bone width and BMC greater in dominant arm	Montoye, 1980
Senior tennis players (M35)	70-84	Radius (SPA)	Bone density 11% greater on dominant side	Huddleston et al, 1980
Inactive (F38) Runners (F42)	39	Phalanx of 5th finger, calcaneous (X ray) Radius (SPA)	Bone mineral in runners greater in finger and radius, but less in calcaneus	Brewer et al, 1983
Weight training (M12) Controls (M50)	19-40	Radius, lumbar spine, trochanter femoral neck (DPA)	Bone density in exercise group greater in lumbar spine, trochanter and femoral neck but not radius	Colletti et al, 1989

Table 4.1.

The effects of mechanical loading on bone turnover: Cross-sectional studies in athletes (continued)

Subject groups Sex and number	Mean age (yrs)	Bone studied (Technique)	Results	Reference
Amenorrheic athletes (F11) Premature ovarian failure (F16) Controls (F50)		Lumbar spine (CT) Radius (SPA)	Amenorrheic athletes: 24% less spinal trabeular bone, Radius no difference	Cann et al, 1984
Runners (Amenorrheic) (F11) Runners (cyclic) (F14)	25	Lumbar spine (DPA) Radius (SPA)	Lumbar spine density Cyclic > Amenorrheic Radius: no difference	Drinkwater et al, 1984
Five grades of physical activity (F136)	20 to pmp	Lumbar spine (L3)(CT)	Activity level influences density at L3	Laval-Jeantet et al, 1984
Runners (Amenorrheic) (F17) Runners (Normal cycles) (F6)	20-29	Lumbar spine (CT) Radius (SPA)	Lumbar spine density: Amenorrheic < control Radius density: No difference	Marcus et al, 1985
Low activity (F19) Moderate activity (F36) High activity (F28)	51.5 53 43	Radius (SPA)	Bone mineral and bone width (adjusted for age and menstrual status) High activity > Moderate > Low	Stillman et al, 1986
Aerobics (F9) Aerobics and weight training (F9) Controls (F9)	20-30	Lumbar spine (DPA)	Bone density: Aerobics and weight training higher than controls and aerobics	Davee et al, 1990

Table 4.1.

The effects of mechanical loading on bone turnover: Cross-sectional studies in athletes (continued)

Subject groups Sex and number	Mean age (yrs)	Bone studied (Technique)	Results	Reference
Runners (M23, F18)	57	Lumbar spine (L1)(CT)	Runners bone mineral > controls (40%)	Lane et al, 1986
Controls (M23,F18)	58			
Professional tennis players (10)	20	Radius (DPA) Ulna (DPA)	BMC increased in tennis players vs controls BMC increased in dominant side (tennis players)	Pirnay et al, 1987
Controls (10)	21			

Abbreviations: M=Male, F=Female, SPA= Single photon absorptiometry, DPA= Dual photon absorptiometry, CT = X-ray computed tomography, NAA= Neutron activation analysis, pmp = post menopausal

(Jacobson et al, 1984), and iii) the lumbar spine but not the upper limb of runners had an increased bone mineral density compared to non-runners (Aloia et al, 1978a; Lane et al, 1986; Marcus et al, 1985). However, the site specific effect of loading on bone has not been confirmed by other studies. Running has been associated with lower bone mineral densities in the lumbar spine of humans (Bilanin et al, 1989) and dogs (Puustjarvi et al, 1991) as well as in the calcaneus of humans (Brewer et al, 1983). However, these negative effects may also be attributed to other factors such as excessive training or secondary hormonal disturbances.

In summary, cross-sectional studies in humans generally indicate that there is a positive association between increased physical activity (increased mechanical loading) and bone formation.

4.5.2.3.3.2. Exercise intervention studies

Intervention studies to document the effects of exercise on bone have been conducted in both animals and humans.

4.5.2.3.3.2.1. Animal studies

The effects of running exercise on bone has been studied in rats (Beyer et al, 1985; LeBlanc et al, 1983; Li et al, 1991; Pohlman et al, 1985; Saville et al, 1969; Silbermann et al, 1990; Swissa-Sivan et al, 1990; Tuukkanen et al, 1991), swine (Woo et al, 1981), and dogs (Puustjarvi et al, 1991). The training was usually conducted for 5-7 days per week but the duration of training varied from 2 to 56 weeks. In most studies the effects of exercise was to either increase the bone mineral content or the total body calcium in the exercise groups (Beyer et al, 1985; LeBlanc et al, 1983; Saville et al, 1969; Swissa-Sivan et al, 1990; Woo et al, 1981), or to reduce the rate of bone loss (Tuukkanen et al, 1991; Silbermann et al, 1990). However, in some studies exercise did not affect the bone mineral content or the total body calcium (Pohlman et al, 1985; Puustjarvi et al, 1991). In general, intervention studies conducted in animals therefore support the hypothesis that exercise (increased mechanical loading) promotes bone formation.

4.5.2.3.3.2.2. Human studies

A number of intervention studies have been reported in which the effect of exercise training on bone in human subjects has been documented. A detailed discussion of each of these studies is beyond the scope of this thesis, but the study methodology and main findings of each study has been summarized in Table 4.2.

Table 4.2.

The effects of mechanical loading on bone turnover: Intervention studies

Age (yrs)	Sex	Groups Active (A) Control (C)	Type	Activity Duration (min)	Times/ week	Length	Measurement Site (Type)	% Change A	C	Reference
18-21	M	A:n=139 C:n=105	Military training	480	6	14/52	Tibia (SPA)	+8/+12	+1/+9	Margulies et al, 1986
19	F	A_1:n=? A_2:n=? C:n=?	Running Weight training 3x8 reps (85%RM)	10 miles wk		8/12 8/12	Lumbar spine BMD (?)	A_1+1.32 A_2+1.21	0	Snow-Harter et al, 1991
23-46	F	A:n=34 C:n=38	Weight training upper & lower body	30	3	1 yr	Spine (DPA) Calcaneous (SPA)	+1 0	-1 0	Gleeson et al, 1990
A:36.4 C:40.4	F	A:n=12 C:n=7	Weight training 8 stations		2	4/12	Spine (CT) Femur	-3 0	0 +1	Rockwell et al, 1989
35-65	F	A:n=80 C:n=62	Endurance dance	50	3	4 yrs	Radius (SPA)	-3	-7	Smith et al, 1989
36-67	F	A_1:n=18	Endurance dance & weight training	50+40	3	1 yr	Radius (SPA) Humerus (SPA)	A_1/A_2 1.2/-2 3.1/3.5	0.5 0.4	Peterson et al, 1991
		A_2:n=17 C :n=19	Endurance dance alone Sedentary	50	3	1 yr	Lumbar spine Neck of femur Wards triangle	0.5/0.6 1.3/0.6 4.2/3.8	-1.3 -1.3 -1.3	
49-65	F	A:n=130 C:n=125	Walking	3miles	2	3 yrs	Radius (CT) Bone tissue density	+1 +4	+1 +4	Sandler et al, 1987

Table 4.2.

The effects of mechanical loading on bone turnover: Intervention studies (continued)

Age (yrs)	Sex	Groups Active (A) Control (C)	Type	Activity Duration (min)	Times/week	Length	Measurement Site (Type)	% Change A	C	Reference
49-65	F	A:n=34 C:n=31	Weight training (back extensions)		5	2 yrs	Spine (DPA)	-3	-2	Sinaki et al, 1989
52.6	F	A:n=9 C:n=9	Presidents Council on Physical fitness	60	3	1 yr Radius	Total body calcium (SPA)	+3	-2	Aloia et al, 1978b
A:55.4 C:57.0	F	A:n=8 C:n=9	Walking	15-40	3	1 yr	Spine (CT)	-6	-4	Cavanaugh et al, 1988
55-70	F	A_1:n=17	Aerobic & weight training	50-60	3	8/12	Spine (DPA) index (NAA)	+5		Dalsky et al, 1988
		A_2:n=18	Aerobics alone	15-20	3	8/12		-1		
		A_3:n=11	Same as A_1	50-60	3	22/12		+6		
		A_4:n=15	A_2 then de-training			13/12		-5		
56	F	A_1:n=17	Aerobics	30	3	1 yr	Calcium bone index (NAA)	+4	-1	Chow et al, 1987a
		A_2:n=16	Aerobics & weight training	40-45	3	1 yr		+8		
50-73	F	A:n=13 C:n=15	Variety (walking, Running, ballgames standing, sitting)	60	2	8/12	Spine (DPA) Forearm (DPA)	+4 0	-3 -4	Krolner et al, 1983
50-63	F	A_1:n=27	A_1: Walking	1-2 miles	2-4	6/12	Radius BMC(SPA)	-2	-2	White et al, 1984
		A_2:n=25	A_2: aerobic dancing	2-5 dances	2-4	6/12	Radius BMC/wdth	-1		
		C:n=21						+2	+1	
								+1		

Table 4.2.

The effects of mechanical loading on bone turnover: Intervention studies (continued)

Age (yrs)	Sex	Groups Active (A) Control (C)	Type	Activity Duration (min)	Times/week	Length	Measurement Site (Type)	% Change A	C	Reference
53-74	F	A:n=14 C:n=26	Warm-up, stretch, strengthen, relaxation, forearm loading	45-55	3	5/12	Radius (CT) Radius (SPA)	+4 -3	-3 +3	Simkin et al, 1986
57-83	F	A_1:n=13	General aerobic training	50	3	10/12	Radius (SPA)	+1	-3	Rikli et al, 1990
		A_2:n=10 C:n=11	Upper body	20	3	10/12		+2		
62	F	A_1:n=57	Squeeze tennis ball	30 sec	7	6/52	Wrist (SPA)	+3		Beverly et al, 1989
		A_2:n=30	Detraining			6/12		-3		
63-84	F	A:n=15 C:n=21	Training (walking, jogging)	40	2	6/12	Calcaneous (DPA)	+5	-2	Rundgren et al, 1984
68.7	M& F	A:n=57 C:n=20	Cycle ergometer	30	3	1 yr	Spine (DPA)	-2	-4	Ismail et al, 1989

Subscript:
Abbreviations: M=Male, F=Female, SPA= Single photon absorptiometry, BMC = Bone mineral content
DPA= Dual photon absorptiometry, CT = X-ray computed tomography,
NAA= Neutron activation analysis.

There is a large degree of variability in the methodology employed by researchers in these studies. These variables include i) age and sex of the groups studied, ii) sample sizes, iii) type, duration, frequency and length of the exercise activity, iv) site and method of measuring the outcome, and v) compliance of the subjects (Oldridge, 1992). The main results are summarized in Table 4.2. as percentage change so that these can be compared between studies. In general most studies have been conducted in older females (pre- and post-menopausal) and the most common exercise activity was walking/running or aerobics.

There have been no well conducted studies in the younger age groups (before peak bone mass has been achieved). In a recently reported study both weight training (1.21%) and running (1.32%) increased lumbar spine bone mineral density in young females (mean age, 19 years) (Snow-Harter, 1991). However, the precise details of study methodology were not described. In another study, bone mass in males (18 to 21 years) increased by 8.3% and 12.4% for the right and left legs respectively after 14 weeks of military training (Margulies et al, 1986). The increases in the "control" group were only 1% and 9.4% for the right and left leg respectively. The "control" group in this study consisted of recruits who interrupted their training mainly as a result of injury and was therefore not a randomly chosen group. In one other study, young females (23 to 46 years) underwent weight training of the upper and lower body for 1 year. The spine bone mineral content in the trained group increased by 1% whereas that in the control group did not change (Gleeson et al, 1990). It therefore appears that in younger individuals there is some evidence that bone mineral content increases with exercise. However, more studies are required to verify these preliminary findings. Furthermore it is important to document the type, frequency, duration and length of activity required for this effect.

Very few studies have reported the effects of physical activity on bone mineral density in pre-menopausal women after peak bone mass has been achieved. In one study endurance dance training was associated with a significant increase in radial bone mineral density in both pre-and post-menopausal women (Smith et al, 1989). In a recent prospective study, the effects of 12 months endurance dance training on the bone density (measured at multiple sites) of pre-menopausal women was reported (Peterson et al, 1991). Three groups of subjects were studied: i) endurance dance training only, ii) endurance dance training and weight training and iii) a sedentary control group. There was a significant increase in bone density in most sites (Except the forearm) in the both the trained groups compared to the sedentary group. Futhermore, the increase in bone density was slightly more in the group that performed weight training in addition to endurance dance training. This study indicates that exercise training, in particular weight training, can increase the bone density in pre-menopausal women.

Numerous studies have reported the effects of exercise training on bone mineral density in post-menopausal women (Table 4.2.). The results of training in this group are mixed. Studies report that exercise training increases (Aloia et al, 1978b; Beverly et al, 1989; Chow et al, 1987a; Dalsky et al, 1988; Krolner et al, 1983; Rikli et al, 1990; Rundgren et al, 1984), retards the decrease (Ismail et al, 1989; Smith et al, 1989), decreases (Cavanaugh et al, 1988; Rockwell et al, 1989; Simkin et al, 1986; Sinaki et al, 1989) or does not affect (Sandler et al, 1987; White et al, 1984) bone mineral density in post-menopausal women (Table 4.2.).

The following general trends can however be observed: i) exercises that load a specific anatomical area usually increase bone mineral density in that area (Beverly et al, 1989; Chow et al, 1987a; Dalsky et al, 1988; Gleeson et al, 1990; Krolner et al, 1983; Rikli et al, 1990; Rundgren et al, 1984), ii) more intense and longer exercise programs appear to be more effective in increasing bone density in post-menopausal women (Snow-Harter et al, 1991) and iii) exercise training in the aged (over 60 years) may be more effective in increasing bone density than in younger post-menopausal women (Beverly et al, 1989; Ismail et al, 1989; Rikli et al, 1990; Rundgren et al, 1984).

4.5.2.3.3.3. Muscle mass, muscle strength and bone density

The associations between muscle mass and bone density as well as muscle strength and bone density provide indirect evidence of the effect of mechanical loading on bone turnover (Snow-Harter et al, 1991). In general there appears to be a direct relationship between i) muscle mass and bone mass (Aloia et al, 1978b; Doyle et al, 1970), and ii) muscle strength and bone density (Bevier et al, 1989; Sinaki et al, 1988).

Although the relationship between muscle strength and bone mineral density is assumed to be site specific, recent evidence indicates that this is not always the case. It has been documented that biceps and not quadriceps strength predicts spinal and femoral neck bone mineral density (Pocock et al, 1989; Snow-Harter et al, 1991). These relationships may be as a result of co-contraction of trunk muscles during arm activity.

4.5.2.3.3.4. Cardiorespiratory fitness and bone density

Regular physical activity is associated with improvements in measures of physical fitness such as maximal oxygen consumption. A positive association between maximal oxygen consumption and bone mineral density is therefore indirect evidence that physical activity affects bone turnover. It has been shown that bone mineral density is related to direct (Bevier et al, 1989) and indirect (Pocock et al, 1986) measures of maximal oxygen consumption.

4.5.2.4. Summary: Mechanical factors affecting bone turnover

It is well documented that the mechanical environment is an important factor determining the normal turnover of bone. The mechanical environment can differ with respect to the magnitude, frequency, rate and distribution of strain application. The precise mechanisms by which i) bone monitors its mechanical environment and ii) the mechanical stimulus to bone is translated into a biological stimulus require further investigation. There is also clinical evidence from animal and human studies that decreased and increased physical activity (mechanical loading) results in decreased and increased bone mass respectively. Muscle mass, muscle strength and maximal oxygen consumption are also related to bone mass and this provides additional indirect evidence that mechanical loading is an important factor affecting bone turnover.

4.5.3. Non-mechanical factors affecting bone turnover

4.5.3.1. Introduction

It has been well documented that a number of non-mechanical factors can affect the resorption and formation of bone (bone turnover). The effects of these factors are complex and they have mostly been studied in relation to specific pathological states. It is beyond the scope this thesis to review each of these states in detail. Rather, this section will take the form of a brief overview of these factors. Specific factors, such as the role of dietary calcium, will be discussed in more detail because calcium supplementation formed the basis of one of the intervention studies described in this thesis (Chapter 7).

It is convenient to classify the non-mechanical factors that affect bone turnover into three groups; nutritional, hormonal and other factors. These groups will be discussed separately.

4.5.3.2. Nutritional factors

4.5.3.2.1. Introduction

A variety of nutritional factors can affect bone turnover. These factors are important in bone metabolism for one of two main reasons: i) they are important substrates for the formation of bone or ii) they play a role in the metabolism of substrates required for bone formation. The main substrates that are important for bone formation are calcium, phosphate, and protein. Of these, calcium is the most important one and will be discussed in detail. The most important nutritional factors that affect substrate metabolism are therefore those that play a role in metabolism of calcium. Nutritional factors that affect calcium metabolism are mainly those that affect calcium absorption from the gastrointestinal tract and calcium excretion from the kidney. These factors will be discussed briefly.

4.5.3.2.2. Calcium

4.5.3.2.2.1. Introduction

Calcium is the major extracellular divalent cation and normal adult man and woman possess 1300g and 1000g calcium respectively. Furthermore, 99% of the calcium is contained in the skeleton with only trivial amounts in the extracellular fluid (Managolas et al, 1988). The main functions of calcium in bone are that it i) is required for mineralization of osteoid, ii) stimulates the secretion of calcium regulating hormones if it is deficient, iii) mediates the intercellular effects of calcium regulating hormones, and iv) stimulates matrix formation directly (Raisz et al, 1983b).

The concentration of calcium in the extracellular fluid has to be maintained in a very narrow range to sustain vital functions of the muscle and the nervous system (Bell et al, 1980). The main regulators of this concentration are the calcium regulating hormones. The influence of these hormones on bone turnover is discussed in more detail in section 4.5.3.3.2.

4.5.3.2.2.2. Calcium homeostasis

There is a constant daily turnover of calcium in the body. Figure 4.3. is a schematic representation of this turnover in an adult man who is in calcium balance. The only source of calcium is through dietary intake (800mg/day). Calcium loss from the body is through the gastrointestinal tract (650mg/day) and the kidney (150mg/day). In the context of bone turnover, it must be noted that there is substantial a daily exchange of approximately 300mg of calcium with the

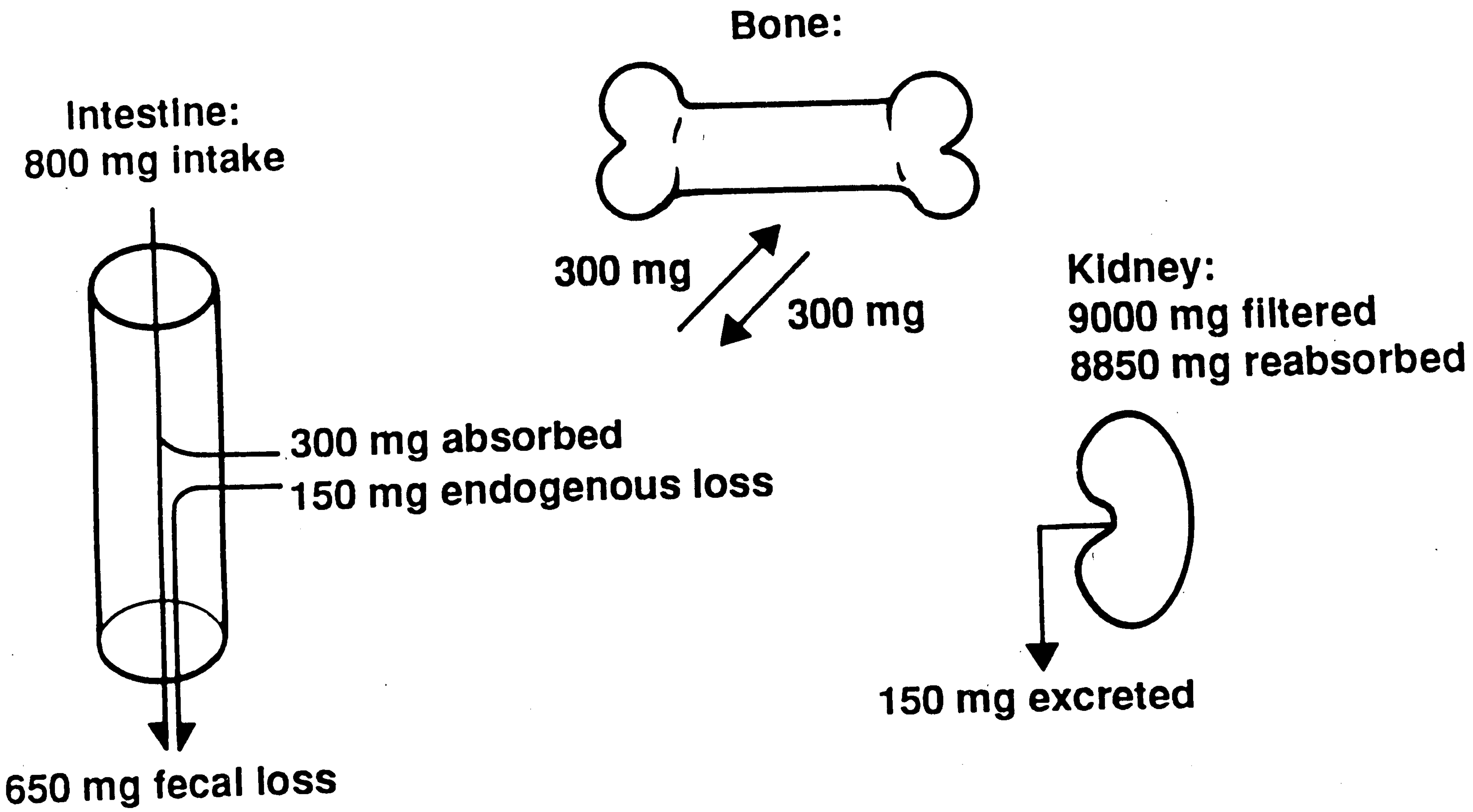

Fig 4.3. Daily calcium balance in adult man Marcus, 1988

skeletal system. Disturbances in calcium homeostasis can affect the normal calcium exchange with bone and are likely to affect normal bone turnover.

Disturbances in the exchange of calcium in bone can be caused by i) an inadequate supply of calcium to the bone, ii) an increased removal of calcium from bone, or iii) a combined effect of i) and ii). The increased removal of calcium from the bone is usually a disturbance of the calcium regulating hormones and this will be discussed in section 4.5.3.3.2.

An inadequate supply of calcium to the bone can result from i) a decreased dietary intake of calcium, ii) poor absorption of ingested calcium, iii) increased renal excretion of calcium, iv) increased fecal loss of calcium, or v) a combination of i) to iv). It must also be noted that a relative inadequate supply of calcium can arise when there is a sudden increased skeletal demand for calcium. This occurs for example during growth, pregnancy, lactation and possibly when there is sudden increased mechanical usage which is associated with accelerated bone turnover.

4.5.3.2.2.3. Dietary calcium intake and bone mass

Dietary intake of calcium rich foods such as dairy products is the main source of calcium in the Western population. A reduced calcium intake can be the result of i) general malnutrition states such as age related decline in food intake, anorexia nervosa (Rigotti et al, 1984), alcoholism (Siegelman, 1978), and fad diets (Myburgh et al, 1988), or ii) lack of preference for dairy products which can be voluntary dairy product restriction or secondary to disease states such as lactose intolerance (Birge et al, 1967).

The recommendations for the normal daily dietary intake of calcium to maintain bone health have been estimated for males and females of various age groups through the use of calcium balance studies (Hegsted et al, 1952; Heaney et al, 1977; Malm, 1968). The RDA's (Recommended Dietary Allowances) of calcium for optimal bone health do however vary from country to country and range from 400mg to 1500mg per day in women (Kanis, 1991). In the United States of America the RDA's for calcium have recently been revised and are depicted in Table 4.3. (Monsen, 1989). These RDA's are still controversial mainly because of i) the difficulty in interpreting the results of the calcium balance studies and ii) the conflicting results from the vast number of epidemiological studies of varying quality and study design (Avioli et al, 1991; Cumming, 1990; Kanis, 1991).

Scientific studies to define the relationship between calcium intake and bone health have essentially been designed to address the following four issues (Marcus,

Table 4.3.

The Recommended Dietary Allowances (RDA's) for calcium

Group		mg/day
Infants	0-6 months	400
	6-12 months	600
Children	1-3 years	800
	4-6 years	800
	7-10 years	800
Males	11-14 years	1200
	15-18 years	1200
	19-24 years	1200
	25-50 years	800
	51 years and over	800
Females	11-14 years	1200
	15-18 years	1200
	19-24 years	1200
	25-50 years	800
	51 years and over	800
	Pregnant	1200
	Lactating	1200

Adapted from Monsen, 1989

1987b): i) the effect of dietary calcium on peak bone mass, ii) the impact of dietary calcium on bone loss during young adult life, iii) the relationship between calcium intake and bone loss at menopause, and iv) the role of increased calcium intake in post-menopausal women and the elderly. A detailed discussion of all the studies that have addressed these issues is beyond the scope of this thesis. However, the findings of some of these studies have recently been reviewed and will be discussed briefly (Avioli et al, 1991; Cumming, 1990; Kanis, 1991; Marcus, 1987b).

Peak bone mass is achieved in the first 3 to 4 decades of life. The evidence that dietary calcium intake influences peak bone mass comes from two main observations (Marcus, 1987b). The first of these is that it has been documented that a low daily calcium intake (500mg/day) in the first two decades of life was associated with a significantly lower bone density compared to a high calcium intake (1100mg/day) (Matkovic et al, 1979). The second observation stems from calcium balance studies in adolescents. In 14 year old girls, it has been documented that in order to maintain a positive calcium balance, sufficient for the increase in skeletal growth, a daily intake of 1000mg calcium is required (Matkovic et al, 1986). It therefore appears that marginal calcium intake during the skeletal growth period can constrain peak bone mass.

The association between low dietary calcium intake and negative bone balance (bone loss) in adults from the age of 35 to 50 years (after peak bone mass has been achieved but before the onset of menopause in females) is less clear. It has been documented, from calcium balance studies, that in contrast to males (Hegsted et al, 1952; Malm, 1968), most pre-menopausal females over 35 years in the USA are in negative daily calcium balance by approximately 25mg calcium per day (Heaney et al, 1977). Based on this finding one would expect that in this age group (35-50 years) i) differences would be detected in the calcium-parathyroid axis between males and females, ii) females would show greater bone turnover than males, and iii) bone loss would be more rapid in females compared to males. In fact, the evidence is that no differences can be observed between males and females with respect to the calcium-parathyroid axis (Marcus, 1987b) or bone turnover (Hoikka, et al, 1981; Melsen et al, 1978). Although bone loss appears to be more rapid in females compared to males in this age group (Riggs et al, 1982), this loss is not only dependent on calcium intake (Riggs et al, 1986).

In a recent report 37 publications between 1966 and 1989, representing the results of 49 separate epidemiologic studies that examined the relationship between calcium intake and bone mass in adults, were reviewed using the quantitative technique of meta-analysis (Cumming, 1990).

Seven of these studies were in pre-menopausal women and were mostly that of a cross-sectional design. No distinction was made in this analysis between age groups less than 35 years and those greater than 35 years. Although the analysis reveals a slight general positive effect of calcium on bone mass in pre-menopausal women, the greatest effect was evident in the two studies where the mean age of the subjects was 29 years (Kanders et al, 1988; Sowers et al, 1985). These findings again emphasize the importance of adequate dietary calcium in the young adult (< 35 years) age group, and is in keeping with the hypothesis that dietary calcium is less important for bone mass in the age groups 35 to 50 years.

In the post-menopausal period two distinct phases are recognized (Marcus, 1987b). The first 2 to 5 years after menopause is characterized by a period rapid bone loss which can be retarded by oestrogen supplementation (Christiansen et al, 1980) but not calcium supplementation (Christiansen et al, 1986). Increased dietary calcium intake in this phase therefore does not appear to alter bone mass.

However, there is substantial evidence that calcium supplementation has a positive effect on bone mass in the elderly. In the previously mentioned review of 49 studies up to 1989, the most profound effect of dietary calcium on bone mass was observed in studies where the mean age of subjects was high (> 80 years) (Cumming, 1990). It can therefore be stated that dietary calcium is an important determinant of bone mass in the elderly (Marcus, 1987b).

In summary, decreased dietary intake of calcium can result from general malnutrition or selective restriction of dairy products. Adequate dietary intake of calcium is important for the development of peak bone mass. High daily intakes of calcium appear to be less important for the maintenance of bone mass in adulthood (after 35 years) and the immediate post-menopausal period. Finally, adequate daily dietary calcium intake is important for bone health in the elderly.

4.5.3.2.2.4. Calcium absorption from the gastrointestinal tract

The adequate absorption of calcium from the gastrointestinal tract is an important component of normal calcium homeostasis. Calcium absorption occurs mainly in the proximal small intestine via an active mechanism which is controlled by 1,25-dihydroxyvitamin D (Bell et al, 1980). Passive or facilitated absorption of calcium occurs in the distal small intestine (Bell et al, 1980) and the colon (Barger-Lux et al, 1989) . The effects of 1,25-dihydroxyvitamin D will be discussed in section 4.5.3.3.2.2. However, a number of other nutritional factors can affect calcium absorption (Heany et al, 1990; Heany et al, 1988;

Pak et al, 1988; Recker et al, 1988; Sheikh et al, 1987). These include the type of calcium ingested (Pak et al, 1988; Recker et al, 1988; Sheikh et al, 1987; Weaver et al, 1991) as well as nutritional factors that affect calcium absorption such as fibre, caffeine and phosphorus.

It has been reported that a high fibre intake in the diet (>30g/day) reduces the availability of calcium for absorption (Cummings et al, 1979; Ismail-Beigi et al, 1977; Reinhold et al, 1976). Furthermore, excessive caffeine (Heaney et al, 1982) and phosphorus ingestion (Zemel et al, 1981) were also found to negatively influence calcium balance. These effects appear to be not only as a result of decreased calcium absorption but also due to increases in calcium excretion (Heaney et al, 1982).

4.5.3.2.2.5. Calcium excretion from the kidney

The loss of calcium from the kidney is primarily under hormonal control (section 4.5.3.3.2.). However, dietary factors also appear to influence calcium excretion from the kidney. As has already been suggested, excessive phosphorus and caffeine intake has been associated with increased renal loss of calcium (Heaney et al, 1982). Furthermore, a high protein intake (142g/day) of purified protein has been documented to result in increased urinary calcium loss (Johnson et al, 1970). Protein intake in the form of meat does not appear to influence calcium balance negatively (Spencer et al, 1978).

4.5.3.2.3. Other nutritional factors

4.5.3.2.3.1. Ethanol

It has been well established that chronic alcoholism is associated with osteopaenia (Bikle et al, 1985; Feitelberg et al, 1987; Lalor et al, 1986) and an increased risk of osteoporotic fractures (Schnitzler et al, 1984; Spencer et al, 1986; Wilkinson et al, 1985). The aetiology of ethanol associated bone disease is not known and may be related to a variety of secondary ethanol related metabolic disturbances. These include alterations in calcium and vitamin D metabolism (Pitts et al, 1986), liver function (Bikle et al, 1985; Lalor et al, 1986), gonadal function (Galvao-Teles et al, 1986), and nutrition (Lalor et al, 1986; Pitts et al, 1986). All these effects may adversely affect bone turnover. However, a direct negative effect of ethanol on osteoblastic function has also been documented (Baran et al, 1980; de Vernejoul et al, 1983; Diamond et al, 1989; Farley et al, 1985). Excessive ethanol intake therefore appears to be an important factor nutritional factor that can affect bone turnover.

4.5.3.2.3.2. Fluoride

The earliest indication that the dietary intake of fluoride affects bone metabolism was reported in 1891. In this report the bones of a dog, which was given fluoride, were reported to be very hard, brittle and difficult to break (Brandl et al, 1881). Fluoride appears to increase bone formation by stimulation of osteoblastic activity (Farley et al, 1983), but this is not preceded by bone resorption as is normally the case (Schenck et al, 1970). The newly formed bone is also poorly mineralized and resembles that of osteomalacia (Vigorita et al, 1983). The bone does however become mineralized with time (Briancon et al, 1981).

There is some epidemiological evidence to indicate that increased intake of fluoride is associated with lower rates of osteoporotic fractures and increased bone density (Bernstein et al, 1966; Harrison, 1990; Leone et al, 1960; Simonen et al, 1985). The results of studies where fluoride treatment was used in combination with other drugs in the treatment of osteoporosis are however conflicting. The following findings have all been reported in response to fluoride treatment: i) decreased vertebral fracture rates (Riggs et al, 1982), ii) increased vertebral bone mass (Harrison et al, 1981), iii) no change in fracture rates (Inkovaara et al, 1975), and iv) increased hip and femur fracture rates (Gutteridge et al, 1984). It has been suggested that fluoride may alter the distribution of calcium from the appendicular cortical bone to the axial skeleton (Hedlund et al, 1987). Although dietary intake of fluoride is important in bone metabolism, its precise effects on bone turnover require further investigation.

4.5.3.2.4. Summary: Nutritional factors

There are important nutritional factors that affect bone turnover. The most important and best studied is calcium. An adequate dietary intake of calcium is of particular importance in i) the achievement of peak bone mass and ii) to decrease the rate of bone loss in the elderly. Nutritional factors such as excessive phosphorus, protein and fibre intake can have detrimental effects on normal calcium metabolism. Ethanol and fluoride also affect bone metabolism but the precise mechanisms require further investigation.

4.5.3.3. Hormonal factors

4.5.3.3.1. Introduction

The normal turnover of bone is influenced by the actions of a number of systemic hormones as well as local growth factors. The systemic hormones that affect bone can be classified as i) calcium regulating hormones that act to maintain normal serum levels of calcium, ii) gonadotrophic hormones, and iii) other hormones such as thyroid hormone, glucocorticoids, insulin and growth hormone. In this review only the effects of the calcium regulating and gonadal hormones will be discussed in some detail.

4.5.3.3.2. Calcium regulating hormones

The principal calcium regulating hormones are parathyroid hormone (PTH), 1,25-dihydroxyvitamin D and calcitonin (Managolas, 1988; Raisz et al, 1983a). A detailed description of their mechanisms of action is beyond the scope of this thesis and have recently been reviewed (Managolas, 1988; Raisz et al, 1983a). However, their main effects on calcium metabolism and bone turnover will be discussed briefly.

4.5.3.3.2.1. Parathyroid hormone

Parathyroid hormone (PTH) is the most important regulator of extracellular calcium concentration (Raisz et al, 1983a). A reduced serum ionized calcium concentration is therefore the primary stimulus for its release from the parathyroid gland. Once released into the circulation, PTH acts on specific high-affinity receptors in bone, the kidney and the intestine to restore extracellular calcium concentration.

The general effect of PTH on bone is to stimulate bone resorption by increasing osteoclast activity and decreasing osteoblast function. The specific effects on osteoclast function are to i) recruit osteoclast precursor cells, ii) activate preexisting osteoclasts, and iii) stimulate osteoclast associated enzyme activities such as acid phosphatase and hyaluronic acid synthesis. The specific effects on osteoblast function are to decrease the i) formation of Type I (bone) collagen, ii) production of alkaline phosphatase, and iii) synthesis of osteocalcin. In addition, PTH stimulates the osteoblasts to produce prostaglandin E_2 which initiates osteoclastic resorption (Managolas, 1988). The detailed effects of PTH on bone will not be discussed further but have been reviewed comprehensively elsewhere (Raisz et al, 1983a).

The main effect of PTH on the kidney is to increase the excretion of phosphate (Managolas, 1988; Raisz et al, 1983a). This is an important function because the calcium which was mobilized from bone would otherwise be redeposited in bone and soft tissues (Raisz et al, 1983a). In addition, PTH promotes renal calcium conservation and inhibits bicarbonate reabsorption. The effects of PTH on the kidney are presumed to be at the level of the ascending segment of the loop of Henle (Managolas, 1988). Finally, PTH also stimulates the enzyme 1 alpha hydroxylase which is responsible for the conversion of 25-hydroxyvitamin D to its active metabolite 1,25-dihydroxyvitamin D. The actions of this metabolite are discussed in section 3.5.3.3.2.2.

The nett effect of PTH on the intestine is to increase the absorption of calcium. This effect is however secondary to the activation of 1,25-dihydroxyvitamin D.

4.5.3.3.2.2. 1,25-dihydroxyvitamin D (Calcitriol)

Although vitamin D can be obtained from the diet, over 90% of the total vitamin D in most Western societies comes from endogenous synthesis. The mechanism of action of active vitamin D is like that of a steroid hormone and it is therefore discussed under the hormonal factors affecting bone turnover rather than with the nutritional factors. The two major forms of vitamin D are vitamin D_2 (ergocalciferol) and vitamin D_3 (cholecalciferol). Ergocalciferol is obtained from ultraviolet radiation of ergosterol in plants.

The main source of cholecalciferol, which is the important vitamin D in this discussion, is derived from the ultraviolet radiation of circulating 7-dehydrocholesterol in the subcutaneous tissue. A provitamin D_3 is formed (Managolas, 1988). This provitamin D_3 undergoes further thermal isomerization to vitamin D_3 over a period of a few days. As previously mentioned, vitamin D_3 can also be obtained from the diet, coming largely from fortified dairy products. Circulating vitamin D_3 is inactive and requires two hydroxylations before it becomes active. The first of these hydroxylations occurs in the liver and is substrate dependent. The product of this hydroxylation, 25-hydroxyvitamin D, can undergo one of two transformations in the renal tubular cells. The potent metabolite 1,25-dihydroxyvitamin D is formed by action of the previously mentioned enzyme 1-alpha hydroxylase. A relatively inactive metabolite 24,25-dihydroxyvitamin D is formed by the action of the enzyme 24R hydroxylase. There is very specific control over the predominant pathway that vitamin D_3 follows at any time. Factors that promote the active pathway (by stimulating 1-alpha hydroxylase) are PTH, hypophosphataemia, and hypocalcaemia. Conversely, hyperphosphataemia, hypoparathyroidism and hypercalcaemia promote the inactive pathway by stimulating the enzyme 24R hydroxylase.

The molecular basis of the action of active vitamin D_3 is that of a steroid hormone. It has specific effects in the intestine, bone and kidney. The main effect on the intestine is to rapidly increase active calcium absorption in the duodenum through an as yet unclear mechanism (Managolas, 1988). It also appears to increase the absorption of phosphorus from the jejunum (Managolas, 1988).

Vitamin D_3 deficiency is best known for its effects on bone in children (rickets) and adults (osteomalacia). Whether these effects are due primary to vitamin D_3 depletion or secondary to decreased calcium and phosphate supply are not clear (Managolas, 1988). There is however evidence that vitamin D_3 has direct effects on bone cells. It has been documented that vitamin D_3, i) has receptors in osteoblasts, ii) modifies collagen production in bone cells, and iii) stimulates the production of osteocalcin in osteoblasts.

The renal effects of vitamin D_3 are not well understood (Managolas, 1988). Vitamin D_3 has been shown to suppress the 1-alpha hydroxylase enzyme activity thereby acting as a negative feedback loop. Furthermore, it appears to interact synergistically with PTH to increase the renal tubular absorption of calcium.

4.5.3.3.2.3. Calcitonin

Calcitonin is a peptide hormone which is secreted by the neuroectodermal cells which are located diffusely throughout the thyroid gland in humans. The main stimulus for secretion is hypercalcaemia. Its main effects are to decrease serum calcium concentration by i) directly inhibiting osteoclastic activity, and ii) antagonizing PTH-induced bone turnover (Managolas, 1988). It also has less well described renal effects and may affect the synthesis of 1,25-dihydroxyvitamin D (Managolas, 1988). The manner in which calcitonin modulates or controls the biological activities of osteoclasts and osteoblasts has also recently been addressed in a workshop (Wallach et al, 1990). The importance of calcitonin as a factor affecting bone turnover is emphasized by the recent successful use of calcitonin in the prevention (McIntyre et al, 1988; Reginster et al, 1987) and treatment of postmenopausal bone loss (Overgaard et al, 1989).

4.5.3.3.3. Gonadal hormones

4.5.3.3.3.1. Oestrogen

Oestrogen is a very important regulator of bone turnover. It is well established that the hypo-oestrogenism in menopausal women is a major predictive factor for post-menopausal osteoporosis (Hillard et al, 1991; Vaananen, 1991). Post-menopausal osteoporosis can to some extent be prevented by the administration of oestrogen (Christiansen et al, 1980). Despite this well established effect, little is known about its precise mechanism of action (Hillard et al, 1991; Raisz et al, 1983b; Vaananen, 1991). A number of mechanisms have been proposed for the effect of oestrogen on bone. The proposed mechanisms are based on observations that hypo-oestrogenism is associated with, i) an increased sensitivity of the bone to the actions of PTH (Heany, 1965), ii) a decreased secretion of calcitonin (Deftos et al, 1980), iii) a decreased fractional absorption of calcium from the gastrointestinal tract (Smith et al, 1986), and iv) decreased serum calcitriol synthesis (Raisz et al, 1983b). Finally, oestrogen may also play a role in the regulation and release of local growth factors that affect bone turnover such as tumor necrosis factor, interleukin-1, and prostaglandins (Hillard et al, 1991).

4.5.3.3.3.2. Progesterone

The paradigm that oestrogen deficiency is the predominant hormonal disturbance in accelerated post-menopausal bone loss has recently been challenged. In a recent review of experimental, epidemiological and clinical data, it has been suggested that progesterone is active in bone metabolism (Prior, 1990; Prior et al, 1990). In this review it is postulated that progesterone i) acts directly on osteoblast receptors or indirectly through a glucocorticoid osteoblast receptor, ii) promotes bone formation and/or increases bone turnover, and/or iii) plays a role in the coupling of bone resorption and formation (Prior, 1990). These possible roles for progesterone require further investigation.

4.5.3.3.3.3. Androgens

The effects of androgens on bone turnover are less well characterized. However, it has been documented that androgens do play a role in normal skeletal metabolism.

Briefly, the evidence for this is i) androgen insufficiency in men is related to the development of osteopaenia (Finkelstein et al, 1987; Greenspan et al, 1989; Seeman et al, 1983), ii) androgen replacement partially reverses the osteopaenia in hypogonadal men (Finkelstein et al, 1989), and iii) the presence of androgen receptors in osteoblastic cells (Orwoll et al, 1991).

4.5.3.3.4. Other systemic hormones and local factors

In addition to calcium regulating and gonadal hormones, several other systemic hormones and local factors affect calcium and bone metabolism (Canalis et al, 1989; Martin et al, 1989; Raisz et al, 1983b; Raisz, 1988; Vaananen, 1991). A detailed discussion of the effects of each of these is beyond the scope of this thesis, but a list of some of these factors and their main effects on either bone formation or resorption is depicted in Table 4.4.

4.5.3.3.5. Summary: Hormonal factors

Hormonal factors affecting bone turnover are either directly or indirectly related to calcium metabolism, or the hormones may have direct effects on bone formation or resorption. The calcium regulating hormones are parathyroid hormone, 1,25-dihydroxyvitamin D and calcitonin. The gonadal hormones, in particular oestrogen also affect bone turnover. A number of

Table 4.4.

The effects of some systemic and local factors on bone turnover

Agent	Bone formation[a]	Bone resorption[b]
Parathyroid hormone	±	+
Calcitonin	±	−
CGRP	±	−
PGE_2	+	+
VIP		+
PTH-related protein	±	+
$1.25(OH)_2D$	+	+
Estrogens	+	−
Androgens	+	−
Glucocorticoids	−	±
Thyroid hormones	+	+
Growth hormone	+	
Insulin	+	
TGFα	+	+
TGFβ	+	−
Tumor necrosis factor-α	+	+
Interleukin-1	+	+
IGF-1	+	
Retinoids	+	+
γ-Interferon		−
Lymphotoxin		+

[a]: (+) means stimulation of proliferation, increase of matrix protein production, or increase of the expression of other markers of osteoblastic phenotype; (−) means inhibition of some of the above-mentioned functions.

[b]: (+) means either increase in resorption rate of individual osteoclast or stimulation of the differentiation pathway of osteoclasts.

Vanaanen, 1991

growth factors and local factors affecting bone turnover have also recently been identified.

4.5.3.4. Other factors

4.5.3.4.1. Genetic factors

It is well established that genetic factors play an important role in bone turnover. The evidence for this has been obtained from studies that have documented i) the peak bone mass of mono- and dizygotic twins (Smith et al, 1973), ii) a positive family history in a high percentage of patients with osteoporosis (Lindsay et al, 1985), and iii) differences in the peak bone mass and fracture rates in different race groups (Cohn et al, 1977a; Cohn et al, 1977b; Smith et al, 1973). In particular, Negroid race groups appear to have a greater peak bone mass than their Caucasian (Cohn et al, 1977a; Trotter et al, 1960) or Asian counterparts (Cohn et al, 1977b). Data from Japanese residents in Hawaii suggests that they have a lower peak bone mass than Caucasians of similar age (Yano et al, 1984).

4.5.3.4.2. Age

The peak bone mass is achieved by the third decade of life (Cohn et al, 1976) or even earlier at late adolescence, as has recently been suggested (Gilsanz et al, 1988; Hoikka et al, 1981). An age related bone loss commences soon after this in both sexes at a rate of approximately 0.3-0.5% per year (Cooper, 1989). Several hypotheses have been proposed to provide the pathophysiological basis for this age-related bone loss. These include, i) an age-related decrease in renal 1,25-dihydroxyvitamin D production, ii) excessive calcium resorption from the skeleton with age resulting in a negative calcium balance, and iii) a decrease in osteoblast function with age (Deftos et al, 1980; Shane, 1988). The rate of age-related bone loss also differs between skeletal sites (Schaadt et al, 1988).

4.5.3.4.3. Gender

It has been well established that there are gender differences in the peak bone mass as well as the age-related bone loss in adult life. Females tend to have a lower peak bone mass and a more rapid loss of bone mass compared to males (Cohn et al, 1977b; Cooper, 1989; Vaananen, 1991).

4.5.3.4.4. Lifestyle factors

One of the most important lifestyle factors that can affect bone turnover, other than those that have already been discussed, is cigarette smoking. In post-menopausal women, smokers have a lower cortical bone area compared to non-smokers (Daniell, 1976). Although smoking results in natural menopause at an earlier age (Jick et al, 1977), the effect of smoking on bone was independent of this factor (de Vernejoul et al, 1983; Daniell, 1978).

4.5.3.4.5. Drugs

A variety of drugs have also been associated with alterations in calcium metabolism or bone turnover. These include heparin, loop diuretics, anti-convulsants, constant gonadotropin releasing hormone (GnRH) infusions, high doses of thyroxine and chemotherapeutic agents (Shane, 1988).

4.5.3.5. Summary: Non-mechanical factors affecting bone turnover

A variety of non-mechanical factors can affect bone turnover and have been summarized in Table 4.5. These importance of considering all these factors in the pathogenesis, aetiology, treatment and prevention of bone stress injuries in athletes has only been identified recently. The evidence that some of these factors are risk factors for bone stress injuries will be reviewed in Chapter 5.4.6.

Table 4.5.

Non-mechanical factors affecting bone turnover

1. Nutritional factors:

a. Substrates for bone formation:
  - Calcium
  - Phosphate
  - Protein

b. Factors affecting calcium metabolism:
  - Protein
  - Fibre
  - Caffeine

c. Other factors:
  - Ethanol
  - Fluoride

2. Hormonal factors:

a. Calcium regulating hormones:
  - Parathyroid hormone
  - Vitamin D_3
  - Calcitonin

b. Gonadal Hormones:
  - Oestrogen
  - Progesterone
  - Androgen

c. Other systemic and local factors

3. Other factors:

a. Genetic

b. Age

c. Gender

d. Lifestyle

e. Drugs

Summary: Chapter 4

- In this chapter the normal structure and function of bone is reviewed.
- Bone is a rigid connective tissue which is made up of a cellular component and a matrix.
- The skeleton is organized into a central and a peripheral compartment.
- The central compartment contains mainly trabecular bone, and the peripheral compartment mainly compact bone.
- Bone is a dynamic tissue that undergoes constant change.
- The changes in bone occur as a result of five fundamental tissue-level activities; growth, modeling, remodeling, repair and inflammation.
- Bone growth increases the number of bone cells and the intercellular material and is controlled by genetic, systemic hormonal and local factors.
- Modeling is the process by which bones achieve and maintain their shape during skeletal growth and is controlled by mechanical and non-mechanical factors.
- Remodeling is the continuous dynamic process, mediated by the basic multicellular unit (BMU), that constantly alters bone throughout life and is controlled by mechanical and non-mechanical factors.
- The mechanical factors controlling bone turnover depend on the magnitude, rate, frequency and distribution of strain application.

- There is evidence from animal and human studies that decreased and increased physical activity (mechanical loading) results in decreased and increased bone mass respectively.
- Muscle mass, muscle strength and maximal oxygen consumption are also related to bone mass.
- The non-mechanical factors affecting bone turnover are nutritional, hormonal and other factors such as genetic factors, age, gender, smoking and drugs.
- An adequate dietary intake of calcium is required for the achievement of peak bone mass and to decrease the rate of bone loss in the elderly.
- Hormonal factors that affect bone turnover are the calcium regulating hormones, gonadal hormones, in particular oestrogen, and local growth factors.
- The importance of reviewing the factors affecting bone turnover, in particular the non-mechanical factors, is that these have recently been associated with an increased risk of developing bone stress injuries.

CHAPTER 5

A REVIEW OF BONE STRESS OVERUSE INJURIES

5.1. Introduction

Physical activity exposes bone to mechanical loading. Mechanical loading can either be impact loading (single force application) or cyclic loading (repetitive force application). Both forms of loading can result in injury to the bony tissue. Impact loading of a sufficient magnitude can result in an acute fracture whereas cyclic loading can lead to bony stress injuries. The latter form of bony injury is a classical example of an overuse injury. It is also the most debilitating of all the overuse injuries associated with physical activity and therefore one of the most important overuse injuries. In this chapter bone stress overuse injuries will be reviewed.

5.2. Historical perspective

In 1855, a Prussian military surgeon first drew attention to a specific condition of painful swollen feet in soldiers returning from long marches (Breithaupt, 1855). Breithaupt considered the condition to be an inflammatory process in the tendon sheaths of the foot secondary to repetitive trauma and called it "Fussgeshwulst" or swollen feet. In 1887 involvement of the periosteum in this condition was first suspected (Pauzat, 1887), but it was only with the advent of X-rays that the pathology of the lesion was described as a fracture of the metatarsal bones (Stechow, 1897). The condition then became known as a "march fracture". In the next five decades "march fractures" were almost exclusively reported in military populations.

It was soon discovered that these injuries were not confined to the metatarsals but occurred in other bones of the lower limb including the calcaneus (Carlson et al, 1944;

Hullinger, 1944), femur (Bingam, 1945; Blickenstaff et al, 1966; Carlson et al, 1944; Provost et al, 1969), tibia (Proctor et al, 1944; Singer et al, 1954), fibula (Burrows, 1948) and the pelvic bones (Leveton, 1946).

The first description of the condition in a non-military population was reported in 1921 (Deutschlander, 1921). However, it was only in the early 1950's that researchers documented these injuries more frequently in non-military populations such as athletes (Devas, 1958), ballet dancers (Burrows, 1956), civilian non-athletes (Singer et al, 1954), and during pregnancy (Swart, 1943). The early terminology describing the condition was also not consistent. Although the term "march" fracture was most popular, a variety of adjectives were used to describe the injury to bone. These included adjectives such as "insufficiency", "exhaustion", "fatigue", insidious", and "creeping" (Hullinger, 1944).

The first theory on the pathophysiology of this condition was proposed in 1943 (Hartley, 1943). Hartley postulated that these injuries were related to "bone exhaustion" and were analogous to fatigue "fractures" commonly seen in solid materials. He was also the first to introduce the name "stress fracture", which is a term still used by authors today.

However, in recent years the term "stress fracture" has been reserved only for those bony overuse injuries where there is clear evidence of a fracture line or a break in the continuity of the bone. A better understanding of the pathophysiology of bony overuse injuries has led to the realization that i) stress fractures are preceded by specific reactions of bone to cyclic mechanical loading and ii) there is a continuum of the bony response to this type of loading ranging from normal adaptation to symptomatic reactions of bone. These reactions are known as "stress reactions" of bone (Jones et al, 1989) or "bone strain" (Matheson et al, 1987b). The current terminology and classification of bone stress injuries requires discussion.

5.3. Terminology and classification

The hypothesis that bone stress injuries are a continuum of injuries ranging from normal remodeling to cortical fractures (stress fractures) was first proposed in 1979 (Roub et al, 1979). At present there is evidence from in vitro and in vivo laboratory studies (section 4.5.), histological studies (section 4.7.), clinical observations (section 4.8.), and radionuclide imaging investigations (section 4.9.) to support this hypothesis. This evidence will be discussed in more detail in the sections as indicated.

A number of systems of classification for this spectrum of injuries have been proposed (Amman et al, 1991; Chisin et al, 1987; Floyd et al, 1987; Matheson et al, 1987b; Matin, 1988; Zwas et al, 1987). The basis for each of these classification systems is similar and a detailed discussion of each is beyond the scope of this thesis. In this thesis the terminology and classification of bones stress injuries will be the same as that which has been proposed in a recent review (Table 5.1.) (Jones et al, 1989).

In this thesis the term "bone stress injuries" will consistently refer to the entire spectrum of injuries (stress reactions and stress fractures). "Stress fractures" will refer to Grade IV bone stress injuries, whereas the term "stress reactions" will include all injuries from Grade I to III (Table 5.1.).

5.4. Incidence

5.4.1. Introduction

Bone stress injuries have been reported to occur in association with a wide variety of physical activities and sports. These activities include military training, distance running, cricket, javelin throw, diving, basketball,

Table 5.1.

The classification and grading of bone stress injuries

Grade	Symptoms	Signs	X-rays	Bone scan	Clinical significance
0	—	—	-ve	+ve	Physiological
I	Pain exacerbated by activity	Minimal tenderness	-ve	+ve	Structural integrity of the bone not endangered
II	Pain associated with recent activity	Mild localized tenderness - No mass	+ve (barely)	+ve	Structural integrity of the bone may be endangered
III	Localized pain May continue after the activity	Marked local tenderness Mass may be palpable	+ve	+ve	Structural integrity of the bone is endangered
IV	Marked pain minimal weight bearing pain	Extremely tender	+ve	+ve	Bone has failed structurally stress fracture

Adapted from Jones et al, 1989

baseball, tennis, dancing, swimming, football, ballet, and wrestling (Markey, 1987; Matheson et al, 1987a). However, there is little information on the precise incidence of these injuries in different sports and activities. It is therefore not possible to compare the incidence of bone stress injuries in different sports or to identify the sport or activity with the highest risk of bone stress injuries. This review of the incidence of bone stress injuries will focus on distance running and military training because these two activities appear to be those where this injury is mostly reported.

5.4.2. Incidence of bone stress injuries in distance runners

The precise incidence of bone stress injuries in distance runners is not known. Since the earliest descriptions of this condition in distance runners, most reports have been in the form of case series, and have been confined to the documentation of stress fractures only. There are no accurate data available on the true incidence (injuries in a population of runners over a specified time period) of bone stress injuries in this population.

Recently a number of well conducted prospective studies have accurately reported the overall incidence of all running related injuries (Chapter 2.2.), but not of bone stress injuries specifically. The limitations of these studies are that i) the details regarding injuries were confined only to the major anatomical site and the severity of injuries, and ii) the injuries were self reported by the runners and were not necessarily verified by a physician. Finally, the lack of uniform diagnostic criteria for bone stress injuries, in particular the failure to define bone stress injuries other than stress fractures, makes comparison between reports difficult.

In several large case series on running injuries, the proportion of stress fractures (excluding other bone stress injuries) has been documented. In these series, stress fractures accounted for between 5 and 6% of injuries in distance runners attending Sports Medicine Clinics (Clement et al, 1981; James et al, 1978; Macintyre et al, 1991). In one of these studies (Clement et al, 1981), the proportion of "tibial stress syndrome" and "metatarsal stress syndrome" injuries were also documented in males (10.6% and 3.3%) and females (16.8% and 3.0%) respectively. The precise diagnostic criteria for these injuries were not described but "stress syndrome" injuries in specific bones presumably referred to bone stress injuries other than stress fractures.

In a follow-up study conducted by the same group 9 years later, the proportion of bone stress injuries was again documented (Macintyre et al, 1991). A comparison of the proportion of bone stress injuries between these two studies is depicted in Table 5.2. From this data it appears that there has been little change in the proportion of tibial stress fractures over the nine year period, except for perhaps a decrease in the proportion of tibial stress syndrome injuries.

In only one prospective study, which was conducted over one year in 60 runners (sprinters, middle and long distance), did the investigators report specific diagnoses for injuries (Lysholm et al, 1987). This study was also unique because the number of training hours over the study period were documented. Although no stress fractures were reported, the authors did diagnose "medial tibial stress syndrome" in 8 cases. On the assumption that these injuries refer to bone stress injuries in the tibia, the following injury statistics can be calculated: i) the proportion of bone stress injuries in the tibia as a percentage of all the injuries was 14%, ii) the annual incidence of bone stress injuries of the tibia in this population of runners was 1.3% and, iii) the incidence of bone stress injuries in the tibia per 1000 training hours was 0.58/1000 hrs. These data are the only data presently available from which the incidence rate of a specific bone stress injury in runners can be calculated.

Table 5.2.

The frequency of bone stress injuries in runners (expressed as a % of all injuries in runners)

	1981	1990
Males		
Tibial stress fractures	2.4	2.5
Tibial stress syndrome	10.6	4.7
Metatarsal stress syndrome	3.3	3.1
Females		
Tibial stress fractures	2.8	4.3
Tibial stress syndrome	16.8	7.1
Metatarsal stress syndrome	3.0	3.8

Adapted from Macintyre et al, 1991

In summary, the true incidence of bone stress injuries in distance runners is not well documented. The proportion (as a percentage of all overuse injuries) of stress fractures in distance runners is approximately 5%. This proportion is closer to 15% if all bone stress injuries are included. In only one study can the annual incidence of bone stress injuries in the tibia in distance runners be calculated as 1.3%.

5.4.3. Incidence of bone stress injuries in military recruits

In the first 120 years following Breithaupt's description of painful swollen feet in soldiers, research reports on stress fractures in military recruits were only in the form of case series. While these studies provided valuable information on the clinical presentation, nature and anatomical distribution of stress fractures, they were of no value in determining the true incidence of the condition during military training. Information on the incidence of stress fractures in military recruits has only become available in the last fifteen years, through the use of valid epidemiological research methodology.

In most of these epidemiological studies the diagnosis of a stress fracture was made using conventional X-rays. Conventional X-rays are not sensitive enough to detect bone stress injuries other than stress fractures (section 5.9.). It was only with the use of diagnostic radioisotope bone scanning that the incidence of all bone stress injuries in military recruits was documented (Milgrom et al, 1985b).

There are a number of epidemiological studies that have documented the incidence of stress fractures or bone stress injuries in military recruits during training. A comparison between the incidences in these studies is not always possible because of differences in the methodology employed, and the failure by some researchers to provide adequate details on their research methodology. The reports differ with respect to factors such as i) the nature of the population studied (sex, age , race), ii) the duration of training (8 weeks to 1 year), iii) the criteria that were used to diagnose a stress fracture or a bone stress injury (clinical criteria, X-rays, radioisotope bone scan), iv) the nature of the training program (hours of marching or formal physical training), v) footwear worn by the soldiers (boots, running shoes), vi) the training surface, vii) the pre-training physical activity status of the population, and viii) the diet.

In most studies details regarding one or more of the above have not been reported. Furthermore, the types of epidemiological studies used also differed and some studies were prospective studies (Gardner et al, 1988; Giladi et al, 1991; Gordon et al, 1986b; Milgrom et al, 1985b), whereas others were retrospective studies (Brudvig et al, 1983) or reports of unpublished data (Jones et al, 1989; Reinker et al, 1979; Scully et al, 1982). Because of the nature of these studies the incidence of bone stress injuries will be discussed separately for gender, age and race. The other factors that may influence the risk for bone stress injuries as well as the possible biological reasons for differences in the incidence according to gender, age and race will be discussed in detail in section 5.5.

5.4.3.1. Gender

There are four studies in which the incidence of stress fractures has been reported in both male and female military recruits during 8 weeks of military training (Fig 5.1.). In all four studies male and female recruits performed the same training. The incidence of stress fractures can therefore be compared between males and females. In all four studies there was a lower incidence of stress fractures in males compared to females.

It has been documented that the incidence of stress fractures in female recruits during 8 weeks of military training ranges from 10-14% (Jones et al, 1989; Protzman et al, 1977; Reinker et al, 1979). However, in one study the incidence was much lower (3.4%) (Brudvig et al, 1983) and in

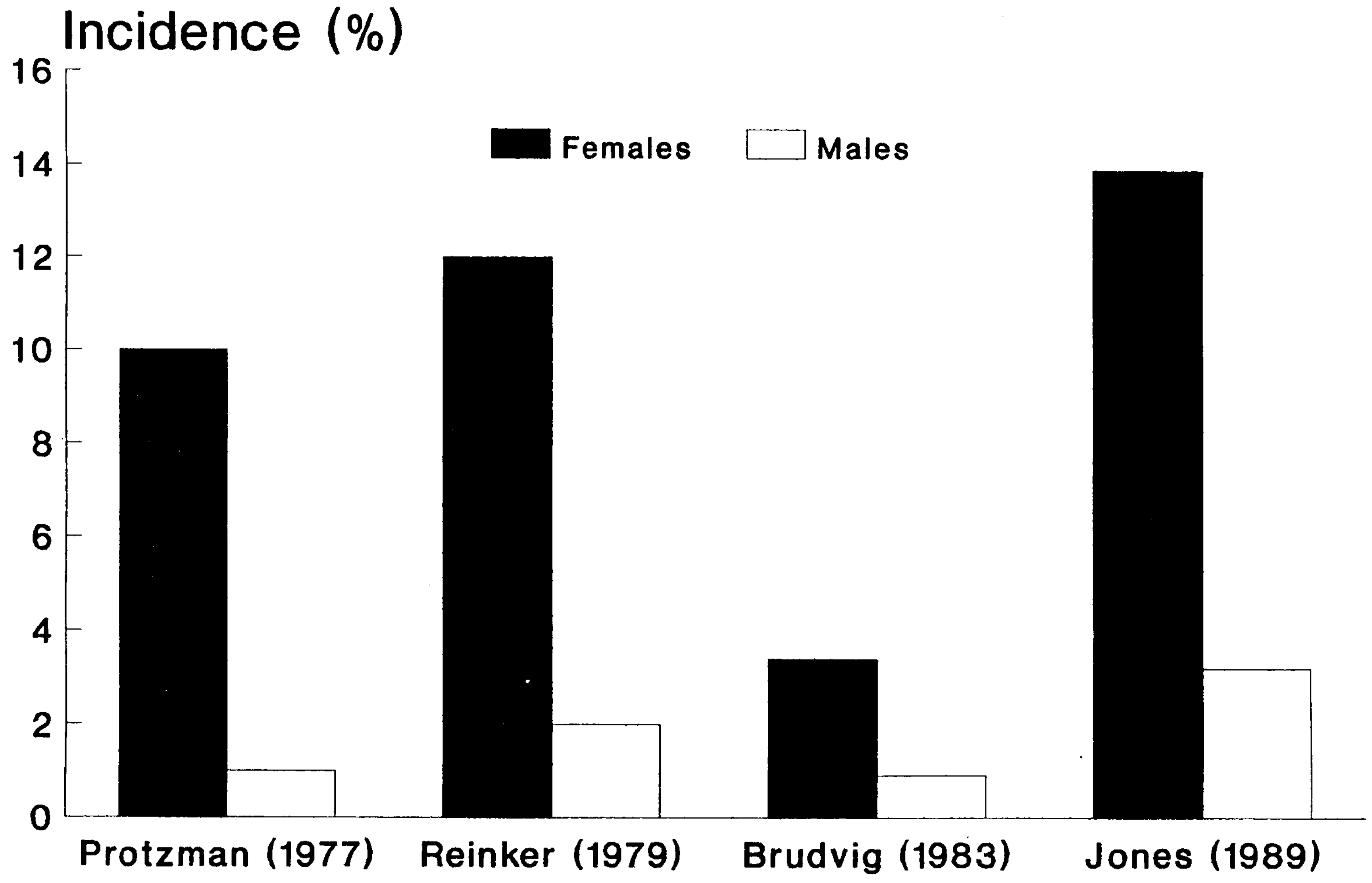

Fig 5.1. The incidence of stress fractures in male and female recruits during 8 weeks of basic military training

another study, which was conducted over 8 weeks in female recruits alone, the incidence was much higher (22%). A comparison between the incidences of stress fractures in females recruits in these studies is not strictly valid because of differences in the research methodology employed. In particular, the nature of the military training programs differed substantially. Other factors that may also influence the incidence of stress fractures such as footwear, training surface and previous physical activity were not described in all the studies.

The incidence of stress fractures in male military recruits has been documented in a number of studies (Table 5.3.). A comparison between different studies is not strictly valid for the same reasons as described above. However, it appears that the incidence of stress fractures is remarkably similar in different studies and varies from 0.9-4.1% (Table 5.3.). It can not be stated whether the differences in the incidences are real or due to methodological differences between the studies.

In all these studies (Table 5.3.), the method of diagnosing stress fractures was by clinical criteria and conventional X-rays. Since 1985, the military physicians in the Israeli Army have used radioisotope bone scans in addition to the above mentioned methods to diagnose bone stress injuries. In two prospective studies the incidence of all bone stress

Table 5.3.

The incidence of stress fractures in male military recruits during basic military training

Reference	n	Training period (weeks)	Incidence (%)
Protzman et al, 1977	1228	8	1.0
Reinker et al, 1979	N/A	N/A	2.0
Scully et al, 1982	6677	8	1.3
Brudvig et al, 1983	16 000	8	0.9
Gordon et al, 1986b	947	10	4.1
Gardner et al, 1988	3025	12	1.3
Jones et al, 1989	124	8	3.2
Jones et al, 1989	323	13	2.2

N/A: Data not available

injuries was documented as 30.8% and 31.0% over a 14 week period of military training (Giladi et al, 1991; Milgrom et al, 1985b). The authors attributed this high incidence to factors such as scrupulous follow-up, a high index of suspicion in the diagnosis of bone stress overuse injuries and the use of the radioisotope bone scan. It is likely that the last factor is the most important one, because bone scans have a high sensitivity for detecting bone stress injuries (section 5.9.). These are the only data documenting the incidence of all bone stress injuries in male military recruits.

5.4.3.2. Age

The association between age and the incidence of stress fractures during military training has been reported in two studies (Brudvig et al, 1983; Gardner et al, 1988). In the first of these, male (n=16 000) and female (n=4422) military recruits of different age groups were followed during 8 weeks of basic military training. The incidence of stresss fractures was documented in different age groups and according to gender (Fig 5.2.). There was an association between increasing age and the incidence of stress fractures. The age-group greater than 35 years had small numbers which may account for the apparent lower incidence (Brudvig et al, 1983).

Fig 5.2. The incidence of stress fractures in military recruits of different ages
Brudvig et al, 1983

In the second study, 3 025 male military recruits were followed up for 14 weeks of military training. In this study, the relative risk (adjusted for pre-training physical activity) for stress fractures in older (> 21 years) compared to younger (< 21 years) recruits was 1.71. These data are consistent with the hypothesis that increasing age may be associated with higher incidences of stress fractures.

5.4.3.3. Race

There have been anecdotal reports to indicate that race may influence the incidence of stress fractures (Bernstein et al, 1944; Prather et al, 1977). However, there are only two studies that have documented an association between incidence of stress fractures during military training and race (Brudvig et al, 1983; Gardner et al, 1988). The details of these two study populations have already been described (section 5.4.3.2.). In the first of these studies the incidence of stress fractures (expressed as %) was 1.92 in Caucasians (males, 1.07; females, 11.83), 0.56 in Blacks (males, 0.23; females 1.39) and 0.62 in other race groups (males, 0.09; females, 4.32) (Brudvig et al, 1983). In the second study the incidence in male recruits was 1.56% for Caucasians, 0.60% for Hispanics and 0.67% for Blacks (Gardner et al, 1988). In both these studies it appears that there is a higher incidence of stress fractures in

Caucasians compared to other race groups. Furthermore, this difference is apparent in both male and female recruits.

5.4.4. Summary: Incidence of bone stress injuries

Stress fractures have been reported to occur in a wide variety of sports and physical activities. The two most frequent activities where stress fractures have been reported are distance running and military training. The precise incidence of bone stress injuries has not been well documented but in one study can be calculated as 0.59/1000 hours of running. Bone stress injuries do however account for 10 to 15% of all injuries seen at a Sports Medicine Clinic.

The incidence of stress fractures in male military recruits undergoing basic military training for 8 to 12 weeks is 1-4%. However, the incidence of all bone stress injuries, as diagnosed by radioisotope bone scan, appears to be 30% for a similar training period. The incidence of stress fractures appears to be higher in i) female compared to male recruits, ii) older compared to younger recruits, and iii) Caucasian compared to Black or Hispanic military recruits.

5.5. Pathogenesis

5.5.1. Introduction

Since the first description of bone stress injuries in 1855 (Breithaupt, 1855), it has been recognized that these injuries are associated with repetitive mechanical loading of the skeleton during physical activity. Repetitive mechanical loading of the skeleton can occur by the application of external forces such as the ground reaction force in walking or running, or internal forces which are generated by muscle contraction.

It has been well documented that repetitive mechanical loading is required for the normal maintenance of skeletal integrity. The evidence for this has already been discussed in detail (Chapter 4.4.). It therefore appears that at some point "normal mechanical loading" becomes "abnormal" and results in bone stress injuries. The pathogenesis of bone stress overuse injuries can therefore be considered as the process whereby this "normal mechanical loading" becomes "abnormal".

It has been hypothesized that repeated mechanical loads of sufficient magnitude can result in microscopic damage (microdamage) to bone. This characteristic would be similar to that which is observed when metals and other materials are subjected to repetitive loading. However, in bone the situation is more complex, because it is not an inert substance, but undergoes continuous turnover. The role of normal bone turnover, in particular its role in the possible repair of microdamage, was first recognized in the early 1960's (Frost, 1991c).

The current hypothesis on the pathogenesis of bone stress injuries is that they are the result of excessive microdamage to bone, the inadequate repair of the microdamage, or a combination of the two.

In this section the pathophysiology of microdamage and repair will be discussed. This will be followed by a discussion on the current hypothesis of the development of bone stress injuries.

5.5.2. Pathophysiology of microdamage in bone

5.5.2.1. Introduction

Physical activity is associated with repeated or cyclic loading of bone. Cyclic loading consists of the repetitive application of mechanical strains to the bone. These strains can differ with respect to the i) magnitude of the strain, ii) rate of strain application, iii) frequency of loading (number of load cycles), and iv) distribution of strain application (Chapter 4.4).

The first study documenting the effects of repetitive mechanical loading on human bone in vitro was presented at a scientific conference in 1952 (Evans, 1952) and subsequently published in 1956 (Evans, 1957). Since then, a number of researchers have investigated the relationship between repetitive strain application and the development of microdamage in bone. Most of these studies have been conducted in an in vitro model using human or animal bone specimens. More recently, this work has been extended to the in vivo animal model. The results of these studies provide valuable scientific evidence for the understanding of the process of microdamage in bone.

5.5.2.2. Pathophysiology of microdamage: In vitro studies

The experimental techniques that have been used in these studies are complex and many variables such as temperature, humidity, nature of loading, and specimen preparation have been shown to influence the test results (Carter et al, 1976; Carter et al, 1981b). A detailed discussion of these variables and the techniques used is beyond the scope of this thesis. However, for the purposes of this discussion, the experimental procedures can briefly be summarized as follows:

- Specimens of bone are prepared from sacrificed animal or human cadaver, postmortem, or amputated material and then subjected to controlled repetitive mechanical loads
- The nature of the loads differ with respect to magnitude of the strain, number of load cycles and the rate of strain application
- The following parameters can be documented; fatigue life (number of cycles to failure of the specimen), mechanical properties of bone (derived from stress/strain curves) after a specific number of cycles, and the microscopic determination of the number and nature of microcracks in the specimen after loading

The major findings of these in vitro studies is summarized in Table 5.4. These data provide convincing scientific evidence that repetitive loading of bone causes microscopically visible areas of damage (microcracking) in bone which eventually leads to failure of the bone. It is also evident that the microdamage is progressive as the number of cycles increases. Their is also evidence that the fatigue failure of bone is reduced by i) high magnitude strain applications (> 2000uE), ii) increased temperature of the bone, and iii) low bone density. The architecture of bone also appears to affect its fatigue life.

Table 5.4.

The pathophysiology of microdamage in bone: A summary of major findings from in vitro studies

- The fatigue life of bone is more strongly controlled by strain magnitude than stress magnitude (Carter et al, 1981b)

- Fatigue life of bone is increased in bone with larger numbers of osteons (Evans et al, 1970)

- The fatigue life of bone is virtually unlimited if strain magnitudes are below 2000uE (Carter, 1984)

- An increase in the magnitude of the load reduces the fatigue life (Carter et al, 1976)

- An increase in the temperature of bone reduces its fatigue life (Carter et al, 1976)

- Repetitive loading of bone causes a progressive loss of strength and stiffness in bone (Carter et al, 1977a; Carter et al, 1977b)

- Histological analysis of bone subjected to repetitive loading in vitro exhibits evidence of microscopic cracking (Carter et al, 1977a)

- Microscopic cracking increases with increasing magnitude of strain application as well as increased frequency of strain application (Forwood et al, 1989)

- The rate of microdamage accumulation appears to be more rapid in compressive than in tensile areas of bone (Carter et al, 1981a)

- A higher bone density requires a greater number of cycles to failure (Carter et al, 1976; Carter et al, 1977b)

- Primary bone is more fatigue resistant than secondary bone (Carter et al, 1976)

The limitations of in vitro studies are that mechanical load application is performed in necrotic bone under artificial laboratory conditions. This does not necessarily reflect the response of bone to these loads in the living animal. In particular, the manner of loading and the strain distribution during physical activity can not be reproduced in vitro (Forwood et al, 1989). It is therefore important to examine the effects of repetitive loads on bone in vivo.

5.5.2.3. Pathophysiology of microdamage: In vivo studies

There have been very few studies that have examined the relationship between repetitive mechanical loading and microdamage in bone using an in vivo animal model (Burr et al, 1985; Carter et al, 1984). However, in one well conducted study the forelimbs of male mongrel dogs were subjected to external mechanical strains of varying magnitudes and frequencies (cycles). The animals were then sacrificed and the bone specimens analyzed (Burr et al, 1985).

In this study a number of important observations were made. The first observation was that, as previously documented in the in vitro model, microcracks developed in bone in response to repetitive loading. Secondly, there appeared to be a threshold of strain magnitude (at a particular frequency of application) required for the development of microcracks in bone. This threshold was approximately 1500uE for 10 000 cycles of load application. The importance of this observation was that it indicated that low strain magnitudes and frequencies can result in microscopic damage. The strain magnitude of 1500uE documented in this study is well within the range that has been measured during normal daily activity in animals (Lanyon et al, 1970; Rubin et al, 1984) and humans (Lanyon et al, 1975). This suggests that microdamage occurs not only as a result of excessive mechanical loading, but also under physiological loads of daily physical activity. Furthermore, it suggests very strongly that a process which constantly repairs areas of microdamage must be present in bone , whether microdamage has occurred as a result of excessive loading or physiological loading.

5.5.2.4. Stages of microdamage

It has been well documented that the microdamage which occurs in response to repetitive mechanical loading is progressive. The evidence, from microscopic examination of bone, indicates that microdamage occurs in a specific sequence that can be divided into four stages (Frost, 1989b).

Stage I: Molecular or ultrastructural damage

This appears to be the earliest stage of damage. There is only indirect evidence that this stage actually exists. It has been demonstrated that very early after repetitive loading, there is a loss of stiffness in the bone but no observable damage on microscopy. This observation has led to the hypothesis there may be some disruption of intermolecular bonds in mineralized bone to account for the loss in stiffness.

Stage II: Prefailure planes

Further accumulation of ultrastructure damage leads to the formation of prefailure planes. These planes can be demonstrated by their increased permeability to basic fuchsin dye. This stage is also not visible under light microscopy.

Stage III: Frank cracks

Frank cracks appear as the next stage of microdamage. This is the first stage that is visible under light microscopy. Cracks also tend to propagate in the bone (more in the longitudinal than the transverse plane).

Stage IV: Complete fracture

This is the final stage of microdamage and is plainly visible on light microscopy.

5.5.2.5. Summary: Pathophysiology of microdamage

It is now well established from in vitro and in vivo studies that microscopic damage to bone occurs in response to repetitive mechanical loading. The damage is progressive and occurs in stages. It has also been demonstrated that a number of factors affect the rate of microdamage in bone. Factors that are associated with increased microdamage are i) strains of high magnitude, ii) increased number of strain cycles, and iii) low bone density. The architecture of the bone is also an important factor determining the amount of microdamage in response to mechanical loading. There also appears to be a threshold of mechanical loading that results in microdamage and this threshold is well within the range of normal daily activity. Finally, it appears there must be a process that is responsible for constantly repairing areas of microdamage. The scientific evidence for the existence of this repair process will now be discussed.

5.5.3. Pathophysiology of microdamage repair in bone

The earliest form of microdamage repair is thought to be a physical-chemical repair rather than histological repair. This form of repair may be important in stage I of microdamage (Frost, 1989b).

Histological repair of microdamage was first observed in 1967 (Tschantz et al, 1967). These investigators documented increased osteoclast and osteoblast activity in association with areas of microdamage in overloaded dog ulnae. However, they could not demonstrate a definite link between specific areas of damage and the repair process. Recently, it has been shown that there is a direct association between bone resorption and microdamage (Burr et al, 1985). In this study, the cutting front of resorption spaces were clearly shown to be directed towards specific areas of microdamage.

Histological repair is therefore the main method for microdamage repair. The process responsible for microdamage repair is remodeling (Burr et al, 1985; Frost, 1988; Frost, 1991c) and the mediator is therefore the BMU (Chapter 4.4.5.). An important implication of this is that the non-mechanical factors affecting remodeling will also affect the repair process. These factors have already been discussed in detail (Chapter 4.5.3.).

5.5.4. Development of a bone stress injury

In the light of the previous discussion on microdamage and repair of microdamage, it appears that the development of a bone stress injury is dependent on the balance between the rate of microdamage production and the rate of microdamage repair. Under normal circumstances, the microdamage produced by normal loading of daily activities is balanced by repair and the process is considered physiological (Frost, 1991c). However, if microdamage production exceeds repair, or if repair is markedly impaired, the process is pathological and bone stress injuries can develop (Frost, 1991c).

Microdamage production commences with the application of a mechanical strain. The "volume" or amount of microdamage per single strain application will depend mainly on the magnitude of the strain. A specific "volume" of microdamage will cause the activation of a specific number of BMUs. Repeated strains of the same magnitude will result in the same "volume" of microdamage and the same number of BMUs will be activated. It therefore follows that repeated strain application will result in an accumulation of activated BMUs. There appears to be a limit to the number of BMUs that can be active at any time. New BMUs can only be activated once previously active ones have completed their cycle. Because these are BMUs involved with remodeling (-ve DB/BMU) a large number of active BMUs will result in weaker bone.

This decreases the fracture strain of the bone and continued loading will eventually bring the magnitude of the applied strain closer to the fracture strain. The final result would be the development of a stress fracture. The development of bone stress injuries therefore appears to be a continuum, starting with normal damage and repair and progressing to increased remodeling and finally development of a fracture.

5.5.5. Summary: Pathogenesis of bone stress injuries

In summary, repetitive strain application to bone is required for normal bone turnover. During normal daily activity this results in areas of microdamage which are adequately repaired by remodeling. However, under circumstances of increased microdamage and/or inadequate microdamage repair, the damage is progressive and eventually leads to bone failure. This concept has important clinical implications, particularly with regard to the identification of aetiological factors associated with, the management of, and the prevention of bone stress overuse injuries.

5.6. Aetiology

5.6.1. Introduction

Specific aetiological factors for bone stress injuries have been identified from clinical and epidemiological studies. It is customary to classify these aetiological factors as either intrinsic or extrinsic (Herring et al, 1987; Renstrom et al, 1985; Taimela et al, 1990). However, it is clear that bone stress injuries occur as a result of excessive microdamage and/or inadequate repair of microdamage. It would therefore be more appropriate to classify the aetiological factors for bone stress injuries as i) those associated with increased microdamage, ii) those associated with inadequate repair of microdamage, and iii) other factors such as age, gender and genetic factors.

5.6.2. Aetiological factors associated with increased microdamage

5.6.2.1. Introduction

The rate of microdamage increases if the mechanical strain that is applied to bone is "excessive". The mechanical strain can be "excessive" in magnitude, rate or frequency of application. Furthermore, alterations in the distribution of the strain application can also result in overloading of areas of bone that are not adapted to the altered mechanical environment. In the clinical setting, specific factors such as training errors, training surface, footwear, biomechanical abnormalities and muscle fatigue can give rise to "excessive" strain application. The evidence that these factors cause "excessive" strain, and may therefore be associated with the aetiology of overuse injuries, will now be discussed.

5.6.2.2. Training errors

It has been postulated that training errors such as sudden increases in weekly training distance (Hulkko et al, 1987; James et al, 1978; Sullivan et al, 1984), hill training, (James et al, 1978), intensity (Myburgh et al, 1988; James et al, 1978), and specific forms of marching (Gilbert et al, 1966) are associated with bone stress injuries. Although there is no documented laboratory evidence, it would seem reasonable to hypothesize that training errors could cause "excessive" strain application. For instance, an increase in the weekly training distance would be equivalent to an increase in frequency of strain application. Downhill running is associated with larger ground reaction forces (Loy et al, 1991) and would therefore cause an increased magnitude of strain application. Specific types of marching such as "heel digging" (Gilbert et al, 1966) may also increase the ground reaction force and therefore the magnitude of strain application.

There are a number of well conducted epidemiological studies to show that increased weekly training distance is associated with the risk of all overuse injuries in distance runners (Koplan et al, 1982; Macera et al, 1989; Walter et al, 1988; Walter et al, 1989). However, there are very few well controlled studies that have documented that training errors are indeed aetiological factors specifically for bone stress injuries.

In one prospective study, a lower weekly marching distance and a lower cumulative marching distance during basic military training did not significantly reduce the overall incidence of stress fractures (Giladi et al, 1985a). However, the onset of stress fractures was delayed by the reduction in marching distance (Giladi et al, 1985a). In one case-control there was no significant difference in training duration and frequency of athletes with "shin soreness" compared to non-injured controls (Myburgh et al, 1988). A sudden increase in training intensity was however more common in the injured athletes (Myburgh et al, 1988).

Apart from the association between increased training intensity and "shin soreness" (Myburgh et al, 1988), there is at best only indirect evidence that training errors are truly associated with the aetiology of bone stress injuries. In one report, the incidence of stress fractures during basic military training was reduced from 4.8% to 1.6% by eliminating activities that generate high ground reaction forces such as running, jumping and double timing from the third week of training (Scully et al, 1982). Other less convincing evidence is that bone stress injuries appear to be common in activities associated with sudden repetitive loading such as basic military training (section 5.4.2.).

5.6.2.3. Training surface

There have been suggestions that training on "hard" surfaces is associated with the aetiology of bone stress injuries (Hulkko et al, 1987; James et al, 1978; Sullivan et al, 1984). However, there have been no well conducted epidemiological investigations to verify this hypothesis.

5.6.2.4. Footwear

It has been suggested that footwear of poor shock absorbing nature is associated with bone stress injuries in military recruits (Gardner et al, 1988; Gilbert et al, 1966) and in runners (Clement et al, 1981; James et al, 1978). There is some laboratory evidence to indicate that "excessive" strain can be reduced by shock absorbing footwear. It has been demonstrated that the magnitude of strain measured in the human tibia during the stance phase of walking can be reduced by the wearing of "shock absorbing" shoes (Lanyon et al, 1975). Furthermore, the skeletal transients (changes in acceleration) at the tibia can be reduced by the wearing of "shock absorbing" shoes (Light et al, 1977) or insoles (Loy et al, 1991).

The epidemiological evidence that shock absorbing footwear decreases the risk of bone stress injuries is however controversial. In one case-control study an association between wearing "worn shoes" and "shin soreness" was documented (Myburgh et al, 1988). It has also been observed that military recruits wearing "newer" shoes were less likely to sustain stress fractures during basic military training (Gardner et al, 1988).

The use of shock absorbing insoles to reduce the incidence of stress fractures has also been investigated but the findings to date have been inconclusive. In two prospective studies viscoelastic insoles did not significantly reduce the incidence of stress fractures in military recruits during basic military training (Gardner et al, 1988) or aerobic dance (Clark et al, 1989). However, two studies from the Israeli Defence Force, demonstrated significant reductions stress fractures at specific sites by wearing a specially constructed semi-rigid orthotic (Milgrom et al, 1985c; Simkin et al, 1989). However, it must be noted that, in these studies, a rearfoot varus post of 3^{o} was added to the orthotics and could have affected the distribution of strain application (Simkin et al, 1989). This orthotic was also only effective in reducing femoral stress fractures in recruits with a high arched foot and metatarsal stress fractures in recruits with a low arched foot (Simkin et al, 1989). The incidence of tibial stress fractures was not affected by wearing the orthotic device (Simkin et al, 1989).

The possible value of shock absorbing footwear in reducing bone stress injuries is an important area for further investigation.

5.6.2.5. Biomechanical abnormalities

It has been postulated that lower limb biomechanical abnormalities are associated with bone stress injuries. Although there is little scientific evidence, it can be hypothesized that lower limb biomechanical abnormalities may be associated with alterations in the distribution of strain application during physical activity. This alteration may overload specific areas of bone and may therefore cause bone stress injuries. The lower limb biomechanical abnormalities that have been postulated as causes of bone stress injuries are listed in Table 5.5. However, very few of these

Table 5.5.

Lower limb biomechanical abnormalities possibly associated with bone stress injuries

1. Static assessment

- Pes planus (Sullivan et al, 1984)
- Pes cavus (Hulkko et al, 1987)
- High arched foot (Simkin et al, 1989)
- Low arched foot (Simkim et al, 1989)
- Forefoot varus (Hulkko et al, 1987; Matheson et al, 1987a)
- Subtalar varus (Hulkko et al, 1987; Matheson et al, 1987a)
- Increased ankle inversion range of movement (Myburgh et al, 1988; Viitasalo et al, 1983)
- Increased ankle eversion range of movement (Myburgh et al, 1988; Viitasalo et al, 1983)
- Tibial varus (Hulkko et al, 1987; Matheson et al, 1987a)
- Genu varus (Matheson et al, 1987a)
- Leg length discrepancy (Hulkko et al, 1987)
- High degree of hip external rotation (Giladi et al, 1991)
- Femoral anteversion (James et al, 1978)

2. Dynamic assessment

- Increased angular displacement between heel strike and the maximally everted position (Viitasalo et al, 1983) abnormalities have been verified as true risk factors in well conducted scientific studies.

In one prospective study a lower limb biomechanical assessment was performed on 312 military recruits prior to training. In this study the subsequent development of a stress fracture during training was related only to increased external rotation of the hip joint (Giladi et al, 1991). In another prospective study conducted on 295 Israeli military recruits, the presence of a high foot arch and a low foot arch were associated with an increased incidence of femoral and metatarsal stress fractures respectively (Simkin et al, 1989).

In two cross-sectional studies the following abnormalities were found to be associated with "shin pain": i) increased ankle inversion and eversion (Myburgh et al, 1988; Viitasalo et al, 1983), and ii) greater displacement between heel strike and maximal ankle eversion during running (Viitasalo et al, 1983). The remainder of the studies listed in Table 5.5. were case series. Most of the biomechanical factors that have been associated with bone stress injuries (Table 5.5.) have therefore not been investigated adequately.

5.6.2.6. Muscle fatigue

It has been postulated that muscle fatigue during physical activity is associated with the development of bone stress injuries (Clement, 1974; Markey, 1987; Matheson et al, 1987a). The rationale for this hypothesis is that muscle contraction is an important natural "shock absorbing" mechanism of the limbs. Muscle fatigue could therefore increase the shock transmission and therefore the magnitude of strain application in bone. This hypothesis has not been verified through well conducted scientific studies.

5.6.3. Aetiological factors associated with inadequate microdamage repair

5.5.3.1. Introduction

It has been documented that areas of microdamage are constantly repaired through the process of remodeling. There are a variety of non-mechanical factors that affect remodeling. These factors have been discussed in detail (Chapter 4.5.3.). In the last decade, there has been some evidence that these non-mechanical factors can be associated with bone stress injuries. In particular, the possible role of nutritional and hormonal factors has received attention. The evidence that these factors may be implicated in the aetiology of bone stress injuries will now be discussed.

5.6.3.2. Nutritional factors

It is well established that an adequate daily calcium intake is required for normal skeletal turnover, particularly during skeletal growth and in old age (Chapter 4.5.3.). One of the main functions of calcium is to provide substrate for the mineralization of osteoid in the formation phase of remodeling. It is therefore reasonable to hypothesize that adequate dietary calcium is required for the remodeling process during microdamage repair. A chronically reduced intake of calcium in a young (< 25 years) physically active individual could have two potential risks; i) a reduced peak bone mass (as measured by bone density) at the end of skeletal growth, and ii) an inadequate rate of microdamage repair.

The possibility that abnormalities in calcium metabolism may predispose to bone stress injuries was first hypothesised in 1983 (Mustajoki et al, 1983). In this study no differences in serum calcium concentrations were observed between recruits with bone stress injuries and uninjured recruits. However, because serum calcium concentrations are very tightly controlled, this finding is not unexpected. These investigators did not attempt to document other parameters of calcium and bone metabolism. The evidence that dietary calcium may be important in the response of bone to dynamic loading was reported in rats in 1986. In this study it was demonstrated that less bone formation occurred in response to repetitive mechanical loading in a calcium deficient compared to a control group of exercising rats (Lanyon et al, 1986).

The first epidemiological evidence in humans supporting the hypothesis that reduced daily dietary calcium intake is associated with bone stress injuries was reported in 1988 (Myburgh et al, 1988). In this case-control study, athletes with "shin soreness" had a lower daily dietary intake of calcium compared to non-injured athletes. In a subsequent report the same workers documented that the daily intake of calcium was lower in athletes with stress fractures (697 ± 242 mg/day) compared to non-injured controls (832 ± 309 mg/day) matched for age, sex, height and exercise history (Myburgh et al, 1990). This association has subsequently been confirmed by others (Grimston et al, 1990a).

There is also further indirect evidence to suggest that a chronic calcium deficient diet predisposes to bone stress injuries. It has now been documented that a reduced bone density is associated with bone stress injuries in athletes (Myburgh et al, 1990) and military recruits (Pouilles et al, 1989). It has been well documented that hormonal disturbance can be responsible for this reduction in bone mineral density in female athletes. However, there is also evidence from animal (Shi et al, 1988; Weinreb et al, 1991; Wu et al, 1990) as well as human studies (Matkovic et al, 1979; Grimston et al, 1990b) that a chronic low dietary calcium intake during the skeletal growth period may result in a decreased bone density and therefore increase the risk of bone stress injuries.

It has also recently been suggested that an adequate dietary intake of calcium (> 800mg/day) and possibly additional calcium supplementation to above 1200mg/day may reduce the risk of bone stress injuries during physical activity (Myburgh et al, 1990).

5.6.3.3. Hormonal factors

It has been well documented that hormonal factors play an important role in normal bone turnover. In particular, gonadal hormones and calcium regulating hormones are important regulators on bone turnover (Chapter 4.5.3.3.).

It has been well documented that i) menstrual dysfunction (amenorrhea and oligomenorrhea) in female athletes is associated with hypo-oestrogenism (Jones et al, 1985), and ii) female athletes with secondary amenorrhea have a higher risk of developing bone stress injuries (Barrow et al, 1988; Drinkwater et al, 1984; Linberg et al, 1984; Lloyd et al, 1986; Martin et al, 1984; Warren et al, 1986). The mechanism for this increased risk is probably related to the negative effects of both menstrual abnormalities (Drinkwater et al, 1986; Drinkwater et al, 1990; Lindberg et al, 1984; Linnel et al, 1984) and hypo-oestrogenism on bone. These factors have already been discussed (Chapter 4.5.3.3.3.). The precise effects of progesterone and testosterone on bone turnover are not clear and have already been discussed (Chapter 4.5.3.3.3.3.).

The association between disturbances in calcium regulating hormones and bone stress injuries has not been well documented. It has been demonstrated that an acute bout of exercise increases the serum parathyroid hormone and osteocalcin concentrations (Nishiyama et al, 1988), but that these levels return to baseline within 60 minutes post-exercise. Furthermore, baseline levels of osteocalcin were also significantly higher in athletes compared to non-athletes (Nishiyama et al, 1988). This may indicate there is an increased bone turnover in athletes which is mediated by an increase in serum PTH concentration after an acute bout of exercise. However, at present there is no evidence that this mechanism plays a role in the aetiology of bone stress injuries during physical activity.

5.6.4. Other factors

It has been well documented that genetic factors, age and gender play a role in normal bone turnover, in particular the achievement and maintenance of bone mass. These factors have already been discussed in detail (Chapter 4.5.3.4.).

It is therefore not surprising that these factors have also been implicated in the aetiology of bone stress injuries. In support of this hypothesis, there is some epidemiological evidence to suggest that the incidence of bone stress injuries is more common in Caucasian race groups, older age and females. The details of these studies have already been discussed (section 5.3.2.).

5.6.5. Summary: Aetiology of bone stress injuries

The aetiological factors related to bone stress injuries can be classified as i) those that either increase the rate of microdamage in bone or impair the rate of microdamage repair, and ii) other factors such as genetic factors, age and gender. There is a distinct lack of epidemiological evidence to implicate factors such as training errors, poor shock absorbing footwear, hard training surfaces, biomechanical abnormalities and muscle fatigue as specific risk factors for excessive bone microdamage and therefore bone stress injuries. However, there is some epidemiological evidence to suggest that dietary calcium deficiency and disturbances of the gonadal hormones are associated with an increased risk for the development of bone stress injuries. However, there have been no well conducted clinical trails to verify this.

5.7. Histopathology

The histopathologic features of bone exposed to repetitive mechanical strain application have been documented in animals and humans (Johnson et al, 1963; Li et al, 1985; Uhthoff et al, 1985). Histologic examination of biopsy material in symptomatic individuals is the most common form of data collection in humans (Johnell et al, 1982; Jones et al, 1989). However, these studies do not provide information on the association between histological abnormalities and the magnitude and frequency of strain application; neither do they provide information of the time course of changes in bone in response to repetitive loading. This information has however been obtained from studies in the animal model (Li et al, 1985).

In this well conducted experiment, repetitive mechanical loads (360 cycles/day, 6 days/week) were applied to the tibia of rabbits for 10 weeks. The exact magnitude of the strain was not documented but it can be assumed that it was constant throughout the study (Li et al, 1985). The histopathologic features in the tibia of sacrificed animals were recorded at intervals during the 10 week study period. The major histopathologic findings in the bone were as follows:

Week 1:

At 2 days increased erythrocytes were observed in the Haversian system vessels which increased further by day 4. Osteoclast resorption, shrinkage of osteocytes and new periosteal collagen formation was evident by day 7.

Week 2:

Small cracks appeared by day 10 but no osteoclasts or osteoblasts were observed. Large osteoclastic cavities were apparent by day 12 and a single layer of osteoblasts was present under the periosteum by day 14.

Week 3:

Incomplete fractures were noted in some specimens and appeared to be due to convergence of cracks. Remodeling was present as evidenced by osteoclasts, capillarisation, enlarged new Haversian systems and cavities half-filled with new bone.

Week 4 to 6:

Histological changes of remodeling were more evident.

Week 7 to 9:

A complete fracture was evident in one specimen. A periosteal reaction was evident in only 55% of specimens. Histologically old and new bone appeared to fuse.

This study showed that i) if bone is subjected to mechanical loads of sufficient magnitude, bone resorption is activated which is soon followed by bone formation, ii) repetitive loading is associated with crack formation, and iii) continued loading results in incomplete and later complete cortical fractures in some specimens. These observations support two important previously mentioned concepts namely i) that bone stress injuries progress from physiological accelerated remodeling to cracks and later stress fractures and ii) that microdamage repair occurs by remodeling (ARF sequence).

Observations in biopsy specimens obtained from humans with bone stress injuries indicate that, in general, similar histologic features to those described for one of the above mentioned time periods can be demonstrated (Johnell et al, 1982; Jones et al, 1989).

5.8. Clinical diagnosis

5.8.1. Introduction

The clinical presentation of bone stress injuries has been well described in a number of case series. The symptoms and findings on physical examination will be discussed briefly.

5.8.2. Symptoms

The main symptom of bone stress injuries is pain of the affected bone (Belkin, 1980; Orava et al, 1991). The onset of the pain is usually gradual but can be fairly sudden (Markey, 1987). In over 90% of cases, there is no history of a direct injury (Matheson et al, 1987a). The pain is usually associated with a recent change in physical activity (Belkin, 1980; James et al, 1978; Markey, 1987; Matheson et al, 1987a; Slocum, 1967; Sullivan et al, 1984) or an alteration in footwear or training surface (Belkin, 1980; Sullivan et al, 1984). There may be a history of initial mild pain experienced only during prolonged running which then gradually progresses to pain on walking, standing and eventually pain may be experienced at rest (Belkin, 1980; Slocum, 1967).

The nature of the pain varies according to the site of injury. In superficial bones (tibia, metatarsals) the pain is sharp and well localized. However, in deeper bones such as the femur the pain can be vague. The severity of the pain does, to some extent, indicate the nature of the injury. In general, stress fractures are associated with more severe pain and usually prevent any form of running.

The history should also include systematic questioning to determine the possible risk factors that may have been responsible for the injury. Information should be obtained regarding the i) training history (onset, duration, load, surface, camber of the training surface or road, frequency), ii) footwear (type, changes, duration of wear, use of orthotics), and iii) risk factors for inadequate bone repair (general medical history, endocrine history, gynecological history, dietary history and the use of medication).

5.8.3. Physical examination

The most common finding on physical examination is tenderness is over the bony area involved (Belkin, 1980; Detmer, 1986; Devereaux et al, 1984; Markey, 1987; Matheson et al, 1987a; Orava et al, 1991). This must be differentiated from tenderness over the periosteal-fascial junction or in the adjacent muscles (Detmer, 1986). Focal tenderness is a more common clinical finding in superficial bones (fibula, tibia and tarsal bones) than in deeper bones such as the femur (Matheson et al, 1987a). It has been suggested that more diffuse tenderness is consistent with bone strain, whereas exquisite tenderness is more indicative of a stress fracture (Detmer, 1986).

In general other findings on physical examination such as swelling are less common except in the tarsal and metatarsal bones (Matheson et al, 1987a). A palpable bony mass, oedema, ecchymoses and associated pyrexia have also been described (Belkin, 1980; Markey, 1987).

A few special clinical tests have also been described to diagnose stress fractures. These are i) severe pain on hopping (a positive "hop test"), ii) severe pain on three point bending of the affected bone (a positive "bending test"), and pain on percussion of the injured bone (a positive "percussion test") (Markey, 1987; Matheson et al, 1987a).

The physical examination should also include, i) a full clinical biomechanical examination (to identify abnormal distribution of mechanical strain), ii) examination of the footwear, and iii) a complete medical examination to identify risk factors for inadequate microdamage repair.

Finally, it has been documented that the clinical diagnosis of stress fractures in certain anatomical sites is not sensitive and a high index of suspicion is required to detect them. These sites are the femur, tarsal bones, tibial plateau, spine, sesamoids and the pelvis (Matheson et al, 1987a). Special investigations are required to make the diagnosis of bone stress injuries in these sites.

5.9. Special investigations

In a patient suspected of having a bone stress injury special investigations may be performed for two main reasons: i) to confirm the diagnosis of a bone stress injury or ii) to identify non-mechanical factors that may affect the ability of bone to respond normally to loading.

5.9.1. Special investigations to confirm the diagnosis of a bone stress injury

5.9.1.1. Conventional radiology

Until the early 1970's, conventional radiology (X-rays) was the only special investigation available to confirm the diagnosis of a stress fracture. The X-ray findings depend mainly on the time elapsed between the onset of symptoms and the time of the examination (Daffner et al, 1982; Markey, 1987). A radiological examination at the onset of symptoms (initial film) is mostly negative (68 to 89%) and only if the examination is repeated 10-14 days later (delayed film), can the typical features of a stress fracture be demonstrated in approximately 80% of cases (Daffner et al, 1982; Prather et al, 1977). In general, X-rays are therefore not sensitive in the detection of early responses of bone to mechanical strain. A "lag" period of 2-12 weeks after the onset of symptoms, before X-rays become positive, has been reported (Matheson et al, 1987a). There are also specific bones such as the talus that are notorious for producing negative radiographs (Matheson et al, 1987a).

Although X-rays are not sensitive for the diagnosis of bone stress injuries, they have a high specificity (100%) (Matheson et al, 1987a; Prather et al, 1977). For this reason, X-rays are still used in the diagnosis of stress fractures, usually in conjunction with other investigations.

The plain X-ray features of stress fractures have been well described and are i) a thin zone of sclerosis (cancellous bone), ii) cortical lucency, iii) a localized periosteal reaction, and iv) fracture lines (Daffner et al, 1982;

Matheson et al, 1987a; Murray et al, 1971; Weissman et al, 1986).

Tomography can also be used to delineate the features of stress fractures (Daffner et al, 1982).

5.9.1.2. Bone scan

The ^{99m}Technetium-labelled methylene diphosphonic acid bone scan was developed in 1971 (Subramanian et al, 1971). This radionuclide is injected intravenously and reacts with phosphorus groups in bone by adsorption onto the calcium of hydroxyapatite (Matheson et al, 1987b). The chemical reaction involves ion exchange on bone surfaces exposed to the circulating radionuclide. The sites of exchange are the periosteal, endosteal, trabecular and Haversian surfaces. The concentration of the radionuclide in the bone is dependent on regional blood flow and remodeling.

In the late-1970's and early 1980's a number of case series have been reported on the use of the bone scan in the diagnosis of stress fractures (Floyd et al, 1987; Geslien et al, 1976; Groshar et al, 1985; Milgrom et al, 1984; Prather et al, 1977; Roub et al, 1979; Rupani et al, 1985; Sullivan et al, 1984; Zwas et al, 1987). Initially only delayed images were obtained 2-4 hours after the intravenous administration of the radiotracer (Geslien et al, 1976;

Prather et al, 1977; Roub et al, 1979), but later more researchers reported findings of the triple-phase bone scan (TPBS) (Amman et al, 1991). The triple-phase bone scan includes i) a radionuclide angiogram (images are taken immediately after intravenous administration usually at 2 second intervals), ii) a blood pool image or tissue phase (taken 1 minute after intravenous administration) and a delayed image (taken 2-4 hours after the administration of the tracer) (Amman et al, 1991; Matheson et al, 1987b; Nagle et al, 1987). The advantages of the TPBS are that it i) permits the estimation of the age of the lesion, ii) permits the estimation of the severity of the injury, and iii) helps to separate bony from soft tissue injury (Amman et al, 1991).

The use of the TPBS in patients with suspected stress fractures has made three important contributions to the understanding of bone stress injuries.

The first of these contributions is that it soon became apparent that the TPBS was a very sensitive diagnostic investigation for the diagnosis of stress fractures. Currently the sensitivity of this investigation for the detection of stress fractures approaches 100% (Amman et al, 1991; Giladi et al, 1985b; Prather et al, 1977). This means that a negative bone scan virtually rules out a stress fracture. This concept has however been challenged (Milgrom et al, 1984).

The principle feature of a stress fracture on a bone scan is an area of focal uptake on the delayed image (Amman et al, 1991). The specificity of the TPBS is however lower because non-traumatic lesions such as tumors, osteomyelitis, bone infarcts and bone dysplasias can also produce areas of increased uptake (Amman et al, 1991).

The second contribution of the TPBS is that it provided the basis for the hypothesis that bone stress injuries occur as a continuum with physiological remodeling on one end of the spectrum, followed by bone stress reactions and the eventual development of a stress fracture at the other end of the spectrum (Amman et al, 1991; Jones et al, 1989; Matheson et al, 1987b). This hypothesis was first introduced in 1979 (Roub et al, 1979). In his study on 35 athletes and 13 controls, Roub and his collegues noted, that on repeated scans, some athletes with stress fractures showed images similar to athletes with shin pain but no stress fractures. They postulated that this represented a shift along the continuum back to an earlier stage in the evolution of a stress fracture.

Recently more evidence supporting this hypothesis has been presented. It is well documented that over 33-45% of positive bone scans in an active population are asymptomatic (Groshar et al, 1985; Matheson et al, 1987b; Zwas et al, 1987) and that some of these patients go on to develop symptoms a few weeks later (Chisin et al, 1987; Zwas et al, 1987). These data again indicate a possible progression in the injury. This hypothesis is also supported by evidence which has already been discussed under the pathogenesis of bone stress injuries and the pathology of bone stress injuries.

The final contribution of the TPBS is that it can help to differentiate bone stress injuries from other lesions such as soft tissue muscle injuries, enthesopathies and chronic compartment syndromes (Matin, 1988).

5.9.1.3. Other special diagnostic investigations

A number of other techniques have been used to confirm the diagnosis of bone stress injuries. These include ultrasound, thermography, computed tomography (CT) and magnetic resonance imaging (MRI) (Amman et al, 1991; Matheson et al, 1987b) . Ultrasound is limited because it relies on the subjective reporting of pain by the patient. Thermography does not distinguish accurately between soft tissue lesions and osseous lesions. The accuracy of these two tests is therefore too low to be of value in clinical practise (Amman et al, 1991).

Computed tomography is less sensitive for detecting stress fractures but is useful to identify the extent and nature of the lesion once it has been identified (Somer et al, 1982). The use of MRI has not been well investigated. However, recent data presented at the 1992 American College of Sports Medicine meeting indicated that, with the recent advances in the development of the techniques, it may become a very sensitive tool to investigate microscopic bone contusion injuries. This however requires further investigation.

5.9.2. Special investigations aimed at identifying non-mechanical factors that may affect the ability of bone to respond normally to loading.

A number of special investigations may be required to identify abnormalities in the non-mechanical factors that affect normal bone remodeling. A detailed discussion of each of these is beyond the scope of this thesis. However, these investigations would include a full dietary analysis for daily calcium intake, a bone density determination, blood tests for hormonal disturbances and possibly gynecological investigations in female athletes with menstrual abnormalities such as oligo- or amenorrhea.

5.10. Management

5.10.1. Introduction

Bone stress injuries are managed conservatively in most instances (Hulkko et al, 1987; Wilson et al, 1969). Surgical intervention is required in 7-10% of cases (Hulkko et al, 1987; Orava et al, 1988). The principles of management of any patient with an overuse injury are to relieve the symptoms and to treat the underlying cause.

In bone stress injuries, symptomatic treatment involves controlling the pain with ice therapy, anti-inflammatory or analgesic medication (Markey, 1987; Matheson et al, 1987a). Although there are no reported clinical trials on the use of these treatment modalities, there is anecdotal evidence that they are effective.

The treatment of the underlying cause in bone stress injuries is more complex. However, the aim of treatment is to reduce the rate of microdamage and, if possible, to increase the rate of microdamage repair.

5.10.2. Reduction of the rate of microdamage

A reduction of the rate of microdamage implies that the magnitude, rate, frequency and distribution of mechanical strain on the affected the bone must be reduced. It is also possible that microdamage can be decreased by muscle strength training and by the use of protective braces.

Rest is the most common treatment modality for bone stress injuries (Belkin, 1980; Hulkko et al, 1987; Markey, 1987; Sullivan et al, 1984). The period of rest is variable and depends on the nature and the site of the injury (Markey, 1987; Matheson et al, 1987a). In general, a recovery period of 3-6 weeks is required for bone stress reactions whereas 6-8 weeks or longer is required for most stress fractures (Belkin, 1980; Hulkko et al, 1987; Markey, 1987; Matheson et al, 1987a). The site of injury also influences the time to recovery. It has been documented that tibial and tarsal stress fractures can take an average of 12 and 17 weeks respectively to recover (Hulkko et al, 1987; Matheson et al, 1987a).

During the rest period alternative activities such as swimming, running in water, cycling or circuit training can be introduced provided that there is no loading of the injured limb (Belkin, 1980; Markey, 1987; Matheson et al, 1987a; Sullivan et al, 1984)). A gradual return to normal activity can be resumed once the symptoms have disappeared which can be as early as 10-14 days after the injury (Matheson et al, 1987a).

Thorough attention must however be given to the training program. The following principles of early training apply: i) a gradual increase in the training load, ii) hill training should be avoided initially, iii) hard training surfaces should be avoided initially, and iv) excessive jumping should be avoided initially. The beneficial effects of specific training principles have not been studied adequately. However, in one prospective study, it has been demonstrated that alternate day training decreased the incidence of stress fractures from 4.8% to 1.6% during basic military training (Scully et al, 1982).

The magnitude of mechanical strain can also be reduced by giving attention to the footwear, in particular the shock absorbing characteristics of the footwear (Sullivan et al, 1984). Furthermore, if biomechanical abnormalities have been identified, attention should be given to correcting these by appropriate shoes or orthosis (Matheson et al, 1987a). The role of footwear and orthotics in the treatment of bone stress injuries has however not been studied in well conducted clinical trials.

The role of muscle strengthening exercise in the treatment bone stress injuries has not been evaluated. This may be important in the treatment of bone stress injuries because it has been suggested that muscle fatigue may play a role in the aetiology of these injuries.

Finally, microdamage can possibly be decreased by the use of braces and immobilization. The successful use of pneumatic leg braces in the treatment of tibial stress fractures has been reported (Dickson et al, 1987; Whitelaw et al, 1991) but has not been studied in well controlled clinical trials.

5.10.3. Increasing the rate of microdamage repair

Microdamage repair occurs by remodeling, which is affected by a number of non-mechanical factors. If abnormalities of these factors have been identified, they must be corrected (Markey, 1987). Two examples would be an inadequate dietary calcium intake or hormonal disturbances in female athletes as manifested by menstrual abnormalities (Markey, 1987). However, there are no well conducted clinical trials to document the effects of either calcium supplementation or hormonal replacement therapy in the management of bone stress injuries.

5.10.4. Surgical treatment

It has been documented that surgical intervention is required in less than 10% of stress fractures (Hulkko et al, 1987; Orava et al, 1988). The most common indication for surgery is delayed union or nonunion (Hulkko et al, 1987; Orava et al, 1988). Other indications for surgery are displaced fractures (Belkin, 1980; Markey, 1987; Wilson et al, 1969) or associated dislocations (Hulkko et al, 1987).

5.11. Prevention

5.11.1. Introduction

Bone stress injuries are the most severe and debilitating of all the overuse injuries associated with physical activity. It is therefore the aim of any sports physician to prevent these injuries. Despite this, very few studies have been conducted to evaluate measures to prevent these injuries. In general, strategies can be aimed at preventing "excessive" microdamage and/or ensuring that optimal repair of microdamage takes place.

5.11.2. Preventing excessive microdamage

In principle, excessive microdamage can be prevented by reducing the magnitude, rate, frequency and abnormal distribution of mechanical strain applied to bone. In practice, this means that particular attention must be given to the nature of the training program and the equipment used (Markey, 1987).

The principles of a "safe" training program have been outlined by many authors (Markey, 1987; Scully et al, 1982). In general, it has been advocated that training should be slow and progressive but be cyclic in nature to allow the skeleton to adapt to its new mechanical environment (Markey, 1987; Hulkko et al, 1987). Furthermore, individuals with similar abilities should preferably train together and progress at their own rate (Markey, 1987). Despite the widespread application of this principle, there are very few well conducted studies to show that this prevents bone stress injuries. Indeed, in only one study to date has this been examined. It has been documented that the incidence of stress fractures during basic military training can be reduced from 4.8% to 1.6% by the adoption of a cyclic rather than a progressive training program (Scully et al, 1982). However, in this report very few details on the precise methodology and results are provided.

It has also been suggested that appropriate equipment, in particular shock absorbing footwear, can prevent bone stress injuries. However, very few studies have examined this hypothesis. One of the first studies to document the effect of shock absorbing footwear on the incidence of overuse injuries in general was conducted in New Zealand Army recruits (Stacy et al, 1984). In this study the introduction of military boots only after 5 weeks of training instead of during the first week, as well as performing physical training with running shoes instead of boots, resulted in a reduction of all injuries from 86% to 53% (Stacy et al, 1984).

It has also been documented that a specially constructed orthotic, when placed inside the military boots of trainees, can reduce the incidence of stress fractures during basic military training (Milgrom et al, 1985c). However, in this study a 3^o rearfoot varus post was added to this orthotic. This post would also affect the lower limb biomechanics and it is therefore not clear whether the reduced incidence was as a result of shock absorption or an alteration of lower limb biomechanics.

In one other well conducted prospective study in military recruits, a viscoelastic polymer insole (Sorbothane) did not significantly reduce the incidence of stress fractures during basic military training (Gardner et al, 1988). However, it has been documented in laboratory studies that Sorbothane transmits more force when loaded than other commercially available shock absorbing insoles (Brodsky et al, 1988). It would therefore be important to evaluate the effect of other insoles, with better shock absorbing capabilities, on the prevention of bone stress injuries.

5.11.3. Optimizing the repair of microdamage

The importance of normal calcium metabolism and endocrine function on remodeling and therefore microdamage repair has already been discussed. The associations between i) menstrual abnormalities, hypo-oestrogenism, decreased bone density and bone stress injuries, as well as ii) a decreased dietary intake of calcium and bone stress injuries have also been discussed.

In particular, it has been suggested that a daily dietary calcium intake above the RDA could reduce the risk for bone stress injuries (Myburgh et al, 1990). However, at present there are no well conducted clinical trials that have documented that calcium supplementation during physical training could reduce the incidence of bone stress injuries.

5.12. Summary: Chapter 5

- In this chapter the classification, incidence, pathogenesis, aetiology, pathology, clinical presentation, special investigations, management and prevention of bone stress injuries is reviewed.
- Bone stress injuries represent a continuum of the bony response to cyclic mechanical loading and include

accelerated physiological remodeling, bone stress reactions and stress fractures.

- Stress fractures represent about 5% of all overuse injuries in distance runners.
- The incidence of stress fractures in military recruits undergoing 8-12 weeks of military training ranges from 1-4%.
- The incidence of stress fractures is higher in female military recruits, older recruits and Caucasian recruits.
- Bone stress injuries occur as a result of an increased rate of microdamage, a decreased rate microdamage repair or a combination of both.
- The rate of microdamage can be increased by greater strain magnitudes, increased number of cycles of load application, low bone density and altered architecture of the bone.
- The rate of microdamage repair can be decreased by disturbances in the non-mechanical factors that control bone turnover.
- Aetiological factors that have been associated with increased microdamage are training errors, hard training surface, poor shock absorbing footwear, biomechanical abnormalities and muscle fatigue.
- Aetiological factors that have been associated with decreased microdamage repair are dietary calcium deficiency and hypo-oestrogenism.
- The histopathological findings, clinical presentation and findings on special investigations of bone stress injuries

support the hypothesis that these injuries represent a continuum of injuries.

- The management of bone stress injuries is to reduce the rate of microdamage (rest), and to increase the rate of microdamage repair (correction of metabolic disturbances).
- The prevention of bone stress injuries by decreasing the rate of microdamage and increasing the rate of microdamage repair requires further investigation.

CHAPTER 6

AN INVESTIGATION OF THE USE OF SHOCK ABSORBING INNER SOLES IN THE PREVENTION OF OVERUSE INJURIES IN MILITARY RECRUITS DURING BASIC TRAINING

6.1. Introduction

Sedentary individuals who start a physical training programme have a substantial risk of developing an exertion-related injury, in particular overuse injuries (Belkin, 1980; Clement et al, 1981; Herring et al, 1987; James et al, 1978; Jones et al, 1989; McKeag et al, 1989; Newell et al, 1984; Sheehan et al, 1977). This risk is particularly evident in new recruits undergoing a period of basic military training (Chapter 3).

A variety of overuse injuries have been described in both civilian and military populations (Clement et al, 1981; Detmer, 1986; James et al, 1978; Jones et al, 1989; Jones et al, 1987; Kowal, 1980). The anatomical location of most of these injuries is the lower limb, in particular the knee and tibial area (Chapters 3). The common injuries at these sites are patellofemoral pain, tibial stress syndrome, and the iliotibial band friction syndrome (Clement et al, 1981; James et al, 1978; McKeag et al, 1989; Taunton et al, 1988). However, bone stress injuries remain the most severe and disabling overuse injuries (Gardner et al, 1988; Giladi et al, 1985a; Jones et al, 1989; Markey, 1987). They are the injuries responsible for most days lost as a result of injuries during basic military training (Chapter 3).

A variety of general aetiological factors have been associated with the development of overuse injuries in distance runners (Chapter 2.2.) and military recruits (Chapter 2.3.). In particular, repetitive force transmission through the tissues of the lower limb and spine has been postulated as a major aetiological factor (Cavanagh et al, 1980; Dickinson et al, 1985; Schuster, 1977; Voloshin et al, 1982; Voloshin et al, 1981; Winter, 1983; Wosk et al, 1981). Repetitive force transmission through bone causes microdamage which, if excessive, can result in bone stress injuries (Chapter 5.5.).

It is therefore not surprising that, in order to reduce the risk of overuse injuries, attempts have been made to improve the shock absorbing capacity of footwear (Cavanagh et al, 1980; Drez, 1980; Schuster, 1977). The running shoe especially has received considerable attention in this regard (Clarke et al, 1983; Cook et al, 1985b; Dufek et al, 1991; Hamill et al, 1988; Komi et al, 1987; Luethi et al, 1987) whilst other sports shoes and, in particular, military footwear have been somewhat neglected (deMoya, 1982; Drez, 1980; Volpin et al, 1989).

Despite the very high incidences of overuse injuries during military training, only a few studies have addressed the possible beneficial effect of improving shock absorption in military footwear (Gardner et al, 1988; Milgrom et al, 1985c). In one study, the addition of a viscoelastic polymer insole placed within a standard military boot did not significantly decrease the incidence of stress fractures, and four other common lower limb injuries (plantar fasciitis, ankle sprains, non-specific knee strains and Achilles tendonitis) (Gardner et al, 1988). Another study found that the addition of a specially constructed orthotic reduced the incidence of stress fractures during basic military training (Milgrom et al, 1985c). However, a rearfoot post was also added to the orthotic used in this study; thus it is not clear whether the reduced injury incidence resulted from increased shock absorption or altered lower limb biomechanics.

The "age" of the running shoe was another significant risk factor in the development of stress fractures in military recruits (Gardner et al, 1988). This finding has been attributed to loss with age of either the mechanical support or the shock absorbing properties of the midsole of the shoe. The latter suggestion is supported by the finding that the shock absorption of a running shoe decreases with increased duration of use (Cook et al, 1985a).

But it has also been shown that viscoelastic insoles do not effectively reduce loading on the locomotor system (Nigg et al, 1988), and that neoprene insoles reduce transmitted force more effectively than do viscoelastic insoles (Brodsky et al, 1988). Thus the failure to demonstrate a significant reduction in injuries in the study by Gardner et al (1988) could possibly be attributed to the use of a viscoelastic insole with little or no shock absorption capacity. Possibly the use of an inner sole with more shock absorbing capacity could have produced a different result.

6.2. Aim of this investigation

The aim of this study was to investigate the effect of a commercially available neoprene insole on the incidence of overuse injuries, in particular bone stress injuries, during basic military training. This study differs from previous studies in the type of insole used. In addition, the incidence of all the overuse injuries suffered during training were investigated.

6.3. Materials and methods:

6.3.1. Subjects

The military recruits that acted as subjects for this study were from the same military base and intake of new recruits as reported in Chapters 3 and 7. One thousand five hundred and eleven (1511) new military recruits acted as subjects. Two hundred and fifty recruits were randomly selected to act as the experimental (E) group; the remainder served as a control (C) group. Transfers to other units resulted in the final number of 237 in the E group and 1151 in the C group. Prior to entering the study all the recruits were examined and declared medically fit for duty. In particular those with one or more gross biomechanical abnormality or a history of previous major injury or illness were excluded.

Height and body weight was determined in a random sample (n=129) of the control group using standard measurement techniques.

6.3.2. Training

The training period was 9 weeks. Details of the training programme that was followed has already been described in Chapter 3. All the groups undertook exactly the same physical training programme - marching, running and walking. Organized physical training sessions were also conducted 3-5 times a week.

6.3.3. Footwear

All the recruits wore standard military footwear (Boot with leather upper and rubber sole) during all activities; standard running shoes were worn during formal physical training sessions. Care was taken to ensure that the footwear fitted well.

The experimental (E) group was issued a pair of flat inner soles. The inner soles were Neoprene impregnated with nitrogen bubbles and covered with stretch nylon (Spenco, Inc Ltd, Waco, Texas, USA). The recruits were instructed to wear these daily in the standard footwear. To ensure that inner soles were worn regularly and not exchanged, regular random inspections of footwear were performed.

On completion of the experimental period a random sample of the experimental group (n=143) completed a questionnaire designed (Appendix C) to examine compliance to the wearing of the inner soles and the subjects' assessment of the comfort and durability of the inner soles.

6.3.4. Injuries

For the purposes of this study an injury was defined as an injury resulting from physical conditioning during basic training that was severe enough to prevent return to normal activities for at least one day after medical consultation (Gordon et al, 1986b). Severe injuries were those that prevented return to normal activities for 4 days or longer; less severe injuries prevented return for 3 days or less. Injuries were classified as overuse if they were not associated with a sudden precipitating event; the latter were regarded as acute traumatic injuries (Greaney et al, 1983).

All the injuries that developed during the 9 weeks were monitored. The injuries were reported to the Base Hospital where the diagnosis was established and treatment instituted by a panel of eight doctors. Before the experimental period, uniform diagnostic criteria were established for common overuse injuries (Appendix A). Due to financial constraints it was not possible to perform bone scans on all the recruits with bone pain. Bone stress reactions (stress syndromes) were therefore diagnosed on the basis of clinical criteria. Stress fractures were diagnosed on the basis of symptoms and clinical signs and confirmed by repeated X-Ray studies (at the time of the injury and repeated at least 14 days after the injury) (Murray et al, 1971; Weissman et al, 1986).

This method of diagnosing stress fractures and bone stress injuries is an obvious limitation of this study. This means that the incidence of stress fractures in this study is likely to be underestimated. However, the use of clinical criteria combined with X-rays has been the method used by most investigators in the United States. The results obtained from this study can therefore be compared to results from studies conducted in the USA. The results from the clinical trial would however not have been affected by this limitation because the same diagnostic criteria were applied to all the injured recruits.

All the injuries were recorded by the examining doctors on injury report forms (Appendix B), which were analyzed on completion of the study. Overall and specific injury rates were determined for each week and the weekly incidence of injury was expressed as injuries/1000 recruits. A mean weekly injury rate (Sum of weekly rates/9) was calculated for overall injuries and each specific injury and the injury rates in the two groups were then compared.

6.3.5. Physical activity questionnaire

A questionnaire (Appendix D) was completed by random samples of the E (n=126) and C (n=134) groups to determine individual physical activity patterns in the 12 months prior to the study. Frequency, duration and intensity of competitive and recreational sport was assessed and the groups' responses were compared. This was to document any possible differences in the pretraining level of physical conditioning in the two groups (Greaney et al, 1983; Kowal, 1980).

6.4. Statistical analysis

The results of the study were analyzed on a personal computer using STATGRAPHICS software (Version 4.0) (STSC, Inc, Maryland, USA). The Chi-square test and Fisher's exact test were used to compare the incidence of injury and the physical activity patterns in the E and C groups. The level of significance was established at $p<0.05$.

6.5. Results

6.5.1. Physical characteristics

The age (mean ± SD) of the recruits was 18.5 ± 1.2 years (range: 17-25). Height and body weight were 178.6 ± 6.9 cm and 70.1 ± 11.4 kg respectively (mean ± SD).

6.5.2. Physical activity questionnaire

The results of the physical activity questionnaire are indicated in Table 6.1. The physical activity pattern in the 12 months prior to the study did not differ significantly in the E and C groups. Most of the subjects in both groups indicated that they participated in sport 1-3 days per week usually for longer than 60 minutes during which they became moderately tired. Most of the subjects rated their subjective assessment of physical fitness prior to the training period at 50-70%.

6.5.3. Inner sole questionnaire

The results of the questionnaire on the inner soles are indicated in Table 6.2. During the nine week period 93.6% of the subjects in the E group indicated that they wore the inner soles for more than 5 days per week. Of the subjects

Table 6.1.

Physical activity questionnaire: Results of the experimental (E) and the control (C) group

		% of E Group (n=126)	% of C Group (n=134)
Days per week:	Daily	12.7	14.2
	5-6	19.8	17.2
	3-5	24.6	20.1
	1-3	31.0	35.1
	< 1	11.9	13.4
Duration (min):	No sport	2.4	3.0
	< 30	4.8	3.7
	30-60	26.2	20.1
	> 60	66.7	73.1
Tiredness:	No sport	3.2	3.0
	Very,very	3.2	7.5
	Very	23.8	23.1
	Moderate	43.7	42.5
	Little	14.3	18.7
	Not tired	4.8	5.2
Fitness (%)	100	0	0
	70-90	12.7	17.2
	50-70	45.2	41.8
	30-50	37.3	32.8
	< 30	4.8	8.2

No significant differences were observed between the experimental and the control groups ($p < 0.05$)

Table 6.2.

Results of the inner sole questionnaire (n=143)

Question:	% Responders:
1. How often did you wear the inner soles?	
Every day	84.6
5-6 days/week	9.0
3-5 days/week	4.2
Less than 3 days/week	2.1
2. How comfortable were the inner soles?	
Very comfortable	21.7
Comfortable	74.8
Not comfortable	2.8
Very unpleasant	0.7
3. How were the inner soles after 9 weeks of wearing?	
Same as new	4.9
Slightly worn (Do not need replacing)	72.7
Worn (Need replacing)	21.7
Disintegrated (Need replacing)	0.7

completing the questionnaire 96.5% found the inner sole comfortable or very comfortable to wear. Only 22.4% of subjects felt the inner sole needed replacement after nine weeks of extensive use.

6.5.4. Injury patterns

Fifty-four (54) injuries (22.8%) were reported in the E group and 367 injuries (31.9%) in the C group during the experimental period. The majority of injuries were overuse injuries in both groups (C group: 317; 86.4%: E group: 49; 90.7%). Only 50 (13.6%) and 5 (9.3%) acute traumatic injuries were reported in the C and E groups respectively. Most of the reported injuries were severe with similar frequencies in both groups (C group, 73.0%: E group, 83.3%).

The anatomical distribution of the overuse injuries for the two groups is indicated in Table 6.3. The injury pattern in the two groups is similar with the most common injuries being tibial stress syndrome and patellofemoral pain. In both groups over 80% of the reported injuries were distributed in the lower leg and knee.

Table 6.4. lists the mean weekly incidence of total and of individual (severe and less severe) injuries sustained during the period for both groups. The mean incidence (injuries/1000 recruits/week) of total injuries (E group=

Table 6.3.

The anatomical distribution of chronic overuse injuries (%) in the experimental and control groups following 9 weeks of basic military training

	Control: (N=317)	Experimental: (N=49)
Upper limb	6.2	4.3
Back	7.7	4.3
Hip	0.9	2.1
Thigh	2.8	6.4
Knee (Total)	45.2	48.9
Patellofemoral pain	13.6	12.8
Iliotibial band	5.0	8.5
Patellar tendonitis	1.9	4.3
Knee (Other)	24.7	23.4
Tibial bone stress	20.4	12.8
Calf	2.8	2.1
Foot	13.9	19.2
Stress Fractures (Total)	4.3	-
Femur	0.3	-
Tibia	3.1	-
Foot	0.9	-

Table 6.4.

The mean incidence (injuries/1000 recruits/week) of common overuse injuries sustained during 9 weeks of basic military training in the experimental (E) and control (C) groups

Injury:		C group:	E group:
All injuries	Total:	36.3	25.8 *
	Severe:	26.5	23.3
	Less severe:	9.8	2.5 *
Stress fractures	Total:	1.4	0.0 +
	Severe:	1.4	0.0 +
	Less severe:	0.0	0.0
Tibial bone stress	Total:	7.6	2.8 *
	Severe:	6.8	2.8 +
	Less severe:	0.8	0.0
Acute lumbar sprain	Total:	1.6	0.7
	Severe:	1.0	0.7
	Less severe:	0.6	0.0
Chronic back pain	Total:	2.4	1.2
	Severe:	1.4	1.2
	Less severe:	1.0	0.0
Patellofemoral pain	Total:	4.3	2.8
	Severe:	3.5	2.8
	Less severe:	0.8	0.0
Iliotibial band	Total:	1.5	1.9
	Severe:	0.8	1.4
	Less severe:	0.7	0.5
Patellar tendonitis	Total:	0.6	0.5
	Severe:	0.2	0.5
	Less severe:	0.4	0.0
Ankle sprains	Total:	1.9	1.4
	Severe:	1.1	1.4
	Less severe:	0.8	0.0
Achilles tendonitis	Total:	0.4	0.5
	Severe:	0.3	0.5
	Less severe:	0.1	0.0

* : Indicates significant difference between groups ($p<0.05$)

+ : Indicates significant difference between groups ($p<0.10$)

25.8; C group= 36.3) and tibial stress syndrome (E group= 2.8; C group= 6.8) was significantly lower in the E group. The mean weekly incidence of stress fractures (E group= 0.0; C group= 1.4) was lower in the E group but not significantly so (0.1>p>0.05).

A total of 14 stress fractures (overall incidence of 1.2%) was reported in the C group. No such injuries occurred in the E group. The distribution of the stress fractures was as follows: femoral shaft (1), tibial shaft (10), metatarsals (3).

6.6. Discussion

The principle finding of this study was that shock absorbing neoprene inner soles significantly reduced the overall incidence of overuse injuries and specifically the incidence of bone stress reactions (syndromes) in the tibia. There was also a noticeable trend towards a reduced incidence of stress fractures in the recruits wearing inner soles. Furthermore, most recruits found the inner soles to be durable (they did not need replacement) and comfortable.

Only two published studies (Gardner et al, 1988; Milgrom et al, 1985c) and one study reported in an Army Technical memorandum (Bensel, 1976) have reported the use of inner soles to prevent bony overuse injuries in recruits. The details of these studies have already been discussed. Our finding of a decreased incidence of stress fractures (C: 1.2% vs E: 0%) supports the findings of Milgrom et al (1985c) but not that of Gardner et al (1988). The incidence of stress fractures in the E group is also the lowest incidence of stress fractures yet to be recorded in recruits undergoing basic military training.

The reason why our findings conflict with those of Gardner et al (1988) is not clear but may be the type of inner sole used. Viscoelastic inner soles have not been shown to significantly reduce vertical impact forces when compared to conventional running shoe inner soles (Nigg et al, 1988). Furthermore, a recent study which compared the material properties of viscoelastic and neoprene inner soles and found neoprene inner soles to be less rigid, resist shear-compression forces and reduce transmitted force better than viscoelastic inner soles (Brodsky et al, 1988).

The overall incidence of injuries in control recruits (31.9%) is slightly less and the incidence in the experimental group (22.8%) considerably less than that of 37.9% previously reported in a similar population of South African military recruits undergoing similar training 3 years previously (Gordon et al, 1986b). The addition of an inner sole to the footwear of soldiers has resulted in a

15.1% reduction in overall injury incidence from that reported by Gordon et al (1986b).

Differences in the definition of an injury makes the comparison of the incidence of injuries reported in the E and C groups of this study and those reported in other studies difficult. Kowal (1980) reported a 26% incidence of injury in male US army recruits, Bensel (1976) a 37% incidence in US marines and Stacy et al (1984) a 65.4% incidence in New Zealand Army recruits. The 22.8% incidence in our E group is therefore the lowest overall incidence of injury (as defined in our study) in military recruits reported to date.

The incidence of acute traumatic injuries in both the C group (13.6%) and the E group (9.3%) is slightly lower than that reported previously by Gordon et al (1986b) (18.3%) for a similar population. The reasons for this are not apparent, and were not the major focus of this study. However, the incidence of acute injuries in all these groups is low, and this again confirms that overuse injuries are the most frequent injuries encountered in this population (Chapter 2.3.).

The anatomical distribution of injuries in both the E and C groups was similar and confirms previous observations that the anatomical sites at which overuse injuries commonly occur in military recruits are the knee and lower leg (Chapter 2.3.). The wearing of inner soles did not alter this pattern substantially despite reducing the incidence of specific injuries.

The aetiological factors commonly associated with bone stress injuries are either factors that increase the rate of microdamage, or decrease the rate of microdamage repair (Chapter 5.6.). In particular, factors such as training errors, anatomic factors, poor shock absorbing shoes and surfaces can increase the rate of microdamage (Chapter 5.6.). Furthermore, there is evidence to suggest that the impact absorbed at heel-strike may play an important role in the aetiology of other chronic injuries such as chronic low back pain (Voloshin et al, 1981) and osteoarthritis (Radin et al, 1982).

In this study, the incidence of chronic low back pain was lower in the E group (1.2/1000 recruits/week) compared to the C group (2.4/1000 recruits/week). However, this difference was not statistically significant. The association between shock transmission and the development of chronic back pain requires further investigation.

Improved shock absorption by footwear should reduce the incidence of overuse injuries associated with repetitive loading but might not alter the incidence of acute injuries or injuries in which excessive or repetitive shock wave transmission is not implicated as an aetiological factor. Our findings of a reduced incidence of tibial stress syndrome, and to a lesser extent, stress fractures in a group of recruits wearing shock absorbing inner soles therefore substantiate this argument.

6.7. Summary: Chapter 6

- Shock absorbing neoprene insoles significantly reduce the overall incidence of overuse injuries and the incidence bone stress reactions in the tibia in military recruits undergoing basic military training.
- There is a tendency for shock absorbing neoprene insoles to reduce the incidence of stress fractures in military recruits undergoing basic military training.
- Shock absorbing neoprene insoles do not alter the incidence of acute traumatic injuries sustained during basic military training.
- Shock absorbing neoprene insoles do not alter the anatomical distribution of overuse injuries sustained during basic military training.
- Shock absorbing neoprene insoles are durable and comfortable for most military recruits.
- It is recommended that shock absorbing insoles be issued to military recruits during basic military training to

reduce the incidence of overuse injuries, in particular tibial bone stress reactions.

CHAPTER 7

AN INVESTIGATION TO EVALUATE THE EFFECTIVENESS OF CALCIUM SUPPLEMENTATION IN THE PREVENTION OF BONE STRESS INJURIES IN MILITARY RECRUITS UNDERGOING BASIC MILITARY TRAINING

7.1. Introduction

Overuse injuries, in particular bone stress injuries, are common during basic military training (Chapter 2.3. and Chapter 5.4.). Bone stress injuries are the most severe and debilitating of all the overuse injuries. The aim for any sports physician is therefore to prevent these injuries. The principles of preventing bone stress injuries are to reduce the rate of microdamage, or to increase the rate of microdamage repair or both (Chapter 5.11.).

Bone is a dynamic tissue that undergoes constant change in response to mechanical strain (Chapter 4.4.). Increases in the magnitude or frequency of the mechanical strain applied to bone can result in microdamage (Chapter 5.5.). The areas of microdamage are constantly repaired by a process of remodeling. The phases of remodeling are bone resorption, new bone formation and mineralization of the osteoid followed by a maintenance phase. These phases are characterized by osteoclastic, osteoblastic and osteocytic function. Normal remodeling, and thus repair, can take place only if the factors regulating bone metabolism are normal (Chapter 5.5.). Recently the association between bone stress injury risk and factors interfering with normal bone metabolism have been investigated.

The association between increased risk of bone stress injury and amenorrhea in athletes has been attributed to hypo-estrogenism and low bone density. The role of diet, in particular low dietary calcium intake, was also implicated as an aetiological factor in bone stress injuries. Athletes presenting with shin soreness were reported to have a decreased dietary calcium intake compared to non-injured controls (Myburgh et al, 1988). In animal studies it has been shown that diets deficient in calcium may decrease the ability of bone to adapt to mechanical strain (Lanyon et al, 1986) and that a high dietary calcium intake has a favorable effect on the biomechanical properties of bone (Ferreti et al, 1985).

It is therefore possible that a high intake of dietary calcium may protect against the development of bone stress injuries. It has been stated that the relative risk of bone stress injury can be reduced if dietary calcium intake is above 120% of the recommended daily intake (Myburgh et al, 1990).

7.2. Aim of this investigation

The aim of this study was to investigate the effect of calcium supplementation in the prevention of bone stress injuries in new military recruits undergoing basic military training.

7.3. Materials and methods

7.3.1. Subjects

Male military recruits that acted as subjects in this study were from the same military base and intake of recruits described in Chapters 3 and 6. Two hundred and fifty recruits were randomly selected to act as the experimental

(E) group; the remainder served as a control (C) group which was the same group that acted as controls in the study discussed in Chapter 6. Transfers to other units resulted in a loss of 3 recruits in the E group and 110 recruits in the C group. The final number of recruits in the E group was therefore 247 and in the C group 1151.

Prior to entering the study all the recruits were examined and declared medically fit for duty. In particular those with one or more gross biomechanical abnormality, a history of previous major injury or illness or any contra-indication to calcium supplementation were excluded from this study. Contra-indications to calcium supplementation were; documented hypercalcaemia or hypercalcuria, renal failure, sarcoidosis and the milk-alkali syndrome. Written informed consent was obtained from all the subjects and the study was approved by the Ethics Committee of the South African Medical Services, Pretoria.

7.3.2. Training

The basic military training period was nine weeks. The details of the training has already been discussed (Chapter 3). All the recruits undertook exactly the same physical training programme which consisted of formal physical training, marching and field training.

7.3.3. Footwear

All the recruits in both the E and C groups wore standard military footwear during the entire experimental period. The footwear consisted of a standard military boot with a leather upper and a rubber sole. Care was taken to ensure that the footwear fitted well.

7.3.4. Calcium administration

The subjects in the E group received 500 mg elemental calcium (Calcium/Sandoz Forte 500) daily for nine weeks starting on the first day of week 1. The E and C group subjects, physical training instructors and medical personnel monitoring the injuries were blind to the hypothesis of the study. Compliance to calcium administration was ensured by controlling the time of calcium tablet administration to coincide with regular daily inspections. A register kept by the instructors was examined after the trial to document compliance. The side effects of the calcium administration was monitored by the medical personnel treating the recruits of the unit.

7.3.5. Dietary assessment

The height, body weight and diets of the subjects and control groups were assessed by selecting a random sample from the E and C groups. Fifty subjects were selected from each group and a dietary questionnaire (Appendix E) was completed. The dietary questionnaire was aimed at establishing average dietary intake over a 24 hour period. The food intake was recorded by each subject. A 24 hour period was regarded as sufficiently accurate compared to the conventional three day or seven day period because the diets of military recruits are very standard. An analysis of the composition of the standard diet which was obtained from the canteen records revealed that dietary assessment over 24 hours would accurately reflect dietary intake over a period of days. The 24 hour dietary record was analyzed using a computerized dietary programme (Program Management, Parklands, Johannesburg, RSA) which is based on the The National Research Institute for Nutritional Diseases food composition tables (Gouws et al, 1981). The daily intake of all the food components including calcium was calculated for both the E and C group samples.

7.3.6. Injuries

For the purposes of this study an injury was defined as an injury resulting from physical conditioning during basic training that was severe enough to prevent return to normal activities for at least one day after medical consultation (Gordon et al, 1986b). Severe injuries were defined as those that prevented return to normal activities for four days or longer; less severe injuries prevented return for three days or less. Injuries were classified as overuse if they were not associated with a sudden precipitating event; the others were regarded as acute traumatic injuries (Greaney et al, 1983).

All injuries during the nine week period were monitored and the injured recruits reported any injury to a member of a pre-selected panel of doctors at the base hospital where the diagnosis was established and treatment instituted. Before the onset of the study, uniform diagnostic criteria were established for common overuse injuries and the panel of doctors applied these criteria (Appendix A). The specifc criteria that were used to diagnose bone stress reactions and stress fractures were the same as those described in Chapter 6. The limitations of using these criteria compared to a bone scan have also been discussed (Chapter 6).

All the injuries were recorded by the examining doctors on injury report forms (Appendix B), which were then analyzed on completion of study. Specific injury rates for the groups were determined for each week, and the weekly incidence of injuries was expressed as injuries per 1000 recruits. A mean weekly injury rate (sum of weekly rates/9) was calculated for each specific injury. The injury rates in the two groups were then compared.

7.4. Statistical analysis

The statistical analysis of the data was performed on a personal computer using STATGRAPHICS software (Version 4.0) (STSC, Inc, Maryland, USA). The chi-square test and Fisher's exact test were used to compare the incidence of injury in the E and C groups. The level of significance was established at $P<0.05$.

7.5. Results

7.5.1. Physical characteristics

The weight (kg) and height (cm) (mean ± SD) of the two groups was 72.8 ± 9.8 (E group) and 71.4 ± 10.3 (C group) and 178 ± 8 (E group) and 180 ± 7 (C group) respectively.

7.5.2. Injury patterns

Fifty one injuries (20.6%) were reported in the E group and 367 injuries (31.9%) in the C group during the experimental period. Most of the injuries were of the overuse type in both groups (C group: 317; 86.4%: E group: 45; 88.2%). Only 50 (13.6%) and 6 (11.8%) acute traumatic injuries were reported in the C and E groups respectively. Most of the injuries were severe with similar frequencies in both groups (C group, 73.0%: E group, 90.2%).

The anatomical distribution of the overuse injuries for the two groups is indicated in Table 7.1. The injury pattern in the two groups was similar with the most common injuries being tibial stress syndrome and patellofemoral pain. In both groups over 80% of the reported injuries were distributed in the lower leg and knee. In Table 7.2 the mean weekly incidence of individual (severe and less severe) injuries sustained during the period is indicated for both groups. The mean weekly incidence (injuries/1000 recruits/week) was similar for all the injuries.

A total of 14 stress fractures (overall incidence of 1.2%) were reported in the C group and 1 stress fracture (0.6%) was reported in the E group. The distribution of the stress fractures of the C group was as follows: femoral shaft (1), tibial shaft (10), metatarsals (3). The stress fracture in the E group occurred in the tibia.

7.5.3. Dietary assessment

The results of a full dietary analysis in the control and experimental group is indicated in Table 7.3. There were no significant differences in intake of dietary components between the two groups. In particular the daily dietary

Table 7.1.

The anatomical distribution of chronic overuse injuries in the experimental and control groups during 9 weeks of basic military training

	Control (N=317)	Experimental (N=45)
Upper limb	6.2	4.4
Back	7.7	8.9
Hip	0.9	0.0
Thigh	2.8	2.2
Knee (Total)	45.2	42.2
Patellofemoral pain	13.6	22.2
Iliotibial band	5.0	4.4
Patellar tendonitis	1.9	0.0
Knee (Other)	24.7	15.6
Tibial bone stress	20.4	33.3
Calf	2.8	2.2
Foot	13.9	4.4
Stress fractures (Total)	4.3	2.2
Femur	0.3	-
Tibia	3.1	-
Foot	0.9	-

No significant differences were observed between the two groups.

Table 7.2.

The mean incidence (injuries/1000 recruits/week) of common injuries sustained during 9 weeks of basic military training in the experimental and control groups

Injury:		Control	Experimental
Stress fractures	Total:	1.4	0.6
	Severe:	1.4	0.6
	Less severe:	0.0	0.0
Tibial bone stress	Total:	7.6	7.1
	Severe:	6.8	5.6
	Less severe:	0.8	1.5
Acute lumbar sprain	Total:	1.6	1.5
	Severe:	1.0	1.1
	Less severe:	0.6	0.1
Chronic back pain	Total:	2.4	1.7
	Severe:	1.4	1.3
	Less severe:	1.0	0.4
Patellofemoral pain	Total:	4.3	4.3
	Severe:	3.5	4.3
	Less severe:	0.8	0.0
Iliotibial band	Total:	1.5	0.9
	Severe:	0.8	0.9
	Less severe:	0.7	0.0
Patellar tendonitis	Total:	0.6	0.0
	Severe:	0.2	0.0
	Less severe:	0.4	0.0
Ankle sprains	Total:	1.9	0.9
	Severe:	1.1	0.9
	Less severe:	0.8	0.0

No significant differences were observed between the incidence of injury in the experimental and control groups.

Table 7.3.

Daily dietary intake of the control and the experimental groups

	Control: (n=50)	Experimental (n=50)
Energy (KJ)	14353± 5805	15338± 9187
Protein (gm)	134± 55	146± 94
Fat (gm)	130± 61	141±100
Carbohydrate (gm)	425±182	451±264
Fibre (gm)	14.5± 6.3	16.1± 9.1
Calcium (mg)	976±737	872±475
Iron (mg)	22± 9	24±13
Magnesium (mg)	379±145	398±207
Phosphate (mg)	1907± 897	1943±1017
Potassium (mg)	3906±1700	4296±2578
Sodium (mg)	2491±1330	3241±3449
Zinc (mg)	21± 9	24±16
Copper (mg)	1.7±0.7	1.9±1.4
Vitamin A (IU)	12239± 5376	13437± 7080
Thiamin (mg)	1.8±0.9	4.6±19.7
Riboflavin (mg)	3.1±1.8	3.1±1.5
Nicotinic acid (mg)	29.2±13.1	32.9±17.1
Vitamin B 6 (mg)	1.97± 0.84	2.18±1.47
Vitamin B 12 (ug)	8.13±4.42	8.95±5.63
Vitamin C (mg)	83±78	80±118
Vitamin D (ug)	2.81±1.11	2.65±0.86
Vitamin E (mg)	20.8±11.1	19.0±11.8

No significant differences were observed between the two groups.

The values indicated are mean±SD.

calcium intake (mean ± SD) was similar in the two groups (C group 976 ± 737 mg/day: E group 872 ± 475 mg/day). The E group received an additional 500mg calcium per day in the form of the calcium supplement. In both groups the daily intake of dietary calcium was in excess of 800mg/day (C group: 122% of RDA and E Group: 172% of RDA) which was the Recommended Dietary Allowance for adult males at the time of the study (US National Academy of Sciences, 1979).

However, as the RDA for calcium in males younger than 25 years has recently been revised (1200mg/day) (Monsen, 1989), the baseline mean daily dietary intake of calcium was 73% and 82% of RDA for the subjects in E and C groups respectively. In addition, all subjects in the E group received an extra 500mg calcium per day in the form of the calcium supplement.

7.5.4. Side effects

No significant side effects to calcium supplementation were reported by the subjects in the experimental group.

7.6. Discussion

The principal finding of this study was that calcium supplementation (500mg/day) did not significantly alter the incidence of bone stress injuries (tibial stress syndrome and stress fractures) in young male military recruits starting with basic military training.

This finding was surprising in view of the evidence showing that calcium deficiency is associated with an increased risk of bone stress injuries. A study conducted in animals showed that during calcium deficiency, less bone is formed in response to mechanical strain (Lanyon et al, 1986). The association between dietary calcium deficiency and the development of "shin soreness" (Myburgh et al, 1988) and stress fractures (Myburgh et al, 1990; Grimston et al, 1990a) has been reviewed (Chapter 4.5.).

However, in this study we failed to demonstrate that calcium supplementation in normal healthy individuals embarking on a program of physical activity influences the risk of developing bone stress injuries. The most likely explanation for this finding is that the daily dietary calcium intake of the two groups (>800mg/day) was sufficient to supply bone with the necessary calcium for mineralization. An addition of 500mg elemental calcium (E group) may therefore have been unnecessary to ensure optimum microdamage repair by remodeling. These findings do not support the hypothesis that the relative risk of bone stress injury decreases with dietary calcium intake above 800mg/day (Myburgh et al, 1990).

It must however be noted, that only a single stress fracture was recorded in the experimental group. The overall stress fracture incidence in the experimental group (0.6%) was markedly lower than in the control group (1.24%). It is conceivable that if a larger numbers of stress fractures had been studied significant differences may have been demonstrated. However, the number of subjects with tibial stress syndrome in both groups was high and was not different between the two groups. It is therefore unlikely that the stress fracture incidence would also show differences, as the mechanism of injury is thought to be the same in both injuries. A further confounding variable is the relative inaccuracy of diagnosing bone stress injuries clinically. Under ideal circumstances, a study such as this one should use a bone scan to confirm the diagnosis of bone stress injuries.

It must also be stated that this study was conducted over only 9 weeks of training, and the recruits in the E group started with the calcium supplementation at the same time as the training. The possibility that a high dietary intake of calcium is required for a period before training commences to optimize microdamage repair must be considered. Finally, a study conducted over a longer period (perhaps long enough for the completion of an ARF sequence) may have shown different results.

The injury patterns in this study were similar to those reported previously (Chapter 2.3.). As expected, most of the injuries were of the overuse type in both groups. The anatomical distribution pattern of the overuse injuries in the two groups was similar to those previously recorded for a similar population (Gordon et al, 1986b).

In summary this study demonstrated that calcium supplementation (500mg/day) in individuals with adequate dietary calcium intake (> 800mg/day), starting with a physical training programme, did not influence the risk of developing bone stress injuries. We recommend that if adequate dietary calcium intake is present (>800 mg/day for young adult males) no further calcium supplementation is required for the prevention of bone stress injuries during military training.

7.7. Summary: Chapter 7

- Supplemental calcium above a daily dietary intake of 800mg did not decrease the risk of bone stress injuries in young male military recruits undergoing basic military training.
- The possibility that a longer study period or calcium supplementation prior to training may have produced different results must be considered.

CHAPTER 8

A REVIEW OF THE ILIOTIBIAL BAND FRICTION SYNDROME

8.1. Definition

The iliotibial band friction syndrome (ITBFS) can be defined as an inflammatory condition on the lateral aspect of the knee resulting from repetitive friction between the iliotibial band and the lateral femoral condyle.

8.2. Historical perspective

The clinical syndrome of pain on the lateral femoral condyle associated with long distance running was first described in 1973 (Nilsson et al, 1973). These authors described the condition as tendoperiostitis in the lateral femoral condyle. Although the condition was mentioned by Colsen and Armour in 1975 (Colsen et al, 1975), the name "iliotibial band friction syndrome" (ITBFS) was given to the condition by Lieutenant Commander James W. Renne of the United States Naval Reserve in 1975. Renne described the clinical features, radiographic findings and management of sixteen cases of the ITBFS in naval officers undergoing 6 months of military training (Renne, 1975).

The ITBFS is now a well described overuse injury of the knee in distance runners (Lindenberg et al, 1984; Noble, 1980; Noble et al, 1982; Orava, 1978; Sutker et al, 1981; Sutker et al, 1985), military recruits (Renne, 1975; Schwellnus et al, 1990), weight lifters (Orava, 1978), downhill skiers (Nillson et al, 1973; Orava, 1978), soccer players (Martens et al, 1989; Orava 1978), cyclists (Martens et al, 1989) and athletes engaged in circuit training (Orava, 1978).

8.3. Anatomy of the iliotibial band

The iliotibial band, also known as the iliotibial tract or the band of Maissiat, is a fibrous structure connecting the ilium to the tibia. Its anatomy was first described by Vesalius in 1552 who considered it as a muscle and therefore grouped it with the other five muscles of the tibia. However, the most comprehensive monograph of an early anatomist on the anatomy and functions of the iliotibial band was written by Jaques Maissiat in 1843 - hence it is also known as "the band of Maissiat". The most comprehensive recent review on the anatomy and functions of the iliotibial band was published more than three decades ago (Kaplan, 1958).

The iliotibial band is unique because it is a structure peculiar to man (Kaplan, 1958). It is only in the human lower extremity that there is an open space between the tendon of the biceps femoris and the vastus lateralis muscles at the knee joint. This space allows the passage of the iliotibial tract for insertion into the lateral tubercle of the tibia (Kaplan, 1958). The erect posture of man, when compared to quadrupeds, is characterized by a change in the position of the pelvis from a horizontal to almost a vertical plane. This change was associated with the development of a large gluteus maximus muscle mass and a strong anterolateral ligament of support - the iliotibial band (Kaplan, 1958).

The iliotibial band originates proximally from the iliac crest, predominantly from the iliac tubercle (Evans, 1979). It also attaches along most of the length of the iliac crest on its most lateral lip. The iliotibial band has also been defined as the vertical component of the fascia lata of the thigh (Evans, 1979). The iliotibial band (vertical fibres of the fascia lata) is intimately associated with the tensor fascia lata muscle anteriorly. The gluteus maximus muscle attaches to the upper part of the horizontal fibres of the fascia lata. Despite the close association of the iliotibial band to these two muscles, it is regarded as an independent structure and not a tendon of either one of these two muscles, as was commonly believed (Kaplan, 1958). The deep fibres of the tensor fascia lata and the gluteus maximus muscles do however blend with the deep surface of the iliotibial band in the region of the greater trochanter of the femur.

The iliotibial band runs distally along the lateral aspect of the thigh. It is connected to the intermuscular septum, and therefore the linea aspera on the femur, from the greater trochanter proximally to the supracondylar tubercle of the lateral condyle of the femur distally (Kaplan, 1958). The distal end of the iliotibial tract is thicker and attaches to i) the lateral border of the patella anteriorly (iliopatellar band), ii) the lateral tibial tubercle (Gerdy's tubercle) and, ii) the anterior fibres of the biceps tendon posteriorly (Kaplan, 1958; Evans, 1979). The functional anatomy of its distal attachment is complex and has recently been reviewed (Terry et al, 1986).

The iliotibial band is thus a fibrous band extending from the iliac crest proximally to the lateral tibial tubercle (Gerdy's tubercle) and adjacent structures distally. Along its course it is attached to the femur except in the area between the upper part of the lateral femoral condyle and the lateral tubercle of the tibia.

8.4. Biomechanics and function of the iliotibial band

The Iliotibial band spans across the hip and the knee joints. These two joints are important during stance and motion of the upright man. The biomechanics and function of the iliotibial band can therefore be considered separately during standing (static) and walking or running (dynamic) functions of the lower limb.

8.4.1. Static functions of the iliotibial band:

The importance of the iliotibial band in maintaining normal balance of the body in stance has been described in one of the earliest monographs detailing its anatomy and function (Maissiat, 1843). However, it was only a century later that this observation was substantiated by some scientific evidence (Inman, 1947). Inman calculated theoretical torque values about the hip joint during one-legged stance in 35 individuals. Using electromyography, he then proceeded to measure the actual torque values in three positions of the pelvis; level pelvis, pelvis tilted up 20^{o}, and with the pelvis sagged. In all these positions the theoretical torque value was greater than the actual torque value, indicating that the fascia lata, and therefore the iliotibial band, contributed significantly to pelvic stability during one-legged stance (Inman, 1947). Furthermore, he noted that the contribution of the fascia lata to the torque was greatest in the sagged pelvis position and least with the pelvis in the tilted position. This study showed firstly, that the iliotibial band is an important structure that provides abductor torque during one-legged stance, and secondly that tension in the band increases with progressive hip adduction.

It is now well established that the combined pull of the gluteus maximus muscle, the tensor fascia lata muscle, and the tension in the iliotibial band is posterior to the axis of rotation of the hip joint during standing (Gose et al, 1989). Minimal hip muscle action, as demonstrated by electromyographic studies, is therefore required during symmetrical standing (Evans, 1979). These findings are further substantiated by the clinical observation that a Trendelenburg gait develops after surgical release of the iliotibial tract (Evans, 1979).

At the knee joint it has been observed that the iliotibial band contributes to the lateral stability of that joint (Kaplan, 1958). In full knee extension, the iliotibial band lies anterior to the axis of rotation of the knee. In this position it helps to maintain the knee in full extension, again with minimal muscle action (Gose et al, 1989). The function of the iliotibial band during standing is therefore to maintain the hip and knee in full extension. This is associated with minimal muscle action and therefore, the iliotibial band has therefore also been named the "Ligament of Idleness" or the "Ligament of Boredom" (Evans, 1979).

8.4.2. Dynamic functions of the iliotibial band

The dynamic functions (during walking and running) of the iliotibial band are not as well described as its static functions. The iliotibial band has important dynamic functions at both the hip and the knee joint.

In hip flexion, such as during the swing phase of running, the ITB is anterior to the axis of rotation of the hip joint (Gose et al, 1989). In this position it helps to maintain hip flexion. With progressive hip extension the band moves posteriorly and crosses the greater trochanter of the femur.

At the knee joint the dynamics of the ITB are similar to that described in the hip joint. In full knee extension the band is anterior to the axis of rotation of the knee joint. With progressive flexion, the band moves posterior to cross the lateral femoral condyle at approximately 30^{o} of knee flexion (Gose et al, 1989). During walking and running hip flexion and knee flexion occur simultaneously during the swing phase, whereas extension occur simultaneously during the stance phase. Walking and running are therefore characterized by repetitive knee and hip flexion and extension movements. This causes repetitive antero-posterior movement of the iliotibial band over the greater trochanter proximally and the lateral femoral condyle distally.

8.5. Aetiology and pathogenesis of the iliotibial band friction syndrome

The mechanism of injury in the iliotibial band friction syndrome is thought to be due to the repetitive antero-posterior movement of the iliotibial band over the lateral femoral condyle (Renne, 1975). As previously mentioned, movement of the ITB across the lateral femoral condyle occurs with the knee at approximately 30^o flexion. A similar but less common condition has been described for the antero-posterior movement occurring at the hip joint. In this condition, the movement causes mechanical irritation of the trochanteric bursa resulting in a trochanteric bursitis.

The frictional force of the ITB over the lateral femoral condyle could be exacerbated if i) the movement is very frequent or ii) if there is increased tension in the ITB during the movement. Factors that are responsible for the development of ITBFS can therefore be classified into either one of these two groups.

It is however conventional to classify aetiological factors associated with overuse injuries as either intrinsic or extrinsic. Although there are a number of postulated intrinsic and extrinsic aetiological factors for ITBFS, none of these have been well studied. All the published reports have been in the form of case series (Lindenberg et al, 1984; Pinshaw et al, 1984; Sutker et al, 1981). It is therefore not possible to identify specific aetiological factors for ITBFS. The postulated intrinsic and extrinsic aetiological factors for ITBFS as well as their postulated mechanism/s of injury will now be discussed in detail.

8.5.1. Intrinsic factors

A number of intrinsic risk factors have been postulated as causes of the ITBFS (Table 8.1.). However, these have all been identified from case series. There are no well conducted case-control or prospective studies that have identified specific intrinsic risk factors for ITBFS.

A leg length discrepancy has been postulated as a cause for ITBFS (Clement et al, 1981; Lindenberg et al, 1984; Pinshaw et al, 1984). This mechanism of injury is not known, but may be related to increased tension in the ITB of the affected limb due to increased adduction in the stance phase of ambulation. There has been no association between the side of injury and the side of the longer or shorter leg (Lindenberg et al, 1984).

Lower limb malalignment has also been postulated as a cause for ITBFS. The following specific abnormalities have been documented in runners with ITBFS: cavus foot (Krissoff et al, 1979; Sutker et al, 1981), rearfoot varus (Krissoff et al, 1979; Lindenberg et al, 1984; Pinshaw et al, 1984), rearfoot valgus (Noble, 1980), forefoot varus (Lindenberg et al, 1984; Pinshaw et al, 1984), and genu varus (Lindenberg et al, 1984; Sutker et al, 1981). Functional genu varus secondary to ligamentous laxity has also been mentioned as a possible intrinsic risk factor (Noble, 1980).

Table 8.1.

Postulated risk factors for the iliotibial band friction syndrome

Intrinsic risk factors

1. Leg length discrepancy
2. Cavus feet
3. Forefoot varus
4. Rearfoot valgus
5. Rearfoot varus
6. Tibial varus
7. Genu varum
8. Somatotype
9. Age
10. Sex
11. Adductor contracture

Extrinsic risk factors

1. Training errors
    - Training volume
    - Type of training
    - Training surface

2. Footwear

The mechanisms by which these abnormalities may cause ITBFS have not been well documented but it has been postulated that they increase the tension in the ITB. As mentioned previously, increased tension in the ITB will increase the frictional force between it and the lateral femoral condyle. Genu varus, tibial varus, rearfoot varus and a cavus foot may all potentially increase the tension in the ITB by nature of their anatomical abnormality (Noble, 1980).

A second group of lower limb biomechanical abnormalities are all associated with increased and/or prolonged subtalar joint pronation during the stance phase of running. Subtalar joint pronation is associated with internal tibial rotation, which in turn will alter the orientation of the lateral tibial tubercle - the distal insertion of the ITB (Noble 1980; Subotnick, 1977; Subotnick, 1978). Internal rotation of this insertion point may increase the tension in the ITB during the rapid extension of the knee at the end of the stance phase, again increasing the frictional force between the ITB and the lateral femoral condyle.

Other intrinsic factors that have been mentioned as possible risk factors for ITBFS are excessive prominence of the lateral femoral condyle (Noble 1980), age, male sex (Orava 1978; Sutker et al, 1985) and ecto- and mesomorphic somatotypes (Sutker et al, 1985). However, there is no scientific evidence to verify these as risk factors.

It again needs to be emphasized that none of these postulated aetiological factors have been well studied, and that the mechanisms of injury that are described are purely speculative.

8.5.2. Extrinsic factors

There are no well conducted studies that identify specific extrinsic risk factors for the development of the ITBFS. In a number of case series extrinsic aetiological factors have been postulated (Table 8.1.). However, because none of these studies included suitable non-injured control groups, no conclusions can be made regarding specific extrinsic risk factors.

The most common training error that has been postulated to cause the ITBFS relates to training volume. Errors in training volume include excessive running distance per week (Firer, 1989; Newell et al, 1984; Noble, 1980; Noble et al, 1982; Sutker et al, 1985), years of training (Sutker et al, 1985), and/or a sudden increase in training (Firer, 1989; Noble, 1980; Noble et al, 1982).

The type of training and the training surface may also be associated with the development of ITBFS. In particular hill training (Newell et al, 1984; Nillson et al, 1973; Noble, 1980; Sutker et al, 1985), speed training (Noble, 1980; Orava, 1978; Sutker et al, 1985), training on cambered roads (Lindenberg et al, 1984; Noble et al, 1982; Sutker et al, 1985) and, training on hard surfaces (Nillson et al, 1973; Sutker et al, 1985) have been associated with ITBFS. The mechanisms by which training errors cause this syndrome has not been well studied. However, it is possible that training errors cause the ITBFS through repetitive movement of the ITB across the lateral femoral condyle (increased weekly distance, sudden increase in training), or that the tension in the ITB is increased (training on a cambered road, hill training, speed training, hard surfaces). However, none of these mechanisms have been well documented.

Finally, footwear, in particular hard running shoes, (Lindenberg et al, 1984), anti-pronation shoes (Sutker et al, 1985) or army boots (Nillson et al, 1973) have been postulated as aetiological factors in the development of the ITBFS. It has been postulated that the mechanisms by which footwear may cause ITBFS is increased tension in the ITB. Again, this has not been investigated scientifically.

8.6. Pathology

The gross pathology and histopathology of ITBFS has been described (Martens et al, 1989; Noble, 1979; Noble, 1980; Orava, 1978; Renne, 1975). It must be pointed out that these studies only described the pathological findings in patients that were treated for the condition by surgery. These cases are not representative of most patients that present with the ITBFS because only chronic cases or cases refractory to conservative treatment are referred for surgery.

At surgery, the macroscopic appearance of the tissue between the distal ITB and the lateral femoral condyle is characterized by features of chronic inflammation (Noble, 1979; Noble, 1980; Martens et al, 1989). The appearance of the tissue has been described as a reddish brown thickening resembling a bursa (Orava, 1978). No true bursae have been observed by most (Noble, 1979; Noble, 1980; Orava, 1978), but in one case, yellow viscous fluid could be aspirated from a "bursa" that developed at the site (Renne, 1975). It is likely that the repetitive mechanical irritation is responsible for the chronic inflammatory response. This process may, in some cases, then cause the formation of a false bursa in the area (Orava, 1978).

Histological examination of tissue removed from the site at surgery revealed fibrous tissue with a synovial-like structure showing many areas of mucoid degeneration or fibrinoid necrosis (Martens et al, 1989). Chronic inflammatory cells have also been noted in specimens (Noble, 1980).

In summary, the pathological findings at surgery of ITBFS are consistent with the proposed mechanism of injury which is repetitive mechanical irritation of the band over the lateral femoral condyle. In long standing cases, such as those that require surgery, the chronic inflammatory response may be associated with the formation of false bursal tissue. Early treatment of the inflammation is thought to be important to decrease the possibility of scarring (Noble, 1979).

8.7. Epidemiology

The incidence of ITBFS (expressed as annual incidence or occurrence per participation hours) has not been documented well for any of the activities in which the condition has been described. In general, ITBFS has been documented in case series where its occurrence is reported as a percentage of the total number of injuries.

In only one prospective study can the annual incidence of ITBFS in a group of runners be calculated. In this study 60 runners (sprinters, middle- and long-distance runners) were followed up for one year and all the injuries were documented. The annual incidence of ITBFS in this group of runners was 1.7%.

In one of the largest published case series on running injuries, ITBFS accounted for 11.8% of all injuries in male marathon runners and 21.2% of all female marathon runners (Macintyre et al, 1991). In this study ITBFS was the second most common injury in male and female marathon runners. In the same series ITBFS was also the second most common injury in recreational runners (males, 6.7%; females, 7.2%), but it was less common in middle distance runners (males, 3.6%; females, 2.7%). In a similar survey of running injuries conducted by the same authors in the same population 10 years ago, ITBFS was responsible for 4.6% and 3.8% of all injuries in male and female runners respectively (Clement et al, 1981). The authors concluded that the frequency of ITBFS, as a percentage of all running injuries, appears to have increased in the last decade (Macintyre et al, 1991).

In most other series the frequency of ITBFS is expressed as a percentage of all lower extremity injuries in runners. This percentage has been documented as 4.7% (Sutker et al, 1985), 5% (James et al, 1978), and 6.4% (Orava, 1978). It has also been reported that between 14% and 17% of all knee injuries in runners are due to ITBFS (James et al, 1978; Newell et al, 1984).

The incidence of ITBFS in military recruits undergoing basic training has not been well documented. In only one study, an incidence of approximately 1.6% over a six month training period can be calculated (Renne, 1975). The epidemiology of ITBFS in other sports has not been studied.

In summary, the precise incidence of ITBFS has not been documented. However, it appears to be a common overuse injury in distance runners and military recruits. Finally, it appears that in the last decade, there is an increase in the frequency of the occurrence of ITBFS in runners (Macintyre et al, 1991).

8.8. Clinical features

The clinical features of ITBFS have been well described. The diagnosis of the condition is easy to make provided a comprehensive history is taken and a thorough clinical examination is performed. The assessment of the patient should also include a clinical biomechanical assessment of the lower limb to identify possible intrinsic risk factors that may be associated with ITBFS.

8.8.1. History

The hallmark of this condition is pain experienced on the lateral aspect of the knee during repetitive flexion and extension movements of the knee. The features of the pain are that it:

- is usually well localized to the lateral femoral condyle
- is sharp in nature
- occasionally radiates inferiorly to Gerdy's tubercle
- is characterized by a sudden onset, usually after a specific time (or distance) of running
- is often more intense at the point when the leg comes into contact with the ground during deceleration (when contraction of tensor fascia lata occurs at 30^{o} knee flexion)
- is often worse during downhill running (contraction of tensor fascia lata)
- can be relieved by walking with a stiff leg.

It is also important to obtain an accurate history of the training habits (recent increases, downhill running), running shoes (recent changes, worn shoes) and running surface (changes, hard road, excessive road camber) from the runner. These factors have all been postulated as training errors associated with ITBFS.

The history should also include questions to exclude symptoms associated with other knee and hip pathology as well as systemic disease.

8.8.2. Clinical examination

The clinical examination should include a general, local and regional examination. The outstanding feature of the local examination is tenderness over the lateral femoral condyle which is located 2cm above the lateral joint line of the knee. The following provocative tests can often reproduce the symptoms:

- Asking the patient to go for a run and repeating the examination
- Rubbing across the lateral femoral condyle with an examining finger
- Holding a finger on the lateral condyle while flexing and extending the knee. Tenderness is classically elicited at 30-40° of knee flexion (Noble, 1979)
- Weight bearing on the affected limb at knee flexion of 30-40° will also reproduce the pain.

8.8.3. Special investigations

No special investigations are required to make the diagnosis of ITBFS. In some cases special investigations may be required to exclude other possible diagnoses (Guten et al, 1983). However, the following special clinical tests are important to perform in order to plan optimal management strategies.

8.8.3.1. Test for iliotibial band tightness (Obers test)

A specific clinical test to document the tightness of the iliotibial band was first described by Frank Ober in 1936 (Ober, 1936). In this test the patient lies with the unaffected limb on the couch. The hip and knee of the unaffected limb are both flexed to 90^{o}. The examiner then stabilizes the pelvis with one hand so that the anterior superior iliac spines are aligned vertically and are perpendicular to the couch surface. With the other hand the examiner then flexes the affected (upper) knee and brings the hip to full extension. The hip is then passively adducted (toward the couch) until resistance is felt. Iliotibial band tightness can then be classified according to the degree of adduction as follows (Gose et al, 1989):

- No tightness: Affected knee touches the couch
- Moderate tightness: Affected knee can be adducted but not touch the couch
- Severe tightness: Affected knee can not be adducted.

The value of performing this test is to determine the degree of tightness of the ITB so that advice can be given to the patient regarding ITB stretching.

8.8.3.2. Clinical biomechanical evaluation

This evaluation should be performed to identify possible lower limb biomechanical abnormalities that have been associated with ITBFS. This information is important for the correct management of the condition. A detailed description of the clinical procedures that are followed in such a clinical biomechanical assessment are described in Appendix B.

8.8.3.3. Isokinetic muscle strength testing

Isokinetic muscle function testing may be performed if there is clinical evidence of ITB tightness which is associated with weakness of the abductors. The abductor/adductor strength ratio may be less than normal. This may require a resistance training program to improve abductor muscle strength.

8.8.4. Differential diagnosis

The differential diagnosis of ITBFS is that of gradual onset of lateral knee pain. In general, the conditions that may simulate the clinical picture of ITBFS can be classified according to injuries or disease in the anatomical adjacent to the ITB. These are listed in Table 8.2.

Table 8.2.

The differential diagnosis of ITBFS

1. Lateral patellar disease:
    - Patellar subluxation/dislocation
    - Lateral retinaculitis
    - Patellofemoral pain
2. Lateral meniscal disease
    - Meniscal tears
    - Meniscal degeneration
    - Meniscal cysts
3. Lateral femoral condyle disease
    - Osteonecrosis
    - Bone stress injuries
4. Tendon injury
    - Popliteus tendonitis
    - Biceps femoris tendonitis
5. Ligamentous injury
    - Lateral collateral ligament
    - Proximal tibio-fibular ligament

8.9. Management of ITBFS

In all the reported case series on ITBFS an approach to management is described. However, these approaches are not based on evidence from controlled clinical trials, but rather on anecdotal observations. In most cases treatment has been aimed at correcting the postulated aetiological factors. There are no well conducted clinical trials that have studied specific treatment modalities for ITBFS.

The approach to management of ITBFS is generally conservative. Surgery is only rarely required. The current approach to management of the ITBFS will therefore be discussed under these two headings.

8.9.1. Conservative management of ITBFS

The conservative management of ITBFS can be divided into two phases based on two important principles of treatment; i) a primary phase aimed at treatment of the inflammatory response and ii) a secondary phase aimed at correction of the underlying aetiological factors and return to sports activity. The duration of the primary phase is usually one to two weeks whereas that of the secondary phase is variable.

8.9.1.1. Primary phase treatment

Primary phase treatment is aimed at reduction of the inflammatory response. The rationale for treating the inflammatory response is to alleviate the symptoms and to limit fibrosis and permanent scarring (Noble, 1979). It is well documented that an inflammatory response can be treated by a number of modalities. These include rest, ice, anti-inflammatory medication and physiotherapeutic modalities.

8.9.1.1.1. Rest

Complete rest has been advocated by some investigators in the primary phase management of ITBFS (Firer, 1989; Martens et al, 1989; Newell et al, 1984; Orava, 1978; Renne, 1975). The rationale for this was to remove the mechanical irritation which was the stimulus responsible for initiating the inflammatory response. However, most runners will not comply with the instruction of complete rest. It is for this reason that others recommend a period of "active rest" as part of the primary phase treatment of ITBFS. "Active rest" may consist of either a reduction of activity (Krissof et al, 1979; Lindenberg et al, 1984; Noble, 1980; Sutker et al, 1985) or an alternative activity (Noble, 1980).

8.9.1.1.2. Anti-inflammatory medication

Anti-inflammatory medication is the most common treatment modality that is used in the primary phase treatment of ITBFS. This medication is usually administered as non-steroidal anti-inflammatory drugs (NSAIDs) (Krissof et al, 1979; Martens et al, 1989; Noble, 1980; Orava, 1978; Renne, 1975; Sutker et al, 1985) but local infiltration of the affected area with corticosteroids has also been widely advocated (Firer, 1989; Martens et al, 1989; Newell et al, 1984; Nillson et al, 1973; Noble, 1979; Noble, 1980; Sutker et al, 1985).

Despite the widespread use of anti-inflammatory medication in the primary phase treatment of this condition, the efficacy of these drugs in the treatment of ITBFS has never been studied in a well controlled clinical trial. The efficacy of anti-inflammatory medication has also never been compared to other treatment modalities such as physiotherapy. Finally, different groups or dosages of anti-inflammatory medication have also never been compared. This information is essential for the prescription of safe and effective treatment in patients with ITBFS.

8.9.1.1.3. Physiotherapeutic modalities

The use of physiotherapy has also been advocated in the primary phase treatment of ITBFS by a number of authors (Martens et al, 1989). In particular modalities such as local ice application (Newell et al, 1984; Noble, 1980; Pinshaw et al, 1984; Sutker et al, 1985), heat (Renne, 1975; Sutker et al, 1981), ultrasound (Nilsson et al, 1973) and short wave diathermy (Orava, 1978) have been used.

Recently, it has also been advocated that vigorous rubbing should be applied over the iliotibial band at its most tender site (Newell et al, 1984). This form of massage is similar to deep transverse friction (DTF) massage, which is a common form of therapeutic massage used by physiotherapists. There is also anecdotal evidence that DTF is beneficial in the treatment of more chronic forms of ITBFS where fibrous adhesions may have formed between the ITB and the lateral femoral condyle.

It should be noted that despite the apparent popularity and possible success of physiotherapy modalities, no clinical trials have been conducted to support its use in the primary phase treatment of ITBFS.

8.9.1.1.4. Summary: Primary phase treatment

In most of the reported case series a combination of the above treatment modalities have been employed. However, a major limitation in all these case series was the lack of control groups. It is therefore impossible to determine the success rate of any of these modalities of treatment, either alone or in combination. The success rate of the treatment (number of patients responding well to treatment), where a number of different treatment modalities have been employed, has been reported as 83% (Sutker et al, 1985) to 100% (Lindenberg et al, 1984). In other series conservative treatment was reported as "successful in most cases". However, at present the evidence for the true success of these modalities in the primary phase treatment of ITBFS is at best anecdotal.

8.9.1.2. Secondary phase treatment

The aims of treatment in this phase are, i) to correct the underlying aetiological factors responsible for the condition and, ii) to assist the sportsperson to return to the full level of competition as rapidly as possible.

The underlying aetiological factors responsible for the condition have not been well documented. The effectiveness of treatment modalities in the secondary phase of treatment has also not been well studied. However, from the reported case series it has been postulated that the problem is usually related to i) extrinsic factors such as training errors or footwear, ii) intrinsic biomechanical abnormalities of the lower limb that may exacerbate the rubbing of the ITB over the lateral femoral condyle or iii) both extrinsic and intrinsic factors.

8.9.1.2.1. Correction of extrinsic factors

It is clear that, in the secondary phase treatment of ITBFS, most authors recommend that attention be given to the correction of possible training errors. These corrections include i) a reduction of weekly running distance (Krissof et al, 1979; Lindenberg et al, 1984; Noble, 1980; Sutker et al, 1985), ii) avoiding hill training (Lindenberg et al, 1984; Newell et al, 1984; Nilsson et al, 1973; Noble, 1980), iii) training on soft surfaces (Lindenberg et al, 1984), iv) decreasing running speed (Lindenberg et al, 1984; Noble, 1980), v) changing the side of the road that the runner normally runs on (Lindenberg et al, 1984; Noble, 1980) and vi) temporary participation in other sports (Noble, 1980; Orava, 1978).

8.9.1.2.2. Correction of intrinsic factors

A number of postulated intrinsic aetiological factors for ITBFS such as age, sex and somatotype are clearly not correctable. However, if there is a lower limb biomechanical abnormality, documented tightness of the ITB or an identifiable muscle weakness, these may be correctable.

The problem in ITBFS is that the correctable lower limb biomechanical abnormalities have not been well identified in controlled studies. It is therefore not surprising that, in general, advice regarding the correction of specific intrinsic factors is often vague (Firer, 1989; Krissof et al, 1979; Newell et al, 1984; Sutker et al, 1981) and that there is a wide variation in the advice given by authors.

It has been suggested that lower limb biomechanical abnormalities can be corrected by i) wearing of appropriate running shoes (Lindenberg et al, 1984; Sutker et al, 1985), ii) alteration of existing footwear (Lindenberg et al, 1984; Pinshaw et al, 1984), or iii) the prescription of an appropriate orthoses (Firer, 1989; Lindenberg et al, 1984; Newell et al, 1984; Pinshaw et al, 1984; Sutker et al, 1981). The method of correction depends on the type and severity of the biomechanical abnormality. A detailed discussion on the different methods that are used to correct these abnormalities is however beyond the scope of this thesis.

Only a few authors have provided more specific advice regarding the correction of intrinsic biomechanical abnormalities. A documented leg length discrepancy appears to be only abnormality where specific advice regarding correction is given (Lindenberg et al, 1984; Pinshaw et al, 1984).

ITB tightness, as detected by Obers test, is a specific postulated intrinsic aetiological factor that may be correctable by stretching. A number of authors have therefore advocated regular stretching of the ITB in the management of ITBFS (Firer, 1989; Lindenberg et al, 1984; Noble et al, 1982; Subotnick, 1978; Sutker et al, 1981). Details regarding specific techniques of stretching have been described (Noble et al, 1982).

Muscle weakness, in particular weakness of the abductor muscles of the hip may be an important correctable intrinsic cause for ITBFS. It has therefore been suggested that strengthening of this muscle group be included in the treatment of ITBFS (Anderson, 1991; McNichol et al, 1981).

8.9.1.2.3. Summary: Secondary phase treatment

A number of factors have been identified as possible causes for ITBFS. However, because none of these have been well studied, it is not possible to give clear guidelines on the most effective management of ITBFS in the secondary phase of treatment.

8.9.2. Surgical management

It is generally accepted that surgical intervention should only be considered after an adequate course of conservative treatment (Anderson, 1991; Firer, 1989; Lindenberg et al, 1984; Martens et al, 1989; Noble, 1980; Orava, 1978; Sutker et al, 1981). This form of treatment is generally required in less than 5% of cases. The procedure that is performed was described in 1980 (Noble, 1980). It was based on the fact that at 30^o knee flexion the posterior fibres of the ITB abut on the lateral epicondyle. In this position these posterior fibres lie across the lateral femoral condyle and a 2cm incision is therefore made to split these posterior fibres. The V shaped defect that results decreases the tension and therefore the friction of the ITB over the lateral condyle. The results of surgery are very good with 80-100% of the athletes returning to running within 2-7 weeks after surgery (Firer, 1989; Martens et al, 1989; Noble, 1980).

8.10. Summary: Chapter 8

- In this chapter the history, anatomy, biomechanics, epidemiology, pathology, aetiology, clinical diagnosis and management of the iliotibial band friction syndrome (ITBFS) is reviewed.
- The ITBFS can be defined as an inflammatory condition on the lateral aspect of the knee resulting from repetitive friction between the iliotibial band and the lateral femoral condyle.
- The ITB is a fibrous structure extending from the iliac crest to the lateral tibial tubercle.
- The ITB has important static and dynamic functions at the hip and knee joint.
- The mechanism of injury in ITBFS is thought to be the repetitive antero-posterior movement of the ITB over the lateral femoral condyle.
- The precise aetiological factors for ITBFS have not been well documented but intrinsic and extrinsic factors have been postulated to cause ITBFS.
- The pathology of ITBFS is chronic inflammation and false bursa formation between the ITB and the lateral femoral condyle.
- The incidence of ITBFS is not known but it accounts for 10-20% of injuries in distance runners.

- The management of ITBFS can be divided into primary phase (decreasing the inflammation) and secondary phase (correcting underlying aetiological factors) treatment.
- The modalities used in the treatment of ITBFS have not been well studied.

CHAPTER 9

AN INVESTIGATION TO IDENTIFY LOWER LIMB BIOMECHANICAL ABNORMALITIES AND OTHER AETIOLOGICAL FACTORS FOR THE ILIOTIBIAL BAND FRICTION SYNDROME

9.1 Introduction

The iliotibial band friction syndrome (ITBFS) is a common overuse injury in distance runners and military recruits (Chapter 8.7.). The frequency of ITBFS, when expressed as a percentage of all running injuries seen by sports medicine practitioners, appears to have increased in the last decade (Macintyre et al, 1991).

Despite this reported increased frequency of occurrence of ITBFS, the aetiological factors associated with the condition have not been well documented (Chapter 8.6.). A number of possible aetiological factors for the ITBFS have been identified from case series. These include training errors, footwear and intrinsic factors such as lower limb biomechanical abnormalities (Chapter 8.7.).

In particular, the following lower limb biomechanical abnormalities have been postulated as causes of ITBFS: i) leg length discrepancy (Clement et al, 1981; Lindenberg et al, 1984; Pinshaw et al, 1984), ii) cavus foot (Krissoff et al, 1979; Sutker et al, 1981), iii) rearfoot varus (Krissoff et al, 1979; Lindenberg et al, 1984; Pinshaw et al, 1984), iv) rearfoot valgus (Noble, 1980), forefoot varus (Lindenberg et al, 1984; Pinshaw et al, 1984), tibial varus (Noble, 1980), and v) genu varus (Lindenberg et al, 1984; Sutker et al, 1981).

However, in none of these studies was a control group of non-injured athletes also studied. There have been no cross-sectional, case control or prospective studies that have investigated the association between lower limb biomechanical abnormalities and the development of ITBFS. It is important to document this association so that appropriate corrective measures can be instituted for the more effective treatment of patients with the ITBFS.

9.2. Aim of the investigation

The aim of this study was to identify the lower limb biomechanical abnormalities associated with the ITBFS in distance runners.

9.3. Methods

9.3.1. Subjects

Sixty distance runners between the ages of 18 and 40 years (males, n=52; females, n=8) who presented to the Sports Medicine Clinic of the University of Cape Town between June 1989 and December 1991 with a diagnosis of unilateral ITBFS acted as subjects for the injured group (I group). The diagnostic criteria for ITBFS were i) a history of pain over the lateral aspect of the distal femur which is associated with activity, ii) point tenderness over the lateral femoral condyle, iii) tenderness over the lateral femoral condyle at 30^o knee flexion (Noble's test), and iv) the absence of other knee pathology on clinical examination of the knee. In all the runners the pain was severe enough to restrict the distance or speed of running or to prevent running.

A control group (C group) (males, n=24; females, n=17) was selected from non-injured runners at several local clubs.

The inclusion criteria that were applied to runners in the control group were specifically designed to ensure that they had adequate exposure to distance running. This was important because the mechanism by which biomechanical abnormalities are presumed to cause overuse injuries is related to the repetitive transmission of forces to the tissue that eventually becomes injured. Care was therefore taken to ensure that the control runners trained at least as much but preferably more than the injured runners. Furthermore, control runners had to be injury free.

The inclusion criteria for the control group were therefore i) a registered club runner for at least 3 years, ii) running an average of more than 40 km per week, iii) never to have suffered from the ITBFS, and iv) not to have suffered from a running related injury in the last 2 years. Because running injuries are very common, and the inclusion criteria were very strict, it was extremely difficult to obtain suitable controls. As a result, the number of control runners was less than that of the injured runners among males.

9.3.2. Measurements

9.3.2.1. General questionnaire

All the runners (I and C groups) completed a comprehensive questionnaire on running (Appendix F) with the assistance of the investigator. Details about their running career (years of running), running performance (best performances in the last year for 21.1km) , training habits (training days per week, distance run per week, average training speed, training surface, preferred side of the road) and past injuries were documented.

9.3.2.2. ITBFS questionnaire

The runners in the injured group also completed a special section in the questionnaire where details regarding the onset of symptoms, side of the injury, and factors associated with ITBFS were recorded.

9.3.2.3. Clinical biomechanical assessment

All the runners underwent a comprehensive lower limb clinical biomechanical assessment. The details of the assessment and precise measurement techniques that were used are described fully in Appendix G. The reliability of these measurement techniques has previously been described (Elveru et al, 1988a; Hoyle et al, 1991). The following parameters were measured:

- Height and weight: Height (cm) and weight (kg) were measured in the subjects using standard techniques.

- Leg length: Leg length was measured in each limb as the distance (mm) between i) the anterior superior iliac spine and ii) the midpoint of the medial malleolus in the supine position. A standard tape measure was used and the same investigator performed all the measurements. The difference in leg length between the two limbs was calculated.

- Knee varus or valgus: The knee alignment was classified normal if the distance between the medial malleoli or the medial epicondyles of the femur was less than 3mm in the standing position. A knee was classified as valgus or varus if the intermalleolar or intercondylar distance was greater than 3 mm respectively.

- Tibial varus or valgus: The tibia of a runner was classified as normal if a line drawn along the anterior border to the tibia from the tibial tubercle to the ankle joint was not convex laterally (tibial varus) or convex medially (tibial valgus).

- Rearfoot varus or valgus: Rearfoot varus or valgus was measured with a standard clinical goniometer in the standing position with the feet together. The angle (^{o}) between i) a line connecting the midpoint of the popliteal crease proximally and the insertion of the Achilles tendon distally and ii) a line bisecting the calcaneus, was taken as the angle of rearfoot varus or valgus.

- Forefoot varus and valgus: Forefoot varus or valgus was measured with a standard clinical goniometer in the supine position with the feet extending over the edge of the examination couch. The angle (^{o}) between i) a projected line perpendicular to the long axis of the calcaneus and ii) a line parallel to the metatarsal heads, was taken as the angle of forefoot varus or valgus.

- Quadriceps angle (Q angle): The Q angle was measured with a standard clinical goniometer in the standing position with the feet together. The angle (^{o}) between i) a line from the anterior superior iliac spine to the midpoint of the patella and ii) a line from the mid point of the patella to the tibial tubercle, was taken as the Q angle.

The results of the measurements were compared between injured and control groups. An analysis of the lower limb biomechanical parameters in male and female control runners showed significant differences between some of the variables

(Table 9.1.). The data on male and female subjects were therefore analyzed separately.

The data obtained from the rearfoot and forefoot measurements were analyzed by two methods. Firstly, all varus values were assigned a negative and all valgus values a positive value. The mean absolute value was then compared between the I and C groups and between the injured and uninjured limb of the I group. Secondly, the prevalence (%) of normal, moderate varus or valgus and severe varus or valgus was compared between the I and C groups. A normal foot was defined as $0-3^{o}$ varus or valgus, moderate varus or valgus was defined as $4-7^{o}$ varus or valgus and severe varus or valgus was defined as $\geq 8^{o}$ varus or valgus.

9.4. Statistical analysis

The data were analyzed on a personal computer using STATGRAPHICS software (Version 4.0) (STSC, Inc, Maryland, USA). Statistical analyses were done using the two-sample t-test to compare the values of measured parameters between groups. The Mann-Whitney test was used for variables that were not normally distributed. The Fisher's exact test and the Chi-square test were used to compare the frequencies of occurrence of variables between the two groups. The level of significance was established at $p<0.05$.

Table 9.1.

Lower limb biomechanical parameters in male and female control subjects

		Males (n=24)	Females (n=17)
1.	Leg length difference (mm)	1.4 ± 3.2	1.5 ± 3.4
2.	Right rearfoot (^{0})	6.6 ± 5.3	6.4 ± 2.2
3.	Left rearfoot (^{0})	7.7 ± 2.5	5.6 ± 2.1*
4.	Right forefoot (^{0})	-4.2 ± 2.5	-3.1 ± 1.7$^+$
5.	Left forefoot (^{0})	-4.2 ± 2.0	-2.4 ± 1.5**
6.	Right Q angle (^{0})	11.3 ± 3.4	15.8 ± 4.2***
7.	Left Q angle (^{0})	11.3 ± 3.0	16.9 ± 4.5***

Values are expressed as the mean ± SD

+: $p < 0.1$
*: $p < 0.05$
**: $p < 0.01$
***: $p < 0.001$

9.5. Results

9.5.1. ITBFS questionnaire

Forty nine (82%) of the injured runners indicated that they could identify specific training factors that were associated with the onset of symptoms of ITBFS. Runners could indicate that more than one factor was associated with the onset of symptoms. The frequency with which these factors were reported by injured runners is depicted in Table 9.2. The most frequent factor listed by runners was an increase in the training distance at the time of injury (39%). This was followed by increased uphill running at the time of injury (27%), increased downhill running at the time of injury (24%), and a change in running surface at the time of injury (22%). A change in running shoes, the preferred side of the road for training, decreased warm-up or more speed training were not frequently listed by runners as factors associated with the onset of symptoms of ITBFS.

Twenty four percent of the injured runners indicated that they had a significant running related injury in the last year. Of these, 10% were previous ITBFS and 14% were other injuries.

ITBFS occurred more frequently in the right limb (62%) compared to the left limb (38%) ($p<0.005$) in the injured

Table 9.2.

Training factors associated with the onset of symptoms of the iliotibial band friction syndrome (n=49)

	At time of symptoms	1 Week before the onset of symptoms	1 Month before the onset of symptoms
Increased distance	19 (39%)	8 (16%)	10 (20%)
Change in surface	11 (22%)	1 (2%)	4 (8%)
Change in side of road	7 (14%)	--	1 (2%)
Increased uphill running	13 (27%)	4 (8%)	2 (4%)
Increased downhill running	12 (24%)	2 (4%)	2 (4%)
Change in running shoes	8 (16%)	2 (4%)	4 (8%)
Shorter warm-up period	1 (2%)	1 (2%)	1 (2%)
Increased speed training	--	2 (4%)	1 (2%)

runners (males and females). Because most of the injured runners were dominant on the right side (males, 83%; females, 88%), there was a also tendency (p=0.05) for runners to develop ITBFS on the dominant limb (58%) compared to the non-dominant limb (42%).

9.5.2. Physical characteristics and training history

The physical characteristics and training histories of the injured and control subjects are depicted in Tables 9.3. and 9.4. for males and females respectively.

The male (33.8 ± 12.0 years) and female (31.0 ± 5.6 years) control runners were significantly older than the male (23.8 ± 5.0 years) and female (24.8 ± 6.5 years) injured runners. The injured male runners have been regular runners for a significantly shorter period compared to control male runners (I, 7 ± 6 years; C, 11 ± 7 years). Furthermore, the training of male injured runners differed substantially from that of male control runners.

Injured male runners trained less frequently (I, 5 ± 1 days/week; C, 6 ± 1 days/week), had a lower weekly training distance (I, 44 ± 28 km/week; C, 77 ± 22 km/week), and trained at a slower running speed (I, 4.7 ± 0.7 min/km; C, 4.2 ± 0.5 min/km) than the control runners. The male control runners also ran faster than injured runners in both the

Table 9.3.

The physical characteristics and training histories of male injured and control runners

	Injured (n=52)	Control (n=24)
Age (years	23.8 ± 5.0	33.8 ± 12.0 ***
Weight (kg)	71.6 ± 7.9	68.3 ± 6.7
Height (cm)	177 ± 15	179 ± 5
Dominance (Right/Left) (%)	83 / 17	82 / 18
Years of running (years)	7 ± 6	11 ± 7**
Training days/week (days)	5 ± 1	6 ± 1**
Training km/week (km)	44 ± 28	77 ± 22***
Training speed (min/km)	4.7 ± 0.7	4.2 ± 0.5**
Training surface:		
Tar (%)	75	77
Gravel (%)	8	23^{+}
Both (%)	2	-
Not reported (%)	15	-
Training side of the road:		
Right (%)	69	59
Left (%)]	6	14
Both (%)	8	27*
Not reported (%)	17	-
Racing times:		
21.1 km (min)	92 ± 17	80 ± 8**
42.2 km (min)	210 ± 37	183 ± 32*

Values are expressed as the mean ± SD or the frequency of occurrence (%) within groups

+: $p < 0.1$ **: $p < 0.01$

*: $p < 0.05$ ***: $p < 0.001$

Table 9.4.

The physical characteristics and training histories of female injured and control runners

	Injured (n=8)	Control (n=17)
Age (years	24.8 ± 6.5	31.0 ± 5.6*
Weight (kg)	59.7 ± 4.5	56.8 ± 6.7
Height (cm)	170 ± 4	165 ± 7
Dominance (Right/Left) (%)	88 / 12	94 / 6
Years of running (years)	3.2 ± 1.7	5.4 ± 3.2
Training days/week (days)	4 ± 2	5 ± 1
Training km/week (km)	37 ± 23	59 ± 15*
Training speed (min/km)	5.1 ± 0.5	5.2 ± 0.5
Training surface:		
Tar (%)	63	88
Gravel (%)	12	12
Both (%)	-	-
Not reported (%)	25	-
Training side of the road:		
Right (%)	38	71
Left (%)]	25	12
Both (%)	12	17
Not reported (%)	25	-
Racing times:		
21.1 km (min)	103 ± 10	103 ± 9
42.2 km (min)	226 ± 17	225 ± 20

Values are expressed as the mean ± SD or the frequency of occurrence (%) within groups

+: $p < 0.1$
*: $p < 0.05$

21.1km race (I, 92 ± 17 min; C, 80 ± 8 min), and the 42.2km race (I, 210 ± 37 min; C, 183 ± 32 min). Furthermore, significantly less male injured runners (8%) trained preferentially on gravel roads compared to male control runners (23%). There was also a tendency ($p<0.1$) for more male injured runners (8%) not to train on both sides of the road compared to male control runners (27%).

In female runners, the injured runners trained significantly less (37 ± 23 km/week) compared to control runners (59 ± 15 km/week). Otherwise, all the other training variables, including the preferred training surface and the preferred side of the road, were similar in female injured compared to control runners.

9.5.3. Lower limb biomechanical parameters

The lower limb biomechanical parameters of the injured and control subjects are depicted in Tables 9.5. and 9.6. for males and females respectively.

There was a significantly greater prevalence of tibial varus in the injured runners compared to control runners for both males (I, 46%; C, 9%) and females (I, 75%; C, 12%).

There was a highly significant difference ($p<0.0001$) in the prevalence of a measurable leg length difference between all

Table 9.5.

The lower limb biomechanical parameters in male injured and control runners

	Injured (n=52)	Control (n=24)	
Knee:			
Normal (%)	27	9	+
Varus (%)	48	55	NS
Valgus (%)	25	36	NS
Tibia:			
Normal (%)	54	91	**
Varus (%)	46	9	**
Leg length difference (mm)	5±5	1±3	**
Rearfoot:			
Absolute value $(^0)$			
Right	7.2±4.5	6.6±5.3	NS
Left	7.6±5.3	7.7±2.5	NS
Severe varus (%)	-/4	5/-	NS/NS
Moderate varus (%)	2/-	-/-	NS/NS
Normal (%)	12/12	-/-	NS/NS
Moderate valgus (%)	37/27	45/55	NS/*
Severe valgus (%)	50/58	50/45	NS/NS
Forefoot:			
Absolute value $(^0)$			
Right	-3.8±3.9	-4.5±2.5	NS
Left	-4.4±3.7	-4.2±2.0	NS
Severe varus (%)	13/21	14/ 9	NS/NS
Moderate varus (%)	48/37	50/50	NS/NS
Normal (%)	33/42	36/41	NS/NS
Moderate valgus (%)	6/-	-/-	
Severe valgus (%)	-/-	-/-	
Q angle:			
Right $(^0)$	14.5± 4.3	11.3±3.4	*
Left $(^0)$	13.0±11.8	11.3±3.0	NS

Values are expressed as the mean ± SD or frequency of occurrence (%) within groups. Values for the right and left lower limbs are indicated as Right/Left.

NS: Not significant
+: $p < 0.1$
*: $p < 0.05$
**: $p < 0.01$
***: $p < 0.001$

Table 9.6.

The lower limb biomechanical parameters in female injured and control runners

	Injured (n=8)	Control (n=17)	
Knee:			
Normal (%)	-	11	NS
Varus (%)	63	71	NS
Valgus (%)	37	18	NS
Tibia:			
Normal (%)	25	88	**
Varus (%)	75	12	**
Leg length difference (mm)	4±5	2±3	NS
Rearfoot:			
Absolute value (^{0})			
Right	5.4±5.5	6.4±2.2	NS
Left	5.9±2.9	5.6±2.1	NS
Severe varus (%)	-/-	-/-	
Moderate varus (%)	-/-	-/-	
Normal (%)	24/24	12/12	NS/NS
Moderate valgus (%)	38/38	71/71	NS/NS
Severe valgus (%)	38/38	18/18	NS/NS
Forefoot:			
Absolute value (^{0})			
Right	-6.6±3.8	-3.1±1.7	
Left	-6.6±4.7	-2.4±1.5	**/*
Severe varus (%)	50/38	-/-	**/*
Moderate varus (%)	25/24	47/12	NS/NS
Normal (%)	25/38	53/88	NS/*
Moderate valgus (%)	-/-	-/-	
Severe valgus (%)	-/-	-/-	
Q angle:			
Right (^{0})	23.5± 4.9	15.8±4.2	*
Left (^{0})	24.0± 5.7	16.9±4.5	+

Values are expressed as the mean ± SD or frequency of occurrence (%) within groups. Values for the right and left lower limbs are indicated as Right/Left.

NS: Not significant
+: $p < 0.1$
*: $p < 0.05$
**: $p < 0.01$
***: $p < 0.001$

the injured runners (male and female) (60%) and all the control runners (male and female) (18%). In the injured runners with a measurable leg length difference (n=36), ITBFS occurred more frequently ($p<0.001$) in the shorter limb (81%) than in the longer limb (19%).

In males there was a significantly greater mean leg length difference between injured (5 ± 5 mm) and control runners (1 ± 3 mm) (Table 9.5.). Although the injured female runners also had a greater mean leg length difference than control runners, this difference was not statistically significant (Table 9.6.).

In injured runners the mean Q angle of the right limb was significantly greater than that of the control runners for both males (I, 14.5 ± 4.3 °; C, 11.3 ± 3.4 °) and females (I, 23.5 ± 4.9 °; C, 15.8 ± 4.2 °) (Tables 9.5. and 9.6. respectively). Although similar tendencies were observed on the left limb in both subgroups, the differences were not statistically significant.

In females, the injured runners had a significantly greater mean forefoot angle on both the right (I, -6.6 ± 3.8 °; C, -3.1 ± 1.7 °) and the left (I, -6.6 ± 4.7 °; C, -2.4 ± 1.5 °) side compared to control runners (Table 9.6.). The negative sign indicates a varus position. Furthermore, the prevalence of severe forefoot varus was greater in injured compared to control female runners for the right (I, 50%, C, 0%) and left (I, 38%; C, 0%) foot. However, no differences in forefoot measurements were observed between injured and control male runners (Table 9.5.).

In male runners, the prevalence of moderate rearfoot valgus of the left foot but not the right was significantly greater in control (55%) compared to injured (27%) runners (Table 9.5.). The prevalence of severe valgus in the left foot was greater in injured (58%) compared to control male runners (45%), but this difference was not statistically significant (Table 9.5.). No differences in the prevalence of rearfoot abnormalities were observed between injured and control female runners (Table 9.6.).

There were no statistically significant differences in the prevalence of knee varus or valgus between the injured and control groups for male (Table 9.5.) and female (Table 9.6.) runners.

Finally, the mean rearfoot, forefoot and quadriceps angles of the injured and uninjured limbs in the injured runners were compared (Table 9.7.). However, no significant differences between the injured and uninjured limbs were observed for any of the variables (Table 9.7.).

Table 9.7.

The lower limb biomechanical parameters in the injured and uninjured limbs of the injured runners

	Injured (n=60)	Uninjured(n=60)	
Rearfoot (^{0})	6.9±4.6	7.4±5.0	NS
Forefoot (^{0})	-4.7±3.7	-4.1±4.1	NS
Q angle (^{0}))	15.8±5.4	15.0±5.6	NS

9.6. Discussion

This is the first cross-sectional study to document an association between specific lower limb biomechanical parameters and the ITBFS in runners. The principle findings of the study are that ITBFS is associated with tibial varus in males and females, a leg length discrepancy in males, an increased quadriceps angle in males and females, and an increased forefoot varus in females. Furthermore, ITBFS occurred more commonly in the dominant and the shorter limbs of injured runners. The most frequently reported training factors associated with the onset of ITBFS were a sudden increased training distance and hill training.

The proposed mechanism of injury in runners with ITBFS is rubbing of the iliotibial band over the lateral femoral condyle during the repetitive knee flexion and extension associated with running. This study investigated the hypothesis that a lower limb biomechanical abnormalities predispose to the development of ITBFS possibly by altering the normal movement of the ITB over the lateral femoral condyle. It is for this reason that care was taken to select a control group of non-injured runners that have never suffered from the condition but that have had adequate exposure to the repetitive knee flexion and extension movement of running.

The exposure to running as indicated by the number of years of running, training days per week and training distance per week, in the control group was therefore, as expected, significantly greater than that of the injured group in male runners. In the female runners the exposure to running was significantly greater in the control group only for training distance per week. Despite the significantly greater exposure to running none of the control runners ever developed the ITBFS. This insures that, from a biomechanical perspective, they constitute a suitable control group. The presence of injury would obviously also contribute to the decreased training volume recorded in the injured runners.

All the runners in the study were older than 18 years and have therefore reached skeletal maturity. Although not well documented, it would be reasonable to assume that the measured lower limb biomechanical parameters do not change significantly between the ages of 18 to 45 years. It is therefore very unlikely that the significant age differences that were documented between the injured and control groups would have influenced the results of this study. These age differences probably reflect the stringent inclusion criteria that were used for the control group, and the fact that individuals, who are predisposed to ITBFS, are likely to develop the condition early in their running careers.

In this study tibial varus was associated with the ITBFS. This abnormality has been postulated as a cause of ITBFS by only one author (Noble, 1980). The precise mechanism by which tibial varus predisposes to ITBFS is not clear. It has been suggested that tibial varus increases the tension in the ITB (Noble, 1980). The increased tension would then presumably result in a more vigorous rubbing of the ITB over the lateral femoral condyle during running. Under these circumstances, stretching exercises for the ITB may be beneficial in the treatment of the condition (Firer, 1989; Lindenberg et al, 1984; Noble et al, 1982; Subotnick, 1978; Sutker et al, 1981).

The association between a leg length discrepancy and the development of ITBFS has been postulated by many authors (Clement et al, 1981; Lindenberg et al, 1984; Pinshaw et al, 1984). This study is the first to document that the prevalence of a measurable leg length discrepancy was significantly greater in the runners with ITBFS (60%) compared to controls (18%). In male runners the mean leg length difference was also significantly greater in the injured compared to the control group. Despite the small sample size of injured female runners (n=7), a similar trend was also observed in females. Furthermore, this study is the first to document that ITBFS occurred more frequently in the shorter (81%) compared to the longer limb (19%) in injured runners. In one previous case series, no association between the side of injury and the longer or shorter limb could be documented (Lindenberg et al, 1984).

It is interesting to note that there was a tendency for ITBFS to occur more frequently in the right limb (p=0.05). In this study most injured runners also preferred to run on the right side of the road where the road surface is lower due to the camber of the road. Any structural leg length difference, where the right limb is shorter than left limb, would therefore be aggravated by a functional leg length difference induced by the effect of the road camber.

The precise mechanism by which a leg length discrepancy may cause the development of ITBFS in the shorter limb is not known. However, it can be postulated that, during normal two-legged stance when the pelvis is tilted downwards on the side of the shorter limb, the abductor muscle group and the ITB are in a shortened position. Prolonged standing could then result in an abduction contracture on the side of the shorter limb. This would then result in an increased tension in the ITB when the hip is forced into adduction during the stance phase of running, particularly when there is an associated functional leg length discrepancy as a result of the camber of the road. In this study the presence or absence of abductor contractures were not investigated. The secondary phase of treatment in patients with a leg length discrepancy and ITBFS would therefore include correction of the leg length difference by appropriate orthotics, alteration of the training surface and stretching of the ITB. The effects of these modalities would however need to be verified by appropriate clinical trials.

A novel finding of this study was that an increased quadriceps angle was associated with ITBFS. Although this was only demonstrated on the right side in both male and female runners, there was also a tendency for the Q angle on the left side to be larger in injured compared to control runners. In addition, the Q angle was greater in the injured compared to the non-injured limbs in the injured runners, although this was not statistically significant (Table 9.7.). The precise mechanism by which an increased Q angle predisposes to the development of ITBFS is not known and would require further investigation.

In this study, excessive forefoot varus was associated with ITBFS in female but not male runners. However, this finding has to be interpreted with caution because of the small sample size of injured female runners (n=7). Forefoot varus has been postulated as a predisposing factor for the development of ITBFS by others (Lindenberg et al, 1984; Pinshaw et al, 1984). The precise mechanism by which forefoot varus may cause ITBFS is not known. However, forefoot varus is associated with prolonged subtalar joint pronation during the stance phase of running. Subtalar joint pronation results in internal tibial rotation which could increase the tension in the ITB. However, further investigation is required to verify this mechanism. The management of this abnormality could be the prescription of appropriate orthotics.

A comparison of the mean rearfoot angle, forefoot angle and Q angle between the injured and the non-injured limb in the runners with ITBFS did not reveal significant differences. This indicates that there is a tendency for the lower limbs to be symmetrical and is therefore not an unexpected finding. This perhaps indicates that once a biomechanical abnormality is present, other factors such as an associated leg length discrepancy or training error must be present for ITBFS to develop in one but not the other limb.

This study also confirms the findings by others that training errors, in particular sudden increases in running distance, hill training, not training on both sides of the road and running on tar are frequently associated with the onset of symptoms of ITBFS (Firer, 1989; Newell et al, 1984; Noble, 1980; Noble et al, 1982; Sutker et al, 1985). The mechanism by which training errors cause ITBFS is related to the increased frequency of flexion/extension movements of the knee or the altered transmission of forces through the lower limb. The management of these training errors is simply to reduce the training volume and to avoid hill training, running on tar or training only on one side of the road.

Finally, in this study a number of previously postulated biomechanical abnormalities were not found to be associated with ITBFS. These include genu varus and rearfoot varus or valgus.

9.7. Summary: Chapter 9

- This study is the first to provide scientific evidence that specific lower limb biomechanical abnormalities are associated with the development of ITBFS.
- These abnormalities include tibial varus, leg length discrepancy, increased quadriceps angle and possibly forefoot varus.
- With the exception of tibial varus and increased quadriceps angle, these abnormalities can be corrected by appropriate footwear with or without additional custom made orthotics.
- The precise mechanism by which these abnormalities predispose to the development of ITBFS are not known, but may be related to increased tension in the ITB during the stance phase of running.
- Stretching of the ITB may therefore also be beneficial in the late phase management of the condition.

- In order to establish a true cause-effect relationship between the abnormalities identified in this study and the development of ITBFS, well controlled clinical trials would have to be conducted to confirm that correction of these factors are indeed effective in treating the injury and preventing recurrance.
- Common training errors can be associated with the onset of ITBFS. These can be corrected by giving the runner appropriate advice.

CHAPTER 10

A NOVEL METHOD FOR ASSESSING THE CLINICAL OUTCOME OF OVERUSE INJURIES IN ATHLETES

10.1. Introduction
10.2. Aim of the investigation
10.3. Methods
10.4. Applications
10.5. Summary

10.1. Introduction

A number of studies have been conducted to assess the effects of treatment modalities in the management of acute sports injuries (Beveridge, 1985; Bouchier-Hayes et al, 1979; Bourne, 1980; Commandre, 1983; Duncan et al, 1988; Muckle, 1974; Noble, 1981; Santilli et al, 1980; Van Heerden, 1977; Williams et al, 1977). Very few studies have investigated the results of treatment in overuse sports injuries (Noble, 1981).

However, the results of published studies are often vague and conflicting because i) a wide variety of injuries were usually studied (Bouchier-Hayes et al, 1979; Bourne, 1980;

Commandre, 1983; Duncan et al, 1988; Muckle, 1974; Noble, 1981; Santilli et al, 1980; Van Heerden, 1977; Williams et al, 1977), ii) the severity and classification of the injuries differed (Bourne, 1980; Muckle, 1974; Noble, 1981; Williams et al, 1977), and iii) very subjective criteria were used to measure the outcome of treatment (Beveridge, 1985; Bouchier-Hayes et al, 1979; Bourne, 1980; Duncan et al, 1988; Muckle, 1974; Noble, 1981; Santilli et al, 1980; Van Heerden, 1977; Williams et al, 1977). The points mentioned under i) and ii) can be corrected by appropriate study design, but there is a need to improve the objectivity of assessing the outcome of treatment.

In acute sports injuries, it is possible to assess the outcome of treatment by objective measurements of the acute inflammatory process such as the area of erythema, degree of swelling and core or surface temperature. Furthermore, the pain experienced by the patient during the day or during specific activities has also been assessed using visual analogue scales (Byrnes et al, 1985; Hill et al, 1989; Tiidius et al, 1983). In most instances however, the patient was asked to record the daily pain experienced at the end of the day or after the activity. This method of assessing pain may not be very accurate because it relies on the patients recollection of pain.

In the study of overuse injuries it must also be remembered that there are usually not local or systemic signs of inflammation. It is therefore not surprising that investigators undertaking clinical trials on overuse injuries, have relied mostly on pain recall or the time taken to return to activity as methods for assessing the outcome of treatment (Noble, 1981). Pain recall has also been recorded usually as the daily pain experienced during rest or daily activity. This again relies heavily on the subjective recollection of pain experienced during the day or the activity. Similarly the return to activity is influenced by many variables other that the treatment used and is therefore prone to bias.

10.2. Aim of the investigation

The aim of this investigation was to develop a more reliable method for assessing the clinical outcome of therapy in athletes presenting with overuse injuries of the lower limbs.

10.3. Methods

10.3.1. Basic principles:

In an attempt to develop a more reliable method for assessing the clinical outcome of treatment in athletes with overuse injuries, the following general principles regarding the clinical presentation of overuse injuries had to be considered:

- the presenting complaint is pain that occurs during activity
- the severity of the condition is usually classified by the degree to which pain interferes with the activity (Lindenberg et al, 1984)
- physical signs that can be quantified such as swelling are usually absent or develop very late in the condition
- special investigations, perhaps with the exception of bone stress injuries, are usually not sufficiently sensitive to monitor progress of the injury or the effect of treatment
- a decrease in pain experienced during the activity is probably the most sensitive indicator of successful treatment.

It was therefore clear that a test that monitored pain during activity rather than relying exclusively on the recollection of pain experienced hours ago was required.

Furthermore, the pain experienced during activity had to be quantifiable and the test would have to be repeatable.

10.3.2. Functional treadmill walk/run test

A functional treadmill walk/run test was developed to assess the clinical outcome of treatment in athletes presenting with overuse injuries of the lower limb. The basic principle of the test is that, instead of relying on the patient to recall pain experienced during activity, pain is recorded at intervals during the activity. In this way recall bias is eliminated. Furthermore, the activity can be reproduced exactly so that repeated measures are possible.

In the test described here, the subject reports to the laboratory wearing suitable running clothes and footwear. The subject should also have refrained from activity in the last 48 hours and should not have taken analgesic medication for at least 10 hours before the test. The test is explained and the athlete is familiarized with the rating of perceived pain scale which is depicted in Fig 10.1.

A standard visual analogue pain scale ranging from 0 (no pain) to 10 (excruciating pain) was used (Hill et al, 1989). A series of pilot studies have indicated that when a pain rating of 7-8 is reached most athletes would spontaneously

0 - No pain
1
2
3
4
5 - Moderate pain
6
7
8
9
10 - Excruciating pain

Fig 10.1. The rating of perceived pain scale stop their activity. This has therefore also been chosen as the point at which the test would be terminated.

Prior to the onset of the test, a baseline pain rating is obtained by asking the subject to point to the number on the pain scale that corresponds closest to the amount of pain experienced in the injured limb at that time. The subject then commences a 1 minute warm-up by walking on the treadmill at a comfortable speed. At the end of the minute a second pain rating is obtained.

The subject then starts with the walk/run test. The gradient is kept constant at 0^o and the speed is increased to the normal training speed of the subject. At the end of each minute the subject is asked to indicate the amount of pain experienced at that time on the pain scale. Adjustments can also be made to increase or decrease the walking/running speed at the end of each minute. The test is terminated at i) the patients request, ii) when the pain rating reaches 8, iii) at a predetermined duration (usually 30 minutes), or iv) if there is a medical indication to terminate the test.

The following parameters are recorded every minute; treadmill speed, distance run, and pain rating. Repeat tests must be conducted under exactly the same conditions; time of day, clothing and footwear, administration of medication, treadmill, and investigator. The treadmill walk/running speed that is chosen at each minute must also correspond exactly to that of previous tests. The speed can only be adjusted if the duration of running of the first test is exceeded by the second or subsequent tests.

10.3.3. Test parameters

The data obtained from the treadmill running test can be expressed as follows: The pain rating can be plotted against distance run or more commonly time. Fig 10.2. depicts three pain vs time graphs that were obtained from a subject. The subject was evaluated before treatment was commenced (Test 1), after 3 days (Test 2), and after 7 days (Test 3) of treatment. All the tests were conducted at the same running speed (12 km/hr) which was the normal training speed of the subject (5 min/km). From the graphs the following parameters can be calculated (Table 10.1.):

10.3.3.1. Total pain experienced during walking/running

This parameter is obtained by calculating the area under the pain rating vs time graph (Fig 10.2.) for each test. The total pain experienced can only be compared between tests if the duration of the tests or the distance run is the same.

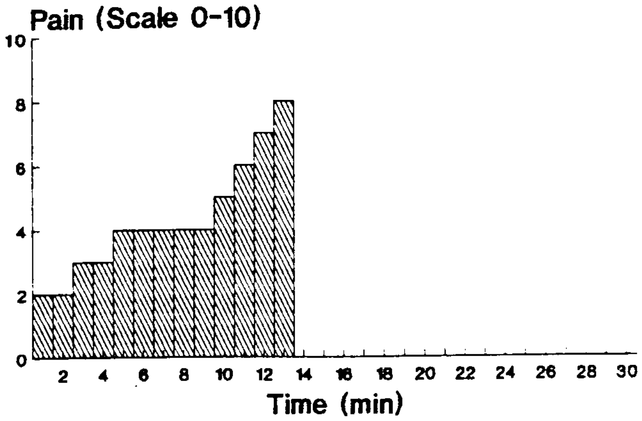

Fig 10.2a. Test 1

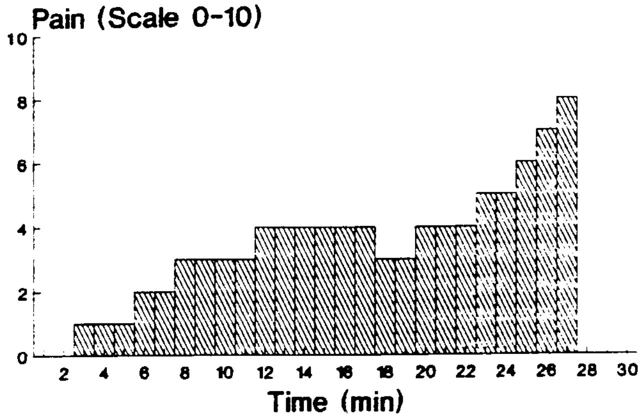

Fig 10.2b. Test 2

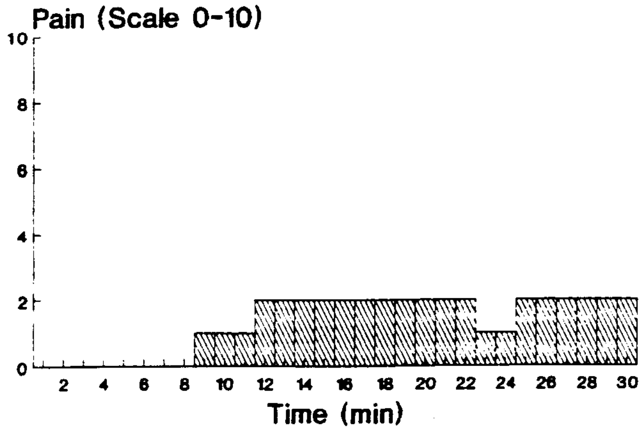

Fig 10.2c. Test 3

Fig 10.2. The pain vs time graphs of a subject performing a treadmill running test (12 km/hr running speed) on three occasions during treatment

Table 10.1.

An example of the parameters that can be calculated from the pain vs time graphs (Fig 10.2.) of a functional treadmill running test in one subject on three test days

Parameter	Test 1	Test 2	Test 3
Total pain (units)	56	92	39
Maximum number of pain units	130	270	300
Percent of maximum pain (%)	43	34	13
Total distance run (km)	2.6	5.2	6.0
Total running time (min)	13	27	30

10.3.3.2. Percentage maximum pain

This parameter can be calculated from the pain rating vs time curve for each test. The maximum number of pain units that the subject could have experienced during the activity is calculated as the duration (minutes) X 10 (maximum rating) (Table 10.1.). The percentage maximum pain units is the total number of pain units experienced divided by the maximum number of possible pain units and expressed as a percentage. This parameter is an indication of the pain experienced by the subject per unit time during running and is of particular value if the subject did not exercise for the same duration in each test.

10.3.3.3. Total distance walked/ran

This parameter is obtained directly from the data sheets (pain vs distance graphs) or calculated from the pain vs time graphs (Fig 10.2.) using the time and the running speed (12 km/hr in this example). This parameter indicates the total distance that the subject walked or ran before the pain was so severe that the test had to be terminated. This parameter is of particular value if the test was not terminated at a predetermined time for example in comparing tests 1 and 2 (Table 10.1.).

10.3.3.4. Total walking/running time

This parameter is also obtained directly from the data sheets (pain vs time graphs) (Table 10.1.) and indicates the total time that the subject walked or ran before the pain was so severe that the test had to be terminated. This parameter is also of particular value if the test was not terminated at a predetermined time (Test 1 vs Test 2).

10.3.4. Analysis of data

Data obtained from the test can be analyzed statistically to document differences in the response to treatment between treatment groups or over time.

10.3.5. Value of the test

The test provides a quantifiable measure of the pain experienced by a subject during physical activity. It does not rely on pain recall, but measures the rating of perceived pain at the time the subject experiences it.

10.3.6. Limitations of the test

The major limitation of the test is that it still relies on the patient's subjective assessment of pain. It does not take into consideration the differences in pain tolerance between subjects. The test would therefore be of greater value in assessing the response of individual patients to treatment over a time period by repeated measures.

10.4. Applications

The main applications of the treadmill walk/run test is in the assessment of treatment outcome in overuse injuries of the lower limb in runners. Similar tests, using the same basic principles, could be developed for other sports. This test was used in the clinical trials on the primary phase treatment of the iliotibial band friction syndrome which are described in Chapters 11 and 12 of this thesis.

10.5. Summary: Chapter 10

- In this chapter a treadmill walk/run test is described which has been developed to assess the outcome of treatment in overuse injuries of the lower limb.
- During repeated tests, the rating of perceived pain is recorded every minute while walking or running on a treadmill at a predetermined speed.
- Specific parameters can be calculated from graphs depicting pain vs time or distance run.

- Statistical analysis can be performed to document differences between treatments over time.
- This test has been used in the clinical trials on the primary phase treatment of the ITBFS which are described in Chapter 11 and 12.

CHAPTER 11

AN INVESTIGATION OF THE USE OF PHYSIOTHERAPEUTIC MODALITIES WITH OR WITHOUT ANTI-INFLAMMATORY AND COMBINED ANTI-INFLAMMATORY/ANALGESIC MEDICATION IN THE PRIMARY PHASE OF TREATMENT OF THE ILIOTIBIAL BAND FRICTION SYNDROME

11.1. Introduction:

Iliotibial band friction syndrome (ITBFS) is a well described overuse injury of the knee. The aetiology, pathology and clinical presentation of ITBFS are reviewed in Chapter 8.

The management of ITBFS can be divided into two phases. The aim of the primary phase treatment is to decrease the inflammation whereas the aim of secondary phase treatment is based on correction of the underlying factors that exacerbate the injury (Chapter 8.9.) In a small group of patients surgery is indicated (Noble, 1979).

In the primary phase the inflammatory process can be treated with rest, ice, oral anti-inflammatory medication, physiotherapy or local steroid injection (Krissof, 1979; Nilsson et al, 1973; Noble, 1980; Sutker et al, 1981; Sutker et al, 1985). It is important to treat the inflammation to reduce the risk of permanent damage with scarring (Noble, 1979).

The use of non steroidal anti-inflammatory drugs (NSAIDS) to decrease the inflammatory process in sports injuries is common amongst sports medicine practitioners (Almekinders, 1990; Calabrese et al, 1986; Clyman, 1986). Despite their widespread use, very few well conducted clinical trials on the use of these drugs in sports injuries have been reported. The major limitations of these previously reported studies are i) poorly defined populations (Bouchier-Hayes et al, 1979; Bourne, 1980; Commandre, 1983; Duncan et al, 1988; Muckle, 1974; Noble, 1981; Santilli et al, 1980; Van Heerden, 1977; Williams et al, 1977), ii) the severity of the injuries were not well defined (Bourne, 1980; Muckle, 1974; Noble, 1981; Williams et al, 1977), iii) the studies were not conducted as double blind studies (Beveridge, 1985; Noble, 1981), and iv) the measures of the therapeutic response were subjective (Beveridge, 1985; Bouchier-Hayes et al, 1979; Bourne, 1980; Duncan et al, 1988; Muckle, 1974; Noble, 1981; Santilli et al, 1980; Van Heerden, 1977; Williams et al, 1977). Furthermore, most studies have been conducted on acute injuries and only one study has documented the use of NSAIDS in chronic overuse injuries (Noble, 1981).

Although conservative treatment with non steroidal anti-inflammatory medication appears to alleviate the symptoms associated with ITBFS after a few days (Nilsson et al, 1973; Renne, 1975), there are no well controlled clinical trials to substantiate this. Furthermore, no studies have been conducted to evaluate the use of physiotherapeutic modalities alone or in combination with anti-inflammatory medication in the treatment of ITBFS. The use of combined analgesic/anti-inflammatory medication has also not been compared to anti-inflammatory medication alone in the management of this injury.

11.2. Aim of the investigation

The aim of this investigation was to compare the use of physiotherapeutic modalities alone or in combination with anti-inflammatory medication (diclophenac sodium) or analgesic/anti-inflammatory medication (Myprodol) in the primary phase treatment of ITBFS.

11.3. Patients and methods

11.3.1. Subjects

Patients presenting with unilateral iliotibial band friction syndrome (ITBFS) were recruited from two sports injury clinics over a period of nine months (April 1989 to December 1989). The two clinics were the Sports Injury Clinic at the University of Cape Town Sports Center and the Biokinetic Center at 1 Military Hospital, Pretoria.

Only patients over the age of 18 years with a confirmed clinical diagnosis of unilateral ITBFS were included in the study. All pregnant patients, those with a history of hypersensitivity to anti-inflammatory or analgesic medication, peptic ulcer disease, asthma, haematological disease, hepatic or renal disease, previous knee surgery and those on concomitant medical therapy were not included in the study.

Each patient was examined and the diagnosis of unilateral ITBFS was made using the following diagnostic criteria:

- History of pain on the lateral aspect of the knee during running (Noble et al, 1982; Renne, 1975; Sutker et al, 1981)
- Tenderness over the lateral femoral condyle (Lindenberg et al, 1984; Orava, 1978; Sutker et al, 1981)
- Tenderness over the lateral femoral condyle aggravated at 30^o of knee flexion (Noble, 1979)
- Normal examination of the knee joint

The severity of the condition was assessed by grading the pain experienced during running as follows (Lindenberg et al, 1984):

Grade 1: Pain after the run and not restricting the distance or the speed of running
Grade 2: Pain during the run but not restricting the distance or the speed of running
Grade 3: Pain during the run and severe enough to restrict distance or speed
Grade 4: Pain so severe that it prevents running

Only patients complaining of Grade 3 or 4 pain were included in the study.

Written informed consent was obtained from all the patients according to guidelines suggested by the American College of Sports Medicine (1988). The study was approved by the Ethics and Research Committee of the Faculty of Medicine of the

University of Cape Town. A running history was obtained from all the patients which included the following details: years of running, duration of symptoms, weekly training distance and average training speed.

11.3.2. Treatment

Forty-nine patients were entered into the trial and randomly divided into three treatment groups (Group 1, 2 and 3) for the first seven days of treatment. Three subjects each from group 1 and 2 were excluded from the final results. The reasons for exclusion were: incomplete follow-up (4), severe side effects (1) and refusal to comply with the physiotherapy treatment program (1). The final number of subjects was 43 (Group 1, n=13; Group 2, n=14; Group 3, n=16). All the groups received treatment as outpatients. The treatment consisted of rest, ice (twice daily local application for 20 minutes) and medication from day 0 to 7. From day 3 to 7 they also received physiotherapy treatment. The physiotherapy treatment at the two centers was the same. There were thus two distinct phases in the treatment programme: day 0 to 3 (rest, ice and medication alone) and day 3 to 7 (added physiotherapy). The physiotherapy treatment programme consisted of i) daily stretching of the ITB (Gose et al, 1989; Noble et al, 1982), ii) daily ultrasound treatment (Nilsson et al, 1973) to the tender area, and iii) transverse frictions (light frictions for 3 minutes, followed by more vigorous frictions for 7 minutes) to the area on days 3, 5 and 7. Ultrasound treatment was administered using a therasonic ultrasound machine (Medical Distributors, Pty Ltd, Cape Town) at a dose of 0.5 W/cm^2. The treatment duration was 5 minutes on days 3 and 4, and 6 minutes on days 5 and 6. The value of transverse frictions in the treatment of this injury is not documented but was included on the basis of anecdotal evidence that it may be effective.

Medication was given for the 7 day period in a double blind, placebo controlled fashion as follows: Group 2 received 50mg diclophenac sodium (Voltaren) three times a day with meals. The tablets were packed into capsules indistinguishable from the capsules used by the other groups. Group 3 received a similar capsule containing 400mg ibuprofen, 500mg paracetamol and 20mg codeine phosphate (Myprodol) three times a day. Group 1 received a placebo capsule three times a day. Compliance was monitored by counting the capsules remaining in the containers on day 7. The code with the identity of the capsules handed to each patient was revealed only after the analysis of all the data was completed.

11.3.3. Assessment of outcome

The efficacy of the treatment was assessed by two methods:
i) conventional daily pain recall on a scale (Byrnes et al, 1985; Hill et al, 1989; Tiidius et al, 1983) and
ii) the functional treadmill running test described in Chapter 10.

On the first visit the patient was familiarized with the pain scale that was used for the daily pain recall and the treadmill running test. The pain scale was a visual analogue scale from 0 to 10 where 0 represented no pain and 10 unbearable pain (Hill et al, 1989). Patients were instructed to record their pain experienced at rest, during walking and overall pain every evening on a pain report form. The decrease in reported pain was compared in the three groups.

The treadmill running test was performed on Day 0, Day 3 and Day 7. The details of the treadmill running test was fully described in Chapter 10. The subjects were dressed in running shorts and vests and wore the same running shoes for all the tests. The running speed was the same for the tests on the three days for each subject and was selected for each subject on the basis of their average daily training speed. A walking test was used for those subjects that were not able to run. The gradient of the treadmill was 0^{o} for all the tests. The tests were always performed at the same time of day (mornings) and on the test day the tests subjects were requested not to take their morning dose of the medication until after the test was completed.

The test was preceded by a warm-up of one minute brisk walking. Each minute during the test subjects were asked to report the level of pain they experienced while running. The test was discontinued if the pain was of such a severity that it would normally decrease the running speed or distance of a runner (7-8 on the pain scale) or after 30 minutes of running. The subjects were free to stop at any time but all complied with the running test protocol as outlined above. The speed and distance run was also recorded every minute.

The pain grading was plotted against time (min) for each subject on day 0, 3 and 7. The area under the pain vs time curve was calculated from the graphs using the minimum time which the subject could run on any of the three days (usually day 0). This area is an indication of the total pain experienced during that time. These data were then compared between the three groups and within groups over the 7 day period.

11.3.4. Side effects

The adverse effects of the medication was assessed on the third and seventh day by a personal interview conducted by the principal investigator. The following information was obtained: Description of symptoms, duration and severity of symptoms (mild, moderate or severe), the relationship of symptoms to the medication and the management.

11.4. Statistical analysis

Statistical analysis was performed by the Institute for Biostatistics of the South African Medical Research Council using the BMPD package on the ISM 4381 main frame computer. Between group comparison for physical characteristics, running history, area under the pain/time curve, total running time, total distance run and daily reported pain was obtained by one way analysis of variance, after testing that there was no sex by group interaction. Significant change over time (from day 0-3, day 0-7 and day 3-7) for the variables within groups was done by the Wilcoxon's signed rank test. The level of significance was established at $p<0.05$, since this is considered a probing experiment. The test level was not adapted according to Banferroni (Neter et al, 1974) for the number of comparisons being made.

11.5. Results

11.5.1. Physical characteristics and running history

Table 11.1. summarizes the age, height, weight and running history of the subjects in each group. There were no significant differences between groups for years of running, average weekly training distance or training speed. In particular the grade and duration of the injury at the onset of the study was similar in all three groups.

11.5.2. Daily pain recall

The mean daily pain scores recorded for overall pain over the treatment period in each group is depicted in Fig 11.1. Pain scores at rest and during walking displayed a similar pattern and are therefore not depicted. The initial mean scores in all three groups decrease in the first two days then are associated with an increase on day 3 followed by a decrease to day 6. There was a significant decrease in pain scores in all three groups from day 0 to 2, day 0 to 6 and day 3 to 6 (Fig 11.1.).

Table 11.1.

Physical characteristics and training history

Variable	Group	Mean ± SD
Age (years)	1	22 ± 5
	2	24 ± 6
	3	22 ± 2
Mass (kg)	1	74 ± 5
	2	72 ± 6
	3	68 ± 7
Height (cm)	1	181 + 3
	2	181 ± 6
	3	178 ± 4
Years of running (years)	1	10 ± 5
	2	5 ± 5
	3	6 ± 6
Duration of symptoms (weeks)	1	6.8 ± 7.1
	2	6.1 ± 8.1
	3	7.4 ± 13.1
Running distance/week	1	44 ± 29
	2	48 ± 33
	3	39 ± 14
Training speed (min/km)	1	4.9 ± 0.3
	2	4.6 ± 1.0
	3	4.6 ± 0.8
Injury grade at presentation	1	3.2 ± 0.4
	2	3.1 ± 0.3
	3	3.3 ± 0.5

No significant differences were observed between groups

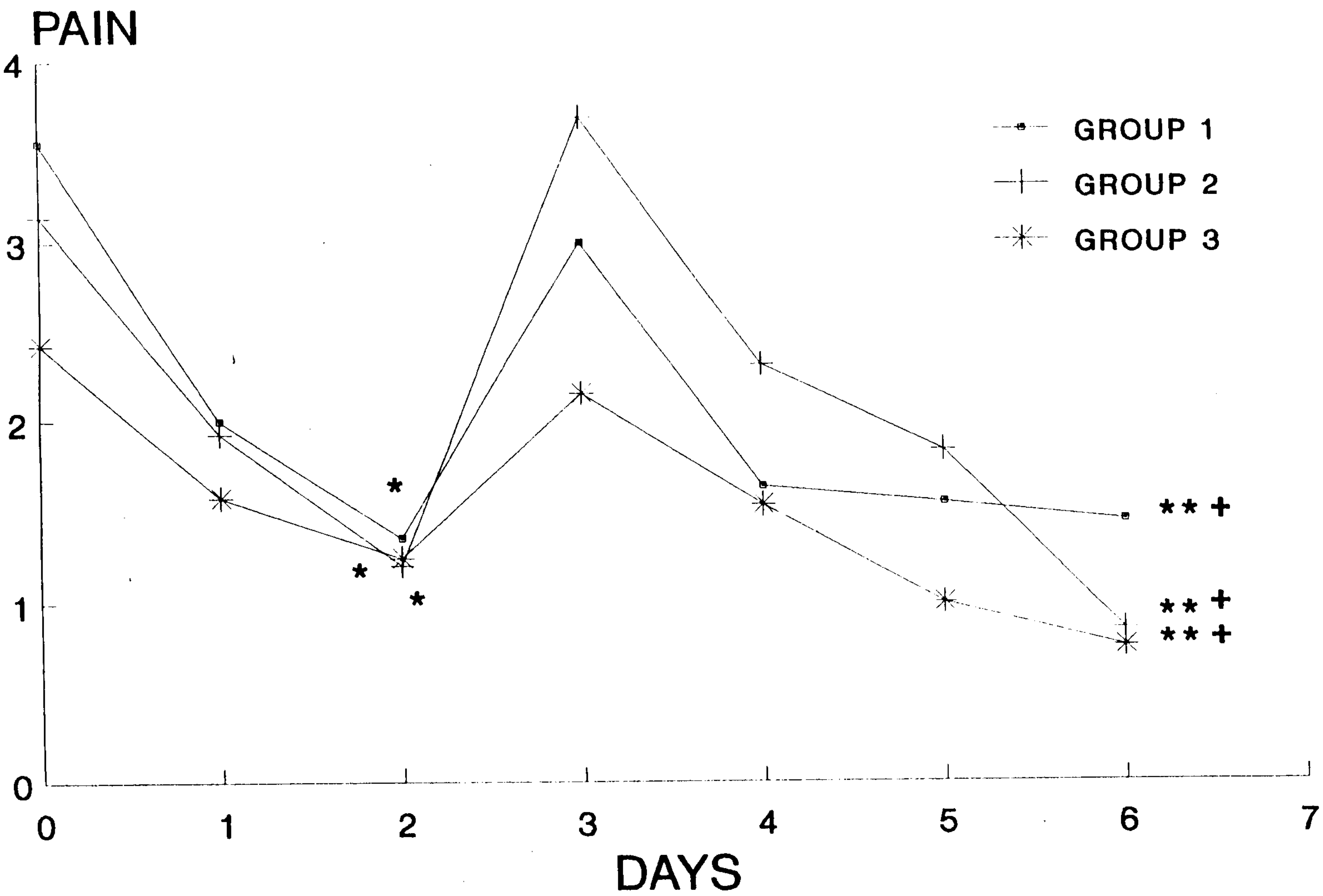

Fig 11.1. The mean overall daily pain recorded in each group. Significant differences ($p<0.05$) are indicated as follows: day 0-2 (*); day 0-6 (**); and day 3-6 (+).

11.5.3. Treadmill running test

The results of pain recorded during the treadmill running test are depicted in Figures 11.2., 11.3., and 11.4. The value for pain (area under the pain vs time curve) for the three groups (Fig 11.2.) was not significantly different between the groups on any of the days. However, there was a significant decrease in the values from day 0 to 3 only for group 3. From day 3 to 7 there was a decrease in the values for groups 1 and 3 but not group 2 and from day 0 to 6 there was a significant decrease in all three groups.

The total distance run did not differ significantly on each of the test days between the groups (Fig 11.3.). In all three groups the total distance run did not change significantly from day 0 to 3 but did increase significantly from day 3 to 7. However, only in group 3 was running distance significantly increased from day 0 to 7.

Total running time did not differ significantly between groups on each of the test days (Fig 11.4.). Group 1 showed a significant reduction in running time from day 0 to 3. The running time was improved significantly in all the groups from day 3 to 7 but only group 3 showed a significant improvement from day 0 to 7.

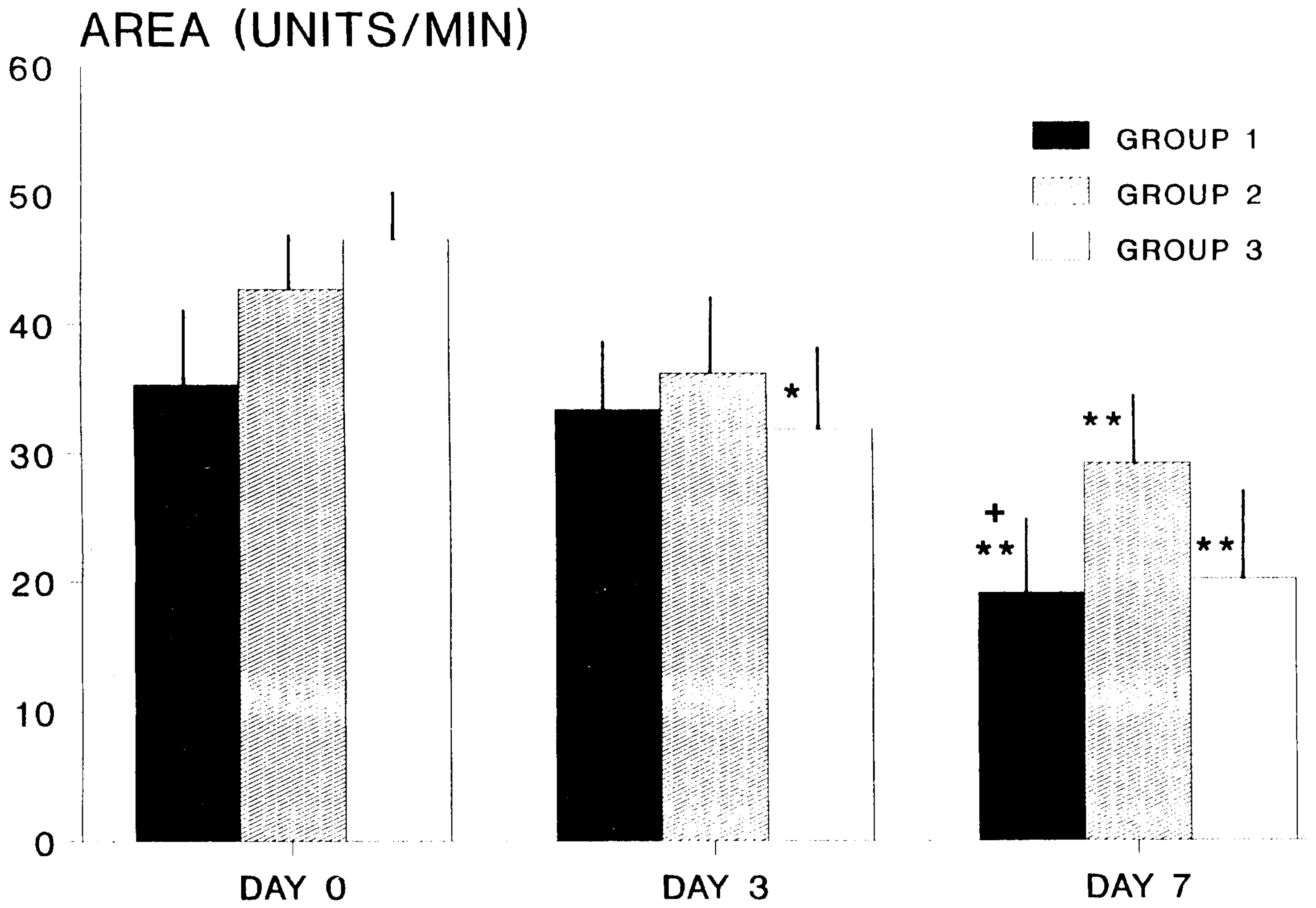

Fig 11.2. The pain experienced during running (area under the pain vs time curve) for the three groups on day 0, 3 and 7. Significant differences ($p<0.05$) are indicated as follows: day 0-3 (*); day 0-7 (**) and day 3-7 (+). Values are mean + SE

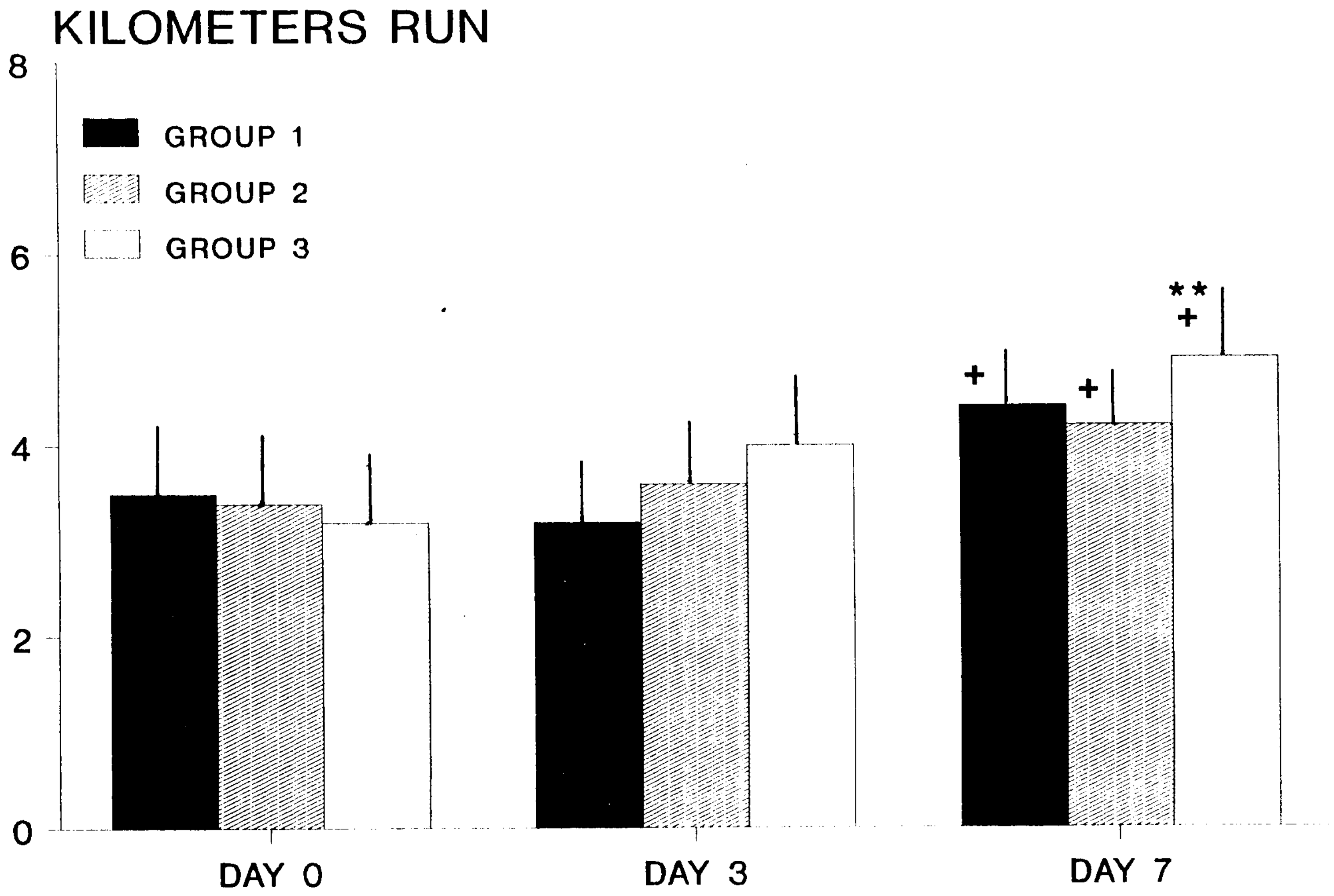

Fig 11.3. The total distance run on each of the test days for the three groups. Significant differences ($p<0.05$) are indicated as follows: day 0-3 (*); day 0-7 (**) and day 3-7 (+). Values are mean ± SE

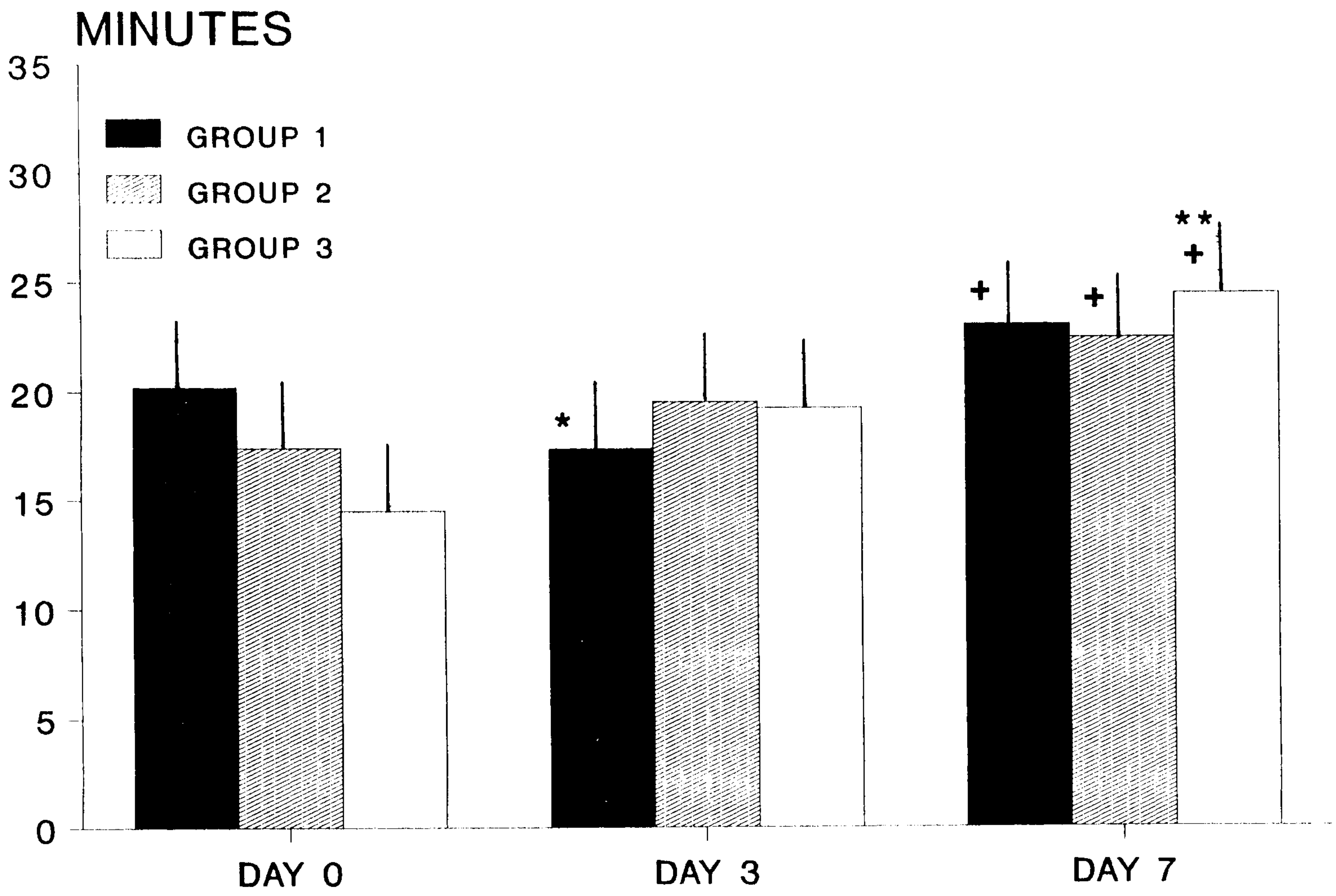

Fig 11.4. The total running time on each of the test days for the three groups. Significant differences ($p<0.05$) are indicated as follows: day 0-3 (*); day 0-7 (**) and day 3-7 (+). Values are mean ± SE

11.5.4. Side effects

The side effects associated with the medication are reported for the three groups in Table 11.2. The incidence (side effects/week) was 38%, 28% and 23% for groups 1, 2 and 3 respectively. The most common side effects were headache and nausea. Only one subject withdrew from the study because of severe nausea (Group 3).

11.6. Discussion

Clinical studies to evaluate the effectiveness of different anti-inflammatory medications in sports injuries are mostly vague, conflicting and difficult to interpret because (i) a wide variety of different injuries are usually studied (ii) the severity of injuries often differ and (iii) they rely on very subjective criteria to measure the outcome of treatment (Clyman, 1986). Iliotibial band friction syndrome (ITBFS) is a well defined, specific injury in which the severity can be graded accurately on the basis of the symptoms (Lindenberg et al, 1984). Its pathology is an inflammatory process (Noble, 1980; Orava, 1978) resulting in pain as the main symptom. This injury is therefore an ideal "model" that can be used to study the effectiveness of different anti-inflammatory or analgesic medications or both.

Table 11.2.

Adverse effects reported in each group

Group	Incidence	Severity	Relationship	Symptoms
1	38% (5/13)	Mild	Unrelated	Nausea
		Mild	Probable	Headache
		Mild	Unrelated	Fatigue
		Mild	Probable	Abdominal pain
		Mild	Unrelated	Dizziness
2	28% (4/14)	Mild	Probable	Nausea
		Moderate	Unrelated	Headache
		Moderate	Probable	Headache
		Moderate	Unrelated	Headache
3	23% (4/17)	Mild	Definite	Headache
		Moderate	Probable	Sore throat
		Moderate	Definite	Nausea
		Severe	Definite	Nausea *

* Significant enough to withdraw from the study

In this study the conventional method of daily pain record assessment showed no significant differences in the outcome of treatment between the three groups (Fig 11.1.). Based on this traditional method of assessing outcome the effectiveness of the three treatment protocols were similar.

In contrast the novel functional treadmill running test (Chapter 10) did demonstrate differences in the response to treatment in the three groups. Only group 3 showed a significant improvement in running time and distance run from day 0 to 7. The values for pain experienced during running (area under the pain vs time graph) decreased significantly from day 0 to 7 for all the groups, perhaps indicating that this parameter is less sensitive than running time or running distance in assessing the outcome of treatment.

The positive effect of adding physiotherapeutic modalities (ultrasound and transverse frictions) to the treatment programme after day 3 is also suggested by this study. Total running time and total distance run were improved in all three groups from day 3 to 7 (Fig 11.3. and 11.4.). The values for pain during running (area under the pain vs time graph) from day 3 to 7 was also improved in group 1 but not groups 2 and 3. The beneficial effect of rest alone from day 3 to 7 was not studied and can therefore not be excluded as an additional factor to explain the decrease in pain from day 3 to 7.

The only medication that had an early effect on the functional test was Myprodol (Group 3) which reduced the pain during running (area under the pain vs time graph) from day 0 to 3 (Fig 11.2.). The daily pain recall scores decreased in all the groups during this period but no significant differences were observed between the groups (Fig 11.1.).

The two principal findings of this study were therefore i) that the most effective treatment to reduce pain during running in the first 3 days of the primary phase treatment for ITBFS is combined analgesic/anti-inflammatory medication (Myprodol), and ii) that a physiotherapy programme together with combined analgesic/anti-inflammatory medication (Myprodol) was the most effective treatment from day 0 to 7 to improve the total running time and total distance run. Treatment with physiotherapy alone from day 3 to 7 was also more effective than when combined with anti-inflammatory medication in reducing pain during running.

The reason for the better performance of the combined analgesic/anti-inflammatory medication is not clear. The most likely explanation is that a greater analgesic effect is achieved which would blunt the pain experienced during running and other daily activities. However, it must be noted that the running test was performed before the morning dose of the medication was taken, at least 10 hours after the last dose. The dose of diclofenac which was administered was 50mg three times a day which is the recommended dose. A low dose of this agent could therefore not account for its relatively poor performance.

Although the mean number of years of running was higher in Group 1 than in the other two groups (not statistically significant), it is very unlikely that this could account for differences in treatment outcome. There is no evidence to indicate that years of running affects prognosis in ITBFS.

The incidence of adverse effects was similar in all three groups indicating that they were probably not related to the medication. It must be noted that one subject on combined analgesic/anti-inflammatory medication (Myprodol) did withdraw because of severe nausea. The other adverse effects were mild and did not affect the treatment outcome.

11.7. Summary: Chapter 11

- Firstly, this study demonstrates that combined analgesic/anti-inflammatory medication (Myprodol) is the most effective early (day 0 to 3) treatment to reduce pain during running.
- Secondly, this study demonstrates that physiotherapy (ultrasound and cross frictions) together with combined analgesic/anti-inflammatory medication (Myprodol) was more effective than the other two treatment regimes to increase the total distance run and total running time in the early phase (day 0 to 7) of treatment for athletes presenting with ITBFS.
- However, from this study it is not clear which modality of physiotherapy (ultrasound, transverse frictions or both) was responsible for the improvement in the condition.
- Further investigation is required to determine the most effective physiotherapy treatment modality (ultrasound or transverse frictions) in the primary phase of treatment of the ITBFS.

CHAPTER 12

AN INVESTIGATION OF THE USE OF DEEP TRANSVERSE FRICTIONS IN THE PRIMARY PHASE OF TREATMENT OF THE ILIOTIBIAL BAND FRICTION SYNDROME

12.1. Introduction:

It has been documented that the combination of analgesic/anti-inflammatory medication together with physiotherapy is effective in the primary phase treatment of the iliotibial band friction syndrome (ITBFS) (Chapter 9). However, in that study a number of physiotherapy modalities were used simultaneously. These included the use of ultrasound and deep transverse frictions.

Deep transverse frictions (DTFs) is a technique that was first described in 1947 and then again in the 1960's. The clinical value of this technique appears to be more widely accepted outside the United States (Bass, 1965; Burry, 1975; Cookson et al, 1979; Cyriax, 1975; Cyriax et al, 1977; De Bruijn, 1985; Ingham, 1981; Lindenberg et al, 1984; Woodman et al, 1982; Winter, 1968). It has been postulated that DTFs are of value in the treatment of chronic inflammatory conditions that are associated with fibrous adhesions because it maintains soft tissue mobility yet causes mechanical breakdown of the adhesions (Bass, 1965; Chamberlain, 1982; Cyriax, 1975; Cyriax et al, 1977). In addition DTFs cause hyperaemia which results in increased blood flow to the injured area. The technique therefore attempts to realign fibres without detaching them from their origins in order to prevent adherence at abnormal sites (Chamberlain, 1982; De Bruijn, 1985; Winter, 1968).

There is anecdotal but minimal experimental evidence that DTFs are of value in the treatment of iliotibial band friction syndrome. In Chapter 11 the first experimental study is described in which a combination of rest, ice, ultrasound, ITB stretches and DTFs significantly improved the pain at rest and during running in athletes with ITBFS. It seems contradictory that friction techniques may be beneficial in an injury in which the mechanism of injury is friction between the iliotibial band and the lateral femoral condyle, but it is hypothesized that DTFs cause a breakdown in fibrous adhesions between the iliotibial band and the underlying tissue. However, there are no clinical trials that document the clinical effectiveness of DTFs in iliotibial band friction syndrome in athletes.

12.2. Aim of this investigation

The aim of this study was therefore to compare the value of adding deep transverse frictions to the well established physiotherapeutic treatment modalities (rest, ice, stretches and ultrasound) in the management of ITBFS. This information is important to obtain because the technique of DTFs is widely used in the early phase treatment of ITBFS.

12.3. Methodology

12.3.1. Subjects

Patients presenting with unilateral iliotibial band friction syndrome (ITBFS) were recruited from the Sports Injury Clinic at the University of Cape Town Sports Center from January to November 1990. Only patients over the age of 18 years with a confirmed clinical diagnosis of unilateral ITBFS were included in the study. All patients with a history of previous knee surgery or those on concomitant medical therapy were excluded from the study.

Each patient was examined and the diagnosis of unilateral ITBFS was made using the following diagnostic criteria:

- History of pain on the lateral aspect of the knee during running (Noble, 1980; Sutker et al, 1985)
- Tenderness over the lateral femoral condyle (Lindenberg et al, 1984; Orava, 1978; Sutker et al, 1981)
- Tenderness over the lateral femoral condyle aggravated at 30^{o} of knee flexion (Noble, 1979)
- Normal examination of the knee joint

The severity of the condition was assessed by grading the pain experienced during running as follows (Lindenberg et al, 1984):

Grade 1: Pain after the run and not restricting the distance or the speed of running

Grade 2: Pain during the run but not restricting the distance or the speed of running

Grade 3: Pain during the run and severe enough to restrict distance or speed

Grade 4: Pain so severe that it prevents running

Only patients complaining of Grade 3 or 4 pain were included in the study.

Written informed consent was obtained from all the patients according to guidelines suggested by the American College of Sports Medicine (1988). The study was approved by the Ethics and Research Committee of the Faculty of Medicine of the University of Cape Town. A running history was obtained from all the patients which included the following details: years of running, duration of symptoms and weekly training distance.

12.3.2. Treatment

Twenty patients were entered into the trial and randomly divided into two treatment groups for the first two weeks of treatment. Three subjects (1 from the experimental group and 2 from the control group) were excluded from the final results. The reasons for exclusion were: incomplete follow-up (2) and refusal to comply with the physiotherapy treatment program (1). The final number of subjects was seventeen.

All the groups received treatment as outpatients. The treatment consisted of rest, ice (twice daily local application for 20 minutes) and baseline physiotherapy treatment. The baseline physiotherapy treatment programme consisted of daily stretching of the ITB (Gose et al, 1989; Noble et al, 1982), and ultrasound treatment (Nilsson et al, 1973) to the tender area on days 3, 4, 5, 6, 7, and 10 of the treatment period. A therasonic ultrasound machine (Medical Distributors, Pty, Ltd, Cape Town) with a 1 MHz head was used for the treatment. The dose was 0.5 W/cm^2 and treatment duration was increased during the treatment period as follows; 5 min (days 3 and 4), 6 min (days 5 and 6) and 7 min (days 7 and 10).

Deep transverse frictions (DTFs) were given to the area in subjects in the experimental group on days 3, 5, 7 and 10 as follows; light frictions for 3 minutes followed by more vigorous frictions for 7 minutes. During treatment the patients experienced discomfort but not severe pain. The same therapist treated all the subjects.

12.3.3. Assessment of outcome

The efficacy of the treatment was assessed by a different therapist who was blind to the treatment group of the patient. Two methods were used to asses clinical outcome of treatment: i) conventional daily pain recall on a scale (Byrnes et al, 1985; Hill et al, 1989; Tiidius et al, 1983) and ii) a functional treadmill running test (Chapter 10).

On the first visit the patient was familiarized with the pain scale that was used for the daily pain recall and the treadmill running test. The pain scale was a visual analogue scale from 0 to 10 where 0 represented no pain and 10 unbearable pain (Hill et al, 1989). Patients were instructed to record their overall pain experienced every day on a pain report form. The mean pain scores for the periods day 0 to 2, day 3 to 6 and day 7 to 14 were calculated from the pain scores of each day as reported by the subjects. The decrease in the mean scores for reported pain in the periods was compared in the two groups.

A functional treadmill running test was performed on Day 0, Day 3, Day 7 and Day 14. The subjects were dressed in running shorts and vests and wore the same running shoes for all the tests. The running speed was the same for the tests on the four days for each subject and was selected for each subject on the basis of their average daily training speed. A walking test was used for those subjects that were not able to run. The gradient of the treadmill was 0^o for all the tests. The tests were always performed at the same time of day.

The test was preceded by a warm-up of one minute brisk walking. During the test subjects were asked to report each minute on the pain they experienced while running. The test was discontinued if the pain was of such a severity that it would normally decrease the running speed or distance of a runner (7-8 on the pain scale) or after 30 minutes of running. The subjects were free to stop at any time but all complied with the running test protocol as outlined above.

The pain grading was plotted against time (min) for each subject on day 0, 3, 7 and 14. The area under the pain vs time curve was calculated from the graphs. The percentage maximum pain was then calculated by dividing the area under the curve into the maximum possible pain experienced by the subject (running time X 10) (Chapter 10). These data were then compared between the groups and within groups over the 14 day period.

12.4. Statistical analysis

Statistical analysis was performed on a personal computer using STATGRAPHICS software (Version 4.0) (STSC, Inc, Maryland USA). A two-way analysis of variance for repeated measures on one variable test was used to determine the effectiveness of treatment over the time period. A post hoc Sheffe's test was used where F ratios indicated statistical significance. A student T-test was used for cross-sectional comparison between groups where applicable. The level of statistical significance was established at $p<0.05$.

12.5. Results

12.5.1. Physical characteristics and running history

Table 12.1. summarizes the age and running history of the subjects in the two groups. There were no significant differences between groups for age, years of running and average weekly training distance. In particular, the grade and duration of the injury at the onset of the study was similar in both groups.

12.5.2. Daily pain recall

The mean daily pain scores recorded for overall pain over the three treatment periods in the two groups are depicted in Fig 12.1. There was a significant decrease in pain scores in both groups over the treatment period but no significant difference was observed between the two groups (Fig 12.1.).

12.5.3. Treadmill running test

The results of pain recorded during the treadmill running test are depicted in Figures 12.2. and 12.3. The value for total pain experienced during running (area under the pain vs time curve) for the two groups (Fig 12.2.) was not significantly different between the groups on any of the days. However, there was a significant decrease in the

Table 12.1.

Physical characteristics and training history

	Experimental (n=9)	Control (n=8)
Age (years)	25 ± 6	29 ± 5
Duration of injury (weeks)	23 ± 17	74 ± 95
Years of running (years)	7.7 ± 5.5	5.4 ± 6.2
Weekly training distance (km)	45 ± 15	64 ± 30
Grade of injury (units)	3.4 ± 0.5	3.4 ± 0.5

No significant differences were observed between groups

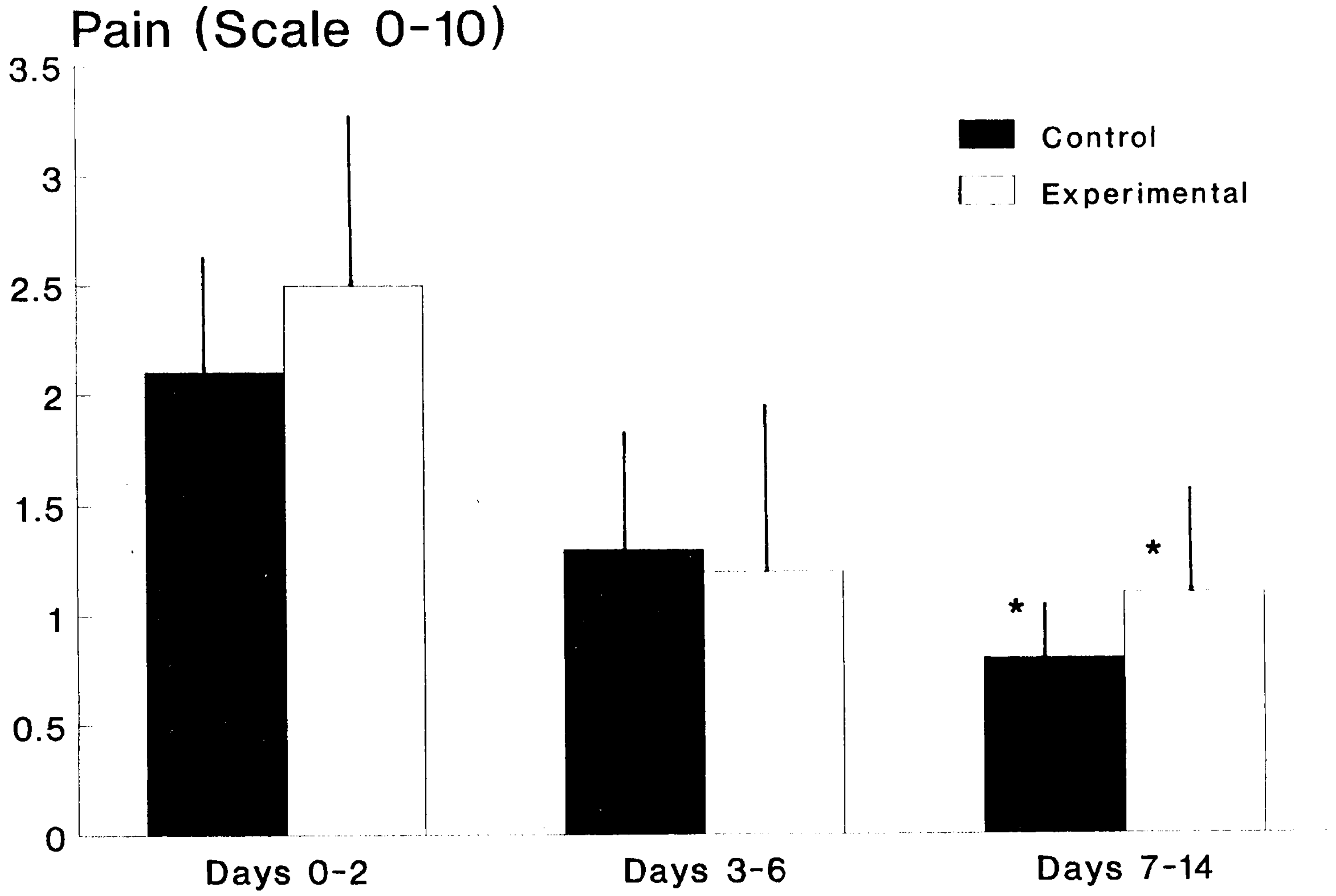

Fig 12.1. The mean daily pain recorded in the two groups for three treatment periods (Days 0-2, 3-6 and 7-14). *: indicates a significant difference ($p<0.05$) from the period (day 0-2). Values are mean ± SE

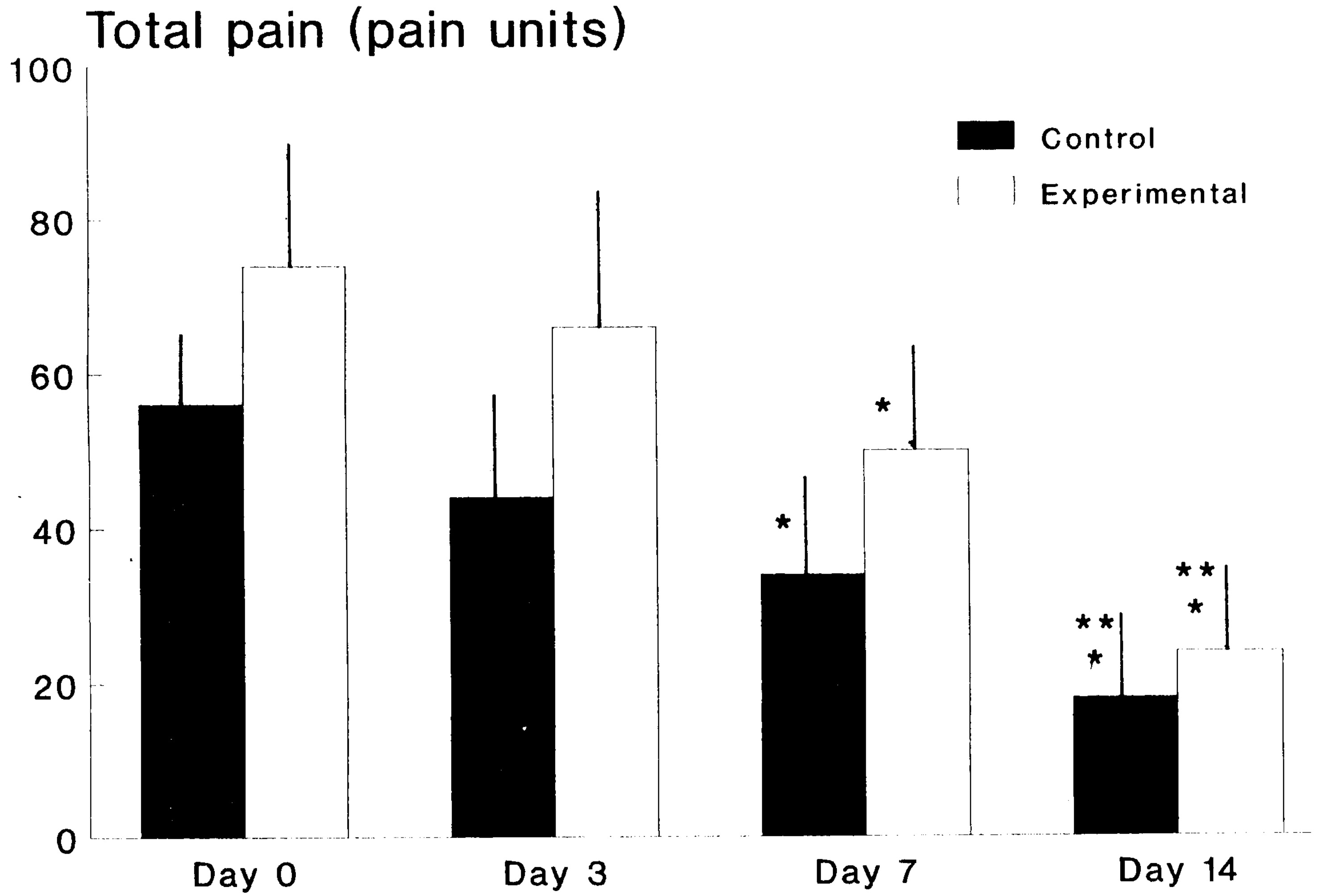

Fig 12.2. The total pain experienced during running for the two groups on day 0, 3, 7 and 14.
*: indicates a significant difference (p<0.05) from day 0. **: indicates a significant difference (p<0.05) from day 3. Values are mean ± SE

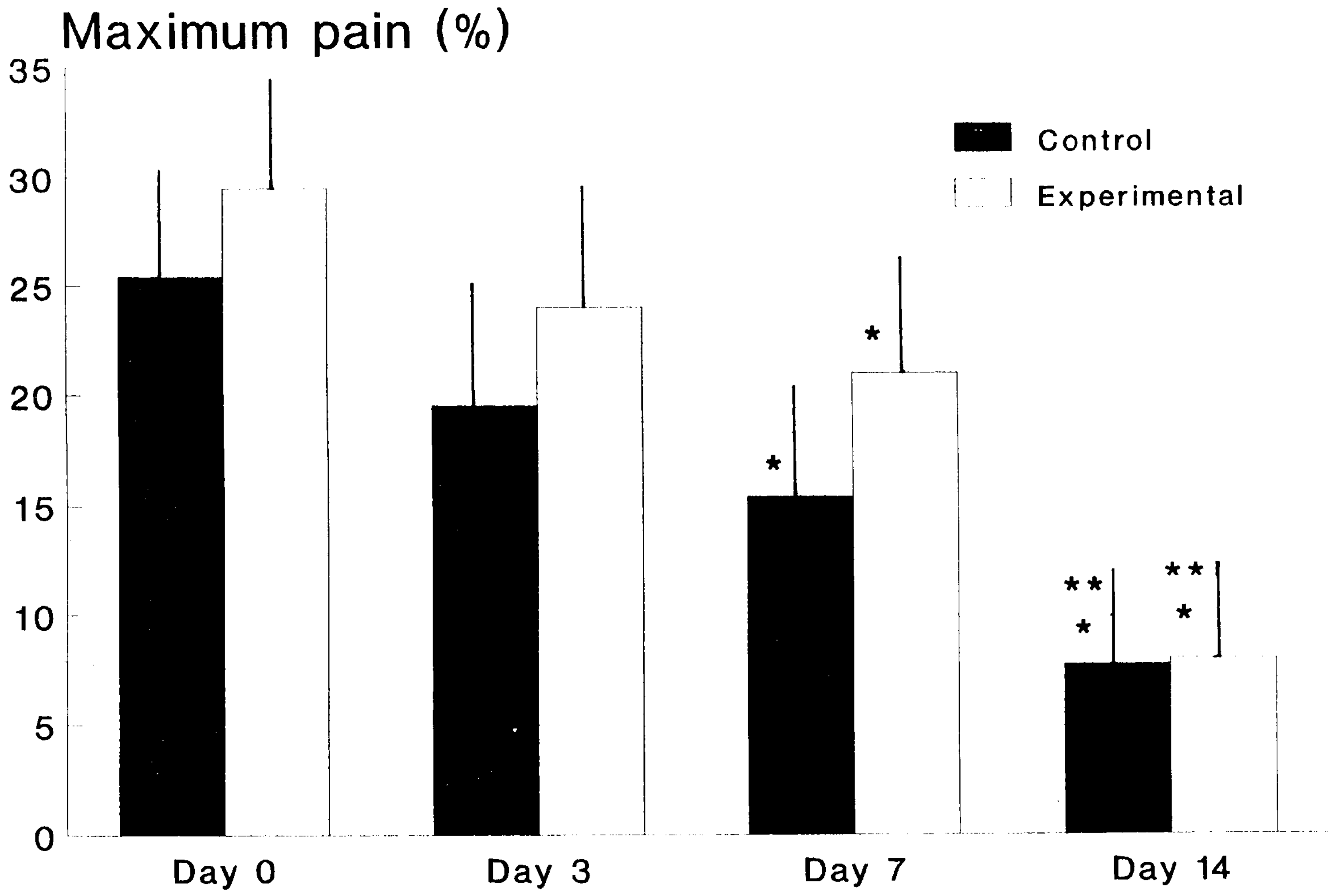

Fig 12.3. The percent (%) maximum pain experienced during running for the two groups on day 0, 3, 7 and 14. *: indicates a significant difference ($p<0.05$) from day 0. **: indicates a significant difference ($p<0.05$) from day 3. Values are mean ± SE

values over the treatment period. There was also a significant reduction in percentage maximum pain experienced during running in both groups over the treatment period (Fig 12.3.). However, there was no difference observed between groups.

12.6. Discussion

The principle finding of this study was that the addition of deep transverse frictions (DTFs) to a standard physiotherapy treatment programme consisting of rest, ice, stretches and ultrasound did not alter the therapeutic outcome of athletes presenting with iliotibial band friction syndrome. There was a significant reduction in overall daily pain as well as pain during running in both treatment groups over the two weeks of therapy.

DTFs are used widely in the treatment of chronic inflammatory conditions (Bass, 1965; Burry, 1975; Cookson et al, 1979; Cyriax, 1975; Cyriax et al, 1977; De Bruijn, 1985; Ingham, 1981; Lindenberg et al, 1984; Woodman et al, 1982; Winter, 1968). However, very few well conducted clinical trials have been conducted to validate this technique. Recently, the value of deep transverse frictions in the treatment of chronic muscle injuries has been documented (Hughes et al, in review).

The possible therapeutic benefit of DTFs in the management of iliotibial band friction syndrome had been suggested by the findings of the clinical trial reported in Chapter 11. In this study a physiotherapy treatment programme consisting of rest, ice, stretches, ultrasound and DTFs successfully decreased daily pain and pain during running after 7 days of treatment. However, this study did not attempt to examine the specific benefits of DTFs in the treatment of ITBFS but rather the therapeutic value of analgesic/anti-inflammatory medication. Furthermore, the duration of the study described in Chapter 11 was only 7 days.

The findings of this study showed that treatment modalities other than DTFs were responsible for the reduction in pain during the 14 day study period. Therefore, the hypothesis that DTFs disrupt fibrous adhesions, induce hyperaemia, increase local blood flow and enhance healing thereby providing additional benefit in the treatment of ITBFS is not confirmed by this study. The addition of DTFs do not however appear to aggravate or delay the clinical outcome in ITBFS during the 14 day study period.

12.7. Summary: Chapter 12

- This study shows that the physiotherapy modalities that are used in the primary phase treatment of ITBFS should not include deep transverse frictions.
- Rest, ice, stretching and ultrasound are effective in decreasing overall daily pain and pain during running during the first 14 days of treatment in patients with ITBFS.

CHAPTER 13

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

13.1. Introduction

The health benefits of regular physical training are well documented. Physical training is also an essential part of basic military training. However, regular physical activity is also associated with a substantial risk of sustaining an injury, in particular an overuse injury. Depending on the nature and the severity of the injury, the individual may have to decrease or stop the physical activity. This could negate the beneficial effects of physical training and also interfere with normal basic military training.

As a sports medical practitioner or military physician it is therefore essential i) to document the extent and nature of overuse injuries during specific activities, ii) to identify aetiological factors associated with these injuries, iii) to diagnose these injuries correctly, iv) to treat these injuries effectively, and v) to prevent these injuries if possible.

The focus of the research presented in this thesis was overuse injuries sustained during physical activity. A general review of the literature revealed that overuse injuries are particularly common in distance running and basic military training. Although the epidemiology of overuse injuries in distance running has recently been well documented, few data are available on the pattern of overuse injuries sustained during basic military training. The first study described in this thesis therefore examined the epidemiology of overuse injuries sustained during basic military training.

It is also clear from the literature that, both in distance running and basic military training, two specific overuse injuries are of particular importance: bone stress injuries and the iliotibial band friction syndrome (ITBFS).

Bone stress injuries were important to study because i) they are very common and ii) they are also the most debilitating of all the overuse injuries and are therefore most likely to interfere with any training programme. Although many researchers have investigated aspects of bone stress injuries, very few studies have focussed specifically on the prevention of these injuries. Two studies were therefore undertaken to investigate i) the role of shock absorbing inner soles and ii) the role of calcium supplementation, on the prevention of bone stress injuries.

The iliotibial band friction syndrome is also an important overuse injury to study because i) there is evidence that it is more common now that a decade ago, and ii) it is an injury whose aetiology and treatment has not been well documented. One study in this thesis therefore investigated aetiological factors associated with this condition. In addition, the results of two clinical trials that were undertaken to examine the effects of different treatment modalities in the primary phase treatment of ITBFS are reported.

The findings of this thesis will therefore be summarized under the main headings of the groups of studies on overuse injuries that were undertaken.

13.2. Epidemiology of overuse injuries in military recruits

The most important findings in the study of the epidemiology of overuse injuries in military recruits undergoing basic military training were that i) overuse injuries are very common, ii) that more than 80% of these injuries occur in the knee, lower leg, ankle and foot, iii) that marching appears to be the type of training responsible for most overuse injuries, and iv) the bone stress injury is the most common specific injury among recruits and is also responsible for the greatest number of lost training days. From this study it was clear that, in order to reduce overuse injuries in military recruits, attention should be directed towards the factors that prevent bone stress injuries. This may require a training program where the number of training hours spent on marching as a form of conditioning should be decreased.

Other directions for future research on overuse injuries during basic military training would be to i) investigate the association between different forms of training and the risk of overuse injuries more closely, and ii) document the incidences of, and risk factors for specific overuse injuries in military recruits undergoing basic military training. For this purpose, future investigators should consider expressing incidence rates not as a percentage of injured recruits over a time period, but rather as injuries per training hours. The incidence rates for specific overuse injuries (injuries per 1000 training hours) that have been presented in this study may be used as a baseline for such future studies.

13.3. Prevention of bone stress injuries

The main findings of the two studies that investigated the prevention of bone stress injuries were i) that shock absorbing neoprene inner soles reduced the total incidence of overuse injuries, in particular bone stress injuries, in military recruits undergoing basic military training, and ii) that calcium supplementation (500 mg/day) did not alter the incidence of bone stress injuries in military recruits whose average daily calcium intake is greater than 800mg per day. From the results of the first of these two studies it can therefore be recommended that military authorities should supply all recruits undergoing basic military training with shock absorbing inner soles to reduce the incidence of overuse injuries, in particular bone stress injuries.

The finding that calcium supplementation did not alter the incidence of bone stress injuries was surprising in view of previous research (Myburgh et al, 1990), and may have been related to i) the short study period, and ii) administration of the calcium supplement at the start of training instead of perhaps a few weeks earlier. These two possibilities will have to be addressed in future studies.

13.4. Lower limb biomechanics and the iliotibial band friction syndrome (ITBFS)

The cross-sectional study on lower limb biomechanical abnormalities and the ITBFS reported in this thesis is the first to show that specific abnormalities are associated with this condition. These are leg length discrepancy, tibial varus, increased Q angle, and forefoot varus. The association between these abnormalities and the ITBFS does however not imply a cause-effect relationship. This relationship would only become apparent if well conducted clinical trials show that correction of these abnormalities prevents recurrences of the condition. Clinical trials such as these should be the focus of future research on the secondary phase treatment of ITBFS.

13.5. Management of the iliotibial band friction syndrome

The management of ITBFS can be divided into a primary phase (treatment of the symptoms) and a secondary phase (correcting the underlying cause). In the studies reported in this thesis the focus was to identify the most effective primary phase treatment of ITBFS. This was of particular importance because no clinical trials have been conducted to study treatment modalities during this phase of treatment.

In order to study the treatment outcome more scientifically a novel method of assessing the outcome of treatment was developed. This method is fully described in this thesis (Chapter 10).

The main findings of the two studies on the primary phase treatment of the ITBFS were that i) a combined analgesic/anti-inflammatory drug was most effective in decreasing pain in the first 3 days of treatment, ii) by adding physiotherapy treatment (iceing the painful area, stretching the ITB and giving ultrasound treatment) from the third day onwards the running time and total distance run of patients with the ITBFS could be increased, and iii) the use of deep transverse frictions is of no benefit in the primary phase treatment of ITBFS despite anecdotal evidence that it improves the condition.

The main focus of future research projects on the management of the ITBFS should focus on the secondary phase management of the condition, as has already been mentioned.

Finally, the research data presented in this thesis has the following practical applications:

- Military authorities should consider measures to reduce the incidence of overuse injuries, in particular bone stress injuries in military recruits during basic training. These measures include i) modification of the training program to include less marching, and ii) providing shock absorbing inner soles to all new recruits.

- Sports physicians who manage athletes suffering from the iliotibial band friction syndrome should consider the instituting the following measures i) routinely performing a comprehensive clinical biomechanical assessment of the lower limb to identify abnormalities, ii) making use of combined anti-inflammatory/analgesic medication in conjunction with physiotherapy (ice, ultrasound, stretching of the ITB) in the primary phase treatment of ITBFS, and iii) correcting underlying biomechanical abnormalities and training errors in the secondary phase of treatment of ITBFS.

APPENDIX A

DIAGNOSTIC CRITERIA FOR COMMON OVERUSE INJURIES IN MILITARY RECRUITS

February, 1989

Dear colleague,

In this document the clinical diagnostic criteria for the six common overuse injuries that form the basis of this study are listed. Please use these criteria to make the diagnosis of the condition and then indicate the diagnosis on the Injury Report Form.

A.1. Stress fractures
A.2. Tibial bone stress reactions (syndrome)
A.3. Patellofemoral pain
A.4. Patellar tendonitis
A.5. Iliotibial band friction syndrome
A.6. Achilles tendonitis/peri-tendonitis

A.1. Stress fractures

A.1.1. Symptoms

- The main presenting symptom is pain.
- The pain is well localized in superficial bones such as the tibia and metatarsals.
- The pain may be vague pain in deeper bones such as the femur and pelvis (a high index of suspicion is required).
- The pain is severe and prevents any form of activity.
- The onset of the pain is usually gradual but may be sudden.
- There is no history of acute trauma in most cases.
- The pain is usually associated with a recent increase in physical activity (training).

A.1.2. Physical signs

A.1.2.1. Tenderness

- There is marked focal tenderness over the bony area involved (more obvious in superficial bones).
- Pain at the injured site is aggravated by hopping, three point bending and percussion over the area.

A.1.2.2. Other physical signs

- There may be a palpable bony mass, oedema, ecchymoses or pyrexia but this is not common.

A.1.3. Special investigations

A.1.3.1. Plain X-rays

- X-rays should be performed on all recruits presenting with bony pain.
- All negative X-rays should be repeated after at least 2 weeks.
- The X-ray findings of a stress fracture are:
    - A local surface haze
    - A line of condensation in the bone
    - Evidence of callus formation
    - Soft tissue swelling which is often the earliest sign
    - Subperiosteal new bone formation
    - Cortical thickening
    - A small fracture line can occasionally be seen

A.1.3.2. Technetium diphosphonate bone scan

- A bone scan should be requested in all cases where the diagnosis can not be established on clinical examination and plain X-rays.
- The main finding of a stress fracture on a bone scan is a localized area of increased uptake.

A.2. Tibial bone stress reactions (syndrome)

A.2.1. Symptoms

- The main presenting symptom is pain over the tibia.
- The pain is well localized to the tibia and must be differentiated from pain in the surrounding soft tissues.
- The pain is usually of a gradual onset and is associated with increased physical activity (training).
- The severity of the pain is variable but usually the recruit can still run although with some discomfort.
- There is no history of an acute traumatic event associated with the pain.

A.2.2. Physical signs

A.2.2.1. Tenderness

- There is diffuse tenderness over the tibia but the tenderness is well localized to bone.
- The Detmer classification should be used to differentiate the pain condition from injuries to the periosteal-fascial junction, and the surrounding muscle (Detmer, 1986).

- The Detmer classification is as follows:
    - Type 1: Bony tenderness over the tibia
    - Type 2: Tenderness at the junction of the periosteum and the fascia
    - Type 3: Tenderness in the surrounding muscle or soft tissues deep within the lower leg
- There may be a palpable irregularity on the surface of the tibia.

A.2.3. Special investigations

A.2.3.1. Plain X-rays

- The X-ray findings are normal (also on repeated X-rays at least two weeks later).

A.2.3.2. Technetium diphosphonate bone scan

- A bone scan should not be requested unless the diagnosis is not clear (for financial reasons).
- The findings on bone scan of tibial bone stress reactions (syndrome) are a diffuse increased uptake along the tibia.

A.3. Patellofemoral pain

A.3.1. Symptoms

- The main presenting symptom is vague anterior knee pain which is associated with physical activity (training).
- The pain may be localized behind the patella or be peripatellar.
- The pain is often described as a dull ache, restless feeling or pressure.
- The pain is aggravated by prolonged knee flexion and relieved by knee extension.
- Other aggravating factors are climbing stairs or walking downhill.
- Other less common symptoms are stiffness after prolonged sitting with the knee in flexion or swelling.

A.3.2. Physical signs

A.3.2.1. Tenderness

- The patella should be palpated carefully and tenderness can be elicited at the inferior pole (very common), medial and lateral retinacula, and the medial and lateral facets of the patella.
- There is also marked tenderness on compression of the patella against the femoral condyles (Patellar compression test).
- The pain can also be reproduced with resisted knee extension.

A.3.2.2. Other physical signs

- Crepitus is an unreliable sign.
- Occasionally a small effusion can be detected.
- There may be visible atrophy of the quadriceps muscle, in particular the vastus medialis obliquus muscle.

A.3.3. Special investigations

- Special investigations are usually not required to make the diagnosis of patellofemoral pain.
- However, X-rays and arthroscopy may be required to make the diagnosis if this is not clear on examination.

A.4. Patellar tendonitis

A.4.1. Symptoms

- The main presenting symptom is anterior knee which is well localized to the infrapatellar tendon.
- The pain is usually associated with physical activity, in particular jumping.
- It is usually described as an ache.
- The onset of the pain is insidious ie. it is not associated with a sudden acute event.
- Other symptoms are a swelling, feeling of weakness, or a feeling of giving way.

A.4.2. Physical signs

- The most important physical sign is tenderness over the patellar tendon.
- The pain can be reproduced by knee extension against resistance.
- There may also be some swelling over the inferior pole of the patella.
- Rarely a calcific mass can be palpated in the tendon in chronic long standing cases.

A.4.3. Special investigations

- No special investigations are required to make the diagnosis.
- In special cases ultrasound, CT scanning or MRI may be performed.

A.5. Iliotibial band friction syndrome

A.5.1. Symptoms

- The main symptom is pain over the lateral aspect of the knee during physical activity (training).
- The onset of pain is usually after running or walking a specific distance.
- The pain is aggravated by downhill running, running on banked surfaces, and repetitive flexion extension movements of the knee.
- The pain is relieved by walking with the knee in full extension.
- The pain may radiate down the lateral joint line and to the proximal tibia.
- Swelling over the lateral femoral condyle can be the presenting symptom in some recruits.

A.5.2. Physical signs

- The main physical sign of ITBFS is tenderness over the lateral femoral condyle.
- This is best elicited with the knee at 30^o of flexion; the point when the ITB crosses over the lateral femoral condyle.
- The pain can also be reproduced if the recruits perform a half-squat. Pain is experienced when the knee is at 30^o of flexion.

A.5.3. Special investigations

- No special investigations are required, except if the diagnosis is not clear on physical examination.

A.6. Achilles tendonitis/peri-tendonitis

A.6.1. Symptoms

- The main symptom of Achilles tendonitis or peri-tendonitis is pain over the Achilles tendon during or after physical activity (training).
- The pain is usually of gradual onset.
- The pain is aggravated by uphill running, low heeled shoes, and repetitive plantar and dorsiflexion movements.
- There may be associated swelling in the Achilles tendon area.

A.6.2. Physical signs

- The most important physical sign is tenderness over the Achilles tendon (usually 5-7 cm proximal to the calcaneal insertion).
- The "painful arc" sign can distinguish between Achilles tendonitis and peri-tendonitis.

- The pain can be reproduced by resisted plantar flexion or by pinching the tendon.
- There may be associated swelling and erythema.

A.6.3. Special investigations

- No special investigations are required, unless the diagnosis is not clear on examination.

APPENDIX B

PROJECT: INJURY REPORT FORM

NAME: ____________________ RANK ________________ FORCE NO: __________

BATTERY: _____________ PLATOON: ____________________ DATE: ____________

GROUP: (INNER SOLE) (SUPPLEMENT) (CONTROL)

HISTORY:

- Main symptom: Pain (Swelling) (Loss of function) (Deformity)
  Other: ____
- Severity: Pain grading: (1) (2) (3) (4)
- Duration: Days: ____________________
- Cause: (Military training) (Sport) (Accident)
  Other: ____
- Site of injury: (Back) (Hip) (Thigh) (Knee) (Shin)
  (Ankle) (Foot)
  Other: ____
- Side injured: (Right) (Left)
- Previous injuries: ____

SPECIFIC DIAGNOSIS: ____

SPECIAL INVESTIGATIONS:

- X Rays: (Yes) (No) Result: __________________________
- Bone Scan: (Yes) (No) Result: __________________________
- Other: ______________________ Result: __________________________

TREATMENT: Type: Duration:

- Medication: _____________________ ___________________ days
- Loss of training days: ___________________ days
- Other: ____________________________ ___________________ days

REFERRAL:

- Department: _____________________ Date: __________________

FOLLOW UP:

- Department: _____________________ Date: __________________

DOCTOR: ________________________________

APPENDIX C

INNER SOLE QUESTIONNAIRE:

PLEASE ANSWER THE FOLLOWING QUESTIONS ON THE INNER SOLES THAT YOU WORE BY CIRCLING THE BEST ANSWER:

How often did you wear the inner soles?
( ) every day
( ) 5-6 times a week
( ) 3-5 times a week
( ) < 3 times a week

How comfortable were the inner soles?
( ) very comfortable
( ) comfortable
( ) not comfortable
( ) very unpleasant

How are the inner soles now after 9 weeks of wearing?
( ) same as new
( ) slightly worn (do not need replacing)
( ) worn (do need replacing)
( ) disintegrated (need replacing)

Did you wear the inner soles
( ) only in your boots?
( ) in your boots and running shoes?

Did you find the inner soles
( ) helped a lot?
( ) helped a little?
( ) made no difference?
( ) were not helpful at all?

Do you think inner soles prevent injuries?

( ) definitely

( ) no

( ) not sure

APPENDIX D

PHYSICAL ACTIVITY QUESTIONNAIRE

PLEASE ANSWER THE FOLLOWING QUESTIONS REGARDING YOUR ACTIVITIES BEFORE YOU CAME TO THE ARMY IE. LAST YEAR

1. Last year, were you
   - ( ) at school?
   - ( ) working?
   - ( ) at university, college, technicon etc?

2. How many days a week did you play sport?
   - ( ) every day
   - ( ) 5-6 times a week
   - ( ) 1-3 times a week
   - ( ) < 1 a week

3. Indicate all the sports that you were doing and the number of times a week you were doing them:

SPORT:		NO OF TIMES A WEEK:
Road running		____________
Athletics (track)		____________
Athletics (field)		____________
Rugby (winter)		____________
Cricket (summer)		____________
Swimming (summer)		____________
Soccer (winter)		____________
Squash		____________
Tennis		____________
Cycling		____________
Gymnasium		____________
Other	____________	____________
	____________	____________
	____________	____________
	____________	____________

4. Of the above, which is your main sport? __________

5. On the days that you participated in your main sport, how much time did you spend doing the sport?
   ( ) less than 30 minutes
   ( ) 30 minutes - 1 hour
   ( ) more than an hour

6. While you were doing your main sport, did you become
   ( ) very, very tired?
   ( ) very tired?
   ( ) moderately tired?
   ( ) a little tired?
   ( ) not tired?

7. How fit do you think you were BEFORE you came to the army?
   ( ) 100% fit
   ( ) 70-90% fit
   ( ) 50-70% fit
   ( ) 30-50% fit
   ( ) 0-30% fit

APPENDIX E

DIETARY QUESTIONNAIRE

GENERAL DETAILS

SURNAME: ______________________________

INITIALS: ______________________________

FORCE NO: ______________________________

BATTERY: ______________________________

PLATOON: ______________________________

WEIGHT (KG): ______________________________

LENGTH (CM): ______________________________

DATE: ________________

The following questionnaire contains questions regarding your diet while you are undergoing basic training. Please answer all the questions as carefully and as accurately as possible.

DIET QUESTIONNAIRE

The following represents all the food that you may eat on an AVERAGE DAY in camp. Please indicate which foodstuffs you eat and also how much of each foodstuff. The following are used to indicate quantity:

- Cups
- Teaspoons
- Tablespoons

The following is an example of how this questionnaire should be completed.

	FOOD:	MARK:	QUANTITY:
-	Eggs	X	2
-	Slice of bread	X	3
-	Sugar (teaspoons)	X	2

Please complete the tables for the following meals:

BREAKFAST:

FOOD:	MARK:	QUANTITY:
Cup of coffee/tea	______	____________
Milk in coffee	______	____________
Sugar in coffee (tsp)	______	____________
Glass of fruit juice	______	____________
Glass of milk	______	____________
Porridge	______	____________
Cereal	______	____________
Milk on cereal	______	____________
Boiled egg	______	____________
Baked egg	______	____________
Bread slices	______	____________
Butter on bread	______	____________
Jam on bread	______	____________
______________	______	____________
______________	______	____________

MID MORNING SNACK:

FOOD:	MARK:	QUANTITY:
Cup of coffee/tea	______	____________
Milk in tea	______	____________
Sugar in tea (tsp)	______	____________
Slice of bread	______	____________
Butter on bread	______	____________
Cheese on bread	______	____________
Jam on bread	______	____________
______________	______	____________
______________	______	____________

LUNCH:

FOOD:	MARK:	QUANTITY:
Glass of fruit juice	______	______________
Portion of meat	______	______________
Spoons of rice	______	______________
Potatoes	______	______________
Spoon of vegetables	_______	______________
Spoon of salads	______	______________
Slice of bread	______	______________
Butter on bread	______	______________
Cheese on bread	______	______________
Jam on bread	______	______________
Potatoes (mash)	______	______________
Cups of pudding	______	______________
Cups of milk	______	______________
________________	______	______________
________________	______	______________

MID AFTERNOON SNACK:

FOOD:	MARK:	QUANTITY:
Cup of coffee/tea	______	______________
Milk in tea	______	______________
Sugar in tea (tsp)	______	______________
Slice of bread	______	______________
Butter on bread	______	______________
Cheese on bread	______	______________
Jam on bread	______	______________
________________	______	______________
________________	______	______________

SUPPER:

FOOD:	MARK:	QUANTITY:
Cup of soup		
Portion of meat		
Spoons of rice		
Potatoes		
Spoon of vegetables		
Spoon of salads		
Slice of bread		
Butter on bread		
Cheese on bread		
Jam on bread		
Potatoes (mash)		
Cups of pudding		
Cups of milk		

LATE NIGHT SNACK:

FOOD:	MARK:	QUANTITY:
Cup of coffee/tea	______	______________
Milk in tea	______	______________
Sugar in tea (tsp)	______	______________
Slice of bread	______	______________
Butter on bread	______	______________
Cheese on bread	______	______________
Jam on bread	______	______________
_________________	______	______________
_________________	______	______________

CANTEEN:

On an average day indicate what you eat from the canteen and how much?

FOOD:	MARK:	QUANTITY:
______________	_____	___________
______________	_____	___________
______________	_____	___________
______________	_____	___________
______________	_____	___________
______________	_____	___________

FOOD FROM HOME:

On an average day indicate what food that you receive from home you eat and how much?

FOOD:	MARK:	QUANTITY:
____________	____	__________
____________	____	__________
____________	____	__________
____________	____	__________
____________	____	__________
____________	____	__________

APPENDIX F

RUNNING QUESTIONNAIRE:

NAME: ______________________ AGE: _____ yrs SEX: _____

ADDRESS: ________________________________ TEL: (H) ______

(w) ______

WEIGHT: ________________

HEIGHT: ________________

MEDICAL HISTORY:

____

____

____

DOMINANCE: R L

____

____

____

____

NAME OTHER SPORTS THAT YOU PARTICIPATE IN AND LEVEL OF PARTICIPATION:

____

____

____

RUNNING HISTORY

1. At what age did you start running > 30km/week? ___ yrs.

2. For how many years have you been training? _______ yrs.

3. How many days per week do you train? ____________ days.

4. What is your average weekly training distance? ____ km.

5. What is your average training speed? __________ min/km.

6. What is your best running time for 5 km? _________ min.

7. Indicate the distance that you compete in and your best time in the last year:

Distance	Tick	Time		
		hours	min	sec
100 m	---	----	----	----
200 m	---	----	----	----
400 m	---	----	----	----
800 m	---	----	----	----
1500 m	---	----	----	----
3000 m	---	----	----	----
8 km	---	----	----	----
15 km	---	----	----	----
21 km	---	----	----	----
42 km	---	----	----	----
Comrades	---	----	----	----

8. How many times a week do you specifically train for:

Speed (Fartlek/Sprints) ______________ /week

Endurance (Long run) ______________ /week

Strength (Gymnasium) ______________ /week

Flexibility (Stretching) ______________ /week

9. What shoes do you wear at present (Brand name)?

____

How long have you worn these (months)? __________months.

10. What other shoes have you used over the past year and for what duration?

BRAND	DURATION (months)
______________	____________________
______________	____________________
______________	____________________

11. How regularly do you train on the following surfaces?

SURFACE	ALWAYS	MOSTLY	SELDOM	NEVER
Tar road	_______	_______	_______	______
Gravel road	_______	_______	_______	______
Grass	_______	_______	_______	______
Right side of road	_______	_______	_______	______
Left side of road	_______	_______	_______	______
Other	_______	_______	_______	______

12. Which of the following do you include in your training and to what extent?

	ALWAYS	MOSTLY	SELDOM	NEVER
Flat ground	_______	_______	_______	______
Some hills	_______	_______	_______	______
Lots of hills	_______	_______	_______	______

13. Do you perform a warm-up routine before training? Y N

14. Please indicate the type of warm-up and duration of each:

	Duration (min)
Slow jog	________
Stretching	________
Rubbing muscles	________
Other	________

15. If you perform a stretch-routine, indicate which muscles are included, how long that stretch is maintained and how many times it is repeated:

MUSCLE GROUP	Duration (sec)	How many times?
Thighs	________	________
Hamstring	________	________
Calves	________	________
Butterfly stretch (groin)	________	________
Back	________	________
Iliotibial band	________	________

16. Do you perform a cool-down after training? Y N

17. Type of cool-down and duration of each:

	Duration (min)
Slow jog	________
Walking	________
Stretching	________
Other	________

APPENDIX G

CLINICAL BIOMECHANICAL ASSESSMENT

G.1. Introduction

There is evidence that certain overuse injuries in athletes are associated with abnormal body alignment. A methodical examination of abnormalities of alignment should therefore be performed by all clinical practitioners dealing with overuse injuries in athletes (Brody, 1982; Gould et al, 1985). The purpose of a clinical biomechanical evaluation is not to replace the normal clinical examination of the injured area but rather to supplement that examination. A clinical biomechanical evaluation is aimed at identifying possible aetiological factors relating to the injury, which could then be corrected by appropriate prescription of footwear and/or orthotics.

The evaluation should be performed on all athletes with overuse injuries of the spine, hip and lower limb. This examination takes approximately 20 minutes to complete and requires minimal equipment. The equipment required for such an evaluation is:

- Clinical goniometer
- Tape measure
- Treadmill (optional)

The purpose of this document is to outline the objectives and methodology of common clinical biomechanical measurements. Although many other forms of biomechanical assessment can also be performed, this provides an outline for an easy practical evaluation. The sequence of the evaluation is structured so that it causes minimal discomfort for the patient and is a rapid assessment which can easily be performed by one examiner. The patient should be barefoot and ideally wear athletic gear only. He/she should also be requested to bring any old as well as new footwear on the day of examination.

The clinical biomechanical examination is carried out in two phases as follows:

Phase 1. Lying
Phase 2. Standing

The details of the examination conducted in each of these phases will now be discussed. Each procedure will be discussed under the headings "Objective" and "Method".

G.2. Phase 1 examination: Lying

G.2.1. Prone

G.2.1.1. Procedure: Marking the line of pull of the calf muscles (Achilles tendon)

G.2.1.1.1. Objective

The objective of this marking line is to establish the line of pull of the calf muscle.

G.2.1.1.2. Method

- The patient lies prone on an examination couch with the ankles over the back edge.
- The patients hips are aligned and the legs fully extended.
- The mid-point of the proximal calf muscle bulk is marked (A).
- The point at which the muscle bulk inserts into the Achilles tendon is marked (B).

- To establish the line of pull of the calf muscle, the two marks (A and B) are connected.

G.2.1.2. Procedure: Marking the line bisecting the calcaneus

G.2.1.2.1. Objective

The objective of marking this line is to delineate the long axis of the calcaneus.

G.2.1.2.2. Method

- The patient is positioned as above (G.2.1.1.2.)
- The mid-point of the insertion of the Achilles tendon into the calcaneus is marked (C).
- With the index finger and the thumb of the left hand on either side of the calcaneus, the mid-point of the calcaneus is marked (D).
- The line bisecting the calcaneus is drawn by connecting marks C and D.

G.2.1.3. Procedure: Measuring forefoot varus/valgus (Gould et al, 1985)

G.2.1.3.1. Objective

The objective of this measurement is to establish whether the patient has a forefoot abnormality (either varus or valgus).

G.2.1.3.2. Method: (Determining neutral position of the subtalar joint) (Gould et al, 1985; Elveru et al, 1988b)

- The first step in measuring forefoot varus or valgus is to determine the neutral position of the subtalar joint. There are 2 methods for determining the neutral position.

G.2.1.3.2.1. Method A (Range of motion)

- The subtalar joint has a rocking motion, and when the foot is pronated or supinated it will swing through an arc. It has been established that approximately one third of the motion is in the direction of pronation (eversion of the calcaneus) whilst two thirds of the motion is in the direction of supination (inversion of the calcaneus). The neutral subtalar position can be determined using this method as follows:

- With the patient prone and the foot vertical (toes pointing downwards) the 4th and 5th metatarsal heads are grasped with the thumb and forefinger.
- The foot is pushed into slight dorsiflexion and then the foot is moved in an arc from extreme pronation to supination.
- A peak at which the foot tends to fall off more easily to either side will be noticed.
- The top of this peak is the neutral position.

G.2.1.3.2.2. Method B (Palpating the head of the talus)

- The head of the talus adducts in pronation and abducts in supination. The head of the talus will therefore become more prominent on either side of the foot as it moves from pronation to supination. The method of obtaining the neutral subtalar position in this fashion is as follows:

- With the patient's position in prone and the foot vertical (toes pointing downwards) the navicular tuberosity on the medial side of the foot is located.
- It is approximately 2.5 cm below and 2.5 cm distal to the middle of the tip of the medial malleolus.
- The index finger is placed over this area slightly proximal to the tuberosity.
- The foot at the 4th and 5th metatarsal are gently grasped with the other hand and the foot is pronated and supinated.

- During pronation the medial side of the head of the talus which protrudes from behind the tuberosity of the navicular will be felt.
- At the same time a sulcus will appear on the lateral aspect of the foot where the head of the talus had been.
- During supination the medial side of the head of the talus will disappear and the sulcus will appear behind the tuberosity of the navicular.
- At the same time the lateral aspect of the head of the talus will become prominent on the outer aspect of the foot.
- At the point where the medial and lateral sides of the head of the talus are neither protruding nor sunken, congruency has been achieved and the subtalar joint is in neutral position.

G.2.1.3.3. Method: (Measuring forefoot varus/valgus)(Gould et al, 1985)

- To obtain the measurement of forefoot abnormalities, the foot is first placed into the neutral subtalar position (using either method A or method B).
- With the thumb on the 4th and 5th metatarsal head the foot is dorsiflexed until a resistance is felt (the foot should then be in the neutral position).
- The examiner now sights down the line bisecting the posterior surface of the calcaneus onto the forefoot (metatarsal heads).

- If the plane of the forefoot (metatarsal heads) is perpendicular to the heel there is no forefoot deviation.
- If it is inverted or everted with respect to the calcaneus then there is either forefoot varus or valgus respectively.
- The one arm of the clinical goniometer is now aligned with the metatarsal heads.
- The other arm of the goniometer is brought into line, by visual projection, with an imaginary line that is perpendicular to the line through the calcaneus.
- The angle between the two goniometer arms is the degree of abnormality in the forefoot.
- The direction of deviation of the forefoot is varus if the forefoot is inverted to the heel and valgus if the forefoot is everted to the heel.

G.2.2. Supine

G.2.2.1. Procedure: Measurement of leg length discrepancy (Gould et al, 1985; Hoyle et al, 1991)

G.2.2.1.1. Objective

The objective of this measurement is to determine whether there is a true leg length discrepancy.

G.2.2.1.2. Method

- With the patient lying in the supine position on an examination couch the iliac crests are first positioned so that a line through the iliac crests is perpendicular to the length of the examination couch.
- The hips should not be rotated.
- The legs are then aligned so that they are in not in abduction or adduction but are together (either touching at the medial femoral condyles or at the medial malleoli).
- With a tape measure the distance between the most prominent part of the anterior-superior iliac spine and the most prominent part of the medial malleolus is measured.
- This procedure is then repeated on the other leg.
- In addition, the length between the most prominent part of the tibial tuberosity and the most prominent point on the medial malleolus can be measured.

G.3. Phase 2 examination: Standing

G.3.1. Position 1 (Facing the examiner)

G.3.1.1. Procedure: Measurement of the quadriceps angle (Q angle) (Gould et al, 1985)

G.3.1.1.1. Objective

The objective is to determine the angle between the lines of pull of the quadriceps muscle and the infrapatellar tendon.

G.3.1.1.2. Method

The patient is positioned as follows.

- The patient is asked to stand upright on a table in a relaxed position with the arms alongside, the feet together, touching either at the inner thigh, medial femoral condyles or the medial malleoli.
- The positions of the following bony points are marked: Anterior superior iliac spine, middle of the superior pole of the patella, middle of the inferior pole of the patella, and tibial tubercle.
- The line between the anterior superior iliac spine and the middle of the superior pole of the patella is connected.
- The line between the tibial tubercle and the middle of the inferior pole of the patella is connected.
- The angle between these two lines is measured and this is the quadriceps angle (Q angle).

G.3.1.2. Procedure: Measurement of valgus or varus of the knee (Gould et al, 1985)

G.3.1.2.1. Objective

The objective is to identify alignment abnormalities at the knee joint.

G.3.1.2.2. Method

- The knees are observed (with the patient in the same position as described above in G.3.1.1.2.) for valgus or varus.
- The distance between the medial femoral condyles or the distance between the malleoli are measured in mm for varus and valgus respectively.

G.3.1.3. Procedure: Documentation of tibial varus or valgus (Gould et al, 1985)

- The patient is asked to stand in the same position as described above (G.3.1.1.2.).
- A line is drawn along the anterior border of the tibia on both sides.
- The tibia is classified as varus if the line is convex laterally and valgus if the line is convex medially.

G.3.2. Position 2. (Facing away from the examiner)

G.3.2.1. Procedure: Measurement of rearfoot valgus or varus (Elveru et al, 1988a; Elveru et al, 1988b; Gould et al, 1985)

G.3.2.1.1. Objective

- The purpose of this investigation is to measure abnormalities of the rearfoot.

G.3.2.1.2. Method

- The patient is positioned as follows: The patient is asked to stand upright on a table and then gradually move the feet together until either the medial femoral condyles or the medial malleoli touch.
- The previously established markings on the rear foot and leg (marking of the line of pull on the calf muscles and marking of the line bisecting the calcaneus) are used to and the angle between these two lines is measured for each foot.
- It should then be documented whether the rearfoot is in valgus or varus.

CLINICAL BIOMECHANICAL EVALUATION: SUMMARY SHEET

NAME____________________AGE_________YRS SEX________DATE_________

INJURY: DIAGNOSIS ___________________________ SIDE:_______(RIGHT/LEFT)

1. EVALUATION

	RIGHT	LEFT
Forefoot	____^{0} varus/valgus	____^{0} varus/valgus
ASIS to MM	____ cm	____ cm
TT to MM	____ cm	____ cm
Intercondylar length	____ mm	____ mm
Quadriceps angle	____ mm	____ mm
Tibia	varus/valgus/normal	varus/valgus/normal
Spine	____________	____________
Rearfoot	____^{0} varus/valgus	____^{0} varus/valgus

2. ASSESSMENT ____

____

3. MANAGEMENT ____

____

4. OBSERVER ____

ASIS: Anterior superior iliac spine; TT: tibial tubercle; MM: Medial malleolus

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