CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Since 1885, when Breithaupt (Jones *et al.*, 1989) first described the painful swollen feet associated with marching in Prussian soldiers, stress fractures have been considered a hazard of military life. Stress fractures represent one of the most common and potentially serious overuse injuries (McBryde, 1985; Hulkko & Orava, 1987; Matheson *et al.*, 1987; Jones *et al.,* 1989; Sterling *et al.*, 1992, Beck *et al.,* 2000; Jones *et al.,* 2002; Shaffer *et al.,* 2006; Trone *et al.,* 2007). In order to prevent injury within the military environment, such as the high incidence of stress fractures sustained by military trainees during BT, the causative factors and the mechanisms by which they interact must be clearly understood. It is only through this understanding that clear guidelines for prevention can be established and followed.

A stress fracture is a partial or complete fracture of a bone resulting from its inability to withstand stress applied in a rhythmic, repeated, subthreshold manner (McBryde, 1985; Bennell *et al.*, 1999). It is a common injury in athletes, dancers and military recruits (Beck *et al.*, 2000; Välimäki *et al.*, 2005). Bone adapts to mechanical loads by the remodeling process in which the lamellar bone is reasorbed by osteoclasts, creating resorption cavities, which are subsequently replaced with more dense osteoblasts. However, since there is a lag between the increased osteoclastic activity and osteoblastic activity, bone is weakened during this time, increasing the risk of microdamage (Roub *et al.*, 1979; Li *et al.*, 1985).

If microdamage accumulates, repetitive loading continues, and remodeling cannot maintain the integrity of the bone, a stress fracture may result (Burr *et al.*, 1985; Schaffler *et al.*, 1989; Schaffler *et al.*, 1990). This develops if the microdamage is too extensive to be repaired by normal remodeling or if depressed remodeling cannot repair normally (Schaffler *et al.,* 1989). On the other hand, there is both in-vitro and in-vivo evidence that metatarsal stress fractures can occur secondary to pure cyclic overloading, without the bone remodeling response (Sharkey *et al.*, 1995; Milgrom *et al.*, 2002).

Understanding the pathophysiology underlying the development of stress fractures is only the first step in its prevention. Despite the general knowledge that stress fractures are one of the leading causes of lost training time, medical expenses, attrition, and decreased readiness in military recruits training and combat readiness, clarity regarding the risk factors for stress fractures has yet to be obtained (Shaffer *et al.*, 2006). To prevent stress fractures, modifiable causes and risk factors must be identified.

Risk factors for exercise and sports-related injuries, including stress fractures, are commonly categorized as intrinsic or extrinsic. Intrinsic factors are characteristics of the individual, sports participant or military recruit, including demographic characteristics, anatomic factors, bone characteristics, physical fitness, and health risk behaviors. Extrinsic risk factors are factors in the environment or external to the individual participant that influence the likelihood of being injured, such as equipment used, PT undertaken and environment or surface on which training occurs (Jones *et al.*, 2002). What makes the clarity regarding risk factors for stress fractures so difficult to obtain is that stress fractures are often a result of various extrinsic and intrinsic factors at a given point in time and not necessarily only intrinsic or extrinsic in nature.

Since the first few citations of case studies with soldiers incurring stress fractures in the nineteenth and early twentieth centuries, potential intrinsic and extrinsic risk factors for stress fractures have been researched (Bernstein *et al.*, 1946; Belkin, 1980; McBryde, 1985; Markey, 1987; Jones *et al.*, 1989; Sterling *et al.*, 1992; Beck *et al.,* 2000; Jones *et al.,* 2002; Shaffer *et al.,* 2006; Trone *et al.,* 2007).

1.2 INTRINSIC RISK FACTORS

1.2.1 Demographic characteristics

These encompass:

- **Sex** - Female sex has been the most commonly identified intrinsic demographic risk factor for stress fractures (Proztman & Griffis, 1977; Reinker & Ozbourne, 1979; Kowal, 1980; Brudvig *et al.*, 1983; Lloyd *et al.*, 1986; Barrow & Saha, 1988; Zahger *et al.*, 1988; Brunet *et al.*, 1990; Myburgh *et al.*, 1990; Friedl *et al.*, 1992; Jones *et al.*, 1993a; Goldberg & Pecora, 1994; Bennell *et al.*, 1996; Bijur *et al.*, 1997; MacLeod *et al.*, 1999; Beck *et al.,* 2000; Bell *et al.,* 2000; Shaffer *et al.*, 2006).
- **Age** - Several studies have examined the association of older age with the risk of stress fractures and have indicated that older age may heighten the risk of stress fractures (Brudvig *et al.*, 1983; Gardner *et al.*, 1988; Shaffer *et al.*, 1999b).
- **Race** - Although race as a risk factor requires further study, it appears as if Caucasians may have a higher risk factor in both athletes as well in military personnel (Brudvig *et al.*, 1983; Barrow & Saha, 1988; Gardner *et al.*, 1988; Friedl *et al.*, 1992; Shaffer *et al.*, 1999b; Shaffer *et al.*, 2006).

1.2.2. Anatomic factors

- **Foot morphology** - Limited available research suggests that foot arch height may influence the risk of incurring stress fractures associated with vigorous PT (Giladi *et al.*, 1985; Montgomery *et al.*, 1989; Kaufman *et al.*, 1999).

- **Q angle** - Contradictory results exist with regard to the Q angle. Some studies have found no relationship between Q angle and stress fracture occurrence, whilst others have found that individuals with a Q angle greater than 15º have a relative risk of stress fracture development that is 5.4 times that of individuals who have an angle less than 15º (Montgomery *et al.*, 1989; Cowan *et al.*, 1996).
- **Leg length discrepancy** - Most studies indicate that the risk for stress fracture development increases if a leg length discrepancy of more than 0.5 centimeters exists (Brunet *et al.*, 1990; Cowan *et al.*, 1996).

1.2.3 Bone characteristics

- **Geometry** - Limited costly studies have shown a trend that smaller bone widths, smaller cross-sectional areas, smaller moments of inertia and a smaller modulus have a higher risk for stress fracture occurrence (Margulies *et al.*, 1986; Milgrom *et al.*, 1988; Milgrom *et al.*, 1989; Pouilles *et al.*, 1989; Beck *et al.*, 1996; Beck *et al.*, 2000; Esterman & Pilotto, 2005).
- **Bone density** - The relationship between bone density and stress fracture development has not clearly been defined. However, evidence exists that the risk factor of low bone density may be more common in women (Margulies *et al.*, 1986; Carbon *et al.*, 1990; Giladi *et al.*, 1991).

1.2.4 Physical fitness

- **Aerobic physical fitness** – Is defined as the body's ability to utilize oxygen efficiently, over an extended period of time in any activity that uses large muscle groups and is rhythmic in nature (American College of Sports Medicine, 2006). Military studies have shown significant associations between low aerobic fitness and a higher risk of stress fracture during BT (Jones *et al.*, 1993a; Shaffer *et al.*, 1999a) muscle strength and muscle endurance (Kaufman *et al.*, 1999; Beck *et al.*, 2000).

- **Flexibility** – Defined as "*…the ability to move a joint through its complete range of motion"* (American College of Sports Medicine, 2006:85). From the numerous flexibility variables that have been assessed to determine the association between flexibility and stress fractures, only range of hip external rotation and range of ankle dorsiflexion have been associated with stress fracture development (Giladi *et al.*, 1987; Montgomery *et al.*, 1989; Giladi *et al.*, 1991; Kaufman *et al.*, 1999).
- **Body composition and stature** – Can be expressed as *"…the relative percentage of body mass that is fat and fat-free tissue"* (American College of Sports Medicine, 2006:57) whilst stature refers to the Height, defined as the distance between the soles of the feet and the vertex, was taken whilst the participant stood up straight, barefoot, with heels, gluteus maximus, upper-back and back of head against the anthropometer (Smit, 1979; Eston & Reilly, 2001). No consistent relationship has been observed between body size and composition and stress fracture risk. However, a bimodal trend, with both the least 'fat' and the most 'fat' individuals, are at greater risk of incurring stress fractures (Finestone *et al.*, 1991; Giladi *et al.*, 1991; Friedl *et al.*, 1992; Beck *et al.*, 1996).

1.2.5 Health risk behaviours

- **Lifestyle behaviours** - Data from military studies indicate that persons who engage in more physical activity, particularly running, will experience fewer stress fractures than their sedentary counterparts (Gardner *et al.*, 1988; Swissa *et al.*, 1989; Taimela *et al.*, 1990; Cowan *et al.*, 1996; Shaffer *et al.*, 1999a).

- **Smoking** - Several studies have found a statistically significant association between cigarette smoking and an overall risk of training-related injuries (Friedl *et al.*, 1992; Altarac *et al.*, 2000; Moroz *et al.*, 2006).
- **Female contraception** – To date, poorly designed studies indicate that the use of oral female contraception may reduce the incidence of stress fracture development (Lloyd *et al.*, 1986; Barrow & Saha, 1988; Myburgh *et al.*, 1990).
- **Medical history of previous injury** - Some authors have reported that an individual with a medical history of stress fractures has a relatively greater risk of developing stress fractures. However, it has been speculated that the association between past injuries with current risk is not simple and may be confounded by other factors such as adequacy to recover and levels of past physical activity (Kuusela, 1984; Milgrom *et al.*, 1985; Giladi *et al.*, 1986; Shaffer *et al.*, 1999a).

1.3 EXTRINSIC RISK FACTORS

1.3.1 Type of physical activity

Military studies indicate that different units and different types of training may place military personnel at different degrees of risk (Kuusela, 1984; Goldberg & Pecora, 1994; Shaffer *et al.*, 1999b).

1.3.1.1 PT

- **Total amount of training done** - Limited studies have found that higher amounts or running are associated with higher incidences of stress fractures (Giladi *et al.*, 1985; Jones *et al.*, 1999; Almeida *et al.*, 1999; Popovich *et al.*, 2000; Armstrong *et al.,* 2004).
- **Duration, frequency and intensity** - Weekly overall injury rates have been shown to be significantly correlated to higher total volumes of total

training including running and marching (Jones *et al.*, 1994; Shaffer *et al.*, 1999a).

1.3.2 Equipment

- **Training shoes** - It appears that the stress fracture risk increases with the age of the training shoes, whilst the price of running shoes is not associated to risk (Gardner *et al.*, 1988; Finestone *et al.*, 1991).
- **Boots and orthotic inserts** – Researcher have found that the incidence of stress fractures may be reduced if the military recruit changes from wearing a military boot to wearing an athletic shoe, as well as if certain orthotic inserts are utilised (Milgrom *et al.*, 1985; Gardner *et al.*, 1988).

1.3.3 Environment

The terrain or surface of the environment on which the activity takes place has also been investigated. Reports have suggested that a change of running surface (particularly hard, rocky terrain) may increase the incidence of stress fractures. The difficulty involved in accurately quantifying running surface parameters, makes it difficult to clearly establish a relationship between training surface and stress fracture development (Zahger *et al.*, 1988; Brunet *et al.*, 1990).

1.4 PROBLEM SETTING

All of the above mentioned markers have been researched, yet few have been clearly identified and many of the findings have been contradictory, especially within the military population (Bennell *et al.*, 1999). The only physical requirement for enlistment and acceptance into voluntarily military service in South Africa has been to pass a basic medical examination (to ensure that the recruit is physically healthy). No additional biomechanical factors are evaluated, nor is a minimum level of physical fitness a requirement for acceptance. Thus it is imperative that research be done to determine:

a. Whether or not intrinsic factors affect the development of stress fractures during BT (Jones & Knapik, 1999; Kaufmann *et al.*, 2000; Bemben *et al.,* 2004; Shaffer *et al.*, 2006) and
b. How extrinsic factors, such as PT, affect the final outcome of both fitness levels and stress fracture development (Jones & Knapik, 1999; Kaufmann *et al.*, 2000; Popovich *et al.*, 2000; Rosendal *et al.*, 2003; Rauh *et al.*, 2005; Rauh *et al.*, 2006; Shaffer *et al.*, 2006).

The specific approach to achieving higher levels of physical fitness while minimizing injury rates depends on the populations being considered (Kaufman *et al.*, 2000; Snyder *et al.,* 2006). As BT is the first step in a military career, there is limited access to the trainees prior to the start of BT. The most effective way to improve the level of physical fitness and, subsequently, improve combat readiness, needs to be developed and researched (Jones & Knapik, 1999; Popovich *et al.,* 2000; Rosendal *et al.*, 2003; Rauh *et al.*, 2006; Snyder *et al.*, 2006).

1.5 RESEARCH QUESTION

For this study, the following research question was used:

"Will the incidence of stress fractures in South African soldiers, who have risk factors, as highlighted in thecurrent literature, be greater than in the South Afrcian soldiers who are not at risk during BT?"

1.6 RESEARCH HYPOTHESIS

In the light of the aim of this study, the following research hypothesis was formulated:

Incidence of stress fractures in military recruits with intrinsic risk factors, as highlighted in the current literature, will increase during BT.

A sub-hypothesis was also formulated from the main hypothesis:

By following clear guidelines, as laid out in the literature on how to prevent stress fracture development, it will assist in explaining the low incidence of stress fracture occurrence.

1.7 GOAL OF THE STUDY

The following goal was set before the study commenced:

To determine the incidence of stress fractures during 12 weeks of BT, by analyzing and monitoring any changes in the military recruits' intrinsic risk factors, from when they reported for training to when they completed the training.

1.8 OBJECTIVES OF THE STUDY

This study aimed to achieve the goal through the following objectives:

1.8.1 Primary objectives

- To determine the incidence of stress fractures during 12 weeks of BT;
- To compare the results of risk indicators obtained from the group of participants who suffered stress fractures during their 12 weeks of BT, to the rest of the original group (controls) who didn't suffer from any stress fractures.

1.8.2 Secondary objective

- To determine whether 12 weeks of BT results in any changes in physical markers whilst following a progressive, scientifically designed, PT programme.

1.9 RESEARCH APPROACH

This study followed a quantitative research approach and the two quantitative research techniques that were used are known as observation and experimentation technique.

1.9.1 Observation technique

This technique provides a means of obtaining data and is a descriptive method of researching certain problems. In this study, the observation technique was used to keep record of all military recruits who developed a stress fracture. This was done through the military medical computerized system as all military medical visits to the unit sick bay are captured onto this system. Additionally, the diagnosis, as well as the results of any radiology scans, is also captured (together with treatment given) (Thomas & Nelson, 2001).

1.9.2 Experimentation

This technique attempts to establish a cause-and-effect relationship. That is, an independent variable (in this case the PT Programme) is manipulated to judge the effect upon a dependant variable (fitness results). Additionally, correlation statistics were used to establish the cause-and-effect relationship (Thomas & Nelson, 2001).

1.10 RESEARCH DESIGN

A research design is the basic plan that guides the data collection and analysis phases of the research project. *It is the framework that specifies the type of information to be collected, the sources of data, and the data collection procedure* (Kinnear & Taylor, 1996: 129). The current study was done in the form of an experiment. Pre-test and Post-test measures were taken for the prospective experimental cohort group (who all underwent BT) on biokinetic and bone density measurements. Fitness test results were also compared to a CG who had undergone BT in the year prior to the EG. The limitations of the findings of this study are that they could only be generalised to the people from the same sample group.

The prospective design implies that the participants were assembled at the beginning of the study (in this case at the start of 12 weeks of BT according to their exposure to a (risk) factor. They were followed over the predetermined 12-week period, and any injury occurrence was monitored and recorded. This was considered a 'strong' design as it enabled accurate comparisons to be made between injured and uninjured groups. These comparisons then lead to true assessment of the incidences and risks which could have lead to casual inferences been drawn. The limiting factor of this type of design is that in order to have enough statistical power, particularly for detection of small differences, sample sizes need to be large. Additionally, rigorous inclusion criteria, as well as drop out rates over the course of the study, limit the number of available, suitable participants.

1.11 RESEARCH PROCEDURE AND STRATEGY

- Identify risk factors for the development of stress fractures in the literature.
- Identify potential intrinsic risk factors for stress fractures in the literature.
- Develop a 12-week PT Exercise Programme for BT.

- Determine if these intrinsic risk factors are measurable and quantifiable.
- Develop a physical testing battery of all possible intrinsic risk factors to be measured.
- Give information regarding the study, and answer all questions that may arise from the cohort group starting 12-week of BT.
- Ask for volunteers for the study and have all volunteers complete and sign the inform consent form.
- Ask participants to read and sign informed consent and then complete questionnaires on their history of sport participation and medical questionnaires.
- Randomly divide participants into five groups and undergo a week of Pre-test physical testing of battery developed above.
- Collect data and participants commence 12 weeks of BT.
- Conduct mid-course fitness tests.
- Follow identical Post-test physical testing and data collection.
- Draw medical records from the military medical main-frame to determine the incidence of stress fractures amongst the group.
- Complete statistical analysis of pre/post test analysis.
- Explain findings.

As stress fractures represent a serious concern within the South African Military environment the first step is to study the literature of research already in existence regarding the definition, diagnosis and the pathophysiology of stress fractures. Additionally a thourough literature review also needs to be done in order to identify possible intrinsic and extrinsic risk factors and attempt to understand the potential relevance to the South African context.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

PT forms an integral part of the physical preparation and conditioning of military personnel. Military historians have repeatedly emphasised the importance of a high level of physical capability as necessary for soldiers to perform their main functions, namely: to protect their country, its territorial integrity and its people, and to contribute positively to peacekeeping as well as peace-enforcing operations (McGaig & Gooderson, 1986; Nye, 1986; Dubik & Fullerton, 1987; Shvartz & Reibold, 1990; Legg & Duggan, 1996; Dyrstad *et al.,* 2006).

New recruits, making the transition from civilian to military life undergo a period of initial BT to equip them with the required optimum physical capability and skill training needed to execute their tasks effectively (Gordon *et al.,* 1986a; Jordaan & Schwellnus, 1994; Knapik *et al.,* 2005; Schaffer *et al.,* 2006). The excessive demands imposed on the musckuloskeletal system during military BT continues to be of utmost concern, as this period of training is often related to high levels of training-related injuries (Gordon *et al.,* 1986c; Jones & Knapik, 1999; Jones *et al.*, 2002; Armstrong *et al.,* 2004; Välimäki *et al.*, 2005; Snyder *et al.,* 2006). Besides imposing substantial medical costs, injuries can prevent the recruit from training for extended periods, as well as reduce the morale of the injured and the group.

2.2 STRESS FRACTURES

Stress fractures represent one of the most common and potentially serious training-related injuries (McBryde, 1985; Hulkko & Orava, 1987; Matheson *et al.*, 1987; Jones *et al.*, 1989; Sterling *et al.*, 1992; Beck *et al.,* 2000; Jones *et al.,* 2002; Shaffer *et al.,* 2006; Trone *et al.,* 2007).

2.2.1 Definition

A stress fracture can be defined as a partial or complete bone fracture that results from its inability to withstand stress applied in a rhythmic, repeated, subthreshold manner (McBryde, 1985; Bennell *et al.*, 1999).

2.2.2 A historical perspective

Stress fractures were first described in 1855 by Brietpaupt (Jones *et al.*, 1989), a Prussian military physician, who observed foot pain and swelling in young military recruits unaccustomed to the rigors of BT. He considered this to be an inflammatory reaction in the tendon sheaths as a result of trauma, and he called the condition *Fussegeshwulst* (Brukner *et al.,* 1999). In 1887, Pauzat (1887) suspected that the periosteum was involved in the condition, but it was not until the advent of radiographs that the signs and symptoms could be attributed to the metatarsals (Stechow, 1897). The condition then became know as a ‘march fracture’ because there was a close association between marching and the onset of symptoms (Brukner *et al.,* 1999).

The first few cited reports of stress fractures were case studies of soldiers incurring such fractures in the nineteenth and early twentieth centuries (Bernstein *et al.*, 1946; Belkin, 1980; McBryde, 1985; Markey, 1987; Jones *et al.*, 1989; Jones *et al.*, 2002). However, it was not until 1956 - more than a century after they had been identified in military recruits- that they were recognised in athletes and reported in the non-military population with increasing frequency (Hartley, 1943; Burrows, 1948; Devas & Sweetman, 1956; Blazina *et al.,* 1962; Berkebile, 1964; Devas, 1969).

Throughout the literature, stress fractures have been described by a variety of terms, which include 'march fracture', 'pied force', 'fatigue fracture', 'crack fracture', 'spontaneous fracture', 'insufficiency fracture', 'pseudofracture' and 'exhaustion fracture' (Jansen, 1926; Dodd, 1933; Roberts & Vogt, 1939; Hullinger, 1944; Burrows, 1948).

Following the radiographic description of metatarsal stress fractures, many and varied attempts were made to develop theories in order to explain the etiology of the injury (Brukner *et al.,* 1999). These theories included spasticity and spasm of the interossei (Jansen, 1926); flat forefoot (Sloane & Sloane, 1936) and non-supportive osteomelytis (Roberts & Vogt, 1939).

2.2.3 Pathophysiology

Bone, a specialized form of dynamic connective tissue, is the hardest tissue in the human body and functions primarily as a supportive structure and secondarily as a protective structure. It adapts to hormonal changes, mechanical stress and nutritional states (Voss *et al.,* 1998), and has gained increasing attention in the past two decades due to the increased incidence of osteoporosis, osteoporotic fractures as well as stress fractures.

Bone is comprised of organic material (mainly Type I collagen) and minerals (mainly calcium hydroxyapatite). Similar to other connective tissue of the musculoskeletal system, bone is able to adapt to repeated mechanical loading by changing its microscopic and macroscopic configuration. In order to understand the development of stress fractures, it is necessary to understand bone's basic biologic and mechanical responses to physical loading (Brukner *et al.,* 1999).

2.3 BONE BIOLOGY

2.3.1 Bone structure and gross anatomy

Taking the body as a whole, the skeleton is divided into two groups- the axial skeleton (bones of the trunk) and the appendicular skeleton (the long bones, ie the limb bones). There are two types of bone - The outer, more dense bone (cortical bone) and the inner, less dense, but more metabolically active bone, (trabecular bone) (Voss *et al.*, 1998).

On the basis of general shape, bones can be classified into three groups: short, flat, and long or tubular. Short bones, such as the vertebral bodies, measure approximately the same in all directions, have relatively thin cortices and are trapezoidal, cuboidal, cuneiform, or irregular in shape. Flat (such as the scapula, lamina of the vertebrae) and tubular bones have one dimension that is much shorter or longer than the other two. Long or tubular bones (such as the femur, tibia), have an expanded metaphysis and an epiphysis at either end of a thick-walled tubular diaphysis (Buckwalter *et al.*, 1995).

Mature bones consist of a central hematopoietic marrow supported and surrounded by bone tissue and periosteum. Most injuries of the skeleton and most orthopaedic treatments, primarily affect the bone tissue and the periosteum.

Eighty percent of the skeleton comprises cortical bone whilst trabecular (cancellous) makes up the remaining twenty percent. Although cortical and cancellous bone have the same composition and material properties, differences in distribution and arrangement are responsible for the differences in the mechanical properties of specific bones and parts of bones (Buckwalter *et al.*, 1995). Appendicular, long bones are mainly cortical; the exception is at the metaphysis and epiphysis. The pelvic bones and vertebral bodies are largely trabecular (Brukner *et al.*, 1999). Cortical bone of the diaphysis provides maximum resistance to torsion and bending whilst in the metaphyses and epiphyses, the thinner cortices and subchondral bone supported by cancellous bone, allow greater deformation to occur under the same load. Thus, the complex formed by the subchondral bone and epiphyseal-metaphyseal trabeculae and cortices not only broadens the bone to form an articular surface, it also helps to absorb impact loads applied across synovial joints, thereby protecting the articular cartilage and subchondral bone from damage (Buckwalter *et al.*, 1995).

On the other hand, trabecular bone is less able to withstand compressive forces due to its greater porosity, higher rate of metabolic activity and greater surface-to-volume ratio (Brukner *et al.*, 1999). Clinically, BMD studies measure areas containing mostly cancellous bone (vertebral bodies, femoral Trochanter, and sacrum) because of its earlier and higher rate of bone turnover and its greater likelihood of demonstrating changes in BMD (Buckwalter *et al.*, 1995).

2.3.2 Microscopic structure of bone

Cortical or trabecular bone consists of woven (fiber or primary) or lamellar (secondary) bone. Woven bone forms the embryonic skeleton and is then resorbed and replaced by mature bone as the skeleton develops. Woven bone is rarely present in the normal human skeleton after the age of four or five years. It can, however, appear at any age in response to osseous or soft-tissue injury, treatments that stimulate the formation of bone, metabolic and neoplastic diseases, or inflammation (Buckwalter *et al.*, 1995, Martini *et al.*, 2001).

Lamellar bone consists of highly oriented, densely packed collagen fibrils found in trabecular bone, the inner and outer circumferential lamellae of cortical bone, the interstitial lamellae of cortical bone, and the lamellae of osteons (Brukner *et al.,* 1999). The fibrils and adjacent lamellae run in different directions, similar to the alternating directions of the wood grain in plywood. The collagen fibrils frequently interconnect, not only within but also between lamellae, thereby increasing the strength of the bone (Buckwalter *et al.*, 1995).

The structural unit of compact bone is called the osteon or Haversian system. Each osteon consists mostly of hard bone matrix arranged in concentric rings, or lamellae, around a central canal (the Haversian canal), orientated along the long axis of the bone. Volkmann's cannals run at right angles to the long axis of the bone, connecting the vascular and nerve supply of the periosteum to those of the Haversian canals and the medullary cavity. Spider-shaped osteocytes lie in small concavities, or lacunae, between the lamellae. Canaliculi, hairlike canals, connect the lacunae to each other and the Haversian canal. These canaliculi tie all the osteocytes in an osteon together, permitting easy diffusion of nutrients and wastes to and from the blood vessels in the Haversian canal. Matrix areas between intact osteons contain incomplete lamellae called interstitial lamellae. These fill gaps between forming osteons or represent remnants of osteons that have been cut through by bone remodeling (Marieb, 1995).

2.3.2.1 Bone cells

Bone is made of both organinc and inorganic components. The organic components include the cells (osteoblast, osteocytes and osteoclasts) and approximately one-third of the matrix. The organic matrix elements are the proteoglycans, glycoproteins and collagen fibres, all of which are secreted by osteoblasts (Marieb, 1995). Their main function is to synthesise and secrete bone's organic matrix. Once they stop forming bone, they both decrease their synthetic activity and remain on the bone surface (bone-lining cells) or they surround themselves with matrix and become osteocytes (Brukner *et al.,* 1999).

The organic constituents of the bone matrix account for the flexibility and resilience that is so characteristic of bone, whilst the bone's macromolecules contribute to the bone's structure and functional qualities (Buckwalter, 1995;

Brukner *et al.,* 1999). Bone-lining cells' main function is to contract and secrete enzymes that remove the thin layer of osteoid that covers the mineralized matrix. Osteoclasts are thereby able to attach to bone and begin resorption (Buckwalter *et al.*, 1995). The interconnections (canniculi) between the various osteocytes, active osteobalsts and bone-lining cells' are said to enable the cells to sense bone deformation by mechanical loads and to coordinate the remodeling process (Brukner *et al.,* 1999). Osteoclasts are giant cells with fifty or more nuclei and are derived from the extraskeletal, hematopoietic stem cells. They are found on bone surfaces undergoing resorption and secrete acids which then dissolve the bony matrix and release stored minerals (Martini *et al.*, 2001).

The remaining 65% of the matrix consists of hydroxypatities or inorganic mineral salts, made up largely by calcium phosphate, calcium carbonate and calcium hydroxide (Marieb, 1995; Brukner, 1999). The matrix's main functions include acting as an ion reservoir and accounts for most of bone's strength and stiffness (Buckwalter, 1995; Brukner *et al.,* 1999). It is the proper combination of organic and inorganic matrix elements that allows for bones to be durable and strong without been brittle (Marieb, 1995).

According to Nattiv and Armsey (1997), the expected age range of peak bone mass accrual is between 25 and 30 years, after which both men and women gradually lose bone mass. Men acquire most of their bone mass at a later age than women do (age 13-17 years compared to 11–14 years). Postmenopausal women or women who are hypoestrogenic for other reasons, have accelerated bone loss caused by increased bone resorption compared with formation.

2.3.3. Bone loading

As PT forms an integral part of the physical preparation and conditioning of military personnel, especially during BT, it is important to understand the effect of the PT on bone and how bone reacts to the training. According to Brukner (1999: 2)

> *"…during physical activity, forces from ground impact and muscle contraction result in bone stress, which is defined as the load or force per unit area that develops on a plane surface, and in bone strain, which is defined as deformation of, or change in, bone dimension. In clinical terms, stress is a measure of the load applied, and strain is the measure of the amount of lengthening or deformation that occurs in a given direction."*

During such military activities as drilling, running and marching, contact with the ground generates forces within the body. The magnitude of these ground-reaction forces varies depending on the activity undertaken, (eg. running) results in ground-reaction forces that are two to five times body weight, whilst jumping and landing activities have been shown to elicit ground-reaction forces up to 12 times body weight (Cavanagh & LaFortune, 1980; McNitt-Gray, 1991). These ground-reaction forces result in transient forces, due to the impact of the foot with the ground, in both walking and running and following the heel strike are transmitted up the skeleton. Newton's three laws can then be used to explain exactly what happens to these transient forces and their path up the skeleton (Whittle, 1999).

> *"…When the downward-traveling foot contacts the ground, an upward force is applied by the ground to the foot (the ground-reaction force), to decelerate it and bring it to rest. This upward force is transmitted through the ankle joint to the tibia and through the knee joint to the femur, so that a 'wave' of force passes up the skeleton, which (in accordance with Newton's second law) must necessarily be associated with acceleration"* (Whittle, 1999: 2).

In the literature, this transient acceleration and its associated force is generally referred to as a 'shock-wave' or 'stress-wave'. Any bone subjected to such an upward force will experience an upward acceleration; if it is traveling downwards at the time, this will cause a reduction in its downward velocity. Since the tibia is typically traveling downwards at the time of initial contact, this upward force will generally stops its downward motion. In addition to these forces applied from below, the bones of the lower limb are also subjected to forces from above, from muscular contraction and body weight, which are transmitted through the hip and knee joints (Whittle, 1999).

Various factors will influence the magnitude and the pathway followed up the skeleton by the above-mentioned forces (Brukner *et al.,* 1999; Umemura *et al.,* 2002; Ducher *et al.,* 2006). These include: the running speed, body weight, mass of foot, velocity of foot, interface thickness, interface elasticity, interface viscosity, type of foot strike, surface, terrain, fatigue and footwear (Nigg & Segesser, 1988; Dufek & Bates, 1991; Whittle, 1999; Umemura *et al.*, 2002; Ducher *et al.*, 2006).

According to Brukner *et al.* (1999) the factors that influence bone's response to mechanical loading are:

- the loads direction
- bone geometry
- bone microarchitecture
- bone density and muscle contraction

2.3.3.1 Loads direction

Bone's stress/ strain behavior is dependant on the bone's orientation to the direction of the force applied (loading). Cortical bone is stronger and stiffer in the longitudinal direction than in the transverse direction, whilst trabecular bone is stronger along the lines of the trabeculae (Brukner, 1999).

Forces load the bone through tension, bending, shear and torsion. Human cortical bone, in both the transverse and longitudinal direction, can withstand greater load in compression than in tension and greater load in tension than in shear. During bending, a combination of tensile loads on one side of the bone and compressive loads on the other side, resulting in the bone giving in on the tensile side (as adult bone is weaker in tension that in compression) (Hall, 2003).

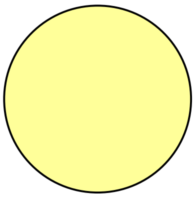
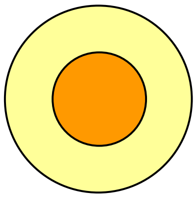
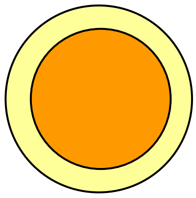
2.3.3.2 Bone geometry

A bone's strength is greatly determined by its geometry. A bone's strength is directly proportional to the bone's cross-sectional area when either tension or compression loads are applied to it. This implies that a larger bone, such as the femur, is more resistant to fracture, than for example, the tibia, as the internal forces are distributed over a larger surface area resulting in lower stresses (Hayes & Gerhart, 1985; Ammann & Rizzoli, 2003).

With bending forces, the bone's cross-sectional area, bone's tissue distribution around a neutral axis as well as the length of the bone will influence the bones' strength (Brukner *et al.,* 1999; Ammann & Rizzoli, 2003). "If the bone tissue is distributed further away from the neutral axis (the axis where the stresses and strains are zero) there is a greater area of inertia which means that it is more efficient in resisting bending." (Brukner et al., 1999: 52).

Each of the cross-sectional areas of the above bones (Table 2.1) are roughly equivalent, yet their bending strengths differ vastly as they have different moments of inertia. This occurs as a result of the way in which the bone is distributed in relation to the central axis of the bending or rotation force applied to the bone. The solid bone on the left has the same amount of area (bone) as the one in the centre, but the latter has a higher moment of inertia as the bone is distributed further away from the central axis; its bending strength is 50% greater (Brukner *et al.,* 1999).

Table 2.1: Bone's moment of inertia properties (Brukner et al., 1999)

			
Area (cm ^{2})	2.77	2.77	2.77
Moment of inertia (cm ^{4})	0.61	1.06	1.54
Bending strength (%)	100	149	193

Studies on Israeli Army Recruits using radiographic methods, showed that stress fracture cases had narrower tibiae (Giladi *et al.*, 1987) and smaller tibial mediolateral cross-sectional moments of inertia (Milgrom *et al.*, 1989). In a previous study of male U.S. Marine Corps recruits using the DEXA method, Beck *et al.* (1996) similarly found that stress fracture cases had lower mediolateral cross-sectional moments of inertia and section moduli in both the distal third of the tibia and the midshaft of the femur. Even though the fracture cases in this study of men were, on average, physically smaller in body weight and anthropometric dimensions, the diaphyseal dimensions remained significantly smaller in fracture cases even after bone shaft geometries were corrected for body size (weight).

Additionally, the length of the bone is directly proportional to the bending moment caused by the loading applied. Thus, the femur, tibia and fibula are subjected to higher bending moments and therefore higher tensile and compressive stresses than the shorter bones of for example, the forearm (Brukner *et al.,* 1999).

2.3.4 Bone microarchitecture

2.3.4.1 Bone density

According to Carter and Hayes (1977), skeletal tissue's compressive strength is approximately proportional to the square of the apparent density. This implies that a small reduction in bone density is associated with a large reduction in bone strength. Clinically, low bone density is associated with greater risk of osteoporotic fracture (Martini *et al.*, 2001).

2.3.4.2 Muscle contraction

Muscles attached to bone also influence the stress distribution and magnitude. According to Brukner *et al.,* (1999) it can both increase as well as decrease the magnitude of stress applied to bone.

Warden *et al.,* (2002) suggested that stress fractures of the ribs in elite rowers may be the result of repeated high-force muscular contractions during the rowing stroke. Different injury mechanisms involving the serratus anterior, obliquus externus abdominis, and the shoulder retractors either alone or in concert, have been presented (Warden *et al.*, 2002). Further evidence that muscle contraction is a potential cause of exercise-induced rib stress fractures is present in work done by Vintheri *et al.,* (2006).

2.3.5 Bone response to loading

The dramatic bone loss which occurs with immobilisation, disuse and weightlessness is evidence that the maintenance of normal bone mass is dependant on repetitive strains (Brukner *et al.,* 1999). Exercise is recognized as usually having a beneficial effect on bone density because of the mechanical loading forces on the skeleton (Snow, 1996; Stewart *et al.,* 2005).

However, Brukner *et al.*, (1999: 6) states that

> *"…bone can also lose strength as a result of repetitive loads imposed during normal daily activity. This loss of strength is attributed to formation and propagation of microscopic cracks within bone. If the load is continually applied, these 'microcracks' can spread and coalesce into 'macrocracks'. If repair does not occur, a stress fracture may eventually result*."

Loading of bone is expressed in microstrain (Duncan & Turner, 1995), with 1000 microstrain representing a force causing a 0.1% change in length. Physiologically, in normal bone, 4000 microstrain is 1/6th of a fracture strain. With less than 50-200 microstrain (the trivial loading zone), normal stimuli to bone is withdrawn, and remodelling is stimulated. This is seen in prolonged bed rest, and leads to a net loss of bone over time.

Strains in the physiological loading zone (about 200-2000 microstrain) are sufficient to maintain bone. When 2000-3000 microstain is exerted onto bone, modelling is stimulated (in this overload zone) resulting in accretion of bone. During modelling the architecture of bone material is controlled by adding *or* removing bone from a surface to create drifts of the material in space. The cells must be activated by some stimulus and then function to form *or* resorb bone.

Functional adaptation to increased loading (eg a new exercise programme) generally occurs via modelling so that the geometry of the bone is altered to improve its resistance to applied loads. The detection of mechanical signals and translation into a biological response is termed mechanotransduction and involves signal transduction between osteocytes and cells at the bone's surface (Duncan & Turner, 1995; Martini *et al.,* 2001). Finally, forces above 4000 microstrain (the pathological overload zone) stimulate repair and adds bone in an unorganized manner (Duncan & Turner, 1995).

Remodelling refers to the process through which fatigue damaged bone is replaced by new bone. It occurs in both growing and adult bones, and determines bone shape and mass in adults. Remodelling occurs in cycles, which involve the breakdown of bone by osteoclasts and the laying down of new bone matrix by osteoblasts or through a coupled process, over time, filling in of the resorped areas may be incomplete. Remodelling occurs at many simultaneous sites throughout the body where bone is experiencing growth, mechanical stress or fractures, or breaks. About 20% of all bone tissue is replaced annually by the remodelling process (Martini *et al.,* 2001). Remodelling occurs in cortical bone on its endosteal and periosteal surfaces, and on the surface of trabeculae bone.

The three main functions of remodelling are: (1) to adapt bone to mechanical loading, (2) to prevent accumulation of microfractures or fatigue damage and (3) to maintain constant blood calcium levels.

There are five phases (Table 2.2) in the bone remodelling process, namely activation, resorption, reversal, formation, and quiescence. The total process takes about four to eight months, and occurs continually throughout life.

Table 2.2: Phases of bone remodelling

PHASE	PHASE EVENTS	
Activation	1	Small area of bone surface is converted from rest to activity by an initiating hormonal, chemical or physical stimulus.
	2	Pre-osteoclasts are attracted to the remodelling sites.
	3	Pre-osteoclasts fuse to form multinucleated osteoclasts.
Resorption	4	Osteoclasts dig out a cavity, called a resorption pit, in spongy bone or burrow a tunnel in compact bone.
	5	Calcium can be released into the blood for use in various body functions.
	6	Osteoclasts disappear.

PHASE	PHASE EVENTS	
Reversal	7	Mesenchymal stem cells, pre-cursors to osteoblasts, appear along the burrow or pit.
	8	Here they proliferate (increase in numbers) and differentiate (change) into preosteoblasts.
	9	This normally lasts 1-2 weeks and during this time, the bone site is weakend. Continued mechanical loading during the reversal phase could therefore result in microdamage accumulation and the beginning of clinical symptomatology.
Formation	10	Osteoblasts then mature into osteoblasts at the surface of the burrow or pit.
	11	Osteoid is released at the site, forming a new soft nonmineralized matrix.
		The new matrix is mineralized with calcium and phosphorous.
Quiescence		Site, with resting lining cells, remains dormant until the next cycle.

2.3.5.1 Microdamage

Above a high loading threshold, fatigue failure of bone can occur causesing microscopic damage of bone. This damage is termed microdamage to bone (Duncan & Turner, 1995). This microdamage accumulates in human bone when repeated loading is undertaken. According to Frost (1989), the progression can be classified into four stages, namely:

- **Stage 1:** Known as the molecular and ultrastructural stage; this is the earliest stage and is characterised by disruption of some intermolecular bonds in the mineralised matrix and a measurable loss in bone stiffness (not visible under direct microscopy).
- **Stage 2**: Increasing physical damage with wholesale disruption of molecular bonds, creates pre-failure planes in the previously impermeable matrix.

- **Stage 3:** The accumulation and progression of pre-failure cracks leads to frank physical cracks that are visible under light microscope. The marked reduction in bone mechanical properties, seen when repetitive loading is undertaken, is attributed to these small cracks (Brukner *et al.,* 1999).
- **Stage 4**: Pre-failure planes and cracks accumulate with continued repetitive loading and at some stage, reach a size whereby so little bone remains to carry the load that a complete fracture results.

During any of these stages, the microdamage is then repaired by "targeted" remodelling to the sites of damage.

2.3.5.2 Microdamage to stress fracture

The insufficient repair of microdamage may be one mechanism leading to the creation of stress fractures. Models for initiation and progression of fatigue fractures (Figure 2.1) suggest that muscle fatigue allows greater strains to be engendered in the bones, leading to initation of microdamage. Repair of microdamage initially creates resorption pits at the start of remodelling. This creates a transient increase in porosity of the tissue and a corresponding reduction in mass and strength. If there is inadequate rest between loading bouts, a positive feedback loop is created that either progresses to a "stress fracture" or weakens the bone sufficiently for a fracture to occur at relatively low magnitudes of loading (Brukner *et al.,* 1999).

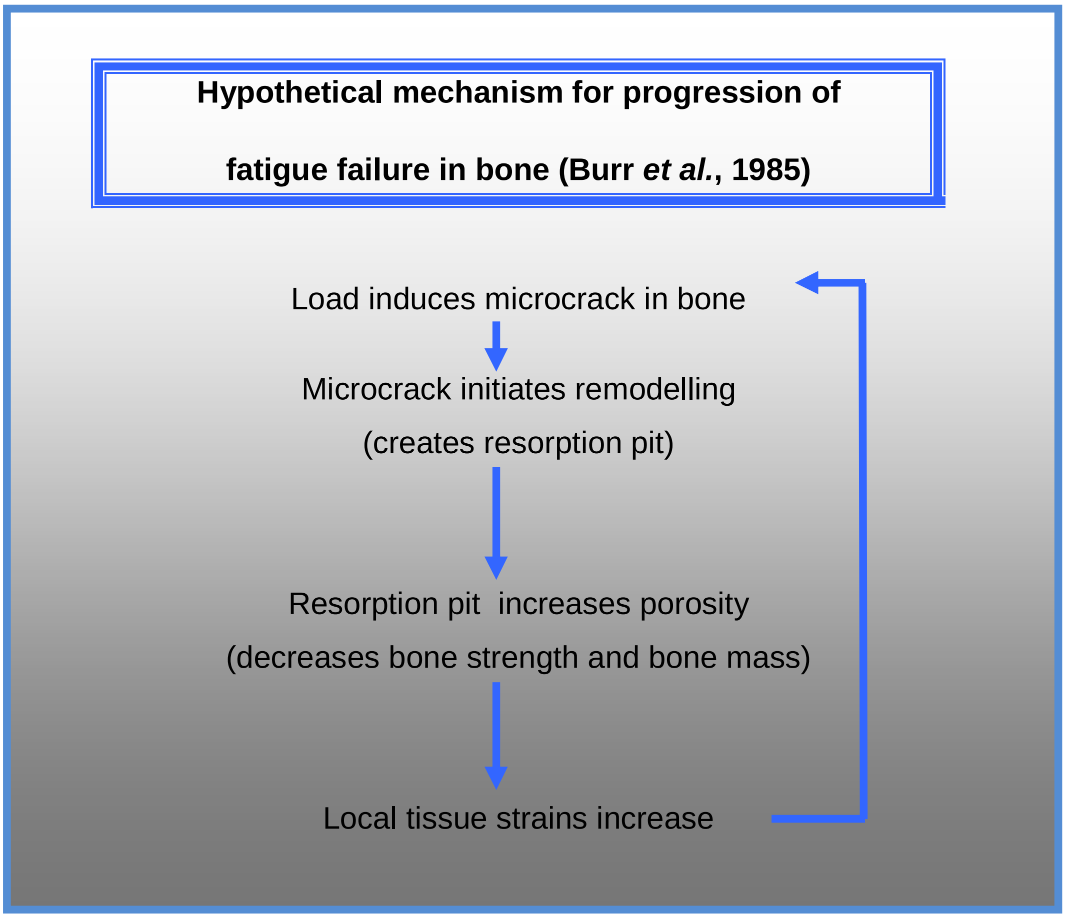


Figure:2.1: Hypothetical mechanism for progression of fatigue failure in bone (Brukner *et al.,* 1999).

The pathogenesis of a stress fracture is presented in Figure 2.2. Loading via ground-reaction force and muscle contraction results in bone strain. This leads to both accelerated remodelling and to microdamage. Remodelling also makes the bone more vulnerable and so increased microdamage can occur at bone sites undergoing remodelling. If the microdamage cannot be repaired by remodelling, then a symptomatic bone injury can occur (Bennell & Brukner, 2005).

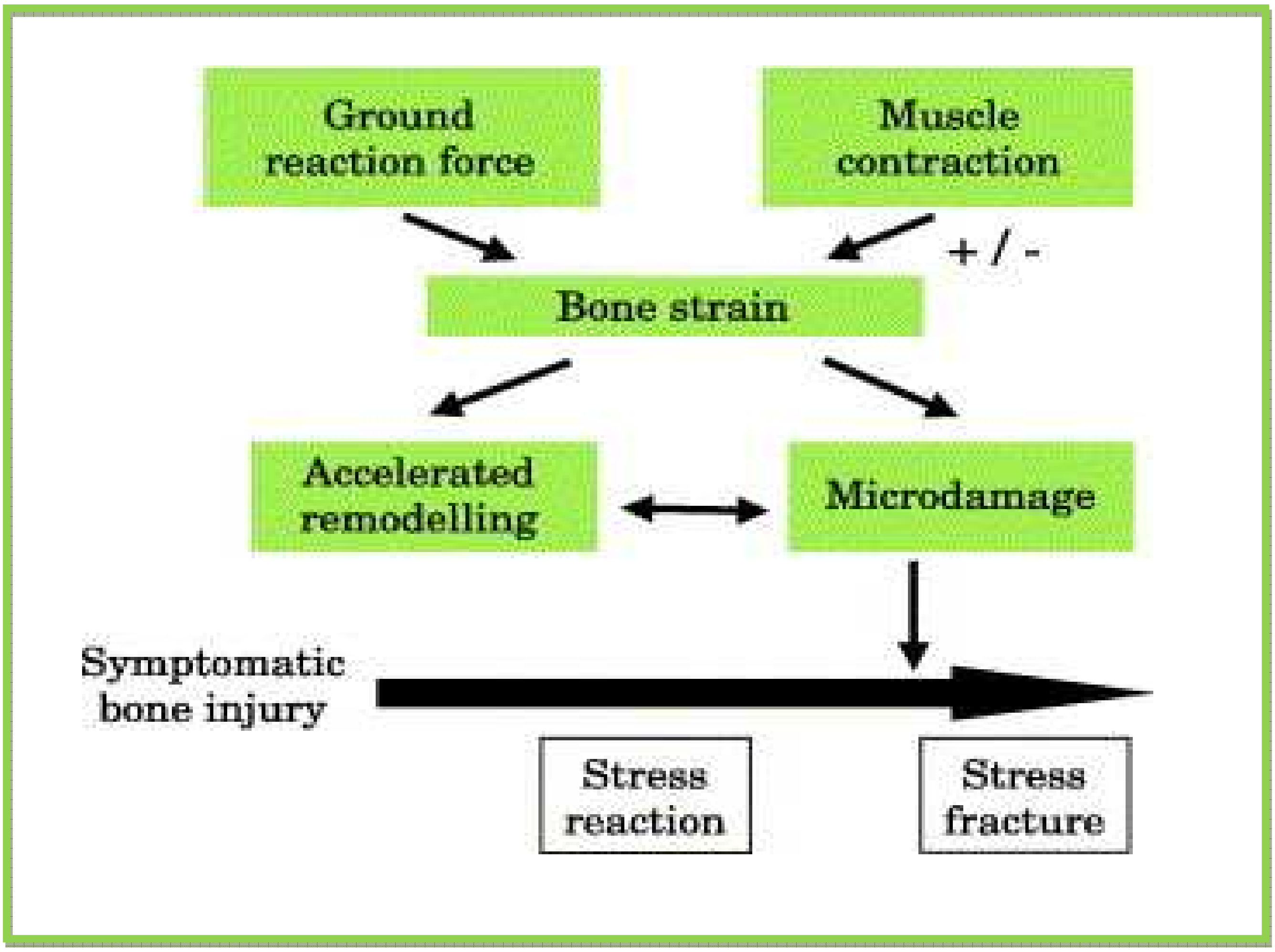


Figure 2.2: Pathogenesis of a stress fracture (Bennell & Brukner, 2005)

2.4 EPIDEMIOLOGY OF STRESS FRACTURES

Epidemiology is the study of diseases in populations, including the relationship between exposure and outcome. Epidemiological data about stress fractures include stress fracture rates, characteristics and stress fracture morbidity. According to Brukner *et al.* (1999) research methods and techniques in the basic sciences are used to isolate the factors under study (independent variables) and the outcomes being measured (dependant measures). In stress fracture research, the most important aim is to establish a causal relationship. This establishes whether a given association is valid, and, by extension, whether an intervention might be effective. The ability to make valid conclusions regarding stress fracture depends on the study design. The following six types of research designs have been used in the study of stress fractures, namely: clinical trials, prospective cohort studies, case-control studies, case series, cross-sectional studies, or surveys and 'mixed' study designs.

2.5 RESEARCH DESIGNS

2.5.1 Clinical trials

These types of studies are best used for evaluating treatment strategies once stress fractures have occurred and are a good design to assess injury prevention strategies. However, if the study's goal is to understand the cause of stress fractures, an observational design is best. The remaining five study designs are considered to be 'observational' as they make observations about the injuries and related factors (Brukner *et al.,* 1999; Thomas & Nelson, 2001).

2.5.2 Prospective cohort studies

The participants of these types of studies are assembled at the beginning of the study according to their exposure to a (risk) factor. They are followed over a predetermined period of time, during which injury occurrence is monitored and recorded. This is considered a 'strong' design as it enables accurate comparisons to be made between the injured and the uninjured groups. These comparisons then lead to true assessment of the incidences and risks which may lead to casual inferences been drawn (Brukner *et al.,* 1999; Thomas & Nelson, 2001).

The limiting factor of this type of design is that in order to have enough statistical power, particularly for detection of small differences, sample sizes have to be large. Additionally, rigorous inclusion criteria, as well as drop-out rates over the course of the study, limit the number of available, suitable participants (Kinnear & Taylor, 1996; Brukner *et al.,* 1999; Thomas & Nelson, 2001).

2.5.3 Case-control studies

Here participants are assembled according to whether or not they have sustained a stress fracture, whereby the injured couples form the cases and the uninjured, the controls. Prior exposure to a risk factor is then determined in each group.

This design allows for stress fracture rates to be calculated yet, may be biased, as a result of selection factors that affect the participants' enrolment and of inaccurate recall of prior exposure. This type of design also allows for risk to be calculated as an odd of exposure in the injured compared with the non-injured controls (Kinnear & Taylor, 1996; Brukner *et al.,* 1999; Thomas & Nelson, 2001).

2.5.4 Case series

A case series can be classified as being either diagnostic or clinical (Jones *et al.*, 2002). Case series are single study groups that consist of individuals who have a stress fracture and who present at a treatment facility. This design allows for the frequency of stress fracture occurrence to be compared to other injuries in the same population of patients. Additionally, they also describe various characteristics which then give an indication of morbidity and lead to conclusions regarding etiology and treatment.

This design is commonly found in the literature however, is limited in that it cannot provide the true incidence of stress fractures, drawing inferences about risk of injury or assessing treatment methodologies ((Kinnear & Taylor, 1996; Brukner *et al.,* 1999; Thomas & Nelson, 2001).

2.5.5 Cross-sectional studies, or surveys

As with case-controlled and cohort studies, these studies document the presence of risk factors and of stress fractures. However, as the presence of a risk factor and the stress fracture are measured at the same time, these studies cannot show whether the risk factor proceeded, caused or resulted from the stress fracture's development. Thus, they cannot establish cause-and-effect relationships (Kinnear & Taylor, 1996; Thomas & Nelson, 2001).

2.5.6 'Mixed' study designs

Aspects of the cohort and case-control studies are combined in this type of study. The findings are limited as they can only be generalised to the people from the same sample group (Brukner *et al.,* 1999; Thomas & Nelson, 2001).

2.6 STRESS FRACTURE RATES IN MILITARY POPULATION

Numerous investigations of military populations have reported the incidence of stress fracture among recruits, cadets, trained soldiers and marines (Protztman & Griffis, 1977; Reinker & Ozbourne, 1979; Kowal, 1980; Black, 1982; Scully & Besterman, 1982; Brudvig *et al.,* 1983; Milgrom *et al.,*1985; Gardner *et al.*, 1988; Gordon *et al.*, 1986c; Jones *et al.*, 1989; Montgomery *et al.*, 1989; Pester & Smith, 1992; Taimela *et al.*, 1990; Jones *et al.*, 1993b; Jodaan & Swellnus, 1994; Milgrom *et al.,* 1994; Shwayhat *et al.,* 1994; Beck *et al.*, 1996; Cowan *et al.*, 1996; Heir & Glomsaker, 1996; Bijur *et al.*, 1997; Rudzki, 1997; Winfield *et al.,* 1997; Almeida *et al.*, 1999; Jones *et al.,* 1999; MacLeod *et al.*, 1999; Shaffer *et al.*, 1999a; Shaffer *et al.*, 1999b; Beck *et al.*, 2000; Lappe *et al.,* 2001; Armstrong *et al.*, 2004; Välimäki *et al.*,2005; Shaffer *et al.*, 2006).

Several of these studies have been specifically geared towards the incidence during the recruits' initial-entry which starts with BT. The stress fracture incidences reported have been sex specific, with the incidence rate during BT ranging from 0.9 to 5.2% in males, and 3.4% to 21.0% in female trainees (Reinker & Ozbourne, 1979; Kowal, 1980; Brudvig *et al.,* 1983; Jones *et al.*, 1993b; Jones *et al.,* 1999).

Various factors must be responsible for the large ranges in incidence occurrence. Possible factors include: recruit type (Army, Air force and Marines); sex and chronogical age; the length and type of BT; the country involved; the diagnostic criteria for stress fractures and the method of injury tracking (Brukner *et al.,* 1999). Most studies done on the incidence of stress fractures were conducted out in the United States of America and most of these studies have had an incidence of less than 10% (Brukner *et al.,* 1999).

Two studies involving the Israeli Military have shown stress fracture incidences as high as 31% and 24% (Milgrom *et al.*, 1994). These high incidences were attributed to meticulous follow-up, high incidence of suspicion, and the use of the isotope bone scan for diagnosis.

There are only two published studies which have looked at stress fracture incidence among South African recruits. The first was carried out in 1982 and formed part of a three-part article (Gordon *et al.*, 1986a; Gordon *et al.*, 1986b; Gordon *et al.,* 1986c). The participants of this study were "**…**young adult South African Servicemen' (Gordon *et al.*, 1986a: 483) reporting for military conscription at the South African Defence Force BT Centre. It appears that all recruits, regardless of their mustering (recruit type), underwent a joint BT period of ten-weeks. This changed since and BT the South African National Defence Force now occurs within mustering, meaning that the Army will have its own BT, the Air Force its own and so forth. Gordon *et al.* (1986c) reported a stress fracture incidence of 4.12% amongst the 947 recruits studied.

The second study by Jordaan and Schwellnus (1994) documented the incidence of overuse injuries sustained by the 1151 recruits during nine weeks of BT in 1989. As with the above study, the recruits underwent a joint BT and the study reported a 1.2% incidence of stress fracture (Table 2.3).

Table 2.3: Incidence of stress fracture rate in military studies undergoing BT

Year of publication	Reference	Population	Participants	Observation period (weeks)	Stress fracture rate
1977	Protzman & Griffis	U.S.-Army	102-F	8	F# = 9.8%
			1228-M		M# = 1.0%
1979	Reinker & Ozbourne	U.S.-Army	NS-F	8	F# = 2.2%
			1198-M		M# = 0.8%
1980	Kowal *et al.*	U.S.-Army	202-M	8	F# = 21.0%
			327-F		M# = 4.0%
1982	Scully & Besterman	U.S.-Army	6677-M	8	M# = 1.3%
1983	Brudvig *et al.*	U.S.-Army	151-F	8	F# = 3.4%
			144-M		M# = 0.9%
1985	Milgrom *et al.*	Israeli –Army	295-M	14	F# = 62.0%
					M# = 31.0%
1988	Gardner *et al.*	U.S.- Marine	3025-M	12	M# = 1.3%
1986c	Gordon *et al.*	South African Defence Force	947-M	10	M# = 4.12%
1989	Jones *et al.*	U.S.-Army	186-F	8	F# = 13.9%
			124-M		M# = 3.2%
1989	Jones *et al.*	U.S.-Army	323-M	13	M# = 2.2%
1989	Montgomery *et al.*	U.S.-Navy Sea, Air, and Land	505-M	8	M# = 6.3%
1990	Taimela *et al.*	Finnish.-Army	823-M	12	M# = 2.7%
1992	Pester & Smith	U.S.-Army	33,059-F	8	F# = 1.1%
			76,237-M		M# = 0.9%
1993	Jones *et al.*	U.S.-Army	186-F	8	F# = 12.3%
			124-M		M# = 2.4%
1993	Jones *et al.*	U.S.-Army	303-M	12	M# = 3.0%

Year of publication	Reference	Population	Participants	Observation period (weeks)	Stress fracture rate
1994	Jordaan & Swellnus	South African Defence Force	1261-M	9	M# = 1.2%
1994	Milgrom *et al*	Israeli –Army	783-M	14	M# = 24.0%
1994	Shwayhat *et a.*	U.S.-Navy Sea, Air, and Land	224-M	25	M# = 6.7%
1996	Beck *et al.*	U.S.-Marine	626-M	12	M# = 4.3%
1996	Cowan *et al.*	U.S.-Infantry	294-M	12	M# = 5.0%
1996	Heir & Glomsaker	Norwegian-Army, Air Force and Navy	6488-M	6-10	M# = 0.2%
1997	Bijur *et al.*	U.S.- Army	85-F	6	F# = 15.0%
			473-M		M# = 2.3%
1997	Rudzki	U.S.-Australian	180-M	12	M# = 1.1%
1997	Winfield	U.S.-Navy	104-F	10	F# = 11.5%
			NS-M		M# = 7.9%
1999	Shaffer *et al.*	U.S.-Marine	1286-M	12	M# = 4.0%
			1078-M		M# = 3.7%
1999	Shaffer *et al.*	U.S.-Navy	8862- F	9	F# = 3.9%
1999	Shaffer *et al.*	U.S.-Marine	2766- F	13	F# = 5.7%
1999	Shaffer *et al.*	U.S.-Marine off.	303- F	10	F# = 9.6%
2000	Beck *et al.*	U.S.-Marine	693-F	12	F# = 5.3%
2001	Lappe *et al.*	U.S.- Army	319-F	8	F# = 8.5%
2004	Armstrong *et al.*	U.S.-Navy	203-F	9	F# = 8.4%
			1021-M		M# = 2.3%
2005	Välimäki *et al.*	Finnish.-Army	179-M	8	M# = 8.4 %
2006	Rauh *et al.*	U.S.- Marine	824	13	F# = 6.8%
2006	Shaffer *et al.*	U.S.- Marine	2962-F	13	F# = 6.1%

Key: # = Stress fracture rates; M = Males; F= Females; NS = Not Stated

The methods used in the diagnosis of a stress fracture play a vital role in the final incidence rate of the various studies. For example, when Bone Scans are used to classify stress fractures, the incidence rate appears to be inflated as more falsepositive results are also likely to be yielded by Bone Scans. This was possibly the case with the Milgrom *et al.*, (1994) study.

Conversly, a radiographic diagnosis may result in a lower incidence rate being reported due to its poor sensitivity (Berger *et al.,* 2007). The different levels of sensitivity and specificity of bone scans and radiographs in detecting stress fractures are relevant to clinicians and researchers. The delayed confirmation of stress fracture diagnoses by radiographs must be factored into both clinical and research protocols (Jones *et al.*, 2002). Regardless of the diagnosis method used, stress fractures are a common problem within the military environment.

What is evident from Table 2.3 and Figure 2.3 is that the stress fracture rates in female military recruits undergoing BT seem to be much higher than in males. This point has been a subject of investigation in the United States Army (Brukner *et al.,* 1999) and, more recently, in the South African Defence Force (Wood & Krüger, 2007).

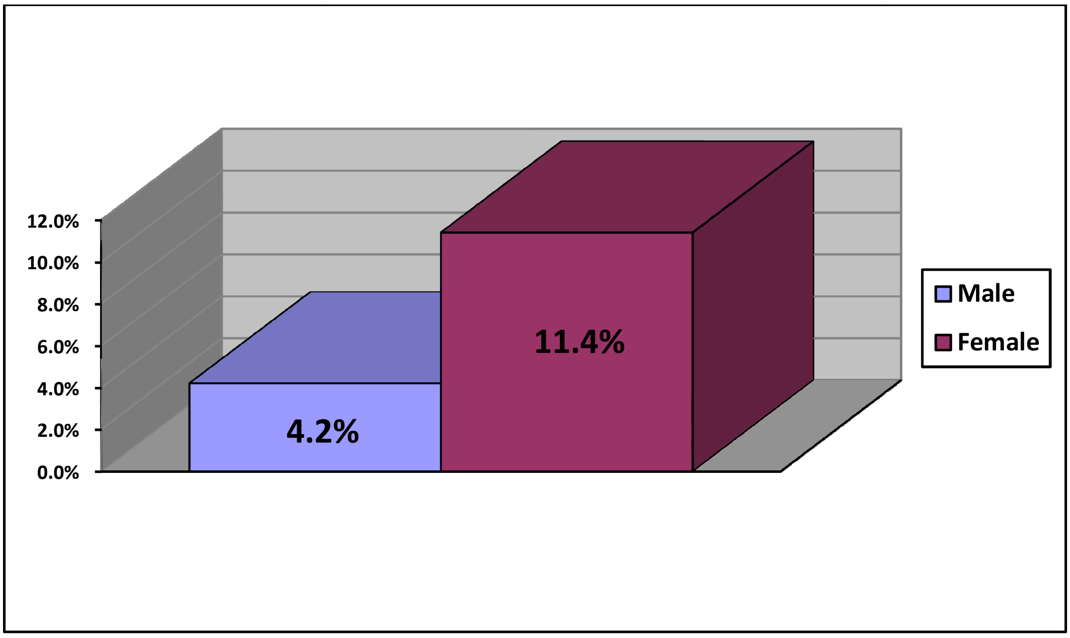


Figure 2.3: Average % stress fracture incidence during BT 1977-2007

2.7 SITE DISTRIBUTION OF STRESS FRACTURES IN MILITARY POPULATIONS

Changes that have occured over the years in military training methodology have had an influence on the site distribution of stress fractures. These changes include emphasizing running rather that marching and using athletic shoes during the initial part of training rather than the army combat boot. Additionally, advances in imaging technology have also influenced the diagnosis of previously undiagnosed injuries (Brukner *et al.,* 1999; Jones *et al.*, 2002; Rauh *et al.*, 2006).

Table 2.4: Site distribution, expressed in percentage, of stress fractures incurred by military recruits undergoing BT

Study	Stress fracture rate	% of Stress Fracture per Anatomic Site					
		Foot	Tibia	Fibula	Femur	Pelvis	Not specified
Reinker & Ozbourne, 1979.	F# = 2.2%	60	40				
	M# = 0.8%	90	10				
Kowal *et al.*, 1980.	F# = 21.0%	11	62		27		
	M# = 4.0%						100
Scully & Besterman, 1982.	M# = 1.3%						100
Brudvig *et al.,* 1983.	F# = 3.4%	43	31	5	11	10	
	M# = 0.9%	65	19	4	8	3	
Milgrom *et al.*, 1985.	M# = 31.0%	9	56		34	1	
Gardner *et al.*, 1988.	M# = 1.3%	37	63 above the foot				
Gordon *et al.*, 1986c.	M# = 4.12%	5	83	None	12		
Jones *et al.*, 1989.	F# = 13.9%						100
	M# = 3.2%						100
Jones *et al.*, 1989.	M# = 2.2%						100
Montgomery *et al.*, 1989.	M# = 6.3%	3	84		13		
Taimela *et al.*, 1990.	M# = 2.7%	50		38	12		
Pester & Smith, 1992.	F# = 1.1%	13	27				
	M# = 0.9%	86	13				
Jones *et al.*, 1993a.	F# = 12.3%						100
	M# = 2.4%						100

Study	Stress fracture rate	% of Stress Fracture per Anatomic Site					
		Foot	Tibia	Fibula	Femur	Pelvis	Not specified
Jones *et al.*, 1993b.	M# = 3.0%						100
Jordaan and Schwellnus, 1994.	M# = 1.2%	21	71	None	8	None	None
Milgrom *et al.*, 1994.	M# = 24.0%		70		30		
Shwayhat *et al.*, 1994.	M# = 6.7%						100
Beck *et al.*, 1996.	M# = 4.3%	41	41	None	19	None	None
Cowan *et al.*, 1996.	M# = 5.0%						100
Heir & Glomsaker, 1996.	M# = 0.2%						100
Bijur *et al.*, 1997.	F# = 15.0%		46				64
	M# = 2.3%		41				59
Rudzki , 1997.	M# = 1.1%		100				
Winfield, 1997.	F# = 11.5%						100
	M# = 7.9%						100
Shaffer *et al.*, 1999a.	M# = 4.0%	45	46	5	2	2	
	M# = 3.7%	67	26		7		
Shaffer *et al.*, 1999b.	F# = 3.9%						100
Shaffer *et al.*, 1999b.	F# = 5.7%						100
Shaffer *et al.*, 1999b.	F# = 9.6%						100
Beck *et al.*, 2000.	F# = 5.3%	35	27	None	27	27	None
Lappe *et al.,* 2001.	F# = 8.5%						100
Armstrong *et al.*, 2004.	F# = 8.4%	None	100	None	None	None	None
	M# = 2.3%	11	72	6	11	None	None
Välimäki *et al.*, 2005.	M# = 8.4 %	73	27	None	None	None	None
Rauh *et al.,* 2006.	F# = 6.8%	10.6	57.6	6.1	10.6	15.2	None
Shaffer *et al.*, 2006.	F# = 5.1%	29.8	24.9	3.9	19.9	21.6	

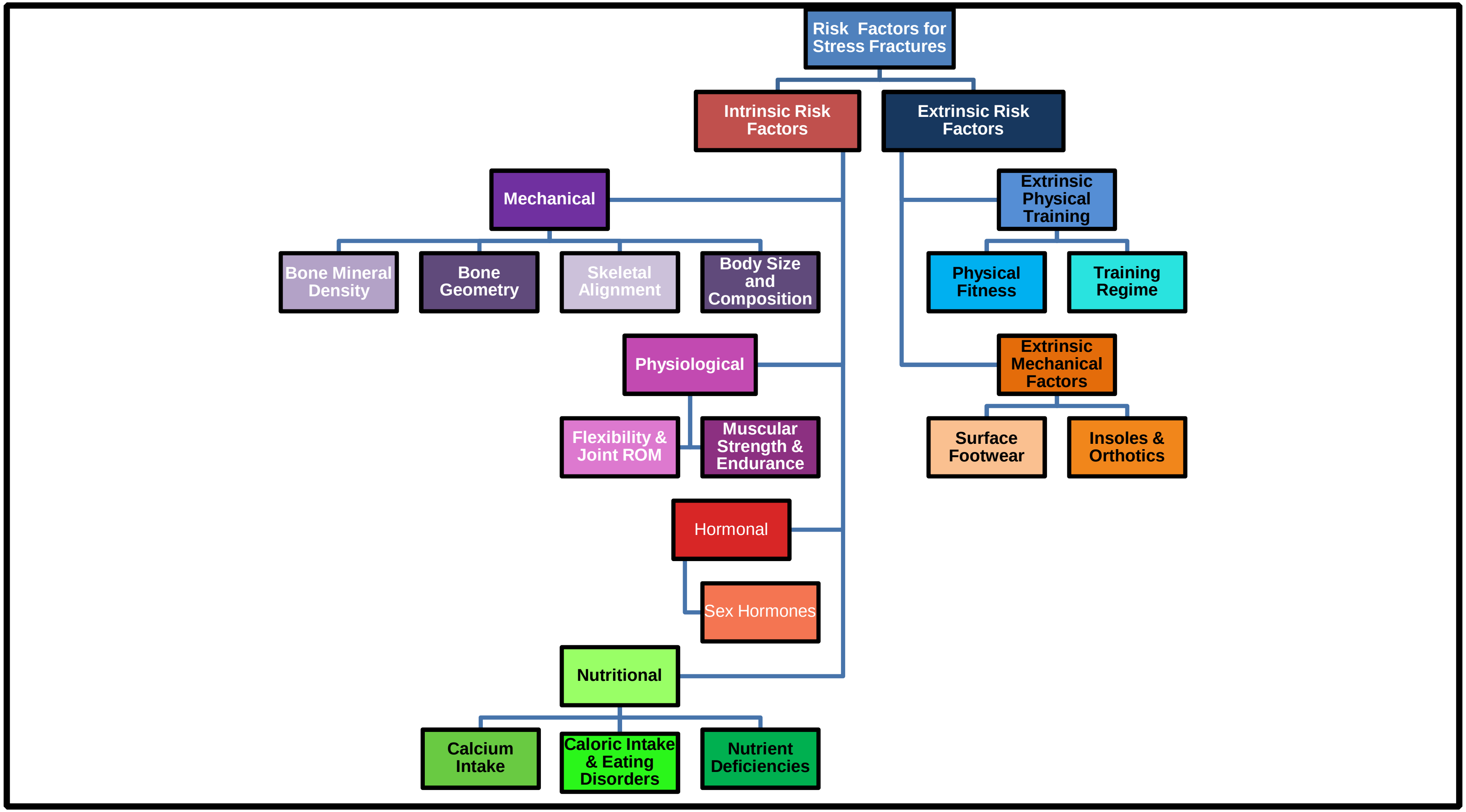
Key: # = Stress fracture rates; M = Males; F = Females; Foot = includes stress fractures of the metatarsal, tarsal, navicular and calcaneus.

From the 1940's through to the early 1990's most of the stress fractures were diagnosed in the foot, mainly in the metatarsals and calcaneus (Hullinger, 1944; Pester & Smith, 1992). During this period, stress fracture incidences in the lower leg, although reported, where not the most common. Studies ranging from the late 1980's through to the present, have reported a greater number of stress fractures in the leg. Stress fractures in the pelvis have also been reported especially amongst the female recruits (Wood & Krüger., 2007).

2.8 RISK FACTORS

Risk factors in exercise and sport-related injuries, including stress fractures, are commonly categorized as intrinsic or extrinsic (Jones *et al.*, 2002). Intrinsic factors are the characteristics of the individual sport or exercise participant, and include demographic characteristics, anatomic factors, bone characteristics, physical fitness and health risk behaviors. Extrinsic risk factors are factors in the environment or external to the individual participant, that influence the likelihood of being injured, such as equipment used or type of sport. Figure 2.4 reflects common intrinsic and extrinsic risk factors for which stress fracture research was identified.

Figure 2.4: Identified intrinsic and extrinsic risk factors within the stress fracture literature



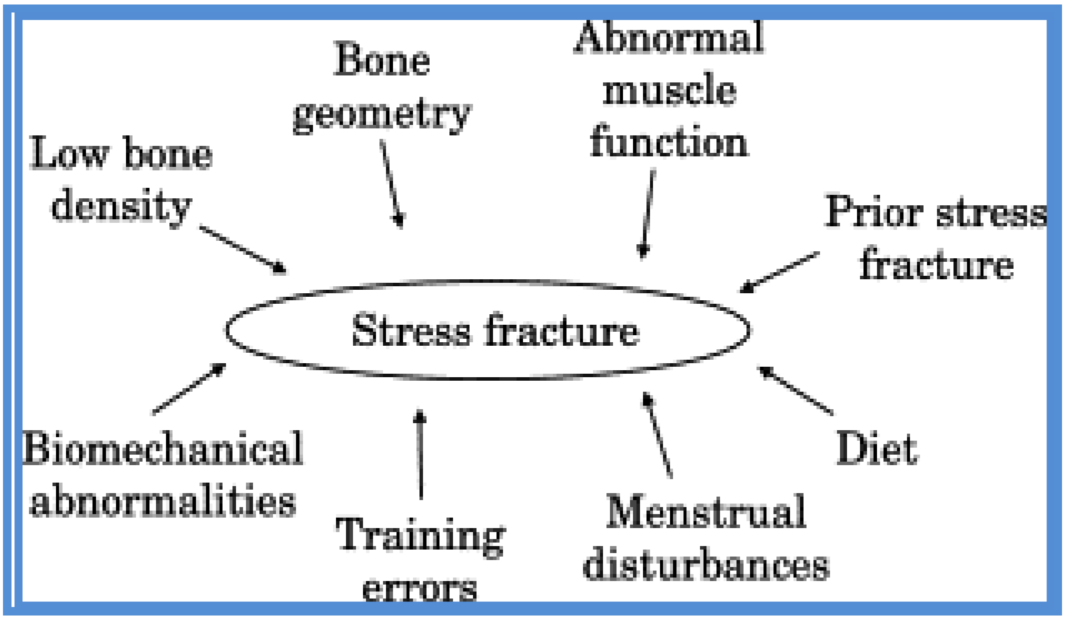


Figure 2.5: Factors that can influence the risk of stress fractures

2.8.1 Intrinsic risk factors

The reviewed studies that generate interest because of their obvious potential application to prevention of stress fractures, are those that look at the potentially modifiable intrinsic risk factors, such as physical fitness, sedentary lifestyle behaviours, or oral contraceptive use. However, possible unchangeable risk factors, such as sex, age, or race, should not be overlooked. These may influence the degree of risk for persons engaged in exercise, sports, or military training as well as play an important role when drawing up a study design and analysis (Jones *et al.*, 2002).

2.8.1.1 Demographic characteristics

2.8.1.1.1 Sex

Amongst demographic factors, the female sex is the most commonly identified intrinsic risk factor for stress fractures (Proztman & Griffis, 1977; Reinker &

Ozbourne, 1979; Kowal, 1980; Brudvig *et al.,* 1983; Lloyd *et al.*, 1986; Barrow & Saha, 1988; Zahger *et al.*, 1988; Brunet *et al.*, 1990; Myburgh *et al.*, 1990; Friedl *et al.*, 1992; Jones *et al.,* 1993a; Goldberg & Pecora, 1994; Bennell *et al.*, 1996; Bijur *et al.*, 1997; MacLeod *et al.*, 1999; Beck *et al.,* 2000; Bell *et al.,* 2000; Jones *et al.*, 2002; Shaffer *et al.*, 2006).

Researchers have shown that women performing the same prescribed physical activities as men during BT, incur stress fractures at incidences 2–10 times higher than those of men (Proztman & Griffis, 1977; Reinker & Ozbourne, 1979; Kowal, 1980; Brudvig *et al.,* 1983; Jones *et al.*, 1993a; Bijur *et al.*, 1997; MacLeod *et al.*, 1999; Armstrong *et al.*, 2004). Bell *et al.* (2000) found that although the crude injury rates indicated that women were at higher risk of injury than men, when the injury rates were adjusted for fitness, no significant difference existed between the two sexes. It therefore appears that much of the relationship between the injury and the sex of the individual may be explained by physical fitness, in particular, aerobic fitness, as opposed to the sex of the individual per se.

Investigation examining risk factors have suggested that this higher incidence of stress fractures in young women may be secondary to decreased BMD associated with eating disorders and irregular menses (Black, 1982; Myburgh *et al.;* 1990; Milgrom *et al.,* 1991). Studies of female runners with amenorrhea and irregular menses have shown greater risks of stress fractures. A retrospective review of medical records for 207 female collegiate athletes found that women with a history of menstrual irregularity experienced an incidence of stress fracture 3.3 times higher than that of women with regular menses (Lloyd *et al.*, 1986).

A survey conducted by Barrow and Saha (1988) on 241 female collegiate distance runners, reported that prevalences of stress fractures among female distance runners with very irregular and irregular menses were 1.3 and 1.7 times higher, respectively, than the prevalence among women with regular menstruation. A study of female college athletes found that seven of 25 women with cases of stress fractures had a history of menstrual irregularity, whilst none of the 25 uninjured controls had such a history (Myburgh *et al.*; 1990). A survey of 1,630 women in the US Army showed that those with a history of amenorrhea lasting more than 6 months were more likely to have experienced one or more stress fractures in their lifetime (Friedl *et al.*; 1992).

While studies, both of civilians and military groups strongly suggest that such an association exists, Armstrong *et al.* (2004) found no significant difference between female participants and female controls in terms of age at menarche onset or the number of reported menstrual periods in the previous 12 months.

2.8.1.1.2 Chronological age

Several military studies have examined the association of older chronological age with a higher risk of stress fractures (Brudvig *et al.,* 1983; Tomlinson *et al.,* 1987; Gardner *et al.*, 1988; Knapik *et al.,* 1993; Jones *et al.,* 1993b; Shaffer *et al.,* 1999a). The data is contradictory with respect to chronological age as a risk factor of stress fractures. Studies in military recruits have had conflicting results as to whether recruits in their late 20's and early 30's are at an increased risk for stress fractures compared to their younger counterparts (Brudvig *et al.,* 1983; Gardner *et al.*, 1988; Milgrom *et al.*, 1994).

Investigation of 15,994 male and 4,428 female Army trainees found that rates of stress fractures during eight weeks of Army BT were significantly higher for successively older chronological age groups (Brudvig *et al.,* 1983). Amongst 3,000 male Marine recruits, during 12 weeks of BT, the cumulative incidence of stress fracture was found to be 1.7 times higher in men over the chronological age of 21 years (Gardner *et al.*, 1988). A separate study of 1,296 male Marine recruits demonstrated a relative hazard of 1.07 per year of greater chronological age, after data was controlled for potentially confounding factors such as race, physical fitness, and physical activity level (Shaffer *et al.,* 1999a). The military studies reviewed indicated that older chronological age may heighten the risk of stress fractures, starting at an early chronological age, and that chronological age should be adjusted for when other risk factors are being assessed.

According to Snyder *et al.* (2006), the distribution of fractures among chronological age groups is more likely to be associated with training volume and intensity than with the chronological ages of the participants. There are no studies in athletes that suggest an independent effect of chronological age on the occurrence of stress fractures. Recently, Maquirriain and Ghisi (2006) found that the stress fracture incidence was significantly higher in male junior tennis players (20.3%) than in professional players (7.5%). They concluded that there was a high absolute risk (12.9%) of stress fractures in elite tennis players over a two year period with junior players having the highest risk.

2.8.1.1.3 Race

Several military studies have examined race as a potential risk factor for stress fractures (Brudvig *et al.,* 1983; Barrow & Saha, 1988; Gardner *et al.,* 1988; Jones *et al.* 1989; Friedl *et al.*, 1992; Milgrom *et al.,* 1994; Shaffer *et al.*, 1999a; Kelly *et al.*, 2000; Lappe *et al.,* 2001; Shaffer *et al.*, 2006).

Brudvig *et al.* (1983) documented that during eight weeks of BT, the cumulative incidence of stress fractures was higher for Caucasian male Army trainees (1.1%) than for African (0.6%) or other Non-White (0.1%) trainees. In this study, Caucasian female trainees during BT had the highest stress fracture rates of any group — 11.8%, compared to 1.4% for African women and 4.3% for other Non-White women.

Gardner *et al.* (1988) showed, in a study of more than 3,000 male Marine recruits followed during eleven weeks of BT, that Caucasian recruits experienced 2.5

times as many stress fractures as Non-White recruits. Friedl *et al.* (1992) conducted a survey of 1,630 women in the Army and found that the lifetime prevalence of self-reported stress fractures among Caucasian or Asian women was 1.6 times higher than that of African women.

Additionally in the Israeli Army, there was a significant difference in the stress-fracture incidence when Ethiopian recruits were compared with both Israeli-born and non-Israeli-born recruits. None of the Ethiopians sustained a stress fracture, in contrast to 24.8% of the other racial groups (Milgrom *et al.,* 1994).

On the contrary Winfield *et al.* (1997) found no significant difference between three racial groups (Caucasians, Africans and others) and their 101 female Marine Corp recruits. However, it must be noted that in this study, only nine stress fractures were sustained overall and the numbers in the Non-White groups were small. Additionally, Shaffer *et al.* (1999b) found no significant differences between Caucasian and Non-White racial groups after a multivariate analysis of data from 1,296 male Marine recruits that controlled for age, physical fitness, physical activity level, and other factors.

Shaffer *et al.* (2006) not only found that the lowest rates of stress fractures were among African women undergoing military training, but also that the Hispanic women were twice more likely to suffer a stress fracture than African women. Kelly *et al.* (2000) observed that Hispanic Navy female recruits had a significantly higher incidence of pelvic stress fractures than do African Navy female recruits. Shaffer *et al.* (2006) also observed a higher incidence rate of stress fractures amongst Asian and Caucasian women when compared to African women, but these rates were not statistically significant.

In the sporting world, a survey of female collegiate distance runners documented that Caucasian runners had a higher career prevalence of stress fractures (diagnosed by radiograph or bone scan) This prevalence that was 2.4 times higher than that of African runners and 1.9 times higher than that of other Non-White runners (Barrow & Saha, 1988). Although the study had a low response rate, the results suggest that the Caucasian race may be a risk factor among both collegiate athletes as well as among military personnel.

Generally, these military studies suggest that risk for stress fractures is greater for both male and female Caucasians than for other racial groups, including Afro-Americans, Hispanics and Ethiopians (Brukner *et al.,* 1999). Although the literature strongly suggests that Africans and Hispanics are less likely to develop stress fractures, the reasons for this are not clear. Even though it has been surmised that in these racial groups, protection may be offered in the form of higher bone density and larger bones, none of the studies have included bone mass or bone geometry as covariates during statistical analysis in order to evaluate the independent effects of race (Kelly *et al.,* 2000; Bennell & Brukner, 2005).

Lappe *et al.* (2001) found the incidence rate of stress fractures to be higher in Caucasians than in Africans. And this risk remained even when it was adjusted for Speed Of Sound (SOS) to account for the higher bone mass of the Africans compared to the other race groups.

Additional explanations for the increase protection offered to the African race include different biomechanical features that may protect against stress fracture development such as foot type and lower limb alignment, or anthropometrical features such as the amount of lean body mass (Giladi *et al.,* 1991; Shaffer *et al.,* 2006).

2.8.1.2 Anatomic factors

A few studies have obtained prospective data on anatomic factors that potentially could influence the risk of stress fractures. These anatomic factors can also be viewed as biomechanical factors as they are surmised to be those characteristics that alter the biomechanics of a movement and in this way, create stress-concentration areas in bone or promote muscle fatigue - possibly predisposing the individual to the development of a stress fracture (Hall, 2003). The biomechanical parameters studied include foot morphology, the Q angle and the discrepancy in leg length.

2.8.1.2.1 Foot morphology

The foot's structure will help determine how much force is absorbed by the foot and how much force is transferred to bone during ground contact. The high - arch foot (pes cavus) is more rigid and less able to absorb shock, so more force passes to the tibia and femur. The low-arch (pes planus) foot is more flexible, as stress is absorbed by the foot's musculoskeletal structures. This type of foot is also less stable during weight bearing and as the muscles have to work harder in order to control the excessive motion. This is surmised to contribute to muscle fatigue. Theoretically either foot type could predispose a person to a stress fracture (Brukner *et al.,* 1999).

The studies in which the link between foot morphology and stress fractures were investigated are summarized in Table 2.5. From the table it appears that that the risk for stress fractures is greater in male recruits who have a high foot arch than in males with a low foot arch (Giladi *et al.,* 1985; Simkin *et al.,* 1989; Brosh & Arcan, 1994; Kaufmann *et al.,* 1999). Giladi *et al.* (1985) found that among 287 Israeli Defense Force (IDF) trainees, persons with the highest foot arches sustained 3.9 times as many stress fractures as those with the lowest arches (pes planus or flat feet) (95% CI: 1.02, 15.38). These finding were supported by the Brosh and Arcan (1994) study in which a contact pressure display method was used to provide foot-ground pressure patterns and derived stress-intensity parameters. This study found that recruits with a high - arch were more likely to have sustained a stress fracture than recruits who had a low - arch.

Table 2.5: Studies that have investigated the association between foot morphology and stress fractures

Reference	Participants	Sample size	Sex	Measurement method	Results
Giladi *et al.*, 1985	Army-Israel	295	Males	Observation-NWB	SF risk greater in high - arch than in low - arch
Matheson *et al.* 1987	Athletes	320	Males	NS	Pronated - tibial and tarsal SF; Cavus - metatarsal and femoral F
Montgomery *et al.*, 1989	SEAL- US	505	Males	Observation-NWB	No relationship to SF
Simkin *et al.*, 1989	Army-Israel	295	Males	X-ray-WB	High – arch - higher risk for femoral and tibial SF Low - arch - higher risk for metatarsal SF
Brunet *et al.* 1990	Athletes	375 1130	Females Males	Self-report questionnaire	No relationship to SF
Brosh & Arcan. 1994	NS	42	Males	Contact - pressure display	High – arches - higher risk of SF
Ekenmann *et al.* 1996	Athletes	29 29	Males Females	Contact pressure during gait	No relationship to SF
Bennel *et al.*, 1996	Athletes	53 58	Females Males	Observation - WB	No relationship to SF
Kaufman *et al.*, 1999	US Navy	449	Males	Observation - WB	No relationship to SF
Constantini *et al.*, 2004	Army-Israel	83	Females	Observation - WB & footprints	No relationship to SF

In contrast, the association between foot type and stress fracture risk has not been reported in all studies investigating this association (Montgomery *et al.,* 1989; Bennel *et al.,* 1996; Ekenmann *et al.,* 1996; Kaufmann *et al.,* 1999). Montgomery *et al.* (1989) found that the incidence of stress fractures was similar in recruits who had cavus, neutral or plantus feet. Additionally, Kaufmann *et al.* (1999) conducted a 25-week prospective study on 449 trainees at the US Naval Special Warfare Training Center, who were classified into three equal-sized groups with high, normal, or low arch height, but found no significant difference between groups. In athletes it appears that foot type, whether assessed visually (Bennel *et al.,* 1996) or with the use of a pressure platform (Ekenmann *et al.,* 1996), is not a predictor of the likelihood of stress fractures.

However, the site of the stress fracture may play a role in the relationship between the foot type and incidence of stress fractures. Simkin *et al.* (1989) found, through the use of radiographs, that femoral and tibial stress fractures were more prevalent when higher arches were present, whilst higher incidences of metatarsal stress fractures were found in recruits with a lower arch. Additionally, researchers may fail to prove an association between specific foot types and stress fractures, because they have not grouped the data according to site of the stress fracture (Brukner *et al.,* 1999).

Available research suggests that foot arch height may influence the risk of incurring stress fractures associated with vigorous PT, but more research will be needed to define the nature of the association between arch type and stress fracture risk, particularly for women.

2.8.1.2.2. Genu varum, genu valgum and genu recurvatum

Other alignment features that have been assessed in relation to stress fractures include the presence of genu varum, genu valgum and genucurvatum. The majority of research assessing this relationship has not found any association with stress fractures (Giladi *et al.,* 1987; Matheson *et al.,* 1987; Montgomery *et al.,* 1989; Milgrom *et al.,* 1994; Bennell *et al.,* 1996). However, a prospective study of 294 male infantry recruits demonstrated a significant trend in stress fracture risk, increasing from persons with varus knees (bowed legs) to persons with the most valgus knees (knock-knees) (Cowan *et al.,* 1996). Additional research, that includes women, on knee morphology and leg alignment is needed.

2.8.1.2.3 Q angle

A second measure of knee alignment, namely, Quadriceps angle or Q angle, showed that male recruits with quadricep angles greater than 15° experienced a cumulative incidence of stress fracture 4.3 times higher than that of male recruits with quadricep angles of 10° or less (Cowan *et al.,* 1996). An analysis of the data obtained on 392 male trainees showed that greater valgus alignment of the knee was a significant risk factor for tibial stress fractures (Finestone *et al.,* 1991). A need exists for further study on this anatomic characteristic in women trainees. The exact degrees of anatomic malalignment will depend on the amount and intensity of training (Cowan *et al.,* 1996).Conversely, in other studies, no relationship has been found between Q angle and stress fracture occurrence (Montgomery *et al.,* 1989; Winfield *et al.*, 1997).

2.8.1.2.4 Leg - length

A leg - length discrepancy is theoretically postulated as a potential risk factor for stress fractures. As a result of the ensuing skeletal realignment and asymmetries in loading, body tortion, and muscle contraction, a leg length discrepancy is theoretically postulated as a potential risk factor for stress fractures (Ammann & Rizzoli, 2003). The majority of studies assessing the association between differences in right and left leg length and risk of stress fracture do suggest an association (Friberg, 1982; Brunet *et al.,* 1990; Bennell *et al.,* 1996).

Friberg (1982) found that in 130 cases of stress fractures in military male recruits, the longer leg was associated with 73% of tibial, metatarsal, and femoral stress fractures, whereas 60% of fibular fractures were found in the shorter leg. Similar findings have been reported in a cross-sectional survey of distance runners which found that the self-reported prevalence of stress fractures was 2.4 times higher amongst men reporting leg length differences, than amongst men without them. Amongst women with leg length differences, the prevalence was 2.3 times higher (Brunet *et al.,* 1990). Additionally, Bennell *et al.* (1996) found that 70% of the women who developed a stress fracture had a leg - length difference of more than 0.5 centimeters (measured in a supine position with a tape measure), compared with 36% of the women who did not have a stress fracture. Contrarily, in a study of 294 Army trainees, no difference in stress fracture incidence was found between persons with measured leg length discrepancies and persons without them (Cowan *et al.,* 1996).

2.8.1.3 Bone characteristics

A number of military and civilian studies have examined the relation between bone characteristics (geometry or density) and the occurrence of stress fractures (Margulies *et al.,* 1986; Milgrom *et al.,* 1988; Milgrom *et al.,* 1989; Pouilles *et al.,* 1989; Carbon *et al.,* 1990; Giladi *et al.,* 1991; Grimston *et al.,* 1991; Beck *et al.,* 1996; Beck *et al.,* 2000; Jones *et al.,*2002). Bone strength is related to both bone density as well as to bone geometry (Brukner *et al.,* 1999; Ducher *et al.,* 2006).

2.8.1.3.1 Bone density

Studies in which the relationship between bone density and stress fracture risk were investigated are contradictory. Several reasons for this have been documented, namely: differences in populations (military or athlete), types of sport, measurement techniques and bone regions under study. Another concern in interpretation of the data is that normally only lumbar spine, radius and/or proximal femur measurements are taken but ideally, to provide evidence for a causal relationship between low bone density and stress fracture, measurements should be taken at bone sites in which stress fractures occur. Unfortunately the prospective cohort study designs do not always make this possible.

With reference to men, contradictory evidence exists to support a causal relationship between bone density and risk of stress fractures. In 91 recruits who developed a stress fracture and in 198 controls no difference was found between their tibial bone densities (Giladi *et al.,* 1991). This finding was echoed in studies by Bennell *et al. (*1996). However, Beck *et al.* (1996) found significantly lower tibial and femoral bone density in 23 male recruits who developed a stress fracture compared to 587 controls who did not. This result may be flawed as the fractured recruits' weight, which was 11% less than the controls, was not statistically controlled for. Since weight is a major predictor of bone density, the groups should have been matched with reference to their weight or the weight should have been statistically controlled for.

Beck *et al.* (2000) conducted another prospective study of 693 female Marine recruits and 626 male Marine recruits and found that those with stress fractures had significantly lower mean bone mineral densities and narrower tibial widths than their controls. Another study reported that BMD was significantly lower among 41 stress fracture patients than among 48 recruits from the same units (matched for age, height, and weight), and that mean bone mineral content (BMC) increased significantly during 12 weeks of military training among 35 uninjured recruits (Pouilles *et al.,* 1989). Marguiles *et al.* (1986) found that mean BMC increased significantly, during fourteen weeks of BT, for both the 105 persons whose training was interrupted by stress fractures and other conditions, and the 144 persons who completed training. However, tibial bone width did not increase. The mean BMC of participants (with stress fractures) in these studies, was lower before training than that of persons who completed the training, but not significantly so.

The results of several of the military studies on BMD, bone width, and other bone parameters would have been much more meaningful and powerful if the investigators had determined the risk or incidence of stress fractures in recruits exhibiting different levels of bone strength (Jones *et al.,* 2002). Nevertheless, an association between lower measures of bone strength and higher risk of stress fractures is strongly suggested by these studies.

Results of civilian studies on the relation between stress fractures and BMD amongst athletes are mixed. Carbon *et al.* (1990) examined nine female athletes with stress fractures and compared to their nine controls, found no differences in mean BMD. Grimston *et al.* (1991) however reported that six female runners with a history of stress fractures had higher mean bone mineral densities in the lumbar spine and femoral neck than eight runners without stress fractures.

2.8.1.3.2 Bone geometry

When bones are loaded in tension or compression, several geometric measurements of lower limb bones (femur, tibia, fibula) provide potential resistance to injury. These measures include:

- the cross-sectional area of long bones - an indicator of the axial strength and resistance to compressive and shear forces;
- the Cross-Sectional Moment Of Inertia (CSMI) - a measure of bones' resistance to bending along either the anterior-posterior axis or the mediolateral axis of the bone;
- the section modulus; and
- BMD and bone width (Jones *et al.,* 2002).

The amount of load the bone can withstand before failing is directly proportional to the cross-sectional area of the bone (Brukner *et al.,* 1999). Bones that have a larger cross-sectional area and in which bone tissue is distributed further away from the neural axis, will be stronger when subjected to a load and will be less likely to fracture (Buckwalter *et al.,* 1995; Hall, 2003; Greene *et al.,* 2005). The strength in bending of the long bone shaft to bending and torsional stresses should be proportional to its section modulus and inversely related to its length.

> *"Current studies show that, independent of body size, those who suffer stress fractures, in both genders, have smaller section moduli in the femur and tibia. Additionally, when section moduli are normalized to bone length in the strength indices, values remain 7% lower in cases of both men and women and in both bones when compared to controls" (Beck et al., 2000: 441).*

These findings are consistent with previous studies (Giladi *et al.,* 1987; Milgrom *et al.,* 1989; Beck *et al.,* 1996; Giladi *et al.,* 1997).

A prospective study performed on 295 Infantry trainees reported that 31% developed 184 stress fractures confirmed by bone scans (Milgrom *et al.,* 1988). A multivariate analysis identified the anterior-to-posterior axis of the CSMI to be the variable most highly associated with stress fracture occurrence. In a follow-up analysis of this data, cumulative incidences of tibial, femoral and total stress fractures were found to be significantly higher in the low-CSMI group, with risk ratios 1.8–3.6 times higher than those in the high-CSMI group (Milgrom *et al.,* 1989). The fact that Army trainees with high tibial CSMIs around the anterior-posterior axis experienced a lower incidence of stress fracture, suggests that bending in the mediolateral direction is a cause of stress fractures (Milgrom *et al.,* 1988; Milgrom *et al.,* 1989). This may also explain why the most common location of tibial stress fractures is the medial cortex (Jones *et al.,* 2002).

Similarly, in a prospective study of 626 male Marine recruits conducted during 12 weeks of BT, 3.7% developed stress fractures, confirmed by bone scans.

Investigators found that mean values for the cross-sectional area, the section modulus, smaller moment of inertia and the width of the tibia, were significantly lower among trainees who developed stress fractures (Beck *et al.,* 1996). Additionally,

> "**…***the smaller dimensions were limited to the long-bone diaphyses, not joint size, which suggest specificity in the structural deficit in the fracture group. Evidence exists that compared with joint size, diaphyseal cross-sectional dimensions are more environmentally influenced. This could indicate that the stress fracture group's bones had not been sufficiently loaded before Basic Training in order to develop cortices strong enough to withstand the subsequent stresses. In military recruits who are subjected to intense, unaccustomed physical activity, the presence of smaller and weaker bones may lead to a higher rate of bone microdamage. If there is inadequate time for adaptive cortical remodeling to occur, a stress fracture could result"* (Brukner *et al.,* 1999:53-54).

2.8.1.4 Physical fitness

Total fitness, also termed wellness, includes mental, emotional, social and physical aspects. It is a broad term denoting dynamic qualities that allow one to satisfy needs regarding mental and emotional stability, social consciousness and adaptability, spirituality and physical health (Weaver *et al.*, 2001).

Physical fitness can be defined as the healthy and efficient functioning of various body systems that allows one to engage in activities of daily living, recreation and leisure. Important components of health-related physical fitness include cardiorespiratory endurance (aerobic physical fitness), muscular strength, muscular endurance, flexibility and body composition (Jones *et al.*, 1999).

Within the military setting, recruit physical fitness is assessed through a standardised physical fitness test. These physical fitness tests differ from country to country and between service corps; however, they are all comprised of a combination of muscle endurance and aerobic fitness tests, such as 2,4km run, maximal push-ups and sit-ups in two minutes, shuttle runs and 4km walk

(Gordon *et al.*, 1986a; Gordon *et al.*, 1986b; Shaffer *et al.*, 1999a; Beck *et al.*, 2000; Bell *et al.*, 2000; Rosendal *et al.*, 2003; Knapik *et al.*, 2005; Dyrstad *et al.,* 2006).

Two methodologies have been utilised to assess the correlation between lack of prior physical activity and/or poor physical conditioning, with the incidence of stress fractures. The first is through the use of questionnaires where the participants report on past and current levels of activity (Montgomery *et al.*, 1989; Gardner *et al.*, 1988; Cline *et al.,* 1998). The second method is comprised of various aerobic fitness tests which indirectly measure the fitness component. Cardiorespiratory endurance is typically measured indirectly by a timed run, where predicted VO_2 max is then calculated; muscle strength and endurance is often measured in the number of sit-ups, push-ups and pull-ups in a specific time frame; flexibility is often assessed using the sit-and-reach method or various goniometric measurements of joints, whilst the body composition is assessed using the skin fold method or DEXA (Jones *et al.,* 1993a; Bijur *et al.,* 1997; Beck *et al.,* 2000; Bell *et al.*, 2000; Knapik *et al.*, 2001;Jones *et al.*, 2002; Rauh *et al.,* 2006; Shaffer *et al.*, 2006).

Some military studies have reported a correlation between self-reported previous physical activity levels and rate of stress fracture during BT, while others have failed to corroborate a relationship. Montgomery *et al.* (1989) found that male trainees, with a running history averaging at least 25 miles per week in the previous year, had a lower incidence of stress fractures (3%) than trainees averaging less than 4 miles per week (11.5%). Similarly, Gardner *et al.* (1988) found the stress fracture rate to be 24 times greater in the previously inactive group than in the very active group. In a prospective cohort study in female US Marines, those who reported running less than 2.8 miles per session, had a 16.3% incidence of stress fractures during BT compared with 3.8%, who ran more than 2.8 miles per session (Winfield *et al.*, 1997).

In a study of female US military recruits, the authors reported that higher leisure activity energy expenditure tended to be associated with a lower stress fracture risk (p = 0.06) (Cline *et al.,* 1998). Similarly, Shaffer *et al.* (1999a) revealed, with the use of an algorithm of five physical activity questions and a 2.4km run time, that 21.6% of 'high risk' individuals experienced more than three times as many stress fractures as 'low risk' individuals. This suggests that the risk of stress fractures is increased by poor physical fitness and low levels of physical activity prior to entering into recruit training.

2.8.1.4.1 Aerobic physical fitness

The most consistently documented risk factor for injuries in US Army studies is low cardiorespiratory endurance, measured by running performance. Both men and women with increasingly low running time, indicate trends of increasing risk of injury (Jones *et al.,* 1993a; Bijur *et al.,* 1997; Shaffer *et al.*, 1999a; Beck *et al.*, 2000; Bell *et al.*, 2000; Jones *et al.*, 2002; Rauh *et al.,* 2006; Rosendal *et al.*, 2003; Knapik *et al.*, 2005; Shaffer *et al.,* 2006). Stress fractures were included amongst the injuries documented, however the link between poor aerobic fitness and stress fracture development was unclear as some studies showed a clear association whilst others did not (Brukner *et al.,* 1999).

The majority of recent researchers tend to suggest that physical fitness or prior physical activity may be a predictor of stress fracture risk in individuals undergoing BT. A study of 1,078 Marine recruits found that lower aerobic fitness, as measured by longer running time on a 1.5 mile (2.4 km) run, was strongly associated with higher cumulative incidence of bonescan or radiographically confirmed stress fractures. Shaffer *et al.* (2006) reaffirmed this in a study that found that low aerobic fitness, as measured by the timed run, was strongly associated with consequent stress fracture injury. As the running time increased (slower runners), the risk of stress fractures increased.

This finding was consistent with three other studies that reported that slower run times were associated with greater risks of lower extremity injury amongst women undergoing military training (Jones *et al.,* 1993a; Bijur *et al.,* 1997; Bell *et al.,* 2000). Jones *et al.* (1993a) reported than in female Army recruits, the slower half of women on an initial entry one mile (1.6 km) run test, experienced significantly more clinically identified stress fractures than the faster women. In the same study, investigators observed that amongst male Army trainees in the slower half of the initial entry one mile run test, 4.8% developed stress fractures as compared to none of the faster recruits.

It seems logical that low aerobic fitness, as measured by a timed run, would be associated with a higher risk of injury during military training. Recruits must repeatedly perform activities such as walking, marching or running, which might increase overuse mechanisms of the musculoskeletal system. Those who are more aerobically fit, may be protected from injury as they may have performed similar types of activities that allowed the body to adapt to the increasingly intense demands on the musculoskeletal system that occur during military training (Shaffer *et al.,* 2006).

A low running distance per week has also been associated with an increase in stress fracture incidence. A study of female Marine Corps officer candidates, who ran 4.5 or fewer kilometers per week before entering officer training, had a higher incidence of stress fractures (Windfield *et al.,* 1997). This finding is similar to that of a study of women undergoing BT that did not run, or reported running less than a mean of 2.4km per run, prior to the start of BT. Because of this, they had an increased risk of overall stress fractures (Shaffer *et al.,* 2006).

Conversely, in a large study of 295 male recruits aged 18 to 20 years neither aerobic fitness, measured by calculating the predicted VO_2 max, nor self-reported pre-training participation in sport activities was related to stress fractures (Swissa *et al.,* 1989). This lack of association was confirmed in other large studies of male recruits (Giladi *et al.,* 1991; Hoffman *et al.,* 1999).

Poor physical conditioning does not seem to apply to athletes, as stress fractures often occur in well conditioned individuals who have been training for years (Välimäki *et al.,* 2005). Although the data is conflicting, low levels of aerobic fitness before BT have been consistently identified as a risk factor amongst women (Jones *et al.,* 1993a; Winfield *et al.,* 1997; Bell *et al.,* 2000; Shaffer *et al.,* 2006). As baseline fitness is a modifiable factor it is an area which requires more attention. Shaffer *et al.* (2006) suggest that objective measures, such as run time, previous aerobic and high activity levels, are consistent in predicting stress fractures during military training for both male and female soldiers.

2.8.1.4.2 Muscle strength and muscle endurance

Although the effect of muscle strength and endurance on injury rates and risks has been well documented, the effect of muscle strength and endurance on injury rates and stress fracture risk in military and athletic populations, has not been the subject of intensive study (Jones & Knapik*,* 1999; Jones *et al,* 2002).

Research on 289 Israeli infantry trainees found that persons who developed stress fractures performed fewer leg thrusts on a timed test, indicating lower muscle endurance (Giladi *et al.,* 1991). An investigation conducted by Beck *et al.* (2000) on 626 male and 693 female Marine recruits found that male and female recruits who sustained stress fractures, performed lower mean numbers of sit-ups on a timed test, indicating lower muscle strength and endurance.

Muscle fatigue is a likely contributor to stress fractures in military recruits (Burr, 1997; Beck *et al.,* 2000; Jones *et al.,* 2002; Armstrong *et al.,* 2004). Muscle fatigue and the resulting increased bone strain, may contribute to stress fracture injury after daily strenuous exercise. Thus, fatigue in the musculature of the lower leg is consistent with the observed incidence of stress fracture and ankle sprain injury in military recruits undergoing rigorous BT (Almeida *et al.,* 1999; Beck *et al.,* 2000; Armstrong *et al.,* 2004). Additionally, significantly smaller thigh girths were reported in recruits who developed stress fractures than those who did not (Beck *et al.,* 2000; Armstrong *et al.,* 2004). In another study, six female runners who had sustained stress fractures, exhibited higher impact and propulsive forces on a force plate than did eight runners who did not have stress fractures (Grimston *et al.,* 1991).

This provides evidence that leg muscles in fracture participants are less likely to generate enough force to protect bone from unnecessary bending (Beck *et al.,* 2000; Armstrong *et al.,* 2004). This finding is supported, in part, by the fact that male participants performed 25 fewer push-ups than the male controls did an indication of lower whole body muscular strength and endurance in the injured male recruits (Armstrong *et al.,* 2004). The effect of muscle strength and endurance on stress fracture risk in military and athletic populations needs further study.

2.8.1.4.3 Flexibility

Flexibility of muscles and joints may directly influence stress fracture risk by altering the forces applied to bone. Numerous variables have been assessed, including range of rear-foot inversion-eversion, ankle plantarflexion-dorsiflexion, knee extension-flexion and hip rotation-extension, together with length of calf muscles, hamstring muscles, quadriceps muscles, hip adductor muscles and hip flexor muscles (Brukner *et al.,* 1999).

Of the variables, only hip external-rotation and ankle dorsiflexion range of motion have been associated, albeit inconsistently, with stress fracture development (Hughes, 1985; Giladi *et al.,* 1987; Giladi *et al.,* 1991; Milgrom *et al.,* 1994).

An Israeli study prospectively assessed hip range of motion among 289 Israeli infantry trainees, of whom 89 subsequently developed stress fractures (Giladi *et al.,* 1987; Giladi *et al.,* 1991). Recruits with external rotation of the hip greater than 65°, experienced an incidence of stress fracture 1.8 times higher than that of recruits with lower degrees of rotation (Giladi *et al.,* 1987). Hip range of motion persisted as a risk factor in a multivariate analysis of the data (Giladi *et al.,* 1991). The risk for tibial stress fracture increased 2% for every 1° increase in hip external-rotation range. However, in three prospective studies, these findings failed to be confirmed (Montgomery *et al.,* 1989; Bennell *et al.,* 1996; Kaufmann *et al.,* 1999). It is possible that the Israeli recruits represent a separate population as their average hip external-rotation range was much higher than that reported by other populations (Brukner *et al.,* 1999).

Hughes (1985) found that restricted ankle-joint dorsiflexion was related to an increased risk of metatarsal stress fractures. The recruits who had a reduced range were 4.6 times more likely to develop a metatarsal stress fracture. Conversely, two studies of more than 400 Navy Special Warfare trainees investigated the association of several measures of lower extremity flexibility, including plantarflexion-dorsiflexion, with stress fractures. Neither found associations between these variables (Montgomery *et al.,* 1989; Kaufmann *et al.,* 1999). This may be because the data was analysed for all stress fracture sites combined, thereby masking a true relationship (Brukner *et al.,* 1999).

The difficulty involved in assessing the role of muscle and joint flexibility in stress fractures, may be related to a number of factors, including the relative imprecise measurement methods, the heterogeneity of these variables and the fact that both increased and decreased flexibility may contribute (Brukner *et al.,* 1999).

According to Shaffer and Uhl (2006), lower extremity stretching before training does not offer a protective effect from stress fractures or reactions. Studies involving stretching concluded that pre-exercise stretching did not reduce the incidence of muscle soreness or lower extremity injuries, including stress fractures, in young active adults involved in running and marching (Yeung & Yeung, 2001; Herbert & Gabriel, 2002). This raises questions about the efficacy of pre-exercise stretching for the prevention of lower extremity injuries, including stress fractures.

2.8.1.5 Body size and composition

Theoretically, body size and soft-tissue composition could affect stress fracture risk both directly, by influencing the forces applied to the bones and indirectly by influencing bone density or menstrual function (Brukner *et al.,* 1999). Various potential risk factors related to body size and composition have been investigated including height, weight, skinfold thickness, Body-Mass Index (BMI), total and regional lean mass and fat mass, limb and segment lengths and body girths and widths. Simple anthropometric techniques have usually been used as measurement tools, however, DEXA is being used with more frequency (despite its cost) due to its high accuracy rate.

Among the athletic population, the role of body-habitus variables has been evaluated, but no researchers have reported differences in height, weight, BMI or fat mass for athletes who have sustained a stress fracture, compared to their matched controls (Barrow & Saha, 1988; Bennell *et al.,* 1996).Failure to show an association may be due to the fact that athletes who play a specific sport tend to be homogenous in body composition and somatotype (Brukner *et al.,* 1999).

In military populations, body size may be a risk factor as the size variations amongst recruits are likely to be greater than those amongst athletes. A few military studies have investigated the relation between the occurrences of stress fractures and body composition and body stature.

BMI has been both directly and inversely associated with stress fracture rates (Zanker & Cooke, 2004). Discrepancies in the literature occur, in part, because of the operational definition of BMI and its application. In studies in which a high BMI has been linked with an increased risk for stress fractures, it is tied to poor physical conditioning (Jones *et al.,* 1993a). In contrast, Drinkwater *et al.* (1986) reported that weight gain - and a resultant increase in BMI - increases BMD and resumption of menses.

A number of prospectively measured indicators of body stature, including weight, height, neck girth, waist girth, thigh girth and calf girth, were found smaller among 23 Marine recruits, who developed stress fractures during 12 weeks of BT than among the 587 recruits who did not develop stress fractures (Beck *et al.,* 1996). BMI (weight (kg)/height (m) ^{2}), a surrogate measure for percentage of body fat, was also significantly lower among stress fracture patients. The authors concluded that "**…***both small body weight and small diaphyseal dimensions relative to body weight are factors predisposing to the development of stress fractures"* (Beck *et al.,* 1996: 645). The researchers surmised that weight packs, and other equipment, were carried regardless of the recruits' body weight. It is also possible that the fracture group's lower BMI was indicative of relatively lower muscle mass and/or poorer physical conditioning before training started.

Similarly, others have reported a risk association between stress fractures and shorter stature (Jones *et al.,* 1993a; Beck *et al.,* 1996), and higher BMI (Lauder *et al.*, 2000).

Conversely, a large study of 392 infantry trainees prospectively assessed height, weight, thigh and calf girths and found no association with stress fracture incidence (Finestone *et al.,* 1991). Similarly, BMI was not significantly associated with the odds of injury in a multivariate analysis of data from another study of Israeli recruits (Giladi *et al.,* 1991). Shaffer *et al.* (2006) also reported no significant association between height, body weight and BMI with stress fracture incidence. Other military studies have also failed to show an association between stress fractures and various parameters of body size (Giladi *et al.,* 1991; Taimela *et al.,* 1990; Winfield *et al.,* 1997; Cline *et al.,* 1998).

Rauh *et al.* (2006) did not show a significant association between height, body weight, or BMI and stress fractures. They did however observe increased, but not significant, trends for stress fractures in those considered overweight and underweight. Their lack of significant findings, however, may be partially due to small numbers of recruits classified as overweight (2.4%) and underweight (7.7%).

Percentage of body fat and BMI could have a bimodal association with injury risk, with both the least “fat” and the most “fat” persons being at greater risk of incurring a stress fracture (Jones *et al.,* 1993a). Therefore, comparisons of mean values for injured and uninjured persons will be especially misleading, as will multivariate analyses that treat BMI as if its association with injury risk were linear.

Acute weight loss was found to be a significant risk factor for stress fracture injuries in both male and female recruits (Armstrong *et al.,* 2004). Whilst, in a study of 2591 Israeli soldiers, those with stress fractures weighed less than the controls (Givon *et al.,* 2000).

In female Marine recruits undergoing BT, a narrow pelvis(widest point from the left to the right side of the iliac crest (≤ 26 cm) was associated with a greater risk of stress fracture (p, 0.09) (Winfield *et al.,* 1997). Women recruits who had a narrow pelvis had a stress fracture incidence of 14% compared to 4% in the women who had a wider pelvis. Thus they had a relative risk of 3.57 greater compared with the ‘normals’. An explanation for this finding is not clear, as a wider pelvis has typically been attributed to increased biomechanic stresses through an increased Q angle. However, it is possible that a narrow pelvis in this group of Marines, is a marker for some other risk factor for stress fractures (Brukner *et al.,* 1999).

2.8.1.6 Menstrual disturbances

2.8.1.6.1 Sex hormone

Compared to the general female population, female athletes have a higher prevalence of menstrual disturbances including anovulation, oligomenorrhoea, and delayed onset of menarche, abnormal luteal phase and amenorrhoea (Nattiv *et al.,* 1997). Stress fractures may, in fact, be more frequent in female athletes with menstrual disturbances (Brukner *et al.,* 1999). Menstrual disturbances may also predispose female recruits to stress fractures.

In a study of 101 female Marines, the incidence of stress fractures in those with fewer than 10 periods per year was 37.5% compared with 6.7% in those with 10 to 13 periods per year (Winfield *et al.,* 1997). Similar results, that suggest a history of amenorrhea as a risk factor for stress fractures support these findings (Friedl *et al.,* 1992, Rauh *et al*., 2005; Rauh *et al.,* 2006; Shaffer *et al.,* 2006). However, Shaffer *et al.* (2006) found that only women who reported no menses during the whole year before commencing with BT had a greater likelihood of stress fracture than did women who reported 10 to 12 menses per year. They also found that female recruits who reported secondary amenorrhoea during the year before training, were at higher risk for pelvic or femoral stress fractures. It suggests that prolonged lack of menses may be a better predictor of stress fracture incidence during a structured military training programme (Rauh *et al.*, 2005; Rauh *et al.,* 2006).

Conversely, Kelly *et al.* (2000) found no association between secondary amenorrhoea and pelvic stress fractures in navy recruits. Cline *et al.* (1998) also found that the menstrual patterns did not differ in a study of 49 female soldiers with stress fractures compared to the 78 soldiers with no orthopaedic injuries, although the number of soldiers, with menstrual disturbances, was relatively low.

The cause for the above may be attributed to lowered estrogen levels resulting in lower bone density, accelerated bone remodeling or negative calcium balance, or the interaction of these variables. Studies have shown lower axial bone density in athletes with amenorrhoea or oligomenorrhoea compared with their eumenorrhoeic counterparts and/or sedentary controls (Drinkwater *et al.,* 1984; Rutherford, 1993; Micklesfield *et al.,* 1995; Tomten *et al.,* 1998).

Estrogen deficiency leads to accelerated bone remodelling. The bone is in a weakened state and hence more likely to accumulate micro damage if subjected to repeated loading, as bone resorption occurs before bone formation during the bone remodeling process. Estrogen loss also causes increased calcium excretion, which can result in a negative calcium balance if dietary calcium is inadequate (Brukner *et al.,* 1999).

2.8.1.6.3 Onset of menarche

The relationship between onset of menarche and risk of stress fracture is unclear. Some authors have found that athletes with stress fractures have a later onset of menarche (Carbon *et al.,* 1990; Bennell *et al.,* 1996), while others have found no relationship (Myburgh *et al.,* 1990; Armstrong *et al.,* 2004). Onset of menarche was an independent risk factor for stress fractures in female track and field athletes, with the risk increasing by a factor of 4.1 for every additional year of age at menarche onset (Bennell *et al.,* 1996). The relationship between onset of menarche and bone density in female athletes is unclear, with some investigators finding significant negative correlations at a number of bone sites (Dhuper *et al.,* 1990; Warren *et al.,* 1991; Robinson *et al.,* 1995) and others not (Myburgh *et al.,* 1990; Rutherford, 1993).

An association between delayed onset of menarche and stress fractures may be explained by a lower rate of bone mineral accretion during adolescence and a resultant decreased peak bone mass (Brukner *et al.,* 1999). A later onset of menarche has also been found in association with menstrual disturbance, decreased body fat or bodyweight, lowered energy intake and excessive pre-menarcheal training (Frisch *et al.,* 1981; Moisan *et al.,* 1990). All of these could feasibly influence stress fracture risk (Brukner *et al.,* 1999).

2.8.1.7 Health risk behaviours

Questionnaires have been used to study associations of injury risks with lifestyle behaviours and habits (eg physical activity and smoking) among military populations (Jones *et al.,* 1999; Popovich *et al.,* 2000; Heir & Eide, 1997 ; Lappe *et al.,* 2001). Questions about levels of physical activity prior to entering the service and the frequency of the activity, have provided important clues on the effect of past activity on current risk of PT related injuries and stress fractures (Jones *et al.,* 1999)

2.8.1.7.1 Lifestyle behaviours

Several military studies have examined the association between previous levels of physical activity and risk of stress fractures during military training (Gardner *et al.,* 1988; Montgomery *et al.,* 1989; Jones *et al.,* 1999; Shaffer *et al.,* 1999a).

Several prospective studies of US Army recruits and US Marine Corps recruits have reported that sedentary lifestyle behaviour prior to entering the military is associated with higher risks of injury during the initial BT (Gardner *et al.,* 1988; Jones *et al.,* 1993a; Jones *et al.,* 1993b). Before the start of training, 3010 Marine recruits completed a survey on past health and health behaviors, rating their previous physical activity level in five categories from inactive to very active. The study documented a significant trend of higher cumulative incidence of nine (radiographically confirmed) stress fractures among those recruits with successively lower levels of previous activity (Gardner *et al.,* 1988).

Another study of Marine recruits showed higher rates of stress fractures among those least physically active prior to BT (Shaffer *et al.,* 1999a). Marine recruits who reported never or only occasionally sweating experienced significantly more stress fractures, along with those with fewer months of running before entering BT. A survey of 449 Navy special warfare trainees (Montgomery *et al.,* 1989) and a study of Finnish Army recruits reported similar findings (Taimela *et al.,* 1990).

Conversely, a military study found no relation between the duration of training or the amount of running prior to BT and stress fracture risk (Swissa *et al.,* 1989).

The preponderance of the data from military studies indicates that person, who engages in more physical activity, particularly running, will experience fewer stress fractures when beginning a physically demanding training programme. Additionally, a college sports medicine clinic reported that, over a three-year period, 67% of stress fractures treated occurred among freshmen, while only 17% occurred amongst sophomores, 9% amongst juniors, and 7% amongst seniors. This suggests that previous activity is protective against future injuries associated with PT (Goldberg & Pecora, 1994; Jones *et al.,* 1999).

2.8.1.7.2 Smoking

Tobacco smoking is another behavioural health risk factor reported to be associated with a higher risk of injury among military recruits. A study investigating the impact of lifestyle behaviours on stress fractures in female army recruits found that both a current and a past history of smoking increased the risk of stress fractures in their cohort of young women. Furthermore, the relative risk increased with increasing packets of cigarettes per day and increased years of smoking. This study was unique as it provided an opportunity to evaluate the association between smoking and risk of stress fractures as the other group normally at risk for stress fractures, such as athletes, usually do not smoke (Lappe *et al.,* 2001).

Similarly, a pre-training survey of 915 female Army trainees determined that those who smoked one or more cigarettes during the year prior to eight weeks of BT incurred stress fractures or stress reactions of bone more frequently than those who did not smoke (RR = 2.2, 95% CI: 1.4, 3.6) (Altarac *et al.,* 2000). Among 1,087 male Army trainees in the study, the risk was higher for those who smoked (RR = 1.4, 95% CI: 0.7, 2.9). A survey of 1,630 women in the Army found that current smokers had increased risks of stress fractures (RR = 1.7, 95% CI: 1.2, 2.1) (Friedl *et al.,* 1992). Similarly, several studies of male Army trainees and soldiers in operational units, found a statistically significant association between cigarette smoking and overall risk of training-related injuries in general (Jones *et al.,* 1993b; Reynolds *et al.,* 1994).

Numerous investigators have reported an inverse relationship between BMD and smoking (Daniell, 1976; Pocock *et al.,* 1989; Slemenda *et al.,* 1992). Slemenda *et al.* (1992) found that the rate of change in radial bone mass was negatively correlated with the number of cigarettes smoked per day. An association of smoking with osteoporotic hip fractures has also been reported (Williams *et al.,* 1982; Grisso *et al.,* 1994; Cummings *et al.,* 1995). Former smokers have a fracture risk that is intermediate between that of people who have never smoked and current smokers (Grisso *et al.,* 1994: Cummings *et al.* 1995). Since both osteoporotic hip fractures and stress fractures are fragility fractures, (they occur during activities which most participants complete without fracturing) it is plausible that smoking might also increase the risk of stress fractures. This aspect merits attention as more than 30% of women in active duty are smokers (Lappe *et al.,* 2001).

Smoking is also predictive of stress fractures even when adjusted for bone density, supports an analysis by Law and Hackshaw (1997) who found that the risk of hip fracture in elderly smokers may be slightly greater than expected from their lower bone density. This suggests that nicotine and/or other smoking products, directly affect the strength of bone (Lappe *et al.,* 2001).

2.8.1.7.3 Alcohol

Long-term excessive alcohol intake has been associated with low bone mass in both male and female groups (Johnell *et al.,* 1982; Diamond *et al.,* 1989; Seeman, 1996). It is also well established that alcohol abuse confers a high risk for fragility fractures, although this risk is said to be more pronounced in men than in women (Johnell *et al.,* 1982; Hemenway *et al.,* 1988; Seeman, 1996).

In persons who drink moderate amounts of alcohol, the association between alcohol intake and fracture is equivocal (Felson *et al.,* 1988; Hemenway *et al.,* 1998). Lappe *et al.* (2001) reported that excessive intake of alcohol, defined as a self-report of ten or more alcoholic drinks a week, is a risk factor for stress fractures, even when controlled for age, bone density and race.

Some researchers have reported a dose response to alcohol for bone loss and fractures (Felson *et al.,* 1988; Hemenway *et al.,* 1998). However, many of the studies of alcohol and bone do not control for smoking. Since the consumption of alcohol often goes hand-in-hand with smoking, it is difficult to ascertain how much of the increased risk of osteopenia and osteoporosis is due to alcohol alone, and how much may be attributed to the additional effects of smoking (Lappe *et al.,* 2001).

In female recruits on BT, excessive alcohol intake was associated with stress fractures even when controlled for smoking (although the relative risk was much less than the unadjusted risk) (Lappe *et al.,* 2001). Alcoholism has been associated with a number of factors known to increase the risk for osteoporotic fractures, namely: liver disease, poor nutrition, malabsorption, parathyroid dysfunction, hypogonadism, vitamin D deficiency, sub-optimal nutrition and increased cortisol output (Carter *et al.,* 1981). Additional, a study investigating the direct effect of ethanol on bone formation found that excessive alcohol consumption decreases bone formation and leads to defective mineralization (Diamond *et al.,* 1989).

2.1.8.7.4 Female contraception

Some authors have claimed that the use of an Oral Contraceptive Pill (OCP) may, theoretically, protect against stress fracture development by providing an additional source of estrogen. This reduces the remodelling rate and in turn, improves bone quality and/or density. However, studies have failed to prove a protective effect between birth control hormone use and the incidence of stress fractures (Bennell *et al.,* 1996; Cline *et al.,* 1998; Rauh *et al.,* 2006; Shaffer *et al.,* 2006).

A two year prospective study found that oral contraceptive treatment in combination with an exercise programme was associated with significant decreases in spine BMC in young sedentary women. Therefore, oral female contraception use may not be as protective for bone as theoretically claimed (Weaver *et al.,* 2001).

Conversely, a cross-sectional study found that runners using the OCP for at least one year, had significantly fewer stress fractures (12%) than non-users (29%). (Barrow & Saha, 1988). This was supported by the findings of Myburgh *et al.* (1990). The weaknesses of study design in both of these investigations suggest the need for more and larger studies on the impact of estrogen - containing oral contraceptives on the incidence of stress fractures (Jones *et al.,* 2002).

2.1.8.7.5 Medical history of previous injury

Studies on risk factors for injury amongst athletes, have shown prior injury to be related to subsequent injury (Macera *et al.,* 1989; Rauh *et al.,* 2000). However, in military studies, the relationship between prior injury and the risk of stress fractures during BT appears to be equivocal (Milgrom *et al.,* 1985; Giladi *et al.,* 1986; Ross & Woodward, 1994; Shaffer *et al.,* 1999b; Rauh *et al.*, 2005; Rauh *et al.,* 2006; Shaffer *et al.,* 2006).

Shaffer *et al.* (1999a) reported a lower risk of stress fracture occurrence amongst male recruits who reported a prior injury with full recovery as compared to male recruits who reported a prior injury without full recovery or no prior injury. They suggested that prior injury may serve as an indicator of past physical activity and that past activity is protective against stress fractures. Similarly, results of a one year medical follow-up study of 66 of 91 recruits who had sustained one or more stress fractures during 14 weeks of BT, was reported on by Milgrom *et al.,* (1985) and Giladi *et al.,* (1986). Their study found that 10.6% of persons with a previous stress fracture, developed a new stress fracture during the year after BT, a risk considerably lower than the original risk of 31%.

However, Milgrom *et al.* (1985) reported that only 1.7% of 60 controls in the study sustained stress fractures. Thus, both groups had lower incidences of stress fracture during the year after BT, but the previous stress fracture group experienced a significantly higher risk than the controls.

Other studies have, however, shown no association between lower-extremity injury and stress fracture or non-stress fracture overuse injury during BT (Rauh *et al.,* 2006; Shaffer *et al.,* 2006).

Authors speculate that the difference in findings may be related to the severity of the previous injury, differing types of injuries as well as the difference in how men and women entering BT report prior injuries (Rauh *et al.*, 2005; Rauh *et al.,* 2006; Shaffer *et al.,* 2006).

2.8.2 Extrinsic risk factors

Although it would seem that extrinsic risk factors would be of great interest, because of their potential impact on risk of injury and their applicability to prevention, few studies have examined this category of factors. Extrinsic risk factors that have been considered include: type of physical activity, PT (which includes training methodologies regarding intensity, duration and frequency as well as training errors), training surfaces and footwear. These should be modifiable and of value for prevention (Brukner *et al.*, 1999; Rosental *et al.*, 2003; Välimäki *et al.*, 2005; Rauh *et al.*, 2006; Shaffer *et al.*, 2006).

2.8.2.1 Type of physical activity/ sport

Goldberg and Pecora (1994) quantified the rates of the relative frequency of stress fractures for different sports. The top ten sports evaluated and the percentage of athletes per season (year) who had stress fractures were as follows: softball, 6.3%; track, 3.7%; basketball, 2.9%; tennis, 2.8%; gymnastics, 2.8%; lacrosse, 2.7%; baseball, 2.6%; volleyball, 2.4%; crew, 2.2%; and field hockey, 2.2%. Of these athletes approximately 60% were male. The authors failed to specify sex when recording the stress fracture incidence amongst college freshman in the different sporting codes.

Military studies indicate that different types of units and different types of training may place military personnel at varying degrees of risk. A study of 120 Finnish male military recruits suggested that paratroopers may be at greater risk of incurring stress fractures than regular or light infantry soldiers (Kuusela, 1984). A medical surveillance report on stress fractures incidence among women undergoing Navy BT, Marine Corps BT or Officer Cadet Training, indicated higher risks among female Marine recruits and Officer Cadets (Shaffer *et al.,* 1999b).

A shortfall in military studies outside of the United States, is that research may be reported on, provided that the anonymity of the study participants and the units or the bases involved is ensured. This then renders it difficult to ascertain the corps as most literature will only provide the level of military training, namely BT, Officers Training, Special Forces Training and so forth. However as BT differs between units and between corps, comparisons are then rendered difficult and in most cases impossible.

All military training is characterised by military activities such as marching, drilling and PT. These activities are critical to operational readiness (Kaufman *et al.,* 2000). However, it is important to understand that the duration and intensity, as well as activity, can differ between countries, within countries between corps and within corps between units.

2.8.2.2 PT

Stress fractures are a common overuse skeletal injury in young military recruits (Black, 1982; Scully & Besterman, 1982; Milgrom *et al.,* 1985; Giladi *et al.,* 1991; Beck *et al.,* 2000), and there appears to be a relationship between the development of such fractures and the level and pattern of activity (Milgrom *et al.,* 1985; Milgrom *et al.,* 1988; Almeida *et al.,* 1999).

However, the contribution of each training component (type, frequency, intensity, volume and rate of change) to the risk of stress fractures is not yet clear. Training may also influence bone indirectly, through changes in levels of circulating hormones, associations with menstrual disturbances and effects on soft tissue composition.

2.8.2.2.1 Type of PT

Almost any athlete or exerciser, who engages in frequent, repetitive activity, may develop a stress fracture (Matheson *et al.*, 1987; Ha *et al.,* 1991; Jones *et al.*, 2002; Rauh *et al.*, 2006; Schaffer *et al.,* 2006). Repetitive weight-bearing activities such as running and marching are the most frequently reported causes of stress fractures (Belkin, 1980; Hulkko & Orava, 1987; Matheson *et al.*, 1987; Jones *et al.*, 1989; Ha *et al.*, 1991).

A number of studies on both female and male individuals in both civilian and military populations have demonstrated a dose–response curve in relation to running and weight-bearing activities and injuries (Pollock *et al.,* 1977; Koplan *et al.*, 1982; Marti *et al.,* 1988; Macera *et al.,* 1989; Jones *et al.,* 1994;). Furthermore, as the frequency, duration or total amount of training increases, the injuries also increase, until a point is reached at which injuries increase disproportionately with changes in physical fitness (Pollock *et al.,* 1977).

At present, little is known about the possible effects of heavy resistance exercise, such as weight lifting, and the likelihood of stress fractures. Resistance training leads to an increase in muscle mass and strength as well as BMD and bone strength, as indicated by measures of bone geometry in female athletes and premenopausal women (Heinrich *et al.,* 1990.; Lohman *et al.,* 1995; Engelke *et al.,* 2006). Theoretically then, progressive heavy resistance training of the musculoskeletal system should induce positive adaptations in bone, that are proportional to the increased load (ie resistance), resulting in an increase in muscle mass and in the bone's resistance to stress fractures. Rauh *et al.* (2006) found that women who had participated in weight-training activities on a regular basis for seven or more months, were less likely to incur a stress fracture but found no significant association between lower-extremity muscle weight-training and non–stress fracture overuse injury. These findings are similar to those of a previous study (Lohman *et al.,* 1995).

2.8.2.2.2 Amount, duration, frequency and intensity of PT

Few military or civilian studies have examined the association between amount of PT or exercise and the incidence of stress fractures. The effect of the amount of running on the risk of stress fractures was investigated in a survey that found that male and female runners, who ran more miles per week, experienced an increased risk of radiograph - or bone scan - diagnosed stress fractures (Brunet *et al.,* 1990). Although the survey design had limitations, these findings were consistent with studies of runners that indicated that higher amounts of running were associated with higher incidences of training injuries in general (Koplan *et al.,* 1982; Marti *et al.,* 1988; Macera *et al.*, 1989; Walter *et al.,* 1989; Jones *et al.,* 1994).

Military studies have shown that various training modifications can decrease the incidence of stress fractures in recruits. These interventions include rest periods (Scully & Besterman, 1982), elimination of running and marching on concrete (Reinker & Ozburne, 1979; Greaney *et al.,* 1983), use of running shoes rather than combat boots (Proztman, 1979; Greaney *et al.,* 1983) and reduction of high impact activity (Scully & Besterman, 1982; Taimela *et al.,* 1990; Pester & Smith 1992). These may reduce stress fracture risks by allowing time for bone microdamage to be repaired and by decreasing the load applied to bone (Brukner *et al.,* 1999).

A preliminary report on alterations in the amounts of running and marching performed by Marine recruits, showed that training units that reduced running mileage experienced lower incidences of stress fractures (Jones *et al.,* 1993b). Additionally, trainees doing the least running not only experienced a 50% lower incidence of injury but performed as well on a final physical fitness test (Jones *et al.,* 1993b). Rudzki (1997) also found that by reducing the running distance in the PT programme of the Australian Army recruits, there was a significant reduction in both the incidence of lower-limb injury and the overall severity of injury.

Armstrong *et al.* (2004) found that the stress fracture incidence increased in their recruits with the cumulative number of miles run during the morning exercise training periods. They found that in the tibias of the susceptible individuals, increased weight-bearing physical activity (eg approximately four weeks of PT) was likely to create localized peak strains that could result in a stress fracture secondary to muscular fatigue (Burr, 1997; Beck *et al.,* 2000; Loucks, 2001).

Conversely, a study of marching mileage and risk of stress fracture, reported that less marching did not result in lower stress fracture rates (Milgrom *et al.,* 1985). The limitation of this study was that it did not control for the amount of running by recruits in the high and low marching mileage units. This hinders interpretation, as stress fracture risks are probably proportionate to total weight-bearing training miles (running, marching, drilling, ceremonial activity) (Jones *et al.,* 2002).

Training errors are a frequent cause of stress fractures. They are typically associated with training volume that is increased too rapidly (eg mileage, frequency) and hill running (Matheson *et al.,* 1987; Almeida *et al.,* 1999). Brunet *et al.* (1990) surveyed 1505 runners and found that increasing mileage correlated with an increase in stress fractures in women but not in men. In a study of ballet dancers, those who trained more than five hours daily, had an estimated risk for stress fracture that was 16 times greater than those who trained less than five hours per day (Kadel *et al.,* 1992).

It has been suggested that training regimens for athletes be individualised. What may be appropriate for most members of a team may be excessive for some (Bennell & Brukner, 2005). However, in a BT military set-up, this is not easily achieved due to the large amount of recruits that need to achieve acceptable levels of combat readiness in an allocated time-frame. This situation is compounded further by the large variation in the entry fitness and conditioning levels of the BT recruits.

Bennell and Brukner (2005: 173) advocate

> *"….it is important to allow adequate recovery time after hard sessions or hard weeks of training. This can be accommodated by developing micro - and macrocycles. Alternating hard and easy training sessions is a microcycle adjustment but graduating the volume of work or alternating harder and easier sessions can also be done weekly or monthly. During periods of increases in training, it is worth introducing these on a step wise basis. For example, introduce the increase then remain at this level for a few weeks until bone becomes adapted to the load".*

2.8.2.3 Equipment

Most studies on the impact of exercise equipment have focused on footwear and orthotic insoles by means of intervention trials (Jones *et al.,* 2002). The aim is to reduce and absorb shock when ground contact is made and to control the motion of the ankle and foot (Brukner *et al.,* 1999).

2.8.2.3.1 Footwear

Although footwear is believed to contribute to stress fractures, the available research is equivocal (Milgrom *et al.,* 1996; Milgrom *et al.,* 1998). Anatomic foot structures, biomechanical factors and stability vary greatly amongst military recruits, however, due to logistical and financial constraints all recruits wear the same type of training footwear. The use of Zohar boots (manufactured in Tel Aviv, Israel) by the Israeli Defense Force reduced tibial strain contributing to stress fractures (Milgrom *et al.,* 1996; Milgrom *et al.,* 1998).

In military training, running in boots is commonplace. Boot manufacturers have modified components to produce a boot that is more lightweight, shock absorbent and has running-shoe characteristics (Bennell *et al.,* 1999). Changing from military boots to athletic shoes may reduce the incidence of stress fractures in the foot (Finestone *et al.,* 1992). An experimental study on 390 infantry recruits investigated whether the incidence of overuse injuries was affected by the type of footwear. Basketball shoes were provided to 187 randomly selected recruits while the remainder wore standard military boots. After 14 weeks of BT, there was no significant difference between overall stress fractures rates in the two footwear groups. However, those training in basketball shoes had a significantly lower incidence of overuse injuries of the foot, suggesting that the effect may be limited to injuries resulting from vertical impact loads (Finestone *et al.,* 1992, Brukner *et al.,* 1999).

The age of a shoe provides an indication of the condition of the midsole of the shoe. Gardner *et al.* (1988) found a significantly higher stress fracture rate in recruits wearing shoes older than six months or worn running shoes. While this could be because of decreased shock absorption in older shoes, age also has a detrimental effect on the mechanical support provided by the shoe (Cook *et al.,* 1990). One study of Marine recruits reported that using running shoes more than one month old at the onset of BT, appeared to be associated with greater risks of stress fractures, while the price of running shoes was not associated with risk (Gardner *et al.,* 1988). No civilian studies, investigating the effect of shoe type, age, or quality on risk of stress fractures, have been identified (Bennell & Brukner, 2005).

2.8.2.3.2 Orthotic insoles

Insole use has gained widespread consideration. Shock absorbing insoles are often used in an attempt to reduce the incidence of overuse injuries. There are many different types of insoles on the market which vary in their ability to absorb shock and change foot biomechanics (Milgrom *et al.,* 1985; Gardner *et al.,* 1988; Jones *et al.,* 2002; Bennell & Brukner, 2005).

Milgrom *et al.* (1985) noted a reduction in stress fractures with the use of a shock-absorbing orthosis. In contrast, Gardner *et al.* (1988) found that the incorporation of an insole, with good shock absorption properties, did not reduce stress fracture incidence in military recruits. The authors of a review evaluating the effect of insoles or other footwear modifications on prevention of stress fractures in the military, concluded that 'the use of insoles inside boots in military recruits during their initial training appears to reduce the number of stress fractures and/or stress reactions of bone by over 50%' (Gillespie & Grant, 2000). Another study published since then also found that various types of orthotic insoles were associated with less foot stress fractures (Mundermann *et al.,* 2001).

2.8.2.4 Surface

Training surface has long been considered a contributor to stress fracture development (Devas & Sweetnam, 1956). Various theories exist regarding the role of training surfaces on stress fracture incidence. Training on hard surfaces increases the mechanical shock to the bone and potentially increases the incidence of stress fractures. Running on soft surfaces requires greater muscular activity, induces early muscle fatigue and contributes to stress fractures (Nattiv & Armsey, 1997). Anatomical and biomechanical problems can be accentuated by cambered or uneven surfaces, while ground - reaction forces are increased by less compliant surfaces (McMahon & Greene, 1979; Steele & Milburn, 1988).

A survey of distance runners found that among those who had been injured, 13% of men and 13% of women attributed the injury occurrence to a change in the type of running surface; 7% of women and 6% of men attributed their injuries to running on hilly terrains (Brunet *et al.,* 1990). The sudden increase of stress fracture incidence, from the usual 1.0–3.5% to 11.4%, prompted Zahger *et al.* (1988) to investigate possible reasons for this occurrence. The only change in PT that could be identified by the investigation was a switch to marching on hilly, rocky terrain instead of the usual flat, predictable terrain. When marching returned to flat, smooth terrain, the incidence of injuries returned to 2.5%.

2.9 BT PROGRAMME

In some countries like Israel, Norway, Italy and Greece, military service is compulsory, whilst in others, like South Africa, military service is done on a voluntary basis (Jordaan & Schwellnus, 1994; Dyrstad *et al.,* 2006). Regardless of whether it is voluntary or compulsory, all military recruits undergo an initial form of military training known as Basic Military or Combat Training. During the BT period, the first two to three months of military service, recruits participate in basic military lessons and PT. This includes drill, regimental aspects, general military aspects, musketry, signal training, shooting, map reading, buddy aid, fire-fighting and PT. The BT Programme used by this cohort is available in Appendix Copy Disk - A.

Some studies have investigated changes that occur with BT (Kowal *et al.,* 1978; Vogel *et al.,* 1978; Daniels *et al.,* 1979; Patton *et al.,* 1980; Marcinik *et al.,* 1985; Legg & Duggan, 1996; Faff & Korneta, 2000). Some studies have found that VO_2 max increases with BT (Kowal *et al.,* 1978; Vogel *et al.*, 1978; Patton *et al.,* 1980) whereas others have documented no changes (Daniels *et al.,* 1979; Marcinik *et al.,* 1985; Faff & Korneta, 2000) or even a reduction (Legg & Duggan, 1996).

2.9.1 PT within the BT programme

Physical fitness is a critical and necessary element of soldiering. Military historians have repeatedly emphasized the importance of a high level of physical capability for the occupational tasks that soldiers are required to perform (Nye, 1986; Dubik & Fullerton, 1987; Knapik *et al.,* 2005; Dyrstad *et al.,* 2006).

Within the South African setting, PT, Sport and Recreation (PTSR) forms an integral part of the physical and psychological preparation and conditioning of members of the military. Adequate physical condition and physical skills are necessary for soldiers to perform their main functions to defend and protect the country, its territorial integrity and its people in accordance with the Constitution and the principles of international law regulations for the use of force. Physical fitness is achieved through mandatory Physical Fitness Training (PT) programmes, which include sport and physical recreational activities (DOD policy on Physical Training, DOD Instruction: SG no 00006/2000).

From an occupational point of view, physical fitness for military personnel may be defined as

> *"…the degree of ability to execute specific physical tasks under specific ambient conditions. Because of the wide variety of physically demanding situations the soldier may be confronted with, it is obvious that a high level of endurance alone will not suffice. Muscular strength, power, power-endurance, speed and flexibility are all likely to be essential facets of physical fitness in the military context"* (Gordon *et al.,* 1986b: 483).

Interestingly, it has been reported that modifications of training schedules prevented soft tissue injuries in the lower extremities of young adults (Shaffer & Uhl, 2006). It is common for healthcare providers and coaches to advise their athletes to start slowly and to progressively build up training to avoid injury. The same approach should be followed in military training. Unfortunately, it is not yet clear whether progressive exercise actually prevents stress reactions and fractures as a result of a void in this literature (Shaffer & Uhl, 2006).

Kaufmann *et al.* (2000: 59) state that

> *"…the most effective way to improve the level of physical fitness may be to alter the training regimen by increasing the duration, frequency, and intensity of the initial training events gradually. This approach accommodates the incoming, poorly fit recruits without compromising the fitness of the graduating recruits. To reduce injuries and maintain fitness*

of Marine recruits, the San Diego MCRD conducted a training intervention trial. The intervention included reduction in the amount of running miles, gradual build-up of exercise and military hiking, and emphasis on aerobic activities in early training phases before progressing to anaerobic activities and strength conditioning. Evaluation of this intervention demonstrated a significant reduction in all overuse type injuries. Lower extremity stress fractures were reduced by 55%, which resulted in 370 fewer stress fractures per year with a cost savings of over $4.5 million at the San Diego MCRD. Outgoing recruit fitness, as measured by the 3-mile timed run at the end of training, remained equally high compared to before the intervention (20':53" versus 20':20")".

These suggestions have also been echoed by other researchers' studies (Heir & Eide, 1997; Rudzki & Cunningham, 1999; Rosendal *et al.,* 2003; Armstrong *et al.,* 2004; Knapik *et al.,* 2004). These researchers stated that reductions in running distance with progressive PT in the early weeks, would avoid overtraining in the early weeks as well as reduce lower limb injuries.

Wood and Krűger (2007) monitored the changes that the PT Instructors course had on selected anthropometrical and physical fitness variables / fitness components. They found positive changes on many fitness and anthropometrical variables, however, a larger strength component should be included in the training to ensure greater positive changes, specifically in muscular strength and muscular endurance. Although this was not PT in BT but in a more specialized military training group (and it was three-weeks shorter than BT), it was also conducted in the South African military setting. Similar findings were determined with regard to aerobic capacity by Cilliers and Gordon (1983).

Marcinik *et al.* (1985) highlighted that the attitudes of the company commanders towards exercise, participation in scheduled exercise sessions and overall leadership style can affect final fitness results. However, the most important factors for improvement in physical fitness are training volume, frequency, intensity and mode of training (Dyrstad *et al.,* 2006).

The South African Defence Force PT Policy states that during the period of BT, four 40 - minute PT periods per week are compulsory. A standardised cyclic-progressive PT programme is followed by all instructors presenting BT, in order to achieve the required results, within the prescribed time with the minimum occurrence of injuries (DOD policy on Physical Training, DOD Instruction: SG no 00006/2000). A new cyclic-progressive PT programme for BT was developed by the author of this study in the capacity of Wing Commander in charge of Research and Development at the Joint PT Sport and Recreation Centre. It was implemented for the first time for the period of this study. This programme with its manual can be seen in Appendix Copy Disk - B and C.

PT has, however, also been shown to be associated with a high rate of injury (Jones *et al.*, 1994; Jones & Knapik, 1999; Trank *et al.*, 2001; Knapik *et al.,* 2004). To counter negative effects of overtraining recent efforts to reduce injuries have focused on modifications in the PT Programme (Knapik *et al.*, 2003; Knapik *et al.,* 2004; Knapik *et al.,* 2005; Dyrstad *et al.*, 2006).

The modification of training programmes has been partially investigated. Two studies evaluated the effect of periods of recovery from weight-bearing stress during the early weeks of Army BT (Scully & Besterman, 1982; Popovich *et al.,* 2000). The first of these studies, a "field trial" conducted at Fort Knox in 1974, divided 880 male trainees into equal-sized test and control groups and compared normal training with training interrupted by a recovery week, with no running, marching or jumping taking place during the third week of the eight weeks of US Army BT (Scully & Besterman, 1982). A 67% decrease in stress fractures in the group given recovery time suggested a possible benefit from this intervention.

Popovich *et al.* (2000) tested the effect of recovery weeks, with no running during the second to fourth weeks of the eight weeks of US Army BT on 1357 male recruits. The study compared the stress fracture incidence of persons from three test companies, that provided a period of recovery from running during the second, third, or fourth week of BT, with the stress fracture incidence of persons from two control companies conducting normal, uninterrupted PT. A sixth company performed more running than usual in the early weeks of training and then had a hiatus in running during the fourth and fifth weeks. The results suggested that a recovery period with limited vigorous weight-bearing training (ie no running) is not likely to make a significant difference in stress fracture incidence. However, the variation in stress fracture rates among units within the test and control groups, was large enough to mask apparent differences between the training modification group and the controls (Bennel & Brukner, 2005).

2.10 STUDY DESIGN

In cohort studies, a group of participants (military or civilian) are monitored longitudinally or prospectively over a predetermined length of time and the presence of specific risk factors (before an injury occurs) is measured. The prospective cohort design's greatest strength is that each individual's risk profile is established before the stress fracture has occurred. Its disadvantages are that it is costly and time consuming, as many military recruits must be sampled so that enough injuries can be generated in order to support meaningful statistical analysis (Brukner *et al.,* 1999).

2.10.1 Advantages of using the military population

Conducting studies to investigate risk factors for stress fractures on military recruits within a military setting has various advantages. Firstly, military training provides a controlled environment and studies are scientifically attractive because they can provide insight into how bone strength differs among otherwise healthy young individuals (Beck *et al.,* 2000). Secondly, it is suggested that the uniformity and consistency of military recruit training provides natural controls for selection bias (Macera, 1992; Jones *et al.,* 1994). Finally, military groups provide the unique opportunity to investigate a large and very homogeneous cohort of young men and women of the same age, enrolled independently of socioeconomic criteria (Casez *et al.,* 1995).

2.10.2 Disadvantages with using the military population

Several disadvantages also exist when conducting research on stress fracture risks within the military. Firstly, military studies have to follow the rules and habits of the military, often resulting in logistical problems which, in turn, often result in no proper randomization, no true control group and difficulties in exact quantification of exercise (Casez *et al.,* 1995). Secondly, when BT recruits have a medical problem, they are seen by a number of different medical care providers in the clinic during the study period and although they are guided by policy, each may have different criteria for assigning restricted duty. Finally, due to the large groups studied in the military set-up, multiple variables are often examined which makes it difficult to determine which interventions are most effective. The multiple strategies may have been successful because different individuals responded to different aspects.

A vast amount of research exists on stress fractures. However fewer studies have investigated the role that potential intrinsic and extrinsic risk factors may play in the development of these fractures, specifically during BT. No studies have been done within the South African military environment in this regard. Additionally a program specifically designed to minimize stress fractures in soldiers during BT has never been documented. Thus in the following chapter the methodlogy employed and procedures followed by the researcher will be outlined and explained.