The Effect of Football Boots on the Structure and Function of the Midfoot and the Relationship to Lower-Extremity Overuse Injuries

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The candidate confirms that the work submitted is her own and that appropriate credit has been given where reference has been made to the work of others.

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The Effect of Football Boots on the Structure and Function of the Midfoot and the Relationship to Lower-Extremity Overuse Injuries

Lower extremity injuries appear to be a problem in the sport of football. An injury questionnaire study revealed that nearly 92% of college and university football players sustained a lower-extremity injury during a single football season and that 25% of these injuries were caused by repetitive-stress or overuse mechanisms. Since footwear has been implicated as one of the causes of lower-extremity overuse injuries, it was identified as an area that needed further investigation. It was theorized that stud placement on the sole of a football boot, with limited midfoot support, adversely affected the function of the foot which could lead to repetitive stress injuries.

The effect of a modified loading condition, with the forefoot and heel elevated to the height of a moulded stud football boot, under static loading conditions showed no differences. It was determined that in order to obtain a truer picture of foot function, dynamic data needed to be collected. Navicular drop was selected as a criterion for measurement because the height of the arch is believed to be functionally significant for the mechanics of the foot. A dynamic method of measuring navicular drop during walking was developed utilizing a ProReflex® motion analysis system. Data were collected for the barefoot condition and while wearing turf trainers, football boots, and sports trainers.

Statistical differences were found between static and dynamic barefoot navicular drop measurements. When using a large sample size, a corrolational relationship was found between the static and dynamic conditions leading to the conclusion that the foot may function similarly between static and dynamic loading conditions. However, further analysis of the timing of the movements showed that the maximum navicular drop occurred late in the stance phase and therefore static measurements might not reflect true foot function during dynamic activity.

The timing curves obtained from the ProReflex® showed that shoes do seem to impair foot function, particularly during the recovery period. All of the shod conditions demonstrated a shorter recovery period, indicating that the foot may be unable to recover fully, and subsequently, may not become a fully rigid structure for propulsion. Maximum navicular drop values were also lower for the shod conditions, with the least amount of deformation occurring with the football boot. This might be caused by the rigid sole of the shoe not allowing the foot to unlock fully so that it can absorb impact forces and adapt to varying terrain.

The effect of footwear on subtalar joint motion was also addressed using the ProReflex® system. No relationship was found between the amount of subtalar pronation or initial pronation velocity and navicular drop measurements in any of the conditions. However, motion curves showed that both structures were pronating to some extent, except the midfoot continued pronating while the rearfoot was beginning to supinate.

The analysis of the motion curves of the navicular drop and subtalar joint indicate that the timing of foot motion is more important than the amount of linear or angular displacement. The relationship between displacement measurements may be negligible when determining the effect of the amount of pronation on the risk of injury. The timing variations seen within the subtalar joint and midfoot could lead to dysfunction of other structures, specifically the soft tissues, which would have to compensate for the altered movement patterns. A weakness or abnormality could lead to a breakdown, which in turn, could lead to injury.

THE EFFECTS FOOTBALL BOOTS ON THE STRUCTURE AND FUNCTION OF THE MIDFOOT AND THE RELATIONSHIP TO LOWER-EXTREMITY OVERUSE INJURIES

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CHAPTER 1

Introduction

1.1 Introduction

Footwear research has always seemed to be an area of much interest with both biomechanists and sports medicine professionals. Since the human body works as a unit, research has shown time and again that what is worn on our feet can have an impact on the rest of the body. More specifically, what happens at the foot can affect the shins, which can affect the knees, hips, back, and so forth (Clement, et. al., 1984; James, et. al., 1978; Jones,1983; McKeag, 1991). In the past twenty years or so, with an increase in the interest of sports and recreation participation, footwear design, specifically, athletic footwear, has improved dramatically. These improvements have appeared primarily in running, walking, and fitness shoes, with footwear designed for the specific foot types and exercise styles.

While research has been successful in improving the design of flat-soled athletic footwear, little has been done in the area of studded footwear, such as the type of shoe worn by football, rugby, and American football players. Running is an integral part of the sport of football (Withers, et. al., 1982) and it was felt that the current design of studded footwear, with studs placed on the heel and forefoot and limited midfoot support, would increase the stresses on the structures of the foot. These stresses could result in many of the same types of overuse and repetitive stress-type injuries seen among runners. Current research shows that almost one-third of all injuries occurring in football are overuse in nature (Ekstrand and Gilquist, 1983a, 1983b; Ekstrand, et. al., 1983; Engstrom, et. al., 1990, 1991; Nielsen and Yde, 1989; Schmidt-Olsen, et. al., 1991). While there have been many studies looking at trauma-related injuries related to studded footwear, and it has been fairly well recognized that studded shoes increase risk for these types of injuries (Ekstrand, et. al., 1983a, 1983b, 1989; Jorgensen, 1984; McMaster, et. al., 1978; Nielsen, et. al., 1989), little research has been done in the area of overuse and repetitive stress injuries associated with studded footwear.

Football is a sport that involves a combination of many aspects of other sports (including, but not limited to: walking, running, cutting, jumping, and sliding) and is usually played on natural turf. The current design of the outdoor, natural surface, football boot is primarily a water-repellent, full-grain leather upper with a padded fold-over tongue. The outsole is made of either rubber or a combination of carbon and gum rubber, with 6 to 16 studs, either of an adjustable-length screw-in or moulded polyurethane type, located on the forefoot and hindfoot regions. The outsole is stitched with a flat or slightly moulded polyurethane midsole for shock absorption. The football boot, unlike most other non-studded athletic shoes, has relatively little internal support or padding at the midfoot region. Many types of football boots, featuring various types of stud shapes and placement patterns are on the market. Stud length can be altered for varying turf conditions with the use of screw-in models and specialized turf shoes are also available for artificial turf condition. However, moulded stud football boots, with a traditional stud pattern of 4 heel and 8 forefoot studs, were selected as the focus of this study since many football players utilize this type of boot. Moulded stud boots are more commonly worn by players in the United States due to the fact that there is a greater variety of playing surfaces and hard surfaces are frequently encountered. Additionally, due to cost factors, many players who can only afford a single type of boot, select the traditional moulded stud boot because of its versatility for most playing conditions.

The theory behind this thesis was that because of football boot design, with stud placement at the heel and forefoot and limited midfoot support, one would expect to see greater structural changes or an altered foot function at the midfoot during gait while wearing football boots. Because of these structural changes and altered foot function of the midfoot, microtrauma can occur in the anatomical structures of the lower extremities, thereby increasing the risk for development of repetitive stress injuries.

In order to test this theory, three inter-related components needed to be addressed (Figure 1.1). The structural component addressed the bony and soft tissue anatomy of the foot and lower leg. The functional component addressed the biomechanics of gait, mechanics of foot structure, and mechanics of injury. The medical component addressed the rate and type of lower-extremity overuse injuries seen in football.

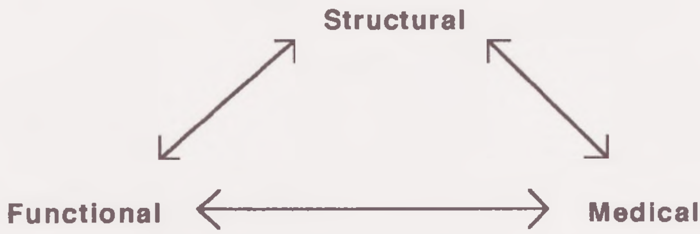


Figure 1.1. Components of the Research Problem

1.2 Thesis Objective(s)

From the structural, functional, and medical information obtained throughout the course of study, it was speculated that a more complete picture of foot function and the resultant effects of specific footwear upon the structures and function of the foot could be developed.

1.2.1 Specific Aims

--To review the current literature and provide an overview of types and causes of lower-extremity overuse injuries.

--To determine the frequency and type of lower-extremity overuse injuries associated with university football players and determine if gender differences exist.

--To review the current literature and provide an overview of foot anatomical structure, the general mechanics of gait, and the specific foot mechanics occurring during gait.

--To analyze static navicular drop in weight-bearing and non-weight-bearing subtalar-neutral positions under various loading conditions.

--To develop a repeatable method to analyze dynamic navicular drop during gait.

--To determine if there is a relationship between static and dynamic navicular drop measurements.

--To determine if foot function differs between walking and running gait.

--To determine the effects of various type of footwear on dynamic navicular drop.

--To determine the timing of various foot segmental movements during gait.

--To determine if a relationship exists between navicular drop and subtalar joint pronation.

--To evaluate the skeletal movement of the midfoot during dynamic movement.

The final part of the thesis will be the application of the results. From the data collected, it is expected to be able to demonstrate how the structure and function of the midfoot change while wearing studded football boots. It is hoped that the results of this study can be used to change the current design of football boots in order to reduce the frequency of lower-extremity overuse injuries. With a reduction of injury, athlete performance can and will be improved.

CHAPTER 2

Overuse Injuries to the Lower Extremities: A Literature Review

2.1 INTRODUCTION

While many definitions for injury exist, Nigg (1985), in his paper on the biomechanics of sports injuries, provides a definition for sports injury that will be adopted for use in this paper. He states:

> "A sports injury is an injury with structural tissue damage which results in a functional impairment of the movement to be executed in the corresponding sport. It is therefore connected with an impairment and/or reduction of sports activity" (Nigg, 1985).

Although this definition does not take into account the severity of injuries, it is understood that any amount of structural tissue damage, however minor, can and will affect performance.

2.2 CAUSES OF INJURIES

Generally, sports injuries occur three ways:

> "1) A single force above the critical limit of the anatomical structures, these injuries are usually classified as acute; 2) re-injury as a result of inadequate healing or rehabilitation of a previously injured structure in which a lower single force is required to reach the critical limits of the anatomical structures, these injuries, although considered chronic, can be described as chronically acute injuries; and 3) cyclic overloading of anatomical structures at a level slightly below critical limits, that over a period of time produces a combined stress effect, these injuries are also known as repetitive stress or overuse chronic injuries (Arnheim, 1997)."

In all of these cases, mechanical overloading of the anatomical structures produces the injury, regardless of whether it is acute or chronic. While the first two injury types can be related to one specific moment, the third is generally a gradual-onset condition that develops over time. It is this type of injury that will be the focus of this paper.

2.3 OVERUSE INJURIES

Overuse injuries pose a unique problem for the sports medicine professional because of their difficulty to evaluate and treat. To effectively treat, rehabilitate and prevent overuse injuries, one must have a thorough understanding of the underlying causes of these injuries. If the causes of the injury are not addressed, a vicious cycle perpetuates until permanent or long term disability occurs (Figure 2.1). This cycle begins with microtrauma-causing injury, leading to clinical symptoms, which in turn causes an individual to alter movement patterns, resulting in muscle weakness and alternative biomechanical movements. All of these conditions result in decreased performance, and unless the cycle is broken, it will continue indefinitely, potentially leading to chronic pain and disability. A difficulty arises because of the fact that overuse injuries have many mechanisms, as varied as the structures involved.

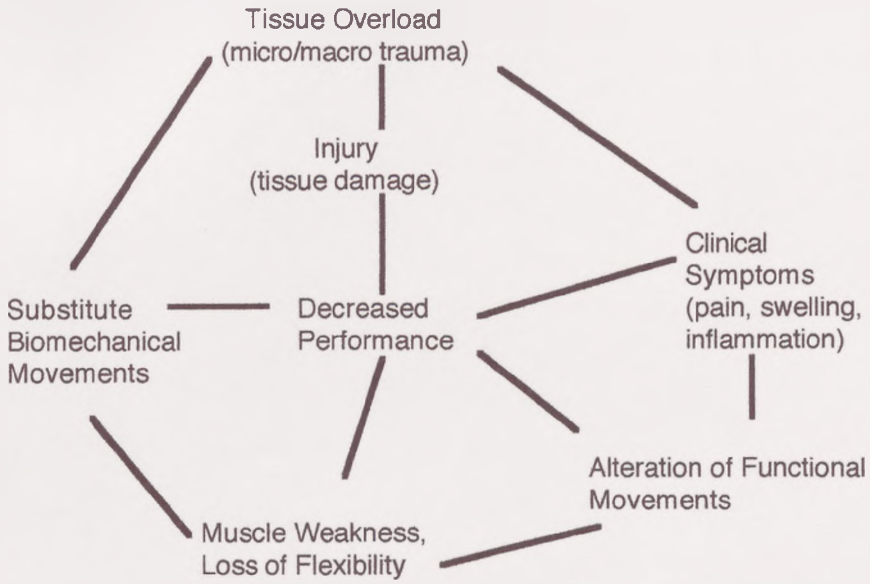


Figure 2.1. The overuse injury cycle.

James, et. al., (1978) determined that most of the causes of overuse injury in runners fell into four categories: training errors, anatomical factors, running shoes, and training surfaces. A study by Jones (1983) of military recruits elaborated on this and identified multiple factors that influenced the development of overuse injuries. These factors include:

1. Fitness levels
2. Physical anomalies
3. Body weight
4. Previous injury
5. Gender
6. Training surface
7. Equipment--footwear
8. Training techniques

These mechanisms can be classified into two fundamental groups, intrinsic causes/defects within the athlete, and extrinsic causes/conditions arising outside of the body (Stanish, 1984). Intrinsic factors include fitness levels of the athlete, body weight, previous injury, gender, and physical anomalies. The latter category is implicated in many overuse conditions, where minor anatomical imperfections alter the body's functional biomechanics eventually leading to injury. Pes planus, pes cavus, excessive Q-angle (the angle between the hip and the knee), malalignment of the patellofemoral joint, muscle imbalance, muscle weakness, and hypo- and hyper-flexibility have all been shown to predispose individuals to certain types of lower-extremity overuse injuries (McKeag, 1991). Extrinsic causes can be related to training errors (for example: doing too much too soon, overtraining, or training at too high intensity), training surface, and footwear. Despite advances in footwear technology, footwear appears to continue to be a major cause of overuse injury.

2.4 LOWER-EXTREMITY OVERUSE INJURIES

2.4.1 Running and Jogging Injuries

Running is an essential component of most sporting activities. It is also one of the most frequently researched, analyzed, and discussed topics of sports biomechanists as well as sports medicine professionals. A substantial number of publications dealing with the biomechanical aspects of running, running shoes, and running injuries can be found in the literature.

It is estimated that 60 - 70% of all runners are affected by injury each year, the majority of which are overuse in nature affecting the lower extremities (Nigg, 1985). A study by Krissoff and Ferris (1979) reported that the most common overuse injuries to runners are those affecting the knee, (patellar tendinitis, patellofemoral tracking dysfunction, illio-tibial band friction syndrome, chondromalacia patellae), Achilles tendinitis, and shin splints. Clement, et. al., (1981) reported that over a 2-year period, 1650 runners were seen in their sportsmedicine clinic. The runners averaged between

19 and 27 miles of running per week and reported 1819 injuries. The following list shows the 10 most common lower-extremity overuse injuries seen during this period:

1. Patellofemoral pain syndrome
2. Tibial stress syndrome
3. Achilles peritendinitis
4. Plantar fasciitis
5. Patellar tendinitis
6. Illio-tibial band friction syndrome
7. Metatarsal stress syndrome
8. Tibial stress fracture
9. Tibialis posterior tendinitis
10. Peroneal tendinitis

They went on to report that the knee and its surrounding structures were involved in about 40% of all overuse injuries in runners. The shin and lower leg were involved in about 25% of the injuries, while the remaining injuries involved the foot and ankle.

2.4.2 Football Injuries

Running is an essential part of the game of football. A video-taped game analysis by Withers, et. al., (1982) revealed that during 90 minutes of match play, a professional soccer player will run between 10 and 12 kilometers, the equivalent of about 6 1/2 to 8 miles. Information obtained from the National Collegiate Athletic Association (USA) and the National Athletic Trainers Association (USA) revealed that most football athletes play 2 games per week and practice 9 - 12 hours per week during the intercollegiate competitive season. Assuming that the practice sessions involve some amount of running activities, it can be estimated that football players average between 16 and 24 miles of running per week. Therefore, one would expect to see similar types of lower-extremity overuse injures in football players that would be seen among runners and joggers.

Several studies have outlined the frequency and types of injuries in football (McMaster, et. al., 1978; Albert, 1983; Ekstrand, et. al., 1983a, 1983b, 1983c; Eriksson, et. al., 1986; Nielsen, et. al.,1989; Brynhildsen, et. al., 1990; Engstrom, et. al., 1988, 1990). It is agreed among all of these studies that the most common injuries in soccer are acute sprains and sprains primarily affecting the lower-extremities. Acute injury rates to the lower extremities were reported to be between 69% and 93%, while overuse injuries were reported to be between 28% and 37%.

The majority of the existing studies tend to focus on acute injury types, or general injury classification (for example: sprains, strain, contusions, and tendinitis) so little or no epidemiological information is available regarding specific types of overuse injuries seen among soccer players.

Because of the amount of running involved during football play, one could expect to see many overuse injuries of the lower extremities. Additionally, due to the movement patterns, ball handling, and quick bursts of speed also involved in football play, one would expect many of these lower-extremity injuries to occur at the foot, ankle, and lower leg. Therein lies the difference between football players and runners. To better understand why the distribution of lower-extremity overuse injuries incurred by football athletes might be different, the types, locations, and causes of these injuries needs to be understood.

2.5 SELECTED OVERUSE INJURIES

2.5.1 Shin Splints (tibial stress syndrome)

The term "shin splints" is a non-specific term that refers to pain in the shin, often leading to great confusion. Therefore, a more specific term has been adopted, tibial stress syndrome, TSS. It can be classified as either anterior or medial tibial stress syndrome, depending on the area of pain. Anterior TSS is characterized by pain along the proximal lateral border of the tibia. Medial TSS involves pain along the distal third of the medial border and is the more common of the two. Tibial stress syndrome is seen frequently in activities that involve a great deal of running, jumping, and landing.

Tibial stress syndromes are caused by repetitive microtraumas resulting in myositis or periostitis. A variety of intrinsic factors such as malalignment problems of the foot, pes cavus, muscle tightness, muscle imbalance, or forefoot supination can contribute to TSS (Jones, et. al., 1987; McKeag, et al., 1989). Extrinsic factors include training errors, terrain, and poor or inadequate footwear (McKeag, et. al., 1989).

2.5.2 Patellar Tendinitis

Jumping, as well as kicking or running may place extreme tension on the knee extension muscle complex resulting in a repetitive stress injury to the patellar tendon. A condition known as patellofemoral stress syndrome, in which there is some deviation of the patella as it tracks in the femoral groove, is often mistaken for patellar tendinitis.

Merchant (1991) found that patellar tendinitis and patellofemoral stress syndrome could be attributed to several factors:

1. Tightness of the hamstrings and gastrocnemius
2. Tightness of the lateral retinaculum
3. Increased Q angle
4. Tightness of the illio-tibial band
5. Pronation of the foot
6. Muscle imbalance between vastus medialis and vastus lateralis of the quadriceps
7. Weak hip adductors

2.5.3 Achilles Tendinitis

Achilles tendinitis, also known as Achilles peritendinitis is an inflammation of the tendon sheath often associated with repetitive or high impact sports. It is seen more commonly in men than women. This condition can be caused by intrinsic factors such as excessive pronation, poor flexibility, and muscle weakness of the gastroc-soleus complex (Clement, et. al., 1984). Extrinsic factors associated with this condition are repetitive uphill running, which can aggravate lack of flexibility, downhill running, which causes increased speed of the tibia during midstance resulting in increased eccentric contractions, causing breakdown of the tendon and muscle, over-training, and poor footwear (Clement, et. al., 1984).

2.5.4 Illio-Tibial Band Friction Syndrome

Illio-tibial band friction syndrome (ITBFS) is an overuse condition commonly occurring in runners and cyclists. Irritation develops at the band's insertion and, where friction is created, over the lateral femoral condyle (Olsen, 1986). Its development has been associated with such extrinsic factors as terrain and training errors (Taunton, et. al., 1986). However, most medical professionals agree that ITBFS is more likely the result of intrinsic anomalies. Jones, et. al., (1987) reports that this condition is associated with a prominent lateral epicondyle, tight illio-tibial band, and excessive lateral ligamentous laxity leading to genu varum (bow legs) about the knee. James, et. al., (1978) has stated that forefoot pronation, leading to internal rotation of the tibia plays a role in this syndrome. Others believe that leg-length discrepancy is to blame (Taunton, et. al., 1986; Martens, 1995).

2.5.5 Peroneal Tendinitis

Peroneal tendinitis is not particularly common but is seen more in individuals who bear weight on the ball of the foot during jogging, running, cutting, and turning (Arnheim,et., al., 1997). Peroneal tendinitis can be a problem in athletes with pes cavus because the foot tends to be in constant supination, which is resisted by the peroneal tendon or those athletes who constantly bear weight on the outside of the foot also place chronic stress on the peroneal tendon (Sammarco, 1995).

2.5.6 Tibialis posterior tendinitis

Tibialis posterior tendinitis is a common injury among athletes with hypermobility or pronated feet (Clement, et. al., 1981). It is a repetitive microtrauma occurring at the pronation phase in movements of jumping, running, or cutting (Arnheim, et. al., 1997). Other causative factors include poor footwear, training errors, lack of flexibility of the gastrocnemius-soleus complex, and muscle imbalance (Clement, et. al., 1981).

2.5.7 Plantar fasciitis

Plantar fasciitis is a repetitive microtrauma overload injury of the attachment of the plantar fascia at the inferior aspect of the calcaneus. It is sometimes referred to as a heel spur, when in actuality, development of a heel spur is the result of prolonged inflammation of the plantar fascia (Andrews, 1983). The development of plantar fasciitis can be related to several factors: repetition of athletic activity, training errors, running mechanics, abnormal anatomy, muscle strength imbalances, and lack of flexibility (Chandler, et. al., 1993). Newell, et. al., (1977) identified abnormal pronation of the foot as a causative factor for plantar fasciitis. McKeag, et. al., (1989) also included lack of flexibility of the gastroc-soleus complex as a factor. Shoes with inadequate heel counters, allowing for excessive rearfoot motion have also been implicated in many cases (Chandler, et. al., 1993).

2.5.8 Exertional Compartment Syndrome

Exertional or exercise induced compartment syndrome occurs most frequently among athletes in sports that involve extensive running. The mechanisms involved are similar to those for medial tibial stress syndrome and in fact, compartment syndrome is often mistaken for this condition. The compartments most frequently affected are the anterior and deep posterior although occasionally the lateral compartment is involved (Arnheim, et. al.,1997).

Compartment syndrome occurs when the tissue fluid pressure has increased because the confines of the fascia or bone together with muscle hypertrophy, compressing muscles, blood vessels, and nerves (Jones, et. al., 1987). With the increase in fluid pressure, muscle ischemia occurs. This could lead to permanent disability. In the chronic condition, these internal pressures rise slowly, causing pain and disability to develop over time.

2.5.9 Stress fracture

Lower extremity stress fractures most commonly occurs in the tibia, but can occur in the tarsals, metatarsals, fibula, femur, spine, or pelvis (Matheson, et. al., 1987). In the lower extremities, the development of stress fractures has been linked to training errors, terrain, and footwear (Frankel, 1978). Athletes with intrinsic anatomical anomalies such as structural forefoot varus, hallux valgus, pes planus, pes cavus, and hyper-mobility are all more easily disposed toward incurring a stress fracture than those athletes whose feet are free of pathological or mechanical defects (Jones, 1983). Stress fractures are more common among women and have been linked to hormonal imbalances, amenorrhea, and nutritional deficiencies (Harries, et. al., 1994).

2.5.10 Tibialis Anterior Tendinitis

Tibialis anterior tendinitis generally manifests itself at the anterior part of the ankle where the tendon crosses the joint. It is a common condition in athletes who run downhill for extended periods of time (Arnheim, et. al., 1997). Other factors include improper footwear, training errors, hard training surfaces, muscle imbalances, and tight Achilles tendon.

2.5.11 Extensor Tendon Inflammation

Inflammation of the extensor tendons of the foot can occur on the dorsal surface of the foot due to localized pressure from shoe wear (Frey and Shereff, 1988). This condition is common, particularly among skiers and other athletes who wear footwear with stiff uppers, or who wear the footwear too tightly (as as seen among football players who wear their shoes too small or lace shoes too tightly).

2.5.12 Flexor tendon inflammation

Athletes who perform repetitive push-off from the forefoot can sustain injury to the flexor tendon. This can be aggravated by an extremely stiff shoe, where the muscle has to work harder to perform push-off (Frey and Shereff, 1988). This condition is generally felt in the posteromedial aspect of the ankle, just behind the posterior tibialis tendon and pain increases during the push-off phase in running.

2.6 STRAIGHT-FORWARD RUNNING vs. FOOTBALL PLAYING

Running/jogging is one of the most common forms of exercise for keeping fit (Stanish, 1984). Coaches and fitness trainers frequently use it as a form of conditioning for their athletes, especially during the pre-season to reach competitive fitness levels and in the off-season to maintain base fitness levels (Golnick and Sembrowich, 1977). Running may be the exercise of choice for most people because it is relatively simple to perform, requires no specific equipment beyond a good pair of running shoes, and can be done just about anywhere, anytime. Most runners/joggers train outdoors, running on sidewalks, through parks, or on the side of the road, while others might go to a local track and run laps. Essentially, the movement is a straight-forward activity, with gradual turns, and varied terrain.

Football is a high-intensity sport characterized by short, quick, non-continuous movements such as sprinting, pivoting, cutting, and backwards jogging. Game analysis by Withers, et. al., (1982) found that most high-intensity work was initiated while the player was already moving. It is well documented that high-intensity activity increases the risk for all types of injury, probably due to increased stresses on the anatomical structures (Roass et. al., 1979; Ekstrand, 1983; Jones, 1983; Keller, et. al., 1987; McKeag, 1991; Inklaar, 1994). The skilled football player is characterized by his/her ability to change direction and initiate movements quickly (Ekblom, 1986). This results in a change in the impact forces, which places stress on different anatomical structures, which could lead to different types of injuries. During straight-forward running, impact forces are typically due to the landing of the foot on the ground (Luethi, et. al., 1984). Impact forces may occur in all three directions, vertical, anterior-posterior, and medial-lateral. The medial-lateral forces are more apparent with changes in direction or terrain (Stefanyshyn and Nigg, 1998). In football, there are additional impact forces from ball contact--dribbling, passing, and shooting. These impact forces are due to the collision of the foot/shoe with the ball, which occurs on the dorsum or medial side of the foot. Unlike the plantar surface which has the heel pad (Ker, et. al., 1989), the dorsum of the foot and medial surface of the foot are not equipped with any impact attenuating structures and the shock is absorbed by the muscles, bones, and ligaments, which could lead to injury.

2.7 CONCLUSION

While the movements and general impact forces of football cannot be changed to reduce injury, other components need to be addressed to lessen their effects. Based on past professional experiences, injury mechanisms, and a review of the literature, three factors can be linked to the majority of the overuse injuries seen in football. They are: training errors; anatomical deficiencies; and poor footwear. While the first component involves education of coaches and changing training techniques, the remaining two components should be addressed before the athlete steps onto the pitch at the beginning of the season.

This should begin with a thorough evaluation of the athlete's anatomical structure and correction of deficiencies, either through a rehabilitation/strengthening/flexibility program, or orthotics if necessary. The second part is to find the appropriate footwear for the athlete's anatomical type and playing style. Unfortunately at this time, athlete specific footwear does not exist in football. The current attitude appears to be "one type is appropriate for all," shoes need to be developed not only for performance, but for foot structure and comfort. Some technological advances in shoe design have been made to reduce the risk for acute injuries, but little has been done for the reduction of overuse injuries, even though nearly one-third of all injuries in soccer are overuse in nature (Ekstrand, et. al., 1983a, 1983b, 1983c; 1990; Engstrom, et. al., 1990, 1991). Therefore, the ideal shoe for reduction of injuries, both acute and chronic, needs to address the following components:

1. Minimize the external and internal impact forces.
2. Distribute forces in a shoe to the appropriate structures so that excessive local pressures are avoided.
3. Provide appropriate friction to perform typical movement tasks and avoid slipping.
4. Align the skeleton properly to minimize excessive internal forces. (Stefanshyn and Nigg, 1998)

Only through a multi-dimensional approach can the rate of injury be reduced in the sport of football as well as other sports that require running as an integral part of the activity.

While one can make assumptions about types and location of lower-extremity overuse injuries a person could expect to see in the sport of football, there is limited information available. Due to this lack of epidemiological information regarding specific overuse injuries, further research is needed to determine rate and type of injuries, as well as identifying potential causitive factors that might increase injury risk.

CHAPTER 3

A Retrospective Study of Football Injuries Among Male and Female University Athletes During a Competitive Season

3.1 INTRODUCTION

Football is the most commonly played sport in the world and is truly an international sport in every sense (Keller, et. al., 1987). During the past 15 years, the sport has experienced rapid growth with participation increasing in every age category and skill level for both males and females (Roass and Nilsson, 1979). In the United States, football, or soccer as it is known, has become one of the most rapidly growing team sports in recent years, especially among women (Brynhildsen, et. al., 1990; Engstrom, et. al., 1991). As the popularity of the sport continues to grow, soccer injuries have become the object of increasing interest among medical personnel, coaches, and athletes alike. To gain a better understanding of how these injuries occur, one must have an understanding of the types of injuries seen among football athletes.

Football is considered to be a contact sport, and by definition, sometimes very physical and is therefore responsible for a large number of acute injuries. The risk for injury is greater when competition is more advanced and the intensity is increased (Roass and Nilsson, 1979). Fortunately the risk for serious injury and permanent disability seldom occurs in football. Instead, it has been well-established that one is more likely to see lower-extremity soft-tissue injuries in the form of strains and sprains (Albert, 1983; Brynhildsen, et. al., 1990; Ekstrand and Gillquist, 1983; Ekstrand, et. al., 1983; Engstrom, et. al., 1990, 1991; Keller, et. al., 1987; McMaster and Maarten, 1978; Nielsen and Yde, 1989; Roass and Nilsson, 1979). While not life-threatening, these injuries can take their toll in time lost from practices and competitions, not to mention the financial losses related to medical expenses (Hoy, et. al., 1992).

Football is a sport that also involves a great deal of walking, running, jogging, and sprinting. On the average, football players stand still 17.1% of the total play time, walk 40.4%, jog 35.1%, run 8.1%, and sprint 0.7% (DiSalvo, 1999). In the duration of a 90 minute match, a football player can cover up to 14 kilometers, depending upon position played (Withers, et. al., 1982). This kind of play, along with other potential risk factors, can lead to the development of overuse/repetitive stress-type injuries. Previous studies have indicated that approximately one-third of football injuries are the result of overuse/repetitive stress (Ekstrand and Gillquist, 1983a, 1983b; Ekstrand, et. al., 1983; Engstrom, et. al., 1990, 1991; Nielsen and Yde, 1989; Schmidt-Olsen, et. al., 1991). However, these studies did not determine the specific types of overuse injuries beyond the general categories of "tendinitis, bursitis, fasciitis" Overuse injuries, though not always as serious as the acute injuries, can still affect the performance of the athlete, perhaps even more so, because they are generally ignored until the pain becomes too great for the athlete to bear. However, in most instances, when an athlete has any degree of pain, he/she cannot perform at 100% of their potential. From a medical standpoint, overuse injuries are often difficult to treat and rehabilitate, because of the difficulty in determining the specific nature and underlying cause of the injury.

With the recent influx of female athletes playing football at more competitive levels, another growing concern among health-care professionals is the frequency and types of injuries seen among female football athletes. A great variation of injury types and frequencies between the sexes has been found in other sports (Whiteside, 1980; Zelisko, et. al., 1982). Therefore, it is inappropriate to transfer data concerning injury epidemiology from male to female soccer athletes. Injuries in male football have been analyzed extensively (Albert, 1983; Berger-Vachon, et. al., 1986; Ekstrand and Gillquist, 1983a, 1983b; Ekstrand, et. al., 1983; Engstrom, et. al., 1990; McMaster and Maarten, 1978; Nielsen and Yde, 1989; Schmidt-Olsen, et. al., 1991). In comparison, there have been relatively few studies concerning female football injuries (Brynhildsen, et. al., 1990; Engstrom, et. al., 1991). Nilsson and Roass (1978) looked at the injury rates between male and female adolescent football athletes, but this was only over a 5-day tournament.

The primary aims of this study were to investigate the incidence and etiology of lower-extremity injuries in collegiate, varsity-level men's and women's football athletes in relation to training and game-playing surfaces, amount of practice, intensity of practices, and number of competitive games played per week. The secondary aims were to investigate the frequency and type of lower-extremity injuries occurring in male and female soccer athletes and to see if differences exist between the sexes.

3.2 MATERIALS AND METHODS

In mid-November of 1997, one hundred questionnaires were posted to college and university certified athletic trainers in the USA. The subjects were selected from a list provided by the National Athletic Trainer's Association, Inc. (USA) utilizing a simple random sampling procedure. Each questionnaire included a self-addressed-stamped envelope to encourage response. A return date was set for December 15, which coincided with the end of fall season, including all post-season play.

The athletic trainers were asked to respond to questions about the varsity, intercollegiate football programs at their institutions, limiting their responses to the Fall, 1997 season. The questions included: size/division of their institution, the number and sex of athletes, practice and game playing surfaces, hours of practice per week, number of games per week, the length of season, as well as specific questions about the frequency of acute, chronic, and overuse/repetitive stress lower-extremity injuries sustained by their football athletes. The latter category was included to accommodate strictly those injuries that were overuse in nature, since chronic injuries are not always caused by repetitive-stress mechanisms. This category was then broken down to specific injuries one would expect to see based on review of literature and past experiences, with the athletic trainers giving the number of each type of injury sustained by their athletes over the duration of the fall season. Separate data were requested for both sexes. A copy of the questionnaire can be found in Appendix B.

Statistical analysis was undertaken and frequency data were compared using a G-test ($p<0.05$). The G-test is similar to the chi-square test, but chosen because it does not require one to distinguish between observed and expected frequencies (Cohen and Holliday, 1996).

3.3 RESULTS

A total of 61 questionnaires, representing all levels of NCAA and NAIA institutions, were returned by the deadline. Of those, 49 reported having varsity, intercollegiate football programs, either male, female, or both, for a total of eight teams. One of these was incomplete and eliminated from the analysis. The remaining 48 questionnaires included data on 78 varsity football teams. These programs, representing a total of 1904 athletes, included 45 women's programs and 33 men's programs, with 1027 and 877 athletes, respectively.

From the questionnaires, a total of 1274 acute lower extremity injuries were reported (female injuries=708, male injuries=566) with a slightly higher percentage of acute injuries being reported for females (Table 3.1). G-test analysis did show a statistical significance at $p<0.05$ ($\chi^2 = 4.14$) between acute injury rates for male and female soccer athletes.

For chronic injuries, a total of 471 injuries were reported (female injuries=273, male injuries=198). Again, the women had a slightly higher percentage of lower-extremity chronic injuries (Table 3.1), and these differences were statistically different at $p<0.05$ ($\chi^2=4.08$) between the two sexes. This category was then broken down into chronic injuries caused by repetitive stress/overuse conditions. A total of 405 chronic, repetitive stress/overuse injuries were reported by the athletic trainers (female injuries=238, male injuries=167). As in the other categories, the women had a slightly higher percentage of injury (Table 1) which were found to be statistically different at $p<0.05$ ($\chi^2=4.83$) between the two sexes.

Although the above results indicate that there were statistically significant differences between the male and female injury rates, further analysis of the data revealed that over three-fourths of the athletes in this study practiced between 9 and 15 hours per week, determined for descriptive purposes as the midrange. Further, the distribution of male to female athletes was more balanced (female=31 teams, 670 athletes; male=29 teams, 762 athletes) within this category. At the higher (>15 hours per week) and lower (<9 hours per week) ends of the spectrum, the distribution of male to female athletes was noticeably skewed toward the female athletes, with over three times as many female athletes than males (female=14 teams, 357 athletes; male=4 teams, 115 athletes). Due to this unequal representation at the two extremes, separate analysis was carried out on the midrange category (Table 3.2). No statistical differences were found between male and female athletes at $p<0.05$ in any of the categories: acute injuries ($\chi^2=3.1$); chronic ($\chi^2=1.88$); and chronic overuse ($\chi^2=1.56$).

TABLE 3.1. INJURY RATES BETWEEN MALE AND FEMALE ATHLETES

Athletes (n)	Acute Injuries (%)*	Chronic Injuries (%)*	Overuse Injuries (%)*
Female (1027)	708 (68.9%)§	273 (26.6%)†	238 (23.2%)‡
Male (877)	566 (64.5%)§	198 (22.6%)†	167 (19.0%)‡
Total (1904)	1274 (66.9%)	471 (24.6%)	405 (21.1%)

*Percentages in each category were determined by dividing the number of female, male, or total injury types respectively by the number of female, male, or total athletes.

§ † ‡ Indicates significantdifferences between male and femalefor each respective category

TABLE 3.2. NON-SIGNIFICANT INJURY RATES BETWEEN MALE AND FEMALE ATHLETES FOR THOSE PRACTICING BETWEEN 9 AND 15 HOURS PER WEEK.

Athletes (n)	Acute Injuries (%)*	Chronic Injuries (%)*	Overuse Injuries (%)*
Female (670)	454 (67.7%)	170 (25.4%)	147 (21.9%)
Male (762)	530 (69.6%)	166 (21.8%)	142 (18.6%)
Total (1784)	984 (55.1%)	336 (18.8%)	289 (16.2%)

*Percentages in each category were determined by dividing the number of female, male, or total injury respectively by the number of female, male, or total athletes.

Different lower-extremity, repetitive stress/overuse injuries were listed in the questionnaire to determine the types of injuries sustained by the soccer athletes (Table

3.3). Shin splints, patellar tendinitis, Achilles tendinitis, and illio-tibial band syndrome were reported as the most common overuse injuries, representing slightly more than sixty percent of the total. The remainder of the overuse injuries consisted of a variety of less common injuries, each representing less than seven percent of the total.

Injuries occurring on grass and artificial turf also showed no statistical differences for acute (χ^2=2.274), chronic (χ^2=3.782), or overuse/repetitive stress (χ^2=1.28) injuries at p<0.05. However, the percentage of injuries was slightly higher for acute injuries on artificial turf. Conversely, the percentage of chronic and overuse/repetitive stress injuries was slightly higher on grass/natural turf (Table 3.4).

TABLE 3.3. FREQUENCY AND TYPE OF LOWER EXTREMITY OVERUSE INJURIES

Injury type	Female (n = 238)	Male (n = 167)	Total (n = 405)
Shin Splints	65 (27.3%)*	42 (25.1%)*	107 (26.4%)*
Patellar Tendinitis	28 (11.8%)	28 (16.8%)	56 (13.8%)
Achilles Tendinitis	20 (8.4%)	24 (14.4%)	44 (10.9%)
IT Band Syndrome	21 (8.8%	20 (12.0%)	41 (10.1%)
Peroneal Tendinitis	15 (6.3%)	13 (7.8%)	28 (6.9%)
Tibialis Posterior Tendinitis	16 (6.7%)	8 (4.8%)	24 (5.9%)
Plantar Fasciitis	16 (6.7%)	8 (4.8%)	24 (5.9%)
Compartment Syndrome	10 (4.2%)	5 (3.0%)	15 (3.7%)
Stress Fractures	10 (4.2%)	3 (1.8%)	13 (3.2%)
Tibialis Anterior Tendinitis	9 (3.8%)	4 (2.4%)	13 (3.2%)
Extensor Tendon Inflammation	4 (1.7%)	8 (4.8%)	12 (3.0%)
Flexor Tendon Inflammation	6 (2.5%)	3 (1.8%)	9 (2.2%)
Other	14 (5.9%)	5 (3.0%)	19 (4.7%)

*Percentages noted in parenthesis were determined by dividing the number of each type of injury sustained by the number of female, male, or total injuries respectively (n).

Finally, injury rates between those that played 1-2 games per week and those who played 3-4 games per week were compared (Table 3.5). There was a significant difference between injury rates of the two classifications, with the teams that played 3-4 games per week having a significantly higher rate of acute injuries (x^2=38.587). There was no significant difference between chronic (x^2=0.228) or overuse/repetitive stress injuries (x^2=0.028) when compared to games played per week.

TABLE 3.4. NATURAL TURF VS. ARTIFICIAL TURF

Turf Type	Number of Teams	Number of Athletes	Acute Injuries (%)*	Chronic Injuries (%)*	Overuse Injuries (%)*
Natural Turf	34	776	504 (64.9%)§	210 (27.1%)	175 (22.6%)
Any Artificial Turf	44	1128	770 (68.3%)§	261 (23.1%)	230 (20.4%)

*Percentages noted in parenthesis were determined by dividing the number of acute, chronic, or total injuries by the number of athletes in each category.

§ Indicates statistical differences between the two turf conditions and acute injury rates.

TABLE 3.5. GAMES PER WEEK AND INJURY RATES

Games per Week	Number of Teams	Number of Athletes	Acute Injuries (%)*	Chronic Injuries (%)*	Overuse Injuries (%)*
1-2	64	1608	1015 (63.1%)§	401 (24.9%)	341 (21.2%)
3-4	14	296	259 (87.5%)§	70 (23.6%)	64 (21.6%)

*Percentages noted in parenthesis were determined by dividing the number of acute, chronic, or overuse injuries by the number of athletes in each category.

§ Indicates statistical differences between games per week and acute injury rates.

3.4 DISCUSSION

Collegiate football players, rather than elite, high school, or youths were selected for this study for several reasons; Title IX (the Gender Equity Act passed by the US Congress) requires that the equipment and facilities at each institution are generally equal for both men and women, the players are recruited because they are highly ambitious and talented athletes, the coaches are employed for their skills and experience, and the medical care is coordinated by an athletic trainer, certified by the National Athletic Trainer's Association (USA), which allows for close surveillance and reporting of injuries.

A number of studies have been conducted to determine injury rates in football from information reported to hospitals or clinics, limiting the injuries to those that are serious enough to require emergency medical treatment (Berger-Vachon, et. al., 1986; Hoy, et. al., 1992; Roass and Nilsson, 1979). Others have limited their studies to one team, a few teams, or one league, resulting in small sample sizes and gender-specific data, using various methods of reporting injuries (Albert, 1983; Brynhildsen, et. al., 1990; Ekstrand, et. al., 1983; Ekstrand and Gillquist, 1983a, 1983b; Engstrom, et. al., 1990; Engstrom, et. al., 1991; McMaster and Maarten, 1978; Nielsen and Yde, 1989; Schmidt-Olsen, et. al., 1991). While the study by Nilsson and Roass (1978) addressed the gender issue and had a very large sample size (n=25,000), the data were collected over a 5-day tournament rather than an entire season and is not necessarily indicative of the injury rates seen throughout a season, which incorporates both practices and games. For this study, NATA certified athletic trainers provided retrospective injury data from an entire fall season. Data were collected from 78 football teams and a total of 1904 athletes. These teams represented 45 women's programs and 33 men's programs from all NCAA and NAIA levels.

Information was obtained for acute, chronic, and repetitive-stress/overuse lower-extremity injuries only. This was based on previous studies showing that the lower extremities are involved in 70% to 93% of all soccer injuries (Ekstrand, et. al., 1983; Ekstrand and Gillquist, 1983a, 1983b; Engstrom, et. al., 1990; Engstrom, et. al., 1991; Nielsen and Yde, 1989; Schmidt-Olsen, et. al., 1991). These same studies show that 28% to 35% of these injuries are overuse in nature. Therefore, additional information was collected about specific overuse injuries. Further, injury analysis was done for both male and female athletes, to see if differences between the sexes existed.

The results of this study indicated that there were statistical differences between the acute, chronic, and repetitive-stress/overuse injury rates between male and female collegiate soccer athletes when looking at the entire group including all practice exposure times. These results concur with earlier studies that show higher rates of injuries for women in similar sports (Whiteside, 1980; Zelisko, et. al., 1982). The study by Nilsson and Roass (1978) showed that female football athletes were twice as likely to sustain an injury than their male counterparts, a ratio very much higher than found in this study.

When further analysis was done, eliminating the high and low practice extremes, (Table 2), there were no statistical differences between the sexes. These results concur with the more recent studies by Engstrom and Johannson (1991) looking at female elite football athletes and those by Ekstrand, et. al., (1983a, 1983b, 1983c) looking at male elite football athletes when they reported similar injury rates for each of the respective sexes. These studies report lower-extremity injury rates of 88%. There were slight differences in overuse injury rates with Engstrom's study of female athletes reporting a slightly lower rate than the males. The similar injury rates between the sexes shown in this study and the studies of Engstrom and Ekstrand could be explained by the impressions of Brynhildsen, et. al., (1990). In his study of female football players, he purported that women now run the same risk for injury as men due to the equalization of coaching and training methods, skills, fitness levels, and playing conditions. In addition to the fact that the male to female ratio in the high and low ends of the practice extremes was disproportionately skewed making comparisons difficult, these ranges revealed extremely high rates of injury, especially among the female athletes. Basic physiological principles can be used to explain the injury rates. Research by Keller, et. al., (1987), and Inklaar (1994), has shown that athletes are more likely to suffer from higher rates of injury when the body is not physically prepared for activity, as seen in the low-end category. Conversely, Nilsson and Roass (1978) found that the risk for injury increases when athletes are exposed to greater amounts of training, as would be the case with the high-end category. They found that injury rates increase when one exceeds the limits in which the body can no longer recover completely between exercise bouts, resulting in muscle fatigue and lost energy stores, thereby lessening the body's defenses against injury.

When looking at specific overuse injuries, some differences were seen between the sexes. For both sexes, "shin splints" was the most common overuse injury. Although the term "shin splints" is not necessarily an accurate description and simply means, "pain in the shins" which could be caused from other conditions, it was listed on the questionnaire to categorize unexplained shin pain. Interestingly, there were some differences in certain types of injuries between the sexes (Table 3.3). The males showed higher rates of patellar tendinitis, Achilles tendinitis, illio-tibial band syndrome, and extensor tendon inflammation. The women reported higher rates of tibialis posterior tendinitis, plantar fasciitis, and stress fractures. In fact, female soccer athletes were 3 times more likely to sustain a stress fracture than male athletes. This result is in accord with other studies in which female athletes are reported to suffer from more stress fractures (Jones and James, 1987; Matheson, et. al., 1987). Several explanations, including many associated with inherent physiological and anatomical differences between the sexes, have been offered to explain this phenomena, however there is no single definitive answer (Harries, et. al., 1994). What was surprising in these results was the higher rates of patellar tendinitis reported in the male athletes. This condition is usually associated with malalignment such as the increased Q-angle seen in many females (Harries, et. al., 1994) so one would expect to see the higher rates of patellar tendinitis among the female athletes rather than the males. Patellar tendinitis has been attributed to, among other things, lack of strength and flexibility in the quadriceps muscles (Taunton, et. al., 1988). A study by Ekstrand and Gillquist (1983) showed that 67% of male soccer players, when compared to non-players of the same age, were less flexible in the lower extremities. Therefore, the higher rate of patellar tendinitis in male soccer players could possibly be attributed to lack of flexibility, although further studies are needed to verify this.

According to this study, the type of playing surface (i.e., grass vs. artificial turf) did not adversely affect injury rates. This finding concurs with that of Ekstrand and Nigg (1989), although they also showed that one should consider the condition of the playing surface, as poor-quality surfaces can increase the risk for both acute and chronic injuries. The condition of the playing surfaces was not taken into consideration in this study and could be considered a limitation. The studies of Ekstrand and Gilquist (1983) have shown that there is an increased rate of injuries on artificial turf only when wearing shoes with studs. Based on their results, they recommended that shoes without studs or specialized turf shoes be worn when practicing or playing on artificial surfaces. These recommendations have since been adopted by most athletes and therefore this study did not take into account footwear type when determining injury rates. From the results found in this and previous works, playing surface type was eliminated as a contributing factor for injury in football.

Practice intensity was determined by the number of scrimmages (intra-squad game-playing situations taking place during practice) played each week. The results of this study indicate that overall injury levels increase with the increase in number of scrimmages, or high-intensity practice sessions played per week. Further, it appears that the optimal level of training would include 3 scrimmages per week or the equivalent of moderate training. Less than or in excess of these levels increases the risk for acute, chronic, and overuse injuries. One can conclude that prolonged high-intensity training increases the risk for injury. This can be supported by the works of Marieb (1998) who found that inadequate rest and recovery between high-intensity exercise bouts resulted in muscle fatigue thereby increasing the risk for injury. Roass and Nilsson (1979) also found that the risk for injury is greater when competition is advanced and intensity is increased. Conversely, from the results of this study, one can conclude that inadequate training increases the risk for injury as well. This could be caused by the lack of fitness needed to sustain prolonged high-intensity exercise such as that found during games and competitions (Roass and Nilsson,1979).

The results of this study indicate that the risk for acute injury increases with the increase in games played per week. Studies have shown that athletes are more likely to suffer an acute injury during competition, especially later in the game when fatigue occurs (Arnheim and Prentice, 1997). Marieb (1998) has put forward some possible explanations: inadequate rest between high-intensity games; athletes' inability to completely recover muscle glycogen stores between games; continuous play during game situations and players' inability to rehydrate leads to dehydration, increasing effects of fatigue; and loss of electrolytes through sweat and dehydration. The results of this study indicate that by playing only 1-2 games per week, rather than 3-4 games, the risk for acute injury decreases by about 25%. However, the number of games played per week does not seem to affect the chronic or overuse injury rates.

A fundamental problem with this and other existing studies is the inconsistent manner in which injury is defined and the way the information is collected. This study attempted to eliminate the collection errors by only sending the questionnaires to NATA certified athletic trainers who coordinate the health care for their soccer teams and keep the appropriate records. The questionnaire did not include a specific definition of acute and chronic injuries, causing possible data error. For example, acute injuries could have been interpreted as any injury that required medical attention (blisters, abrasions, contusions) or only those injuries that required time-off from the activity. Secondly, the design of the questionnaire was flawed in the fact that it did not take into account those athletes that had multiple injuries, but rather looked only at the overall incidence compared to the total number of athletes. Additionally, because this was a retrospective questionnaire, there may have been inadequate reporting of the injuries since one must rely on the record-keeping of the athletic trainers. Unfortunately, due to the lack of consistent injury-reporting standards, there is still a great variation of injury record keeping among various athletic trainers and facilities and the injuries may not have been accurately reported in the questionnaire. Future studies, conducted prospectively, with specific injury definitions are needed for more consistent and accurate data collection.

Another problem with this and any other questionnaire-format research is the interpretation of the questionnaire itself. Although the questionnaire was designed to eliminate some of these errors, each individual may have interpreted each question in a different way and answered according to their own interpretation. Despite the limitations of this study, some interesting and important trends emerged, indicating a need for additional studies that eliminate some of the data collection errors.

Because football is a contact sport, injuries are bound to occur. The causes for injuries in football have been attributed to many factors: equipment (including footwear), playing surfaces, rule violations, collisions, lack of conditioning/strength/warm-up, overtraining, training methods, as well as intrinsic factors (Ekstrand, et. al., 1983a, 1983b; Ekstrand and Gillquist, 1983a, 1983b; Ekstrand and Nigg, 1989; Inklaar, 1994; McMaster and Maarten, 1978; Nielsen and Yde, 1989). Existing studies show that football athletes of both sexes sustain relatively high rates of injury, especially to the lower extremities (Albert, 1983; Berger-Vachon, et. al., 1986; Brynhildsen, et. al., 1990; Ekstrand et. al., 1983; Ekstrand and Gillquist, 1983a, 1983b; Engstrom et. al., 1991, 1990; Hoy, et. al., 1992; McMaster and Maarten,1978; Nielsen and Yde, 1989; Nilsson and Roass, 1978; Pardon, 1977; Roass and Nillson, 1979; Schmidt-Olsen, et. al., 1991). Overuse injuries continue to be a concern, since this and other studies show that approximately one-third of all soccer injuries are overuse in nature and further studies would be warranted (Albert, 1983; Berger-Vachon, et. al., 1986; Brynhildsen, et. al., 1990; Ekstrand et. al., 1983; Ekstrand and Gillquist, 1983a, 1983b; Engstrom et. al., 1990, 1991; Hoy, et. al., 1992; McMaster and Maarten,1978; Nielsen and Yde, 1989; Nilsson and Roass, 1978; Pardon, 1977; Roass and Nillson, 1979; Schmidt-Olsen, et. al., 1991). This study, like the others, showed that there was a relatively high percentage of acute, chronic, and overuse injuries for both male and female collegiate soccer players. Incidence of injury seems to depend upon the population being studied, i.e. age, gender, level of competition (Inklaar, 1994). Further studies looking at different levels of football play should be conducted to see if similar injury rates exists between the sexes at different ages and different skill levels.

The results of this study indicate that although the injury rates are statistically different between the sexes, the injury-gender gap is closing, at least in the sport of football, especially when practice extremes are eliminated. When the high and low practice extremes are discounted, the ratio of male to female athletes is comparable, and it appears that female football athletes run no greater risk for injury than males. Female athletes now have more opportunities to compete in athletics at younger ages, becoming technically skilled, physically fit, and equal to their male counterparts in every sense. While this study only focuses on one sport, it would be interesting to see if this trend continues in other similar sports.

Finally, it can be concluded that nearly one-fourth to one-third of all injuries sustained in football are chronic or overuse in nature. Further, the shin, foot and ankle regions accounted for nearly 70% of these injuries, with 25% involving the knee and surrounding structures. The remaining 5% fell into the “other” category. As mentioned in the previous chapter, these results indicate that the types of lower-extremity overuse injuries seen in football are similar to those seen among runners, but that the distribution of these injuries are different. Among intercollegiate football players, the majority of the lower-extremity overuse injuries occur in the shin and lower-leg regions rather than the knee as seen among runners. Therein lies the difference between football players and runners. To better understand why this distribution of injuries might be different, the anatomy and mechanics of the foot, as well as the effect of footwear, needs to be addressed in further detail.

CHAPTER 4

Foot Anatomy and Mechanics: A Review of Literature

4.1 ANATOMY OF THE FOOT

The ankle/foot complex must meet the demands of: (1) providing a stable base of support for the body in a variety of weight-bearing postures without undue muscular activity and energy expenditure and (2) acting as a rigid lever for effective push-off during gait. It meets these demands through the interaction of its 26 bones, 23 compound joints, and extensive musculature.

4.2 SKELETAL STRUCTURE

The shape of the foot bones provides the basis of structural stability of the foot. The bones articulate in such a way to form a skeletal structure that provides a strong foundation for weight-bearing and mobility. Each foot consists of 26 bones (7 tarsals, 5 metatarsals, and 14 phalanges), plus the distal ends of the tibia and fibula, which help form the ankle joint. To facilitate description and understanding of the foot and ankle complex, the bones of the foot are traditionally divided into three functional segments (Figure 4.1): the hindfoot or posterior segment; midfoot or middle segment; and forefoot or anterior segment. Although divided for reference, the entire foot works together to form a very complex and intricate structure.

4.2.1 Hindfoot

The hindfoot consists of the talus and calcaneus, and for the purpose of this paper will also include the distal ends of the tibia and fibula.

The distal end of the tibia expands into a large, weight-bearing area called the trochlear surface, which transmits downward pressure to the foot (Arnheim and Prentice, 1997). From the medial aspect, a bony process, called the medial malleolus, projects inferiorly and forms the inner bulge of the ankle. The medial malleolus forms half of a

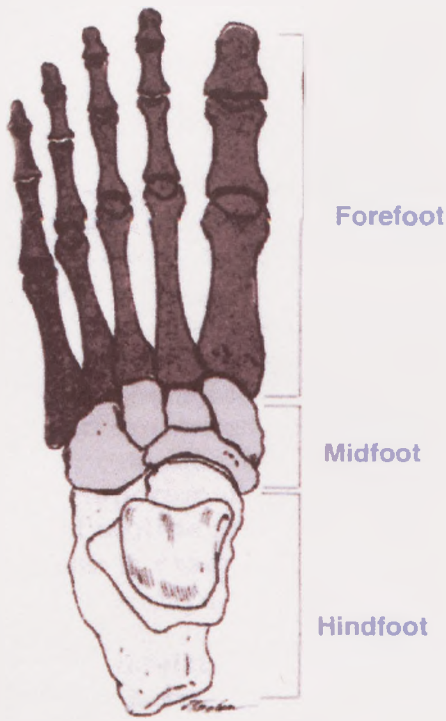


Figure 4.1. Functional Segments of the Foot. (Adapted from Norkin and Levange, 1992)

"saddle" which sits upon the talus. Many tendons run behind the medial malleolus and insert into the bones of the foot.

The distal end of the fibula also has an expanded end forming the lateral malleolus, which is situated at a level lower than and slightly posterior to the medial malleolus. The lateral malleolus is seen as the outer bulge of the ankle and forms the other half of the "saddle" sitting upon the talus, almost reaching the calcaneus. Unlike the tibia, the distal end of the fibula does not bear weight (Arnheim and Prentice, 1997), although many muscles of the foot originate from this area, and their tendons pass around the lateral malleolus to insert into the bones of the foot.

Moving downward from the tibia and fibula is a wedge-shaped bone called the talus. The talus is one of the main weight-bearing bones of the foot (Arnheim and

Prentice, 1997). It is unique among the foot bones in having no muscles attached to it. The body of the talus has three articular surfaces: a large lateral facet, a smaller medial facet, and a trochlear or superior facet. These surfaces articulate with the trochlear surface (formed by the fibula and tibia), and medial malleolus of the tibia and the lateral malleolus of the fibula. The talus narrows anteriorly into a neck, in front of which is a head. The head provides an articulating surface for the navicular bone. Posteriorly, a groove for a tendon is found separating the posterior and medial tubercles. The inferior surface of the talus is somewhat 'double-saddle-shaped' articulating with the superior surface of the calcaneus. On the anteriormedial aspect of the talus is a facet for the spring ligament. This ligament assists in the support of the medial longitudinal arch.

The calcaneus is the largest and the most posteriorly situated bone of the tarsus. To visualize the calcaneus simply, it can be divided into three portions, with the posterior portion forming the heel of the foot and providing an attachment for the Achilles tendon; the middle or center portion providing the body, with the upper surface articulating with the talus; and the anterior portion projecting forward and articulating with the cuboid. With the simple model of the calcaneus in mind, the calcaneus carries the whole weight of the body inferiorly and posteriorly on a structure called the tuber calcaneal. Moving superiorly and anteriorly, on the upper, middle surface, is an area which articulates with the talus by three facets. Projecting medially from the middle facet is the sustentaculum tali. Beneath this structure run some of the tendons passing behind the malleolus to the foot. At its most anterior point, the calcaneus articulates with the cuboid. The lateral aspect has two small projections for ligamentous attachments.

4.2.2 Midfoot

The midfoot area is composed of the navicular, cuboid, and the medial, intermediate/middle, and lateral cuneiform bones.

The navicular is a curved, boat-shaped bone that articulates proximally with the talus, distally with the three cuneiform bones and laterally with the cuboid. On the medial side is a large protuberance called the navicular tuberosity. It is this structure that is the landmark for the medial longitudinal arch (Hawes, 1992) that will be discussed in detail later. The plantar surface of the bone is narrow and roughened for the attachment of ligaments and muscles.

The cuboid is a square-shaped bone that articulates proximally with the calcaneus, distally with the fourth and fifth metatarsals, and laterally with the navicular and lateral cuneiform. Its proximal articulating surface is slightly concave from top to bottom, but flat from side to side. Distally, the articulating surface is almost flat with a slight ridge dividing it into two facets. On the plantar surface is a large groove for the tendon of the peroneus longus and the rest is roughened to allow for the attachment of the long and short plantar ligaments.

The wedge-shaped medial (first), intermediate (second), and lateral (third) cuneiform bones are situated between the navicular and the first three metatarsals. The lateral cuneiform bone also articulates laterally with the cuboid bone. The medial cuneiform bone is the largest, while the middle cuneiform bone is the smallest. The medial cuneiform has its apex projecting upwards and its base downwards while the intermediate and lateral cuneiforms have the apex projecting downwards with the base upwards, contributing to the shape of the transverse tarsal arch. These three bones fit snugly together side-by-side to form a close-fitting, curved articulating surface for the navicular bone. At the distal ends, these bones fan out slightly to articulate with the corresponding metatarsal. These bones allow for spreading of the metatarsals during weight bearing. Many tendons pass through grooves situated on the cuneiform bones.

4.2.3 Forefoot

The forefoot consists of the five metatarsals and the 14 phalanges and covers the largest area of the foot.

Distal to the cuboid and cuneiform bones are the five metatarsal bones which fan out slightly from the midfoot to play an important role in supporting the weight of the body (Hicks, 1953). The metatarsals are numbered 1 through 5 beginning with the medial side (great toe) of the foot. The first metatarsal is very short and stout, and carries a great deal of weight. The remaining four metatarsals are slender, with their heads distal and their bases proximal. The base of the second metatarsal is wedged between the medial and lateral cuneiform because the smaller intermediate bone does not project as far distally. The head of the first metatarsal, where it articulates with the proximal phalanx forms the "ball" of the foot.

The phalanges are small bones that form the toes of the foot. Each toe has three phalanges; proximal, middle, and distal, except for the great toe or hallux, which does not have a middle phalanx. The proximal and distal phalanges of the hallux, like the first metatarsal, are stouter than those of the other toes.

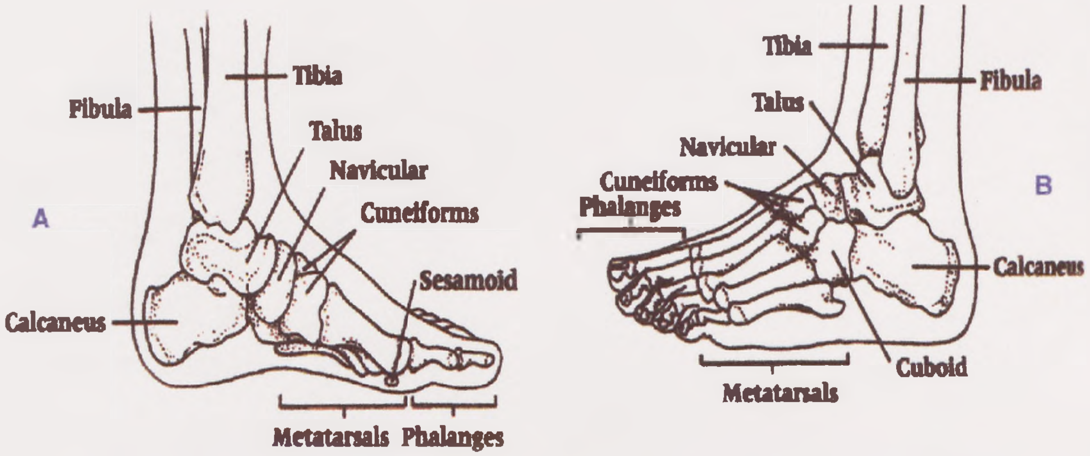


Figure 4.2. Bony Structures of the Foot. A. Medial view, B. Lateral view. (Arnheim and Prentice, 1997)

4.3 JOINTS

The many bones of the foot articulate with each other to form 23 compound joints. However, rather than elaborate on each of these joints, the primary joints of the hindfoot and midfoot will be discussed as these two areas will be the focus of the research presented in this thesis.

4.3.1 Ankle Joint

The ankle joint is formed by the articulation of the distal ends of the tibia and fibula with the talus. It is classified as a hinge joint, allowing for plantar flexion and dorsiflexion of the foot. The projections of the medial and lateral malleoli grip the talus firmly and are reinforced by strong collateral ligaments. Unfortunately, to allow for movement of the ankle, the anterior and posterior components are thin and weak. The entire joint is covered with a synovial joint capsule.

4.3.2 Subtalar Joint

The subtalar or talocalcaneal joint, is a plane joint covered by a synovial joint capsule. It is formed by the articulation of the posterior facet of the talus and the posterior facet on the upper surface of the calcaneus. The shape of these facets allows for supination and pronation of the foot.

4.3.3 Transverse Tarsal Joint

The transverse tarsal joint, or midtarsal joint is a compound joint consisting of the talonavicular joint and the calcaneocuboid joint (Figure 4.3). The talonavicular joint is an articulation of the navicular bone and the talar head. The calcaneocuboid joint is formed by the anterior calcaneus articulating with the cuboid bone. These two joints form an S-shaped line that transects the foot horizontally, essentially providing the dividing line between the hindfoot and midfoot. During weight bearing, transverse tarsal joint motion is considered to be motion of the talus and calcaneus on the relatively fixed navicular and cuboid bones (Elftman, 1960). This motion, like that of the subtalar joint, also allows for supination and pronation of the foot.

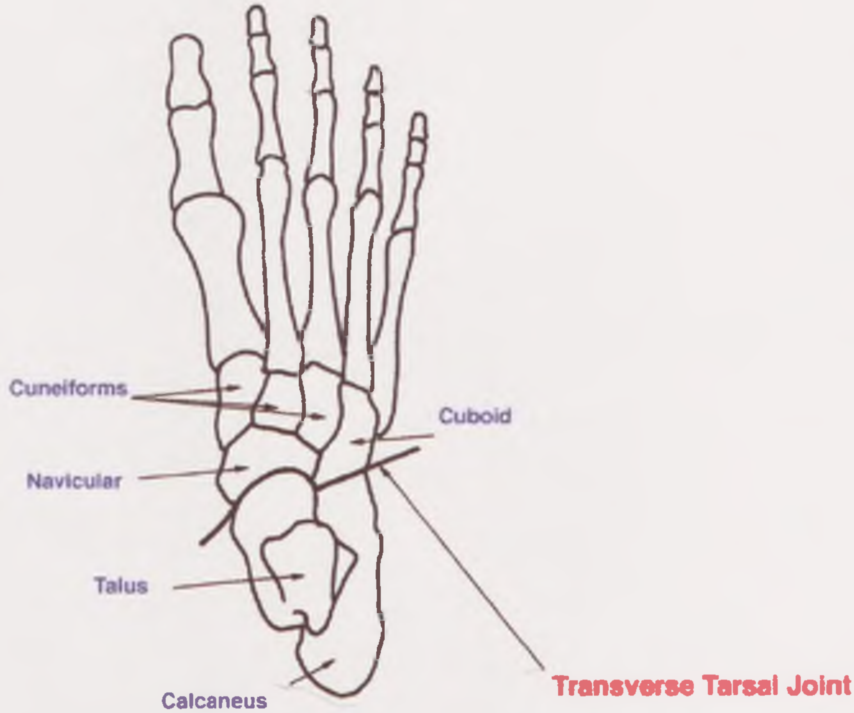


Figure 4.3. The talonavicular joint and calcaneocuboid joint form a compound joint known as the Transverse Tarsal Joint that transects the foot (Adapted from Norkin and Levange, 1992)

4.3.4 Intertarsal Joints

The five joints that make up the intertarsal joints include the three slightly convex navicular facets with the slightly concave facets of the cuneiforms, the relatively flat facets between the cuboid and lateral cuneiform, and between the cuboid and the lateral navicular. These articulating surfaces allow gliding motion in many directions between the tarsal bones.

4.3.5 Tarsometatarsal Joints

The tarsometatarsal joints are plane synovial joints formed by the distal tarsal row and by the bases of the metatarsals. The first three joints are formed by the three cuneiforms articulating with the corresponding metatarsal. The latter two joints are formed by the cubiod articulating with the bases of metatarsals four and five. The tarsometatarsal joints are primarily a continuation of the transverse tarsal joint, compensating for extreme hindfoot motion (Root, et. al., 1977).

4.3.6 Metatarsophalangeal and Interphalangeal Joints

The remaining joints of the foot are classified as hinge joints between the metatarsals and phalanges, and between the phalanges themselves. The primary motions occurring at these joints is plantar flexion (flexion) and dorsiflexion (extension), with secondary motions of abduction and adduction of the toes. The “break” line, formed by the metatarsophalangeal joints, allows the weight-bearing heel to rise during prior to push-off during gait.

4.4 PLANTAR APONEUROSIS

The plantar aponeurosis is a thick, fibrous band that runs nearly the entire length of the plantar surface of the foot, covering all of the soft tissue structures of the foot (Figure 4.4). While not technically a ligament, it does connect two bony surfaces together and is often classified as such. The plantar aponeurosis begins posteriorly on the calcaneus and runs anteriorly to attach to the proximal phalanx of each toe, forming a “tie-beam” for the support of the longitudinal arches (Hicks, 1954). The plantar aponeurosis also acts to assist muscular function during gait as well as protect the muscles of the foot from excessive motion that could lead to injury (Sammarco, 1989). It also functions to maintain the longitudinal arch of the foot and assist in absorbing forces in the midtarsal joints (Kim and Voloshin, 1995).

4.5 FAT PAD

A layer of subcutaneous adipose tissue, called the fat pad, superficially cushions all plantar structures of the foot. This pad is particularly thick on the heel to dampen the effect of the heel contacting the ground at the heel-strike phase of the gait cycle. The area surrounding the distal Achilles tendon as it crosses the posterior calcaneus is surrounded with fat as well.

Figure 4.4. The Plantar Aponeurosis (Arnheim and Prentice, 1997)

4.6 MUSCLES

There are two groups of muscles that affect the foot and its function, they are: extrinsic, which originate in the lower leg and insert into the foot; and the intrinsic, which originate and insert in the foot.

4.6.1 Extrinsic

The extrinsic muscles of the foot all have their origins at various sites on the tibia and fibula of the lower leg (Figure 4.5). Depending on their location and placement, these muscles of the leg promote movements of the ankle, foot, and toes and are responsible for controlling the foot lever during the gait cycle (Ambagtsheer, 1978).

Muscles originating in the anterior part of the lower leg are the primary dorsiflexors of the foot and ankle, inserting on to the dorsal surfaces of the foot. These muscles include the tibialis anterior, which, In addition to being the primary dorsiflexor of the foot, is also believed to be a secondary supporter of the medial longitudinal arch (Marieb, 1998). Other anterior muscles are: the extensor digitorum longus, the peroneus tertius, and the extensor hallucis longus.

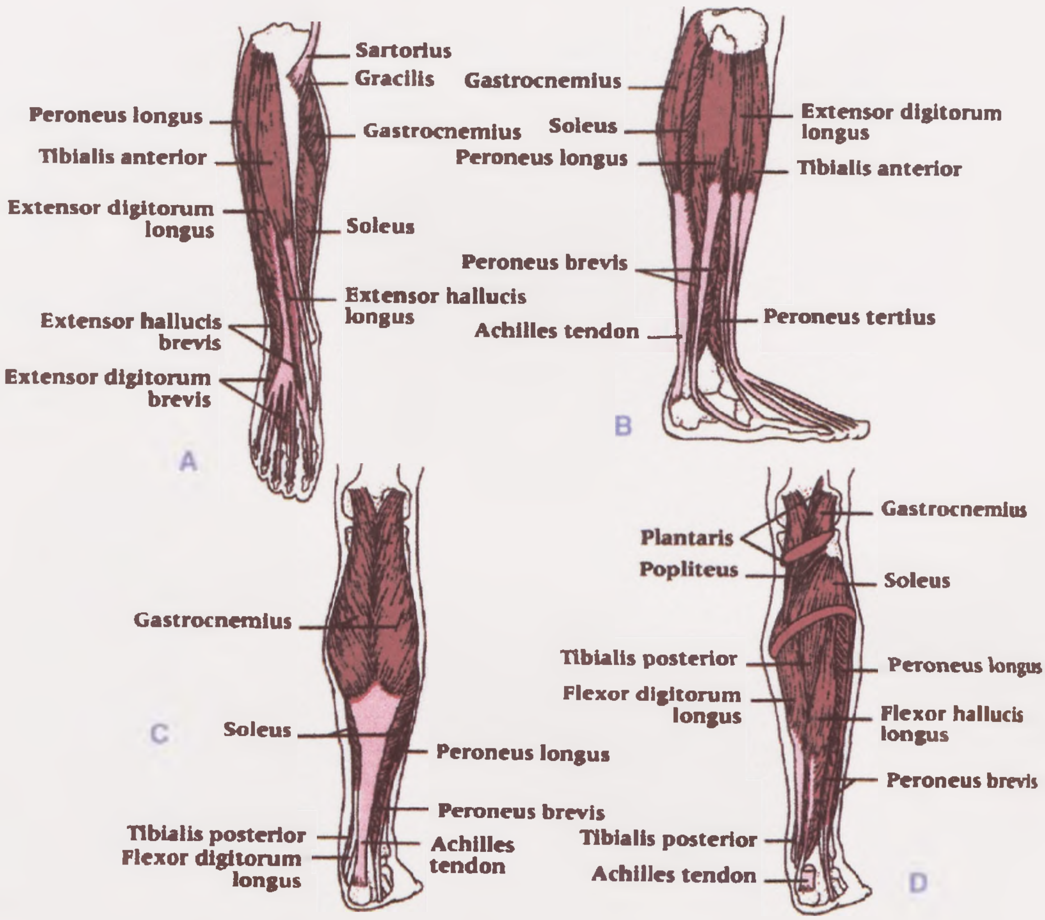


Figure 4.5. Extrinsic Muscles of the Lower Leg and Foot.
A. Anterior view, B. Lateral view,
C. Posterior view (superficial structures),
D. Posterior view (deep structures
(Arnheim and Prentice, 1997)

The muscles that originate in the lateral leg--the peroneus longs and peroneus brevis--act to plantarflex and evert the foot. Additionally, these muscles stabilize the lateral ankle and the lateral longitudinal arch of the foot (Helfet, 1980).

Muscles originating in the posterior part of the lower leg are the primary plantar flexors of the foot and ankle, inserting on to the plantar surfaces of the foot. The superficial posterior muscles--the gastrocnemius, soleus, and plantaris--all converge to form the Achilles tendon, which inserts onto the posterior part of the calcaneus. The deep posterior muscles which insert on the foot are: the flexor digitorum longus, the flexor hallucis longus, and the tibialis posterior. The flexor digitorum longus and flexor hallucis longus are important in allowing for push-off during gait (Marieb, 1998), while the tibialis posterior is considered to be the primary stabilizing muscle of the medial longitudinal arch (Basmajian, 1963).

4.6.2 Intrinsic

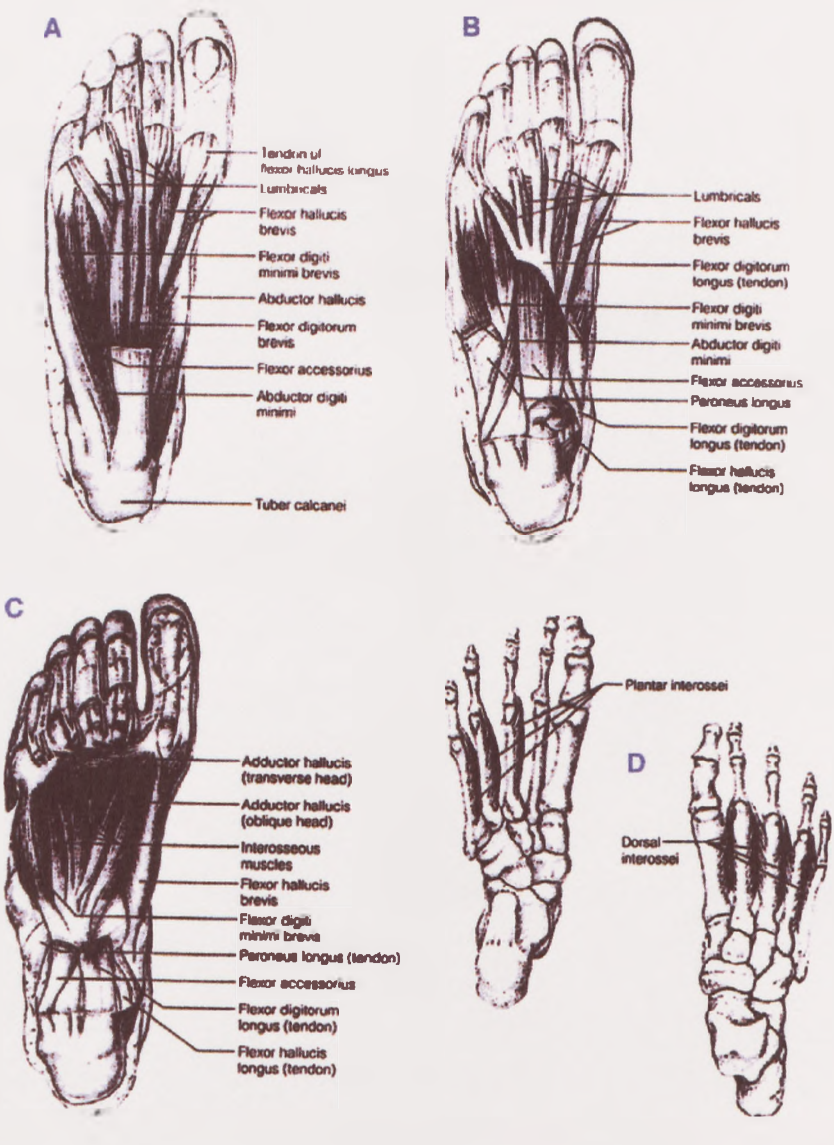


Figure 4.6. Intrinsic Muscles of the Foot. A. First (superficial) layer, B. Second layer, C. Third layer, D. Fourth (deepest) layer (Spence and Mason, 1979)

The extensive intrinsic musculature of the foot help to flex, extend, abduct, and adduct the toes, and to some extent help support the arches of the foot (Helfet, 1980; Mann, 1964; Marieb, 1998; Riegger, 1988). The foot contains many muscles, located in a small space, similar to the structure of the hand. Unlike the hand, the foot does not perform fine motor skills, but rather, acts to support the body during weight bearing and locomotion (Helfet, 1980; Mann, 1964; Riegger, 1988). Apart from the extensor digitorun brevis located on the dorsal surface of the foot, the remaining muscles are located on the plantar aspect, arranged in four layers from superficial to deep (Figure 4.6).

The most superficial layer, or the first layer of plantar muscles is made up of the flexor digitorum brevis, the abductor hallucis and the abductor digiti minimi. The second layer is made up of the flexor accessorius and the lumbricals. The third layer is made up of the flexor hallucis brevis, adductor hallucis, and the flexor digiti minimi brevis. The fourth and deepest layer of the plantar muscles is made up of the three plantar and four dorsal interossei muscles.

4.7 ARCHES OF THE FOOT

The foot is described as having four arches (Arnheim and Prentice, 1997), two longitudinal and two horizontal (Figure 4.7). The two longitudinal arches are: the lateral longitudinal arch and the medial longitudinal arch. The two horizontal arches are: the transverse tarsal arch, and the metatarsal arch. There is much debate over the actual existence of two horizontal arches. Most medical professionals acknowledge the existence of the two horizontal arches (Arnheim and Prentice, 1997; Hoppenfeld, 1976; Norkin, et. al., 1992; Riegger, 1988), however, many in the scientific fields question or ignore their existence (Lapidus, 1943; Morton, 1924; Salathe, 1986). Still others only recognize one horizontal arch that encompasses the entire foot (Elftman, 1938; Hicks, 1955; Jones, 1941; Sammarco, 1989). While the function of the horizontal arches may be questionable from a mechanical standpoint, one only has to perform a visual inspection of the foot to acknowledge their existence and so they will be included within the context of this thesis.

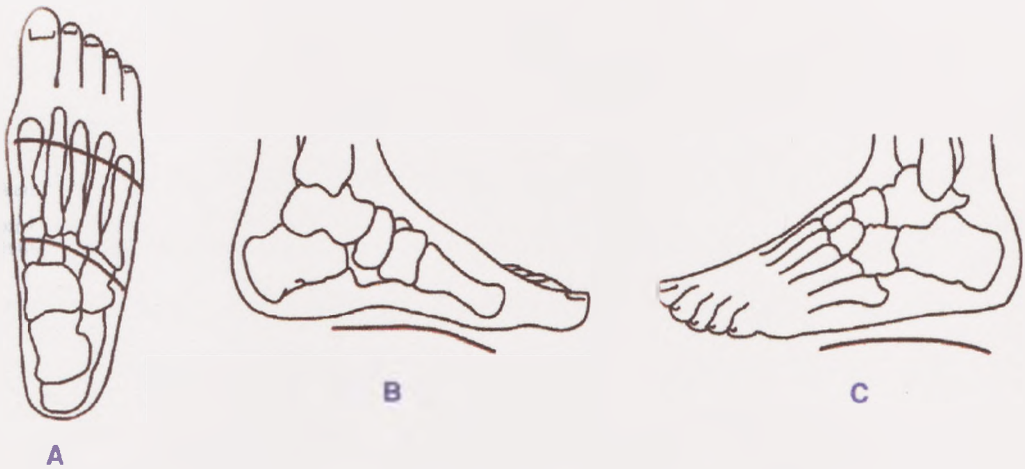


Figure 4.7. Arches of the Foot. A. Metatarsal and transverse arches, B. Medial longitudinal arch, C. Lateral longitudinal arch (Arnheim and Prentice, 1997)

The formation of the arches allows for the support of the body weight with the least expenditure of anatomical material, and provides protection for the nerves and vascular supply on the plantar aspect of the foot (Arnheim and Prentice, 1997; Riegger, 1988; Saltzman, 1995).

The mechanism of arch support in the foot remains controversial despite years of investigation. According to some theories, the arches are maintained by the contraction of muscles (Keith, 1929; Gray's Anatomy, 1998 ed.); others believe that the arches are supported strictly by skeletal and ligamentous structures (Basmajian, 1954; Morton, 1935); while others believe that arch support is achieved through a combination of both muscles and skeletal/ligamentous tissue (Harris, 1948; Hicks, 1954, 1955; Jones, 1941; Lapidus, 1943; Reigger, 1992; Salzmaan, 1995; Wright, 1964). There seems to be overwhelming support for the latter theory, and it is also the view of the author. Therefore, the anatomical elements of the arches of the foot will be addressed with this in mind. Specific mechanics will be discussed later.

4.7.1 Lateral Longitudinal Arch

From the lateral view, the foot has a relatively low arch formed by metatarsals 4 and 5, the cuboid, and the calcaneus, with the cuboid at its apex. The lateral longitudinal arch commonly bears the weight of the body before the medial arch comes into play (Sammarco, 1989). It yields by flattening at the hinged surface between the cuboid and metatarsals 4 and 5 (Hicks, 1961). The lateral part of the plantar aponeurosis acts as a tie-beam beneath the arch, preventing excessive spread and deformation (Hicks, 1961). The peroneus longus tendon also helps to support the lateral longitudinal arch, passing under the cuboid at the apex and inserting onto the medial side of the foot, resting in a groove on the dorsal surface of the cuboid.

3.7.2 Medial Longitudinal Arch

The medial longitudinal arch is formed anteriorly by metatarsals 1, 2, and 3, the cuneiforms, and the navicular and posteriorly by the talus, and calcaneus. The head of the talus is the keystone between the posterior and anterior parts of the arch, while the navicular tuberosity marks its apex (Helfet, 1980). The medial longitudinal arch is higher than the lateral and is generally easily seen in a footprint (Cavenagh, 1987). It is not apparent in young children (Bordelon, 1983) or in individuals with rigid flat feet (Subotnick, 1981). In the normal foot, under pressure from above, the medial longitudinal arch tends to flatten at the hinge surfaces between the talus and navicular, and between the navicular and cuneiform bones (Hicks, 1961), but not to the extent that the skin comes into contact with the ground, unlike the lateral side of the foot. The reason for this is the fact that the medial longitudinal arch is well supported by both ligaments and muscles.

The ligaments play a substantial part in connecting the bones together and providing support for the arch, the most important being the plantar aponeurosis which acts as a tie-beam between the calcaneus and the phalanges (Hicks, 1961). If the plantar aponeurosis is shortened by extending the toes, then this acts to draw the calcaneus and the phalanges toward each other, thus increasing the height of the medial longitudinal arch. The spring ligament (plantarcalcaneo-navicular ligament), running between the sustentaculum tali of the calcaneus and the navicular tuberosity helps to support the medial longitudinal arch by supporting the head of the talus. In this way it helps to maintain the forward direction of pressure from above towards the heads of the metatarsals (Norkin and Levangie, 1992). Finally, located beneath the plantar aponeurosis, the long plantar ligament--running from the plantar surface of the calcaneus and attaching onto the ridge of the cuboid--and the short plantar ligament, form an additional tie-beam support for the arch (Helfet, 1980).

The muscles and tendons are indispensable to the maintenance of the arches as they come into play when excessive pressure is put upon the foot and its arches. Extrinsic muscles contribute more to the maintenance of the medial longitudinal arch, while intrinsic muscles assist more in the maintenance of the horizontal arches (Helfet,1980).

The primary muscles involved in the maintenance and function of the medial longitudinal arch include: the flexor hallucis longus, the flexor digitorum longus, the tibialis posterior, and tibialis anterior. The flexor hallucis longus, whose tendon passes across the sole of the foot from the sustentaculum tali to the base of the terminal phalanx, acts as a tie-beam which help to prevent the spreading of the two pillars of the arch (the calcaneus and the phalanges), helping to maintain the arch (Riegger, 1988). The tibialis posterior contributes by supporting the spring ligament (Palastanga, 1994). The tibialis posterior tendon passes behind the medial malleolus of the tibia and is inserted on the underside of the navicular tuberosity. This tendon passes deep to the spring ligament, thereby assisting it in the support of the head of the talus. As mentioned previously, the tendon of the tibialis anterior is believed to provide some contribution to the elevation of the medial longitudinal arch, but this is relatively slight.

4.7.3 Transverse Tarsal Arch

The transverse tarsal arch is a horizontal arch formed by the cuneiforms and the cuboid. When the feet are placed side by side, a complete transverse arch is formed with each foot contributing half an arch (Helfet,1980). The medial cuneiforms of each foot provide the apex of this arch. If looking at each foot individually, the transverse tarsal arch has a slightly concave appearance, with the middle cuneiform bone forming the apex. The tibialis anterior probably contributes something to the maintenance of this arch, but more important is the tendon of the peroneus longus, which crosses the foot from the lateral border of the cuboid to the medial border of the medial cuneiform, thereby drawing these two borders and forming a concave undersurface to the tarsal area of the foot (Helfet, 1980).

4.7.4 Metatarsal Arch

The metatarsal arch, runs horizontally along the heads of the five metatarsal bones and is strung together by ligaments. At the level of the metatarsal heads, it is more visually apparent than the transverse tarsal arch, with the second metatarsal forming the apex of the arc (Hoppenfeld, 1976). The primary muscle involved in its maintenance is the transverse portion of the adductor hallucis which runs across the sole of the foot along the metatarsophalangeal joints (Helfet, 1980).

4.8 MECHANICS OF THE FOOT AND ARCHES DURING THE WALKING GAIT CYCLE

Before one can understand and assess the mechanics of the foot, one needs to have an understanding of the general gait cycle. There are two phases to the normal walking cycle: the stance phase, when the foot is on the ground; and the swing phase, when it is moving forward. For descriptive purposes, the action of only one leg will be discussed. The complete cycle includes the activities that occur from point of initial contact of one extremity to the point at which the same extremity contacts the ground again.

4.8.1 Stance Phase

The stance phase of gait begins the instant that one extremity contacts the ground and continues only as long as some portion of the foot is in contact with the ground (Figure 4.8). Most problems involving the lower extremities become apparent in this phase since, because it bears weight and constitutes 60% of gait, it undergoes the greater stress (Hoppenfeld, 1976). The stance phase can be broken down into five sub-points: heel strike, the instant that one foot contacts the ground; foot flat, occurring immediately after heel strike and is the point at which the foot fully contacts the ground and the opposite or follow-through leg is behind the support leg; midstance, the point at which the body weight is directly over the supporting lower extremity and the follow-through leg is adjacent to the support leg; heel off, the point at which the heel of the foot leaves the ground and the follow-through leg is also starting to make contact with the ground; and finally, toe off, the point at which only the toe of the support foot is in contact with the ground and the opposite leg has made full contact with the ground (Norkin and Levangie, 1992). During the latter two points, when the opposite leg is also in contact with the ground is a period often referred to as double-stance.

A period that can be referred to as the terminal stance phase occurs from the end of the midstance to a point just prior to initial contact of the adjacent extremity. This may occur directly before or slightly after heel-off (Norkin and Levangie, 1992).

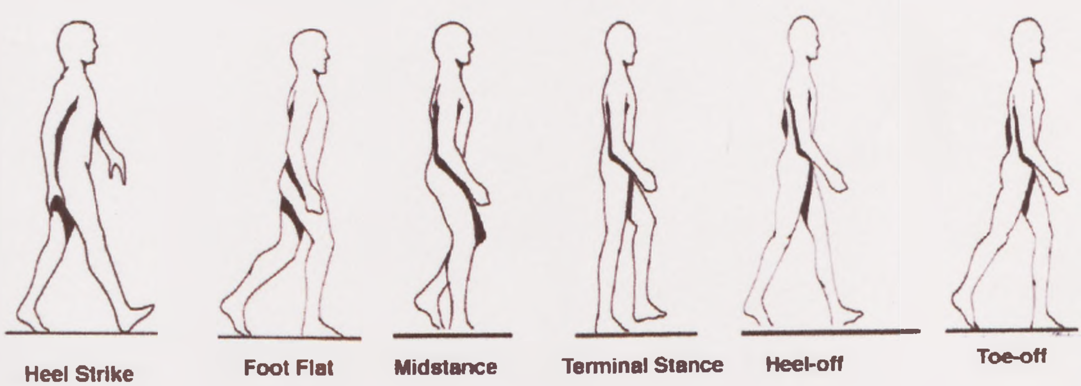


Figure 4.8. Stance Phase of the Walking Gait (Modified from Norkin and Levange, 1992)

One of the primary differences between walking gait and running gait is the fact that during running, there is a period in which neither foot is making contact with the ground.

4.8.2 Swing Phase

The swing phase begins as soon as the toe of the foot leaves the ground and ceases just prior to heel strike or contact of the same foot (Figure 4.9). During the swing phase, the reference foot does not contact the ground at any time. Fewer problems become evident in this phase since the extremity is no longer subjected to the stresses of weight bearing and support, however, those problems that do become apparent usually involve structures higher up the kinetic chain such as the knee, hip, and pelvis (Hoppenfeld, 1976). The swing phase can be divided into three sub-phases: acceleration, beginning once the toe of the foot leaves the ground and continues until the foot is directly under the body; midswing, occurring when the foot passes directly beneath the body; and deceleration, occurring when the tibia passes beyond the perpendicular and the knee is extending in preparation for heel strike (Norkin and Levangie, 1992).

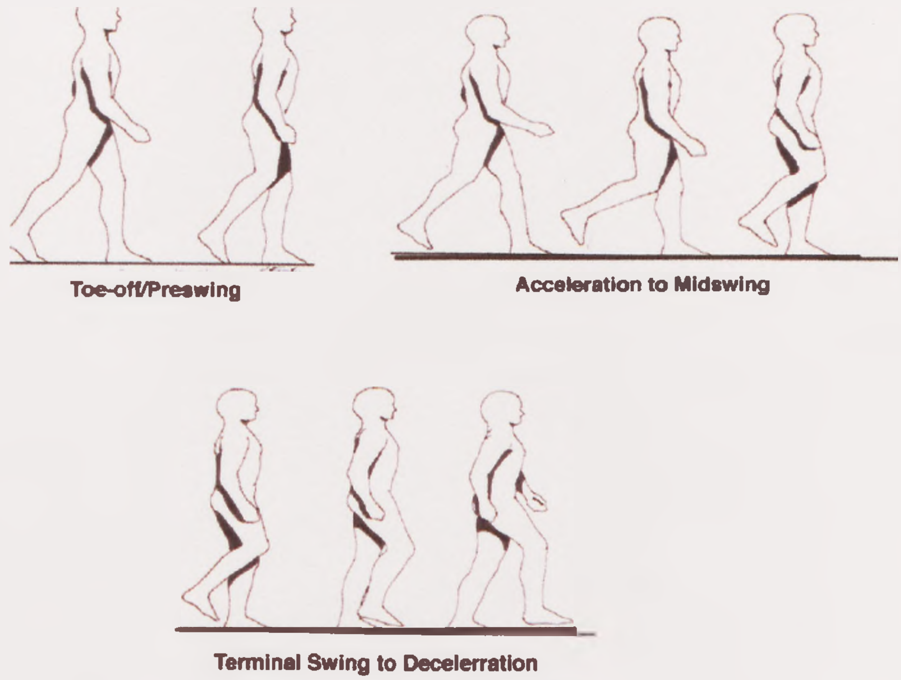


Figure 4.9. Swing Phase of the Walking Gait (Modified from Norkin and Levange, 1992)

4.9 FOOT MECHANICS DURING GAIT

4.9.1 Barefoot Conditions

The movements of lower-extremity segments during the gait cycle directly and indirectly contribute to the creation of motion in the foot during the support phase of walking. Pronation and supination have been identified as the most important set of movements within the foot, serving as a torque transmitter, responding to the load of body weight and the movements of the limbs superior to the foot (Czerniecki, 1988). An understanding of the mechanisms contributing to pronation and supination in the foot is necessary if one is to be able to accurately assess foot function and gait abnormalities.

When contact is made with the ground in walking, the foot must be flexible as it adapts to the contact surface, semi-rigid as it absorbs and transmits the force of impact, and rigid as it propels the body forward (Rodgers, 1988). Pronation and supination movements in the foot are important in determining the extent to which the foot will behave as a flexible or rigid body (Knutzen and Price, 1994). Both pronation and supination occur passively when the foot meets the ground, changing the movement from an open kinetic chain to a closed kinetic chain (Nuber, 1988; Donatelli, 1987).

At heel strike, the vertical ground forces are transmitted to the calcaneus, which is usually slightly inverted, making the force application on the lateral aspect of the calcaneus. At this time, the foot is in a slightly supinated position.

After contact is made with the supporting surface, the foot is forced into pronation, where the primary activity is at the subtalar joint (Figure 4.10). Pronation occurs in response to the force of the body weight imposed on the lateral aspect of the joint--the subtalar joint allows the calcaneus to move laterally into eversion while the talus moves medially into plantarflexion and adduction, (Donatelli, 1987; Marshal, 1988). As pronation takes place, the calcaneo-cuboid and talo-navicular joint axis become parallel, unlocking the midtarsal joint and creating flexibility in the forefoot (Marshall, 1988: Ting, et. al., 1988). These actions allow the foot to become a flexible and accommodating structure that can absorb impact forces and adapt to varying surfaces (Knutzen and Price, 1994).

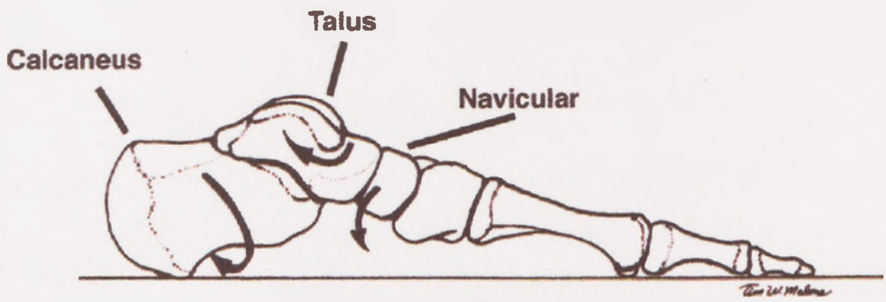


Figure 4.10. Movements of the calcaneus, talus, and navicular bones after contact is made with the supporting structure during walking gait (Modified from Norkin and Levange, 1992)

As the body moves over the foot into the midstance position, the lower limb begins to rotate laterally (Rodgers, 1988). At about or just after midstance, supination is initiated in the foot as this rotation is absorbed by the talus. The calcaneus inverts and pushes the talus into dorsiflexion and abduction (Donatelli, 1987; Marshall, 1988). At the midtarsal joint, the calcaneo-cuboid and the talo-navicular joint axes are forced into a nonparallel relationship to each other, locking the transverse tarsal joint and creating rigidity in the forefoot (Marshall, 1988; Ting, et. al., 1988). These actions allow the foot to become a stable rigid body that optimizes force application for propulsion (Knutzen and Price, 1994).

Until now, the mechanics of the foot have been described by what occurs passively, due to a combination of bone shape, gravity, and body weight. However, even though these supination and pronation movements are initiated passively, there is still considerable muscular activity involved to control the movements. During the heel strike and support phase, the tibialis anterior acts to lower the foot eccentrically to the ground and restrain the eversion component of pronation (Rodgers, 1988; Nuber, 1988). The tibialis posterior is active later in the cycle to eccentrically control passive eversion in the foot (Nuber, 1988). Finally, the intrinsic muscles of the foot offer control over the arch and the midfoot (Rodgers, 1988; Nuber, 1988).

In addition to the bones and muscles of the foot, another structure that assists in the second supination phase is the plantar aponeurosis. As the foot moves into dorsiflexion and the heel starts to rise prior to toe-off, the plantar aponeurosis tightens on the plantar surface creating maximal tension and a windlass effect (Rodgers, 1988). This action, along the positioning of the cuboid and navicular bones, creates additional rigidity in the foot.

During the running cycle, supination and pronation of the foot occur at certain specific times. After the foot strikes the ground, it rapidly goes from supination to pronation and remains pronated for about 70% of the support phase. The foot then begins to undergo supination for the push-off phase and remains in supination during the swing phase until the foot makes contact with the supporting surface once again (Knutzen and Orice, 1994).

4.9.2 Shod Conditions

The previous section on foot mechanics during gait applies only to a bare or unshod foot. Once footwear is added, changes occur to the foot, and subsequently, the lower leg, knee, hip, and further up the kinetic chain.

Immediately after heel strike, as the foot goes from supination to pronation, the mechanics of the foot and leg are significantly influenced by the shoe construction in that a shoe increases angular displacement as well as angular velocity--the foot pronates at a high rate (Luethi and Stacoff, 1987; Luethi, et. al., 1984; Nigg, 1985). This increased pronation velocity results in fast eccentric loading of the muscles, tendons, and supporting ligaments which could lead to an increased risk of injury (Luethi and Stacoff, 1987).

During the period in which the entire foot is in contact with the ground and the foot is in pronation, shoes have been shown to increase the range of maximum pronation (Nigg, et. al., 1990). In a shoe with a soft midsole, overpronation, which has been identified as one of the most common causes of running injuries, may occur.

Finally, during the heel-off to toe-off phase, as the foot supinates and starts to become a rigid lever for propulsion, the barefoot generally has a straighter take-off angle. While wearing shoes, the foot often remains in the overpronated position, even during push-off, (Nigg, et. al., 1990). When this occurs, the foot does not become a fully rigid structure, requiring the muscles and the Achilles tendon to overcompensate. This overcompensation can potentially lead to injuries within these structures.

4.10 ANOMOLIES OF THE FOOT AND ARCH

Before one can look at the anomolies of the foot and arches, one must have a knowledge of the structure of the normal foot. In the normal foot, the medial malleolus, navicular tuberosity, and the head of the first metatarsal lie in a straight line. Deviations from this normal position can result in conditions known as pes planus or pes cavus. While "normal" is being used as a descriptive term from a visual standpoint, it must be noted that it is possible for an individual to have a pes planus or pes cavus foot appearance that functions without any causing any apparant mechanical or physical problems.

4.10.1 Pes Planus (Flatfoot)

Pes Planus or flatfoot is characterized by an absent or reduced medial longitudinal arch and may be either flexible or rigid. A rigid flatfoot is a structural deformity that may be a hereditary condition where the medial longitudinal arch is absent in the non-weight-bearing and weight-bearing positions. In the flexible flatfoot, the arch is reduced during normal weight-bearing but is apparent during non-weight-bearing. The flexible flatfoot is the most common of the two.

In both types of pes planus, there is displacement of the talus anteriorly, medially, and inferiorly; depression and pronation of the calcaneus; and depression of the navicular (Norkin and Levangie, 1992). One form of flat feet can result from stretching of the spring ligament so that the talus rotates downward and the line of pressure is directed downwards, towards the plantar surface, rather than forwards to the metatarsal heads (Norkin, et al., 1992; Subotnick, 1980). Pes planus interferes with push-off during walking because the foot is unable to assume the supinated position and become a rigid lever for push-off in gait. Pronation in a closed kinetic chain also causes medial rotation of the tibia and may affect knee and joint function.

4.10.2 Pes Cavus (High Arch)

A less common but potentially more serious problem exists in individuals with a pes cavus condition commonly known as high arches. This condition can also be rigid or flexible. In rigid pes cavus, the medial longitudinal arch is present and appears abnormally high in the non-weight-bearing position, with no normal deformation of the arch during weight-bearing. Flexible pes cavus is occurs when the arch appears abnormally high during non-weight-bearing, but depresses slightly to normal during weight-bearing. Again, it is the more common form of the two.

In a pes cavus foot, the subtalar and transverse talar joints may be locked into supination. This extreme supination of the foot is accompanied by abduction of the head of the talus and inversion of the calcaneus. During gait, pes cavus interferes with shock absorption and the ability to adapt to uneven terrain (Norkin and Levangie, 1992). The resulting hindfoot supination causes lateral rotary stresses on the leg, which can, in turn, adversely affect the ankle, knee, and hip joints.

4.11 IMPLICATIONS FOR FUTURE RESEARCH

In the previous chapter, it was revealed that one fourth to one third of all lower-extremity injuries in football were overuse in nature. This, combined with the literature discussed in this chapter indicate that the foot is a very complex structure and that external components, such as footwear, training surfaces, and even the gait itself can adversely affect foot function, leading to these overuse injuries. Therefore, it appears that these issues need to be addressed in order to determine what can be done to reduce the risk of these injuries.

Training surfaces vary considerably between sites, climates, and countries, and were considered beyond the scope of this document. It has previously been established that there are links between training surfaces and injuries, with many overuse injuries occurring on hard-ground surfaces, the type that is frequently seen in the United States.

Gait type is also as varied as the individual involved and was also considered beyond the scope of this document, however, differences between walking and running gait will need to be explored to see if the foot functions differently between the two conditions.

Finally, this leaves the issue of the effects of footwear. Football boots differ from other athletic shoes due to the lack of midfoot support and the added impact forces of the studs placed on the sole of the shoe. In football there are currently three types of footwear worn by athletes: screw-in stud, multi-stud turf, and moulded stud. Moulded stud shoes were selected as the focus of this document because there are fewer variables connected with this type of boot compared with the screw-in models. Multi-stud turf shoes have already been addressed in other studies.

The purpose of this thesis was to determine the effects of football boots on the structure and function of the foot. In order to accomplish this task, a technique(s) needed to be developed in order to look at and measure the foot structures. The midfoot was chosen as the focus of these studies because the navicular bone appears to be one of the key structures of the foot during gait. Additionally, the navicular tuberosity has been determined to be the apex of the medial longitudinal arch, a structure that has long been associated with foot function. The navicular tuberosity has the added advantage of being easily identified and palpated externally.

Once a technique has been developed for viewing and measuring the foot structures, specifically the navicular bone, the next step would be to find a way to utilize this technique to measure/visualize these structures while the foot is covered with a football boot. As mentioned in the introduction, it was hypothesized that the stud placement on the sole of the football boot, combined with lack of internal arch support would adversely affect the foot structures, leading to the development of overuse injuries in the lower extremities. Therefore, the purpose of this research thesis was to determine if, indeed, this was true. If so, specifically, how the structures of the foot were affected.

Chapter 5

The Use of Footprints and Navicular Drop to Determine Foot Type, Arch Height, and Static Foot Function

5.1 INTRODUCTION

During normal weight bearing, the foot changes shape, widening and lengthening, with the arches flattening slightly. The amount of deformation is limited by skeletal structures and soft tissue, the ground surface, and in some cases, footwear (Manter, 1946). The location of the studs on a football boot, at the heel and forefoot, leaves the midfoot relatively unsupported during weight-bearing. Assuming that the studs do not penetrate the ground fully, it is theorized that during the stance phase, the loading continues downward through the midfoot region while the ground reaction forces are acting on the heel and forefoot. In theory, the actions of these forces on the foot could result in increased structural changes in the midfoot region. If these structural changes occur, they could then result in mechanical changes in the lower leg/foot/ankle complex, which over a period of time could cause repetitive stress/overuse injuries to the lower extremities.

The height of the arch is believed to be functionally significant for the mechanics of the foot. It is well established that individuals with abnormally high [pes cavus] or low [pes planus] arches run a greater risk for development of overuse injuries to the lower extremities (Clement, et. al.,1981; Jones, 1983; Kibler, et. al., 1991; McKeag, et. al.,1989; Micheli, 1986; Stanish, 1984; Subotnick, 1975). Determination of the distribution of footsole pressure under load is helpful in clarifying various kinds of foot-related complaints as well as the changes in the function and structure of the foot (Cavanagh, et. al., 1987). In view of this, it appeared essential to study the patterns of footsole imprints and changes in arch height in normal subjects under various loading conditions to see if differences exist. The purpose of this study was to obtain information about how the midfoot and the medial longitudinal arch react when 1) the foot is in a non-weight-bearing position; 2) the foot is in a normal, static, weight-bearing position; and 3) the foot is in a static, weight-bearing position while the forefoot and heel are elevated to the height of the stud on a standard football boot, without support to the midfoot region.

Many attempts have been made to predict arch height (and therefore foot function) from footprints (Clarke, 1933; Irwin, 1937; Clarke 1982; Hening, et. al., 1985; Cavanagh, 1985, 1987; Freychat, et. al.,1996). Perhaps the most commonly utilized footprint measurement in recent years is the arch index (Figure 5.1), developed by Cavanagh and Rodgers (1987). With this method, a toe-less footprint is used. A line segment is drawn between the point centered on the second toe and the most posterior point on the heel and is called the foot axis (Figure 5.1A). Parallel lines, perpendicular to the axis divide the toeless footprint into equal thirds (Figure 5.1B).

The arch index is calculated as the ratio of the area of the middle third of the footprint to the entire toeless footprint area. The calculation of the arch index, AI, is then:

$$AI = \frac{B}{A+B+C}$$

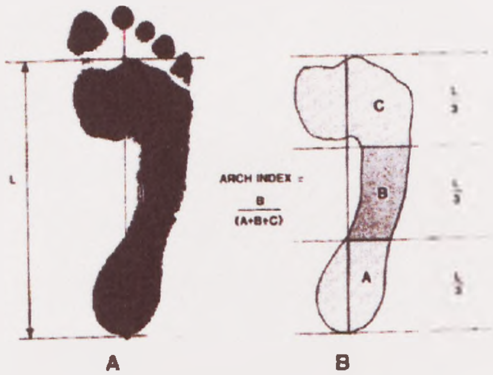


Figure 5.1. The Arch Index. A. Foot axis (L= length of toeless footprint), B. Dividing the toeles footprint into equal thirds (Cavanagh and Rodgers, 1987)

This is then compared to previously determined values for classification of foot type where:

high arch	$AI \leq 0.21$
normal arch	$0.21 \leq AI < 0.26$
low arch	$AI \leq 0.26$

Another technique for determining arch height and predicting static foot function is the "navicular drop." This technique was originally developed by Brody (1982) as a method for evaluation of injured runners. He theorized that changes in navicular height from the floor are related to changes in the midtarsal joint. Additionally, since the navicular tuberosity has been determined to be apex of the medial longitudinal arch, changes in its height from the floor can be related to changes in the medial longitudinal arch, which tends to lengthen and flatten under the pressure of weight-bearing. This technique has since been adapted for dynamic measurements and is utilized by Sell, et. al. (1994) for assessing subtalar joint position, and by Hawes, et. al. (1992) as a method for classifying foot type.

5.2 SUBJECTS

For this preliminary study, 5 individuals (2 men, 3 women) were recruited from within the sport sciences department at the University of Leeds.

5.3 METHODS AND MATERIALS

5.3.1 Screening and Anatomical Marking

Using a standard evaluation form developed by following the guidelines outlined by Hoppenfeld (1976) (Appendix C), all subjects were screened for abnormalities, and appeared to have normal gaits and no history of foot pain or discomfort. If, during the screening process the subject was unable to perform any functional test or had a history of foot injury or pain, they would have been excluded from the study. Additionally, the height and weight of each subject was obtained. During the screening process, with the subject seated on a table and the foot placed in a neutral position, the skin was marked in ink on the medial and lateral sides of the foot at a level proximal to the metatarsal heads and at the transverse tarsal arch. These were used as the landmarks for placing the blocks of wood that were to simulate stud placement on a football boot. Also during the screening process, with the subject seated on a table and the foot placed in a neutral position, the skin over the most palpable portion of the navicular tuberosity was marked with a small dot of ink. This mark was then used as the landmark for which all measurements for the navicular drop test were taken.

Measurements were only obtained for one foot, in this case the right foot, as previous studies by Munro, et. al.(1987) and Hamill, et. al. (1984) observed no significant differences between right and left feet on multivariable analysis in healthy, symptom-free subjects.

All procedures were repeated over a three-day period to determine measurement reliability and consistency of marking anatomical landmarks.

5.3.2 Footprints

The subject was seated with the knee flexed at a 90° angle and the tibia/fibula lined up directly over the talus and mid-calcaneus in a neutral position on a wooden platform. A wooden slat was placed directly behind the heel to allow for repositioning of the foot. The foot was removed from the platform and a piece of construction paper was placed over the platform surface. The plantar surface of the foot was lightly sprayed with a water-based solution containing a black food dye and then repositioned in the neutral non-weight-bearing position on the paper-covered platform (Figure 5.2A). The subject held this position for a few seconds and then gently removed the foot from the paper. The paper was removed from the platform immediately and the foot imprint was traced before the water solution dried. For step two, the above procedure was repeated, except the subject was asked to stand and assume a static weight-bearing position after the foot had been sprayed with the water solution and placed in the neutral position over the paper-covered platform (Figure 5.2B). The subject was then seated before removing the foot from the paper and tracing the footprint. Finally, the above procedures were again used except two blocks of wood, measuring 15 mm in height (the height of a standard soccer stud) were placed under the foot, one under the forefoot at the level of the metatarsal heads and the other under the hindfoot at the level of the transverse tarsal arch, roughly the same position of the studs of a soccer boot. A thin, flexible piece of

Figure 5.2A. Non-weight-bearing

Figure 5.2B. Weight-bearing

Figure 5.2C. Weight-bearing with heel and forefoot elevated 15 mm

Figure 5.2. Footprint Collection Process

plastic was placed over the two blocks of wood and the construction paper was placed over the piece of plastic. The foot was sprayed, placed in the appropriate position, and the subject was asked to stand. In this position, the forefoot and heel were supported by the blocks of wood, leaving the midfoot unsupported except for the thin sheet of plastic. The other foot was also elevated to 15 mm so that the body weight would be evenly supported (Figure 5.2C). As before, the subject sat before removing the foot from the paper.

5.3.3 Navicular Drop

The subject was seated with the knee flexed at a 90° angle and the tibia/fibula lined up directly over the talus and mid-calcaneus in a neutral position and the height of the navicular was taken in the non-weight-bearing position. A 3" x 5" index card was placed vertically on the inner side of the foot, just anterior to the skin marker over the navicular. The difference from the tabletop to the mark on the navicular tuberosity was marked on the card with a line (Figure 5.3A). Without moving the foot, the subject was asked to stand and assume a static weight-bearing position and again the navicular height was marked on the card (Figure 5.3B). The difference between the two lines in millimeters (mm) was determined to be the navicular drop. The subject was then seated back in the neutral position and two blocks of wood, measuring 15 mm in height were placed under the foot, one under the forefoot at the level of the metatarsal heads and the other under the hindfoot at the level of the transverse tarsal arch, roughly the same position of the studs of a football boot. The navicular height from the tabletop was again marked on the index card in the seated (Figure 5.4A) and standing position while the forefoot and heel were elevated (Figure 5.4B). As before, the difference between the two lines was determined to be the navicular drop. To determine if differences exist between the two loading conditions, the height of the blocks of wood, 15 mm, was subtracted from the navicular heights obtained in this trial, and then compared to the unloaded trials.

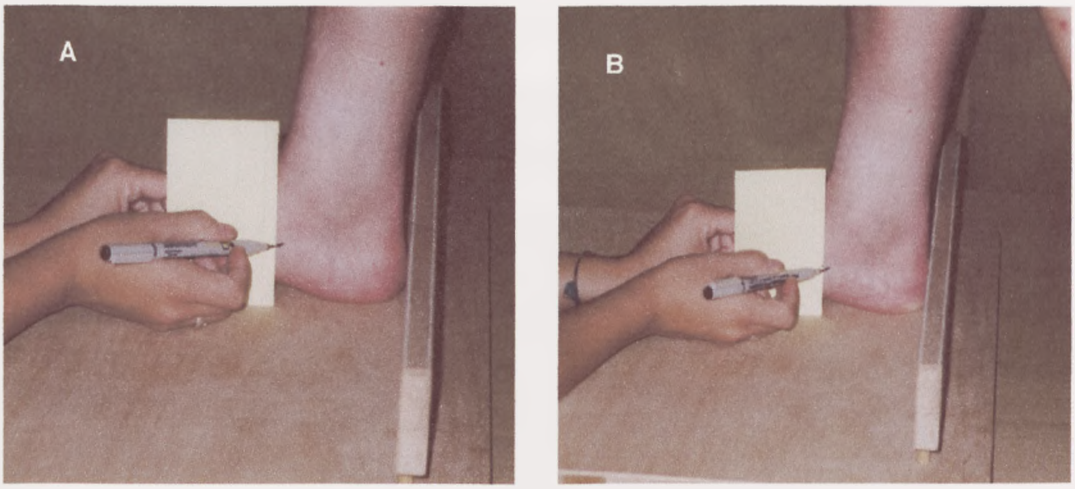


Figure 5.3. Brody's Navicular Drop Test.
A. Non-weight-bearing, B. Weight-bearing

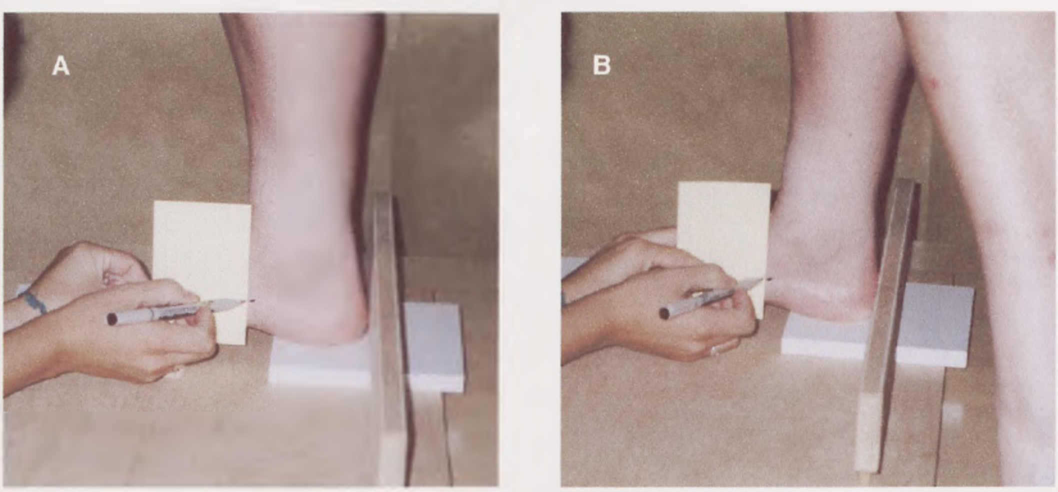


Figure 5.4. Brody's Navicular Drop Test with Forefoot and Heel Elevated 15 mm.
A. Non-weight-bearing, B. Weight-bearing

5.4 RESULTS AND DISCUSSION

The navicular drop results for all of the subject over the three day period from this study can be seen in Table 5.1. An ANOVA for correlated means showed no statistical differences between the data collected over the three day period (day 1, f=.01, p=0.91; day 2, f=.02, p=0.90; day 3, f=.06, p=0.81). Therefore it was determined that the measurement tool was reliable and there was consistency in marking the anatomical landmarks.

Table 5.1. Navicular Drop Results for the Five Subjects for the Three Day Period

Subject	Normal Navicular Drop (mm)	Navicular Drop with Forefoot and Heel Elevated 15 mm (mm)
1-Day 1	4	4
1-Day 2	5	4
1-Day 3	4	3
2-Day 1	9	9
2-Day 2	8	9
2-Day 3	9	9
3-Day 1	9	10
3-Day 2	9	9
3-Day 3	9	9
4-Day 1	4	3
4-Day 2	4	4
4-Day 3	5	4
5-Day 1	5	6
5-Day 2	5	6
5-Day 3	6	6
Mean±SD	**6.33±2.19***	**6.33±2.58***

* No statistical differences.

While the shape of the footprints obtained in this study varied between the non weight-bearing, weight-bearing, and weight-bearing with forefoot and hindfoot elevated 15 mm (Figure 5.5), these results were determined to be inconclusive due to the inability to differentiate between soft tissue deformation and changes in underlying skeletal structure. This could have also been influenced by the placement of the blocks at the forefoot and heel, combined with the fact that there was no support at the midfoot. Cobey and Sella (1981) have suggested that feet of similar structure (as determined by x-ray) can exhibit differing footprints due to soft tissue influences. This could place severe limits on inferences concerning foot structure that can be made from footprints. However,

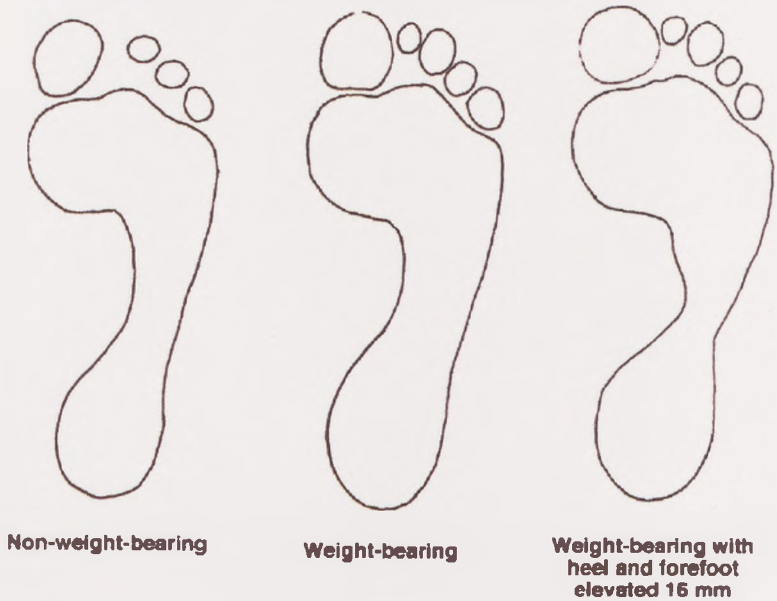


Figure 5.5. Footprints from a single subject during data collection

the footprints obtained in this study indicated that weight distribution tended to shift laterally when the forefoot and heel were elevated. This was also noted visually, with subjects tending to exhibit a lateral sway even though they were instructed to stand normally.

An ANOVA for correlated means also revealed no statistical differences between the navicular drop between normal weight-bearing and when the forefoot and heel were elevated (f=0, p=1.0).

While the simple design of this study allowed for full view of the foot with the forefoot and heel elevated the height of a football stud, there were several drawbacks. First, it relied on manual measurements, which are inherently prone to human error. Second, it could only be performed in a static position, and therefore could only offer information regarding foot function during one position. Third, the forefoot and hindfoot were elevated on a flat surface, rather than the "rocker bottom" contour of a normal shoe sole. Fourth, the measurements were all obtained while the foot was originally positioned in subtalar neutral, which may not be a natural stance for the subject.

5.5 CONCLUSIONS

Due to the limitations of this study and the lack of useful results, it was determined that additional research needs to be conducted, collecting data dynamically. Once an appropriate method was established, further analysis was undertaken looking at the effects of footwear on the anatomical structures of the foot.

Chapter 6

ProReflex® Analysis of Navicular Drop--A Repeatability Study

6.1 INTRODUCTION

Gait in humans has been shown to be a complex activity involving precise timing and interactions between segments in the lower-extremity chain. However, little is known of the function of the complex bone, joint, and soft-tissue interactions within the foot during gait.

Most studies which have attempted to investigate the role of bone structure, ligaments and muscles have been limited to static loading conditions. Several of these static measurements are commonly utilized in the clinical setting to predict dynamic foot function and in the treatment and evaluation of lower extremity dysfunction. However, studies by Hamill, et. al. (1989), and McPoil, et. al. (1996), have found that static evaluation measurements are not valid predictors of dynamic foot function, but rather, can only provide the clinician with information regarding the range of motion and static alignment of the lower extremity and foot. Therefore, in order to get a more accurate picture of foot function researchers and clinicians alike must evaluate the foot during dynamic movements.

The height of the medial longitudinal arch of the foot has been suggested as an important structural feature of the foot (Nigg, et. al., 1993). Clinically, arch height has been used as a predictor of risk for lower-extremity injuries. Flat feet (pes planus) are often associated with overuse injuries such as shin splints, Achilles tendinitis, and plantar fasciitis, while high arches (pes cavus) are often associated with stress fractures in the foot and lower leg. Many evaluation techniques have been used clinically to determine arch height (and therefore foot function), including various methods of footprint analysis discussed earlier, but perhaps the most widely recognized is the navicular drop test, developed by David Brody, M.D. in the early 1980's. The navicular drop test addresses the plantar-flexion component of talar motion and can be used to assess the amount of subtalar pronation (Picciano, et. al., 1993). This technique, while widely recognized, has some notable drawbacks. First, it is performed in a static position. Second, it does not take into account soft tissue deformity of the fatty pad, located on the sole of the foot. This is problematic due to the fact that the thickness of the fatty pad decreases with age and continuous overloading (Hutton, et. al., 1979). And finally, manual placement of the patient into a subtalar neutral position is prone to error.

Using the following 17 different standard clinical static measurements:

1) Hip internal rotation in a prone position
2) Hip external rotation in a prone position
3) Malleolar torsion
4) Ankle dorsiflexion with knee joint fully extended
5) Ankle dorsiflexion with knee joint flexed to 90°
6) First metatarsophalangeal joint extension
7) Tibiofibular varus with both feet in contact with the ground
8) Tibiofibular varum while standing on a single leg
9) The difference between the two tibiofibular varum measurements
10) The height of the navicular tuberosity from the ground in a relaxed standing posture
11) The height of the navicular tuberosity from the floor with the subtalar joints positioned in neutral
12) The difference between the two navicular height measurements
13) Subtalar joint inversion
14) Subtalar joint eversion
15) Subtalar joint neutral position
16) First ray position
17) Forefoot position

McPoil, et. al., (1996) found that these foot measurements did not predict dynamic foot function in all but one of the measurements. The closest correlation was found with the navicular drop test, (test number 12) than with any of the others. Since the navicular bone is considered to be the apex of the medial longitudinal arch, is easily palpated, and is found to have some correlation to foot function, it will continue to be used in the clinical setting until a better test is developed.

The purpose of this project was twofold. Firstly, to develop a method to evaluate navicular height and the height of the medial longitudinal arch during dynamic movement. Secondly, to see if the results obtained utilizing this method were repeatable over a period of time as well as between individual trials. A method was developed utilizing a modified navicular drop test and collecting data dynamically with a ProReflex® motion analysis system.

6.2 SUBJECTS

Four healthy volunteers (male; aged 20-24 years; mass, 77.75±6.45 kg; height, 1.778±0.42 m) recruited from the School of Biomedical Sciences at the University of Leeds acted as subjects for this study. The subjects were all football players at varying levels of ability, and each played at least one game of football a week. Visual foot examination and goniometric measurements of the subtalar joint revealed 1 subject with pes planus and 1 subject with a flexible pes cavus foot. The remaining 2 subjects were classified as having normal feet.

6.3 EQUIPMENT AND SETUP

For this study, a single-camera ProReflex® system was used. This system consisted of a ProReflex® 250 camera, a Macintosh computer with MacReflex 3.41f17 PPC software (Qualysis©, 1997), a monitor to check the setup of the camera, and 3 mm reflective markers that were attached to the navicular tuberosity, calcaneal tuberosity, and joint space of the head of the first metatarsal of the right foot (Figure 6.1). The basic principle of the system is to expose the reflective markers to infrared light and detect the light reflected by the markers.

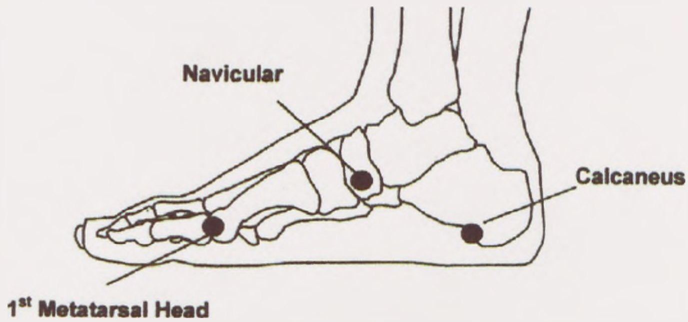


Figure 6.1. Placement of reflective markers

As only 2-dimensional data was required, only one ProReflex® camera was used. This was set up 700 mm from the platform walking area at a right angle. A platform, 100 mm high, 250 mm wide, and 500 mm long was constructed and the entire surface was covered with a 20 mm thick artificial grass to allow for adequate penetration of the studs of the football boots. Twenty-five millimeter reflective markers were placed at each end separated by a distance of 460 mm. This was used to scale the data. Additional larger platforms of the same height were placed on each side of the measurement platform so that the subject would be walking on an even surface. Finally, a wooden rod was placed next to the camera parallel to the lens to provide a guideline for foot placement for the subject so that the camera would have an unobscured view of the entire foot, allowing for better data collection (Figure 6.2).

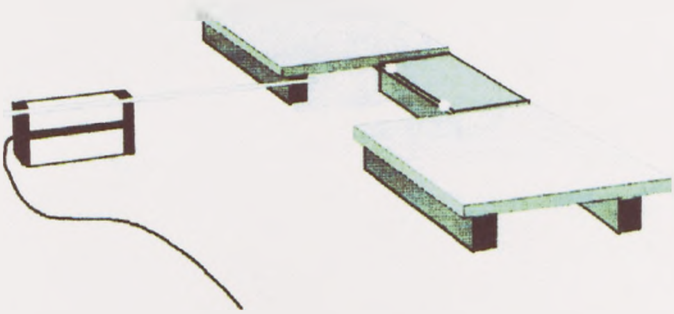


Figure 6.2. ProReflex® hardware set-up

Data were collected for a period of 3 seconds, and digitized measurements were obtained at a rate of 120 frames per second.

6.4 METHODS

Initially, static navicular drop, utilizing the Brody method was obtained for each of the subjects. The subjects were seated, and the foot was placed in the subtalar neutral position. The navicular tuberosity was palpated and marked with an ink pen. An index card was placed perpendicular to the foot and the height of the navicular tuberosity was recorded. The subject was then instructed to stand without moving the foot and the navicular tuberosity height was again recorded on the index card. Navicular drop--the difference between the two marks--was then measured and recorded.

Reflective markers were attached to the anatomical points on the foot with double-sided adhesive tape. The subjects were then instructed to walk normally in front of the camera, and data was collected for the first step (Figure 6.3). The subjects were allowed to practice so that the right foot would land in the appropriate spot in front of the camera without altering their usual walking pattern.

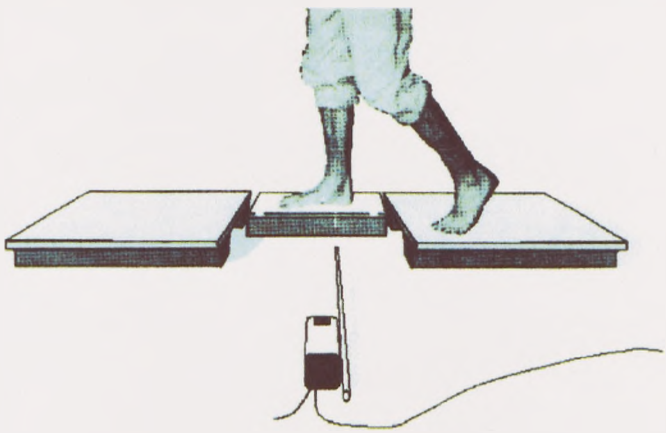


Figure 6.3. Dynamic data collection while walking

Ten clear trials were recorded. A clear trial was determined to be one that the five markers (3 foot and 2 reference) were captured by the camera LED indicator. However, even though the camera showed that five markers were captured throughout the full movement, subsequent analysis revealed that each trial did have a few missed frames (≤15). Therefore, the software's "fill-in" command was used to interpolate the data for the missed frames. If, at any time, there were more than 4 sequential frames missing, the entire trial was considered invalid.

Once the barefoot trials were recorded, the same methods were repeated with the subjects wearing different types of footwear: turf trainers (Mitre, Assassin Hard Ground Trainer, style # F2385), moulded stud football boots (Mitre, Hoddle Pro-Fit P.U., style #F1204), and sports trainers (Mitre, Daytona Senior, style #SS99). To allow for viewing of the markers placed on the foot, each of the right shoes had windows of approximately 30 mm x 30 mm, cut out over the three marker points at the calcaneus, navicular tuberosity, and head of the first metatarsal. Before each series of trials was conducted, the three markers were rechecked for clear visibility and placement over the original ink spots on the skin as the markers did have a tendency to move while the subjects were changing footwear. The subjects wore the same type of footwear on each foot during the data collection process, although data was collected for the right foot only.

The entire data collection process, including obtaining the static navicular drop measurement was repeated for each of the subjects over a four day period.

6.5 DATA ANALYSIS

The three markers on the foot formed a triangle in which the navicular tuberosity, the sole of the foot, and the head of the first metatarsal formed a right triangle (Figure 6.4A).

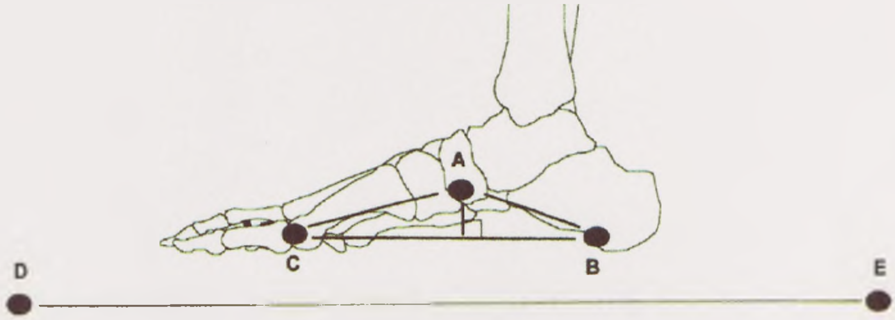


Figure 6.4A. Marker placement for calculations.

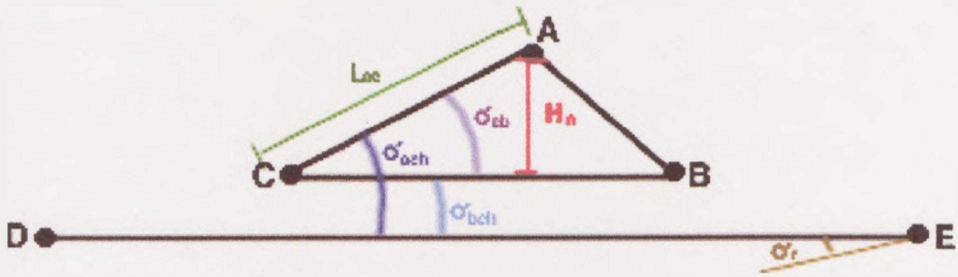


Figure 6.4B. References for calculations.

The data from the ProReflex® was converted onto a spreadsheet and x and y coordinates were obtained for each of the markers for each of the frames.

The following calculations were made to obtain a numerical value for navicular height in millimeters:

Where $X_{a,b,c,d,e}$ are the X coordinates and $Y_{a,b,c,d,e}$ are the Y coordinates for the correponding markers seen in Figure 6.4A and 6.4B.

Step 1: Calculating the scale (S) in millimeters.

$$S = \left(\sqrt{(x_d - x_e)^2 + (y_d - y_e)^2}\right) \div 460$$

Step 2: Calculating the base angle (σ_r).

$$\sigma_r = \tan^{-1}\left((y_e - y_d) \div (x_e - x_d)\right)$$

Step 3: Calculating the length from navicular tuberosity to head of first metatarsal (L_{ac}).

$$L_{ac} = \left(\sqrt{(x_c - x_a)^2 + (y_c - y_a)^2}\right) \div S$$

Step 4: Calculating angle of line to the horizontal A-C (σ_{ach}).

$$\sigma_{ach} = \left(\tan^{-1}\left((y_c - y_a) \div (x_c - x_a)\right)\right) - \sigma_r$$

Step 5: Calculating angle of line to the horizontal B-C (σ_{bch}).

$$\sigma_{bch} = \left(\tan^{-1}\left((y_c - y_a) \div (x_c - x_a)\right)\right) - \sigma_r$$

Step 6: Calculating angle between line A-C and B-C (σ_{abc}).

$$\sigma_{abc} = \sigma_{ac} - \sigma_{bch}$$

Step 7: Calculating navicular height (h_n).

$$h_n = (\sin \sigma_{abc})\ (L_{ab})$$

Once the navicular height was determined for each frame, the highest and lowest measurements were found. The difference between these two measurements was determined to be dynamic navicular drop.

The mean and standard deviation were calculated for the results from the ten trials for each condition. Prior to data analysis, a standard deviation of ≤ 1.0 mm was determined to be an acceptable margin of error within each of the conditions. The results for each individual were then compared utilizing an ANOVA for correlated means to see if there were any differences ($p<0.05$) between the results obtained over the four days for each of the conditions. Further analysis utilizing a post hoc Tukey test was undertaken to see where, if any, the differences occurred. Sandler's A statistic (Sandler, 1955), mathematically equivalent to the t-test (Cohen and Holliday, 1996), was used to compare the static and dynamic navicular drop results. This test was selected because it was easily calculated using a hand calculator using the formula:

$$A = \frac{\text{the sum of the squares of the differences}}{\text{the square of the sum of the differences}} = \frac{(\Sigma D^2)}{(\Sigma D)^2}$$

6.6 RESULTS

The results of this study indicate that there were no statistically significant differences between the results for the four subjects over the four day period (f=346.31, p=1.19). In subjects 2, 3, and 4, there were no statistically significant differences between the results obtained for each day in any of the conditions. However, in the remaining subject (subject 1), there was a statistically significant difference in the results obtained over the four days when wearing turf trainers. A post hoc Tukey test indicated that this difference occurred between the results found for the turf trainers in days 1 and 3. Other than these two days, all of the rest of the results for this subject were not significantly different. Individual results are listed in Table 6.1.

The mean static navicular drop for the four subjects was 9.27±1.87 mm. Sandler's A statistic revealed that there was a statistical difference between the static navicular drop measurements and the dynamic navicular drop for the barefoot condition between subjects (A=0.12, p<0.05). Subjects 1 and 2 demonstrated the largest differences between static and dynamic navicular drop and these were found to be statistically significant (subject 1, A=0.25, p<0.05; subject 2, A=0.26, p<0.05).

Table 6.1. Statistical analysis results for each subject for each condition over a four day testing period.

Subject	Condition	F value	P value
1	Barefoot	1.75	0.175
1	Turf Trainers	3.47	0.026*
1	Football Boots	1.53	0.224
1	Sports Trainers	2.82	0.053
2	Barefoot	1.00	0.407
2	Turf Trainers	2.28	0.096
2	Football Boots	2.07	0.122
2	Sports Trainers	0.94	0.431
3	Barefoot	0.48	0.696
3	Turf Trainers	1.06	0.380
3	Football Boots	1.80	0.164
3	Sports Trainers	1.32	0.283
4	Barefoot	1.55	0.219
4	Turf Trainers	1.28	0.297
4	Football Boots	0.63	0.599
4	Sports Trainers	0.72	0.548

* Statistically significant.

No statistical differences were found between static and dynamic navicular drop in subjects 3 (A=0.55, p>0.05) and 4 (A=0.62, p>0.05). The mean dynamic navicular drop for all of the subjects in the barefoot condition was 6.70±1.86 mm. The overall means for dynamic navicular drop in the turf trainer, football boots, and sports trainers were, 5.36±1.30 mm, 4.91±1.08 mm, and 5.95±1.66 mm respectively. Mean results are listed in Table 6.2. Individual subject results and combined means can be found in Appendix D. While there were statistically significant differences between the static and dynamic navicular drop measurements, it was expected that the two measurements would be related and therefore significantly correlated. However, only a very low correlation (r=-0.083, Pearson product moment correlation) was obtained.

Table 6.2. Mean±SD navicular drop measurements for individual subjects.

Subject	Static (mm)	Barefoot (mm)	Turf Trainers (mm)	Football Boots (mm)	Sports Trainers (mm)
1	11.50±0.58	4.55±0.42	5.33±0.56	5.33±0.64	5.36±0.49
2	8.75±0.6	6.35±0.34	4.48±0.45	4.21±0.30	5.41±0.42
3	10.25±0.96	9.50±0.51	7.35±0.35	6.33±0.42	8.60±0.51
4	7.00±0.82	6.32±0.61	4.33±0.60	3.80±0.31	4.37±0.31
Combined Means±SD	**9.34±1.86**	**6.70±1.86**	**5.36±1.30**	**4.91±1.08**	**5.95±1.66**

6.7 DISCUSSION

Two-dimensional data were collected utilizing a single-camera ProReflex® system, capturing the first step of the right foot during a walking gait cycle. Data were recorded from a non-weight-bearing position prior to heel-strike, to a full weight-bearing position during the support/stance phase, and back to non-weight-bearing after toe-off. A study by Oggero, et. al. (1997), indicated that the first step of the gait cycle is adequate for obtaining consistent data, if the length of that step is not altered to accommodate the equipment. The set-up of the equipment utilized in this study could be changed to accommodate stride length for each of the subjects and therefore this should not be considered a limitation to the study. Subjects were also given adequate time to familiarize themselves with the equipment set-up and adjustments could be made prior to data collection. Further, a single foot was selected for analysis, in this case, the right foot, due to the fact that studies have shown that comparisons between left and right asymptomatic feet revealed no statistical differences in terms of joint rotations, arch height, and foot alignment under identical testing conditions (Kitaoka, et. al., 1995; Shereff, et. al., 1990; Steele, et. al., 1980). Therefore, it was felt that bilateral analysis was not necessary and would not adversely affect the results.

After analysis had been carried out, the results indicate that the methodology utilized in this study is a valid measurement tool for dynamic navicular drop in various loading conditions. Further, it appears that the results obtained are repeatable, at least over a four day period. It should be noted that the four days were not consecutive, and that the time between testing trials for each subject varied from one to three days. The maximum period of total data collection ranged from four to eight days. This time variance did not appear to affect results, although one subject did have a significantly significant difference in one shoe condition. Analysis revealed that this difference occurred between days one and three, while wearing turf trainers. The remaining days showed no differences. There were no statistical differences between days in any of the other subjects.

The results of this study indicate that there was a significant difference in navicular drop between the static measurements obtained utilizing the Brody method and those obtained from the dynamic barefoot loading conditions. It might be expected that the static measurements would be greater than the dynamic measurements because the static measure is taken relative to the floor and the dynamic measure is taken relative to a line connecting the calcaneus to the joint line of the first metatarsal head. However, both methods isolate the navicular bone and provide a measurement of its movement. The static method takes the difference between non-weight-bearing navicular height and the weight-bearing navicular height (for example: a subject has a navicular tuberosity height of 56 mm from the floor in the non-weight-bearing position and 46 mm from the floor in the weight-bearing position, therefore, the navicular tuberosity has moved, or dropped, 10 mm). With dynamic measurements, while the navicular drop is being determined relative to the calcaneus and metatarsal head rather than the floor, only the movement of the navicular bone is being determined. The only real difference between the two measurements is that the dynamic method eliminates the effect of the fat pad and soft tissue compression on the sole of the foot (Ker, et. al., 1987, 1989). Although Brody's static navicular drop test is utilized widely in the clinical setting to predict dynamic foot function, based upon the results of this study revealing statistical differences and a low correlation between the static and dynamic measurements, it would appear that there is little relationship between static measurements and dynamic function of the arch of the foot. This concurs with the findings of Hamill, et. al., (1989), McPoil, et. al., (1996), and Mueller, et. al., (1993). However, due to the small sample size, further testing utilizing a larger sample size is indicated. In this study, interestingly, subjects 1 and 2 were both determined to have "normal" feet during the pre-testing physical evaluation. The pre-test physical evaluation revealed that subject 3 exhibited pes planus, while the remaining subject exhibited a flexible pes cavus foot. These preliminary results indicate that different foot types affect dynamic navicular drop and that the "abnormal" foot functions similarly in static and dynamic loading conditions. Kernozek and Ricard (1990) demonstrated that arch type is not a good predictor of maximum pronation, but is a good predictor of total rearfoot motion. A study by Knutzen and Price (1994) found that foot type, as determined by static measurements, did not contribute significantly to the prediction of pronation at contact or during the support phase of walking. However, Clarke, et. al., (1984,) and Lapidus (1987), found a positive relationship between arch type and pronation. Therefore, further studies need to be conducted utilizing a larger sample size to determine if foot type does affect dynamic navicular drop. Additional studies looking at rearfoot motion should also be conducted in order to obtain a complete picture of the foot as it functions dynamically.

While the ProReflex® method does appear to be a viable testing method for measuring dynamic navicular drop, there are some limitations within the design of the study itself. Marker placement could be considered one of the most obvious limitations. Palpation of bony anatomical landmarks is often difficult (Hamill, et. al., 1989; Sell, et. al., 1994; Subotnick, 1975), and unreliable marker placement, along with soft tissue movement can influence values obtained. However, these same researchers have indicated that trained individuals (i.e., physicians, physical therapists, athletic trainers, podiatrists, etc.) have a much higher intratestor reliability and are able to accurately identify anatomical landmarks with little difficulty. Since the author of this paper is a Certified Athletic Trainer (USA), marker placement should not be considered a major limitation to this study.

Another potential limitation in this study is the methodology involved with obtaining the static navicular drop measurements. As mentioned previously, this is a widely recognized method of assessing static navicular drop and a few of the limitations have already been addressed. However, one limitation that cannot be overlooked is the position of the subjects' centre of gravity and natural postural sway while standing. It was observed during this study that when a subject was moving his upper body or when the body swayed forward or backward, the navicular height changed. In fact, looking at the results obtained for static navicular drop, there were variances of up to 2 mm between days, but these variances were not apparent in the dynamic navicular drop. In an attempt to eliminate or reduce the possible effects of body movement and postural sway during data collection the subject was instructed to face forward with arms to the side, and to stand as still as possible until data collection was complete. A review of literature has revealed a limited amount research on the effects of natural postural sway on static navicular drop. Therefore, additional research is needed to determine if the body's natural postural sway does affect static navicular drop measurements.

6.8 CONCLUSIONS

From the results of this study it can be concluded this method, utilizing a 2-dimensional motion analysis system, can be a simple option for dynamic foot evaluation and that repeatable, consistent linear measurements can be obtained for dynamic navicular drop during various loading conditions. Further, it appears that the foot functions differently in static and dynamic loading conditions and that perhaps Brody's navicular drop test as a predictor of foot function needs to be re-evaluated for its use in the clinical setting.

Further analysis, utilizing larger sample sizes need to be conducted in order to more accurately determine the extent of these differences in static and dynamic loading conditions. Additional analysis also needs to be carried out on the effects of various types of footwear on dynamic navicular drop. Finally, running gait needs to be analyzed to determine if differences exist between walking and running dynamic conditions.

Chapter 7

ProReflex® Analysis of Navicular Drop During Dynamic Movement-A Comparison of Walking and Running Conditions and How They Relate to Static Navicular Drop Measurements

7.1 INTRODUCTION

A comparison between walking and running shows differences in gait. During walking, there is always a period in which one or both feet maintain contact with the ground. This is lost during running. As gait speed increases, a flight phase develops in which both feet are off the ground (Subotnick, 1985). The stance phase of gait is similar in both walking and running although the duration is different (Subotnick, 1985). In walking, the stance phase consists of approximately 60% of the total movement, while in running, this phase decreases to about 33% of the gait (Nuber, 1988). Nuber goes on to suggest that as gait velocity increases, there are distinct changes in joint range of motion and electromyographic activity. Specifically, he purports that surrounding musculature plays a primary role in the absorption of increased loads that are experienced during running. The one thing that is universally accepted is the fact that gait, both walking and running, is a very complex activity, and while it has been extensively studied, little is known about how the foot functions during dynamic activity.

Based on this information, and the fact that running is an important part of the sport of football, it was necessary to determine the effect of a running gait on the medial longitudinal arch, looking specifically at navicular drop. The results found in the previous chapter indicate that the ProReflex® method for assessing dynamic navicular drop is a viable method for determining navicular drop during a normal walking gait.

The purpose of this experiment was twofold. Firstly, to apply the methodology outlined in Chapter 6 to see if differences in navicular height exist between barefoot walking and running dynamic loading conditions. Secondly, to see if differences in navicular height exist between static and dynamic loading conditions, for both walking and running.

7.2 SUBJECTS

Twelve healthy volunteers (6 male, 6 female, ages 19-26), acted as subjects for this study. The subjects were all recruited from within the Centre for Studies in Physical Education and Sports Sciences at the University of Leeds. Visual foot examination and subsequent goniometric measurement of the subtalar joint revealed 3 subjects with pes planus or flat-foot, one subject with a flexible pes cavus foot, and one with a rigid pes cavus foot. All subjects appeard to have functionally “normal” feet, with no history of injury, pain, or discomfort.

7.3 EQUIPMENT AND SETUP

The equipment and setup for this study was the same as that utilized in Chapter 6 and covered in detail in the “Equipment and Setup” section of that Chapter. However, since the purpose of this study was to look at differences between walking and running gait, the subjects were all tested while barefoot only and therefore, the artificial grass surface was removed.

7.4 METHODS

As in the previous study (Chapter 6), static navicular drop was obtained for each of the subjects and reflective markers were attached to the anatomical points on the foot with double-sided adhesive tape. While barefoot, the subjects were instructed to walk normally in front of the camera, and data were collected for the first step. The subjects were allowed to practice so that the right foot would land in the appropriate spot in front of the camera without altering their usual walking pattern. Five trials were recorded. This procedure was then repeated except the subjects were instructed to run instead of walk, again collecting data for the first step.

7.5 DATA ANALYSIS

The marker placement over the calcaneus, navicular bone, and at the head of the first metatarsal provided the reference points for calculations. The mathematical equations covered in the Chapter 6-Data Analysis section were utilized to obtain a numerical value for navicular height in millimeters. Once the navicular height was determined for each frame, the highest and lowest measurements were found. The difference between these two measurements was determined to be dynamic navicular drop.

Using Snedecor and Cochran's (1980) formula for determining sample size (n):

$$n = \frac{4\sigma^2}{L^2}$$

Where σ is the standard deviation, and L is the allowable error of the sample mean. For the calculations to determine sample size in this study, standard deviation was 1 and allowable error of the sample mean was 1.

5 trials were determined to be adequate to obtain consistent and reliable results. The average navicular drop from the five trials, both walking and running, was calculated. The results from the two methods were compared utilizing an ANOVA for correlated means to see if there were any differences (p<0.05) between the static weight-bearing navicular drop and dynamic navicular drop during walking and running conditions. Further analysis utilizing a post hoc Tukey test was undertaken to see where, if any, the differences occurred.

7.6 RESULTS

The mean static navicular drop for the 12 subjects was 10.67 ±4.04 mm. The mean navicular drop for the walking gait was 6.61 ± 0.89 mm, while the mean navicular drop for the running gait was 7.83 ± 0.91 mm. Individual results for each subject are listed in Appendix F. Statistical differences were found between the static and dynamic navicular drop data (p=0.004, F=6.55). Further analysis was conducted to see if a correlation existed between the two conditions. The results indicated that there was a very low correlation between the static and walking conditions (r=0.144, Pearson product moment correlation), while there was a modest correlation between the static and running conditions (r=0.411).

Table 7.1. Mean±SD navicular drop measurements

Static (mm)	Walking (mm)	Running (mm)
10.67±4.04	6.61±0.89	7.83±0.91

Finally, the results of the walking and running conditions were compared and statistical differences were found (F=5.32, *p*=0.01). While there were statistical differences between the walking and running conditions, there was a modest correlation between the two (r=0.686). Further, when subject 8 was eliminated from the analysis, there was a very high correlation between the two (r=0.902). Subject 8 was the only subject with a walking navicular drop that was higher than that obtained for running. Either way, both of these correlations were statistically significant (df=10, r=0.686, critical value=0.532).

7.7 DISCUSSION

Since the primary goal of this study was to determine if there were statistical differences between walking and running, the barefoot condition was selected to allow for clear, unimpaired data collection without the added factors potentially caused by footwear.

The results of this study indicate that the differences between walking and running navicular drop were significant but that there was a correlation between the two conditions. Further, this correlation was significant. The navicular drop during running averaged 1.5 mm greater than during walking. Video analysis of arch height by Nachbauer and Nigg (1992) found that arch flattening tended to be slightly greater, but not statistically significant (as determined by a single factor ANOVA), while running when compared to a static measurement, and that the amount of deformation did not seem to change in relationship to the speed of running. Based upon Nigg's results and the walking-running correlation found within this study, it could be concluded that the midfoot functions similarly during the stance/support phase of both walking and running, but that the speed and timing of the movement is much faster during a running gait. There has also been great debate over how external forces acting upon the foot affect the structures. Kitakoa, et. al., (1995) found that there were significant changes in arch height under increased loads in cadaver specimens. The differences found between studies could be explained by the fact that cadaver specimens were used in Kitakoa's study and that muscular activity could not be taken into account. Electromyographic studies by Basmajian and Stecko (1963) and Mann and Inman (1964) showed that intrinsic muscular activity does seem to act upon the arch during walking and could affect arch deformation. A more recent study by Thordarson, et. al., (1995) showed that muscle activity in the foot, ankle, and lower leg increased with corresponding increased loads. While it is universally accepted that the forces acting on the foot are much greater during running, it appears that the skeletal structures of the midfoot do not function differently. These forces may be absorbed by other anatomical structures of the foot and lower leg not addressed in this study. While the results of this study found that statistically significant differences exist between the running and walking conditions, one could argue that this may not be a true reflection of dynamic foot function due to the fact that data was collected for the first step only and while it is possible to reach full speed in one step during walking, it is difficult to achieve maximum speed during the first step of running.

As in the Repeatability Study (Chapter 6), and the studies of Hamill, et. al., (1989), McPoil, et. al., (1996), and Mueller, et. al., (1993), the results of this study also found that there was a significant difference in navicular drop between static and dynamic loading conditions. According to Mueller, reasons for the variance might include the following: static navicular drop does not fully represent foot and ankle pronation; errors are contained in the measure of navicular drop; and other factors such as soft tissue and joint capsule flexibility, tibial varum, tibial torsion, and hip rotation deformities. The values obtained for the static navicular drop were greater than those obtained for the dynamic conditions in all but one subject. These differences varied from a high of 11.24 mm to a low of 1.72 mm, with an mean of 3.73 mm. The overall mean of 10.67 mm drop was considerably higher than those values reported by McPoil, et. al., (1996) and Mueller, et.

al., (1993), who both reported values of around 7 mm for a "normal" foot and >10 mm for an "abnormal" foot. However, the results of this study did concur with those of Brody, who reported that a "normal" static navicular drop was around 10 mm and that anything greater than 15 mm would be considered "abnormal." None of the researchers provide guidelines for classifying individuals with abnormally high arches. Using Brody's classification system, two subjects in this study would have been classified as having an "abnormal" foot. Using the classifications recommended by McPoil and Mueller, seven subjects would have fallen within this category. But clearly, all subjects were functionally healthy. While the static measurements were found to be statistically different from the dynamic measurements, there was a low correlation between the static and walking measurements and a modest correlation between the walking and running measurements. Both of these correlations were considered non-significant, however, this may not be a true reflection of static and dynamic correlation due to the small sample size. Therefore further testing, utilizing a larger sample size would be warranted.

7.8 CONCLUSIONS

Based upon the results of this study, it can be concluded that while there are differences in navicular drop between running and walking conditions there is a statistically significant correlation between the two and that the foot functions similarly during the two types of gait. The statistical differences and subsequent correlations that were seen between static and dynamic navicular drop measurements suggest that the foot does function differently during movement. While non-significant low to modest correlations exist between the static and dynamic conditions, further analysis utilizing a larger sample size is necessary to determine if this is a true indication of the relationship between the two conditions.

Based upon the results of this study, future research will look at the first step of the walking gait only, due to the significant correlation seen between the walking and running gaits. Further, a larger sample size will be utilized to analyze static and dynamic measurements, as well as what effects, if any, footwear has on the function of the foot.

Finally, a larger sample size should allow for a typical cross section of subjects with different foot types, i.e., pes cavus, normal, or pes planus, which could allow for analysis of how foot type affects navicular drop and hence, foot function.

Chapter 8

ProReflex® Analysis of the Effects of Footwear on Dynamic Navicular Drop

8.1 INTRODUCTION

Existing research has shown that sport shoes have a variety of effects on human movement and performance. Shoe design has been implicated in many load-related injuries by several researchers (Bates, 1989; Nigg, 1987; Stacoff, et. al., 1988). Sport shoes that are not appropriate for the individual needs of the athlete may force the lower-extremities into movement patterns that overload specific structures, resulting in chronic pain and/or injuries. In sports that require footwear with studs there is the added variable of stud placement potentially increasing loads placed on the foot and its anatomical structures, thus changing the movement patterns and resulting in overload. Unlike other sport shoes that allow for the entire plantar surface of the foot to maintain contact with the ground during the stance phase, studded footwear provides impaired support for the midfoot/arch region during this phase, especially on hard-ground conditions when the studs do not penetrate the ground completely. It is theorized that these changes, over time, could result in an overstretching of the supporting tissues of the foot, allowing for greater movement of the skeletal structures, leading to mechanical changes of the gait, eventually resulting in repetitive-stress/overload injuries to the lower extremities.

While it is well-established that external factors such as footwear can influence the mechanics and function of the lower extremities, most research involving gait has been applied to the unshod or bare foot. However, there have been investigators that have attempted to address this issue (Andreasson, et. al,1986; Bates, 1989; Clarke, et. al., 1982; Dufek, et. al., 1991; Gross, et. al., 1989; Jorgensen, 1990; Komi, et. al., 1987; Nigg, et. al., 1987, 1992, 1998; Reinschmidt, et. al., 1992; Shorten, 1993; Stacoff, et. al., 1988, 1989, 1991). Most of these studies have addressed ground reaction forces, torques, subtalar joint motion, and gross body movements in the lower extremities and inferred the results to foot function. Many have also used in-shoe pressure distribution systems to obtain information regarding pressure patterns. The underlying problem is the fact that because the shoe covers the foot, analysis of foot function is difficult. Stacoff, Reinschmidt, and Nigg all attempted to address subtalar joint function and movements by cutting windows in the shoe to allow for measurement during movement. Most non-invasive methods of looking at the foot within a shoe involve the use of x-ray analysis, and until recently, this has been limited to static measurements only.

The results of the repeatability study (Chapter 6) indicated that the 2-dimensional methodology for assessing dynamic navicualr drop is a useful method for determining midfoot/arch function while walking. The results of Chapter 7, utilizing similar methodology, revealed that although there were statistical differences in changes to navicular drop between walking and running conditions, there was a statistically significant correlation between the two, indicating that the foot functions similarly during walking and running. Additionally, both of the previous studies have shown a statistical difference between static and dynamic navicular drop. However, further analysis revealed a very low (as seen in Chapter 6) to modest (as seen in Chapter 7) correlation between the static and dynamic conditions. Neither of these were found to be statistically significant, indicating that perhaps the foot functions differently during dynamic activity. Since both of these studies were carried out on small sample sizes, further analysis is necessary to determine if this is a true reflection of differences between static and dynamic conditions. The studies covered in Chapters 6 and 7 provided valuable information regarding midfoot function during dynamic activity, but perhaps more importantly, it appears that the methodology can also offer additional information regarding the timing of maximum navicular drop. This can be a useful tool in determining how the shoe might affect function of the foot.

The purpose of this study was to apply the methodology of Chapter 6 to a larger sample size in order to: 1) determine the effects of various types of footwear on dynamic navicular drop and to see if differences exist; 2) determine the timing of maximum navicular drop during the stance phase of the gait cycle; 3) determine if arch type, as determined by a static classification system, affects dynamic navicular drop; and 4) determine if there is a correlation between static and dynamic navicular drop.

8.2 SUBJECTS

Twenty-six healthy volunteers (male; aged 23.2±3.6 years; mass, 76.2±9.6 kg; height, 1.79±.65 m) recruited from the School of Biomedical Sciences at the University of Leeds, the University of Leeds Football Club, and 3 local football clubs, acted as subjects for this study. The subjects were all football players at varying levels of abilities, and each played at least one game of football a week. Visual foot examination and goniometric measurements of the subtalar joint revealed 7 subjects with pes planus and 2 subjects with pes cavus feet. Again, all subjects appeared to have functionally health feet.

8.3 EQUIPMENT AND SETUP

The equipment and setup for this study was the same as that utilized in Chapter 6 and covered in detail in the "Equipment and Setup" section of that chapter.

8.4 METHODS

The methods for this study were the same as those utilized in Chapter 6 and covered in detail in the Methods section of that chapter. However, again using Snedecor and Cochran's (1980) formula for determining sample size, 5 trials were determined to be adequate to obtain consistent and reliable results, therefore five rather than ten clear trials were conducted for each of the testing conditions. Additionally, because the methodology was determined to be repeatable and consistent, the subjects were tested only once, rather than four times.

8.5 DATA ANALYSIS

The marker placement over the calcaneus, navicular bone, and at the head of the first metatarsal provided the reference points for calculations. The mathematical equations covered in Chapter 6-Data Analysis section were utilized to obtain a numerical value for navicular height in millimeters. As in the previous two chapters, once the navicular height was determined for each frame, the highest and lowest measurements were found. The difference between these two measurements was determined to be dynamic navicular drop.

The mean navicular drop from the five trials in each of the conditions (i.e. barefoot, football boots, turf trainers, and sports trainers) was then calculated. The results from the four conditions were compared utilizing an ANOVA for correlated means to see if there were any differences ($p<0.05$) between the conditions. Further analysis utilizing a post hoc Tukey test was undertaken to see where, if any, the differences occurred. Additionally, the results obtained for the barefoot dynamic navicular drop and those obtained for static navicular drop were also compared utilizing the ANOVA for correlated means to see if there were any differences ($p<0.05$) between the conditions. A correlation coefficient was utilized to see if a correlation existed between the static and dynamic conditions.

Once the maximum navicular drop was calculated for each of the trials, the corresponding frame number was identified. Using the playback option, the entire movement was again tracked frame by frame utilizing the ProReflex® software. The frame number of maximum navicular drop was found and compared to the total motion to determine when maximum navicular drop occurred during the stance phase.

8.6 RESULTS

The mean static navicular drop for the 26 subjects was 9.00±2.76 mm. The mean navicular drop for the barefoot walking condition was 5.80±1.58 mm, while the mean dynamic navicular drop while wearing the turf trainers, football boots, and sports trainers was 5.23±1.21 mm, 4.85±1.36 mm, and 5.67±1.19 mm respectively (Table 8.1). Individual results for each subject can be found in Appendix G. A one-way ANOVA for correlated means showed that there were statistical differences in dynamic navicular drop between the four walking conditions ($F=44.10$, $P=0.00$). Further analysis, utilizing a post hoc Tukey test indicated that there were statistical differences between the barefoot condition and those while wearing turf trainers and football boots. Statistical differences were also found between the football boots and sports trainer conditions, but there were no differences between football boots and turf trainers. Additionally, no statistical differences were found between the barefoot condition and that while wearing sports trainers. Finally, no statistical differences were found in dynamic navicular drop while wearing turf trainers and sports trainers.

Table 8.1. Mean±SD Navicular Drop (mm) for all Testing Conditions

Static	Barefoot	Turf Trainers	Football Boots	Sports Trainers
9.00±2.76*	5.80±1.58*§	5.23±1.21§	4.85±1.36§†	5.67±1.19†

* Significant differences between static and dynamic barefoot conditions.
§ Significant differences between barefoot, turf trainers and football boot conditions.
† Significant differences between football boots and sports trainer conditions.

When comparing dynamic barefoot navicular drop to foot type, statistical differences were found ($F=16.39$, $p=0.00$). A post hoc Tukey test revealed that there were statistical differences between the normal foot and those subjects who exhibited pes planus feet. However, no statistical differences were found between the normal foot and the pes cavus foot. Additionally, no statistical differences were found between the pes cavus and pes planus feet. A summary of these results can be found in Table 8.2. The mean navicular drop for the subjects with normal feet was 5.29±1.15 mm, pes cavus was 5.44±0.17 mm, and pes planus was 7.06±2.05 mm.

Table 8.2. Mean±SD Navicular Drop Measurements (mm) for Different Foot Types

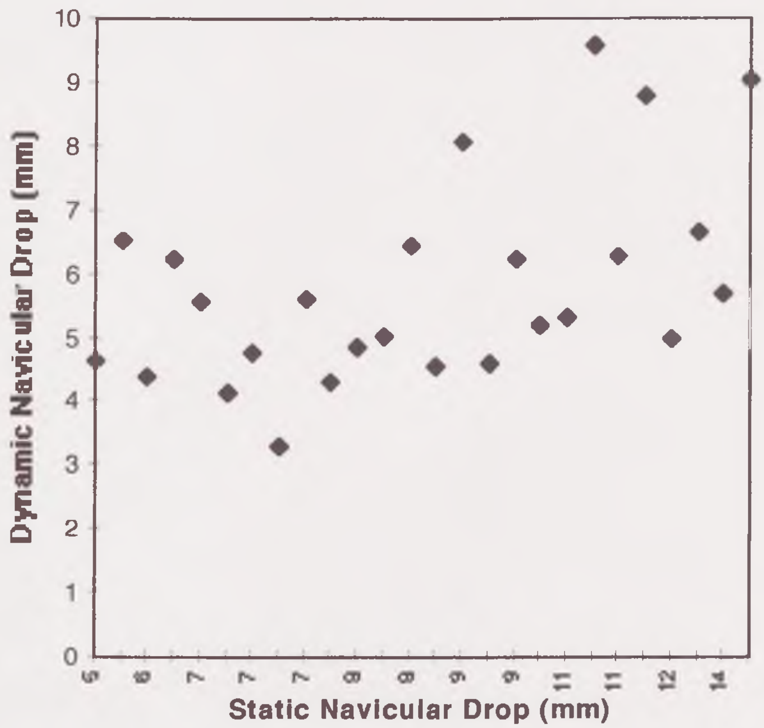
Normal	Pes Planus	Pes Cavus
5.29±1.15*	7.06±2.05*	5.44±0.17

* Statistical differences between the normal and pes planus foot types.

Statistical differences were also found between the static and dynamic barefoot navicular drop conditions ($F=50.47$, $p=0.00$). Analysis was then carried out to see if there was a correlation between the two and a modest correlation was found to exist ($r=0.499$).

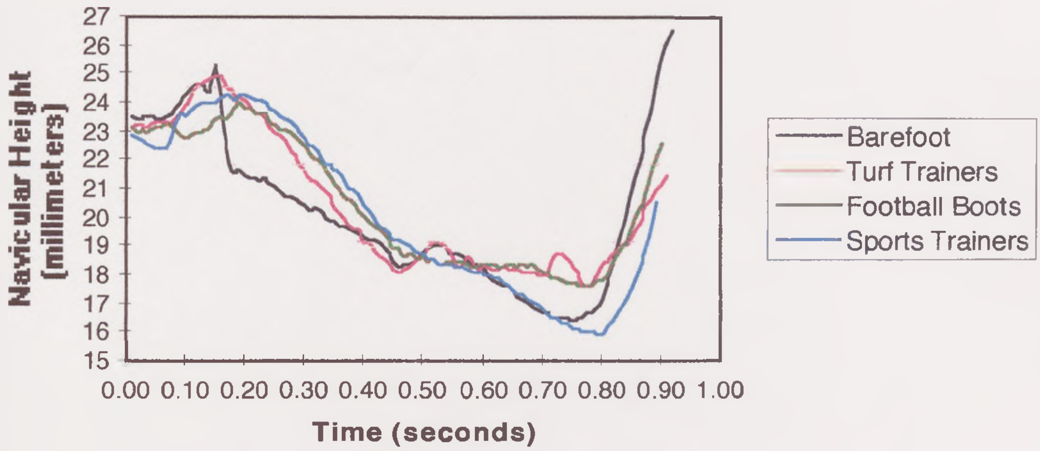
However, this modest correlation was determined to be statistically significant (df=24, r=0.499>0.388). A comparison static and barefoot dynamic navicular drop can be seen in Figure 8.1.

Figure 8.1. A Comparison of Static and Dynamic Barefoot Navicular Drop for all Subjects



Finally, the timing of the navicular drop was addressed. Because this was an observation of the motion only, statistical analysis could not be carried out. It was observed that the maximum navicular drop occurred at the terminal stance period of the stance phase. Further, it was observed that while the subjects were wearing shoes, particularly football boots and turf trainers, that although the maximum navicular drop was less, it occurred for a longer period, with a shorter recovery time in which the foot returned to the non-weight-bearing navicular drop values. This is demonstrated in Figure 8.2.

Figure 8.2. Navicular Height Curves Throughout Stance Phase for all Conditions



8.7 DISCUSSION

The primary purpose of this study was to determine the effects of various types of footwear on dynamic navicular drop. Initially, due to the stud placement and limited midfoot support, one expected to see the greatest navicular drop while wearing football boots. Surprisingly, the highest mean navicular drop was found within the barefoot condition, followed by the sports trainers, the turf trainers, and finally the football boots. The only condition that was statistically different was the football boots. While many footwear research studies have found that there is greater pronation while wearing shoes than while barefoot (Bates, et. al., 1979; Cavanagh, et. al., 1984; Clarke, et. al., 1984; Stacoff, et. al, 1988), Rasch and Burke (1978) observed that locomotion in barefoot subjects differs from shod subjects in that barefoot subjects "grasp" with their digits when they walk, and their medial longitudinal arch changes from highly arched during the swing phase to completely flat during the stance phase. This could explain the differences in the barefoot results seen in this study. Further, Robbins and Hanna (1987), described the foot of the normally shod individual as "rigid," i.e., the main bony arches are unable to yield on normal loading. With barefoot conditions considered "normal" within the context of this study, one could conclude that this is what is happening with the shod conditions, thereby explaining the lower navicular drop measurements obtained. Robbins and

Hanna go on to explain that the musculature and soft tissue of the foot and lower leg must carry the load and absorb impact. This could, in turn lead to stress upon these structures which could result in overuse injuries.

When looking at the timing of navicular drop, the maximum occurred at the terminal stance period of the stance phase in all conditions. This trend has also been noted by Wearing, et. al., (1998) and Kitakoa, et. al., (1995). The maximum navicular drop/terminal stance period was then followed by a quick recovery period in which the foot is supposed to become a fully rigid structure to allow for propulsion of the body. While this was observed within all conditions, some variances were also noted. Figure 8.1 demonstrates a typical gait cycle navicular drop curve, following the navicular drop through the early non-weight-bearing period prior to heel strike through toe-off and the beginning of the non-weight-bearing swing phase. As seen on the graph, the navicular drop curves for the barefoot and the sport trainer conditions are similar, with the exception of the shorter recovery period seen for the sports trainers. The navicular drop curves for the turf trainers and the football boots were also similar, but the maximum value was less than those obtained for the barefoot and sports trainers. Again, the shorter recovery time was seen with the football boots and turf trainers. What should be noted is the lower maximum navicular drop values for these two conditions. Further, the curves seem to exhibit a longer length of time at or near maximum navicular drop, while the curves seen for the barefoot and sports trainer conditions continue their movement downward. These curves demonstrate that the shoes do seem to impair foot function, particularly during the recovery period. It could be concluded from these and the rest of the results that, due to the shortened recovery period seen while wearing footwear, the foot does not recover fully, i.e., the calcaneo-cuboid and talo navicular joint axes are still partially parallel and the midtarsal joint is still partially flexible, and therefore does not become a fully rigid structure for propulsion. Because the transverse tarsal joint is not fully locked, the soft tissues of the foot and lower leg must compensate in order for propulsion to occur. Again, this could lead to injury of the lower extremity. It could also be argued that the lower navicular drop measurements seen with the turf trainers and football boots could be a result of the calcaneo-cuboid and talo-navicular joint axis not becoming fully parallel and unlocking the midtarsal joint fully, thereby not allowing the foot to become a flexible and accommodating structure that can absorb impact forces and adapt to varying surfaces. This too, could lead to an increased injury risk to the lower extremities.

Analysis was carried out to see if foot type, as determined by a static classification system, affected navicular drop. The results indicate that there was a statistical difference between the normal foot and the pes planus foot, although no statistical differences were seen between the normal and pes cavus foot or between the pes cavus and pes planus feet. However, it must be noted that there were only two subjects that fell into the pes cavus category and due to this small sample size, it could be argued that this is not a true reflection of pes cavus foot function. The differences seen between the normal and the pes planus foot indicate that the pes planus foot does function differently than the normal foot and assuming that navicular drop is a measurement of pronation, greater pronation is seen with the pes planus foot. These results are supported by Clarke, et. al., (1984), Kernozek and Ricard (1990), and Lapidus (1963) who all found a positive relationship between arch type and pronation, with flat arched people demonstrating more pronation. Kernozek and Ricard, also found that flat arched-people exhibited the greatest rearfoot motion, followed by high-arched and then normal-arched individuals.

As in the previous studies of Chapters 6 and 7, the results of this study also found that there was a significant difference in navicular drop between static and dynamic loading conditions. The values obtained for the static navicular drop were greater than those obtained for the dynamic conditions in all subjects, with static values ranging from a low of 5 mm to a high of 16 mm, and the dynamic barefoot values ranging from a low of 3.30 ± 0.25 to a high of 9.57 ± 0.41. The mean of 8.12 ± 1.83 mm drop for the "normal" foot was slightly higher than those values reported by McPoil, et. al., (1996) and Mueller, et. al., (1993), who both noted values of around 7 mm for a "normal" foot, conversely, the values were slightly lower than those reported by Brody, who noted that a "normal" static navicular drop was around 10 mm. The subjects with pes planus feet had an mean static navicular drop of 11.14 ± 3.72 mm, which corresponded with McPoil's and Mueller's guidelines >10 mm for an "abnormal" foot. Brody, reported that a navicular drop of >15 mm would be considered "abnormal." While the static measurements were found to be statistically different from the dynamic measurements, there was a modest correlation between the two. Further, this modest correlation was considered significant. In addition to the studies of McPoil, et. al., (1996), Mueller, et. al., (1993), and Brody, (1982), Hamill, et. al., (1989) found that there was a statistically significant correlation between static and dynamic arch index patterns. A study by Sandrey, et. al., (1996), again using static and dynamic foot tracings, also found that the static foot tracings covered more area than the dynamic foot tracings. The findings of these researchers and the results of this study indicate that the foot may function similarly during static and dynamic loading conditions. However, while one might be able to predict foot function from static navicular drop measurements, after seeing the navicular drop timing curves, one has to consider that many things are occurring within the foot during dynamic activity and that these motions cannot be explained through the use of a simple index card test. The study by Sandrey, et. al., (1996) also indicated that while the foot tracings were larger with the static measurements, the shape of the tracing changed with dynamic activity. Therefore, one must also consider the timing of the movements of various segments when looking at whole foot function.

As with any non-invasive kinematic study which requires external marking of soft tissue over anatomical landmarks, there are margins for error. The method used in this study is no exception and further studies looking at this issue are warranted. Further, one might question the practice of cutting holes within the shoe to allow for viewing of the markers as this might alter the integrity of the shoe and therefore the results obtained. An additional study, using x-ray fluoroscopy will be utilized to address the issue of marker placement, as well as to determine whether or not cutting windows in the shoe will affect the results. Another limitation of this study was the fact that all of the motions were analyzed utilizing a walking gait rather than a running gait. The walking gait was selected for several reasons. Firstly, the results of Chapter 7 indicate that there was a statistically significant correlation between the walking and running conditions, indicating that the foot functions similarly between the two conditions. Secondly, because data were being collected for the first step of a gait cycle only, it was possible for an individual to obtain maximum velocity for the first step during walking (Oggero, et. al., 1997), and the data obtained would be a truer reflection of normal foot function. Thirdly, the fluoroscope which will be used in a future study for this thesis will only allow for the data collection of a walking gait. Therefore, in order to get a more accurate comparison, similar methodology criteria must be used.

8.8 CONCLUSIONS

Based upon the results of this study, it appears that dynamic maximum navicular drop occurs during the terminal stance period of the stance phase during all of the conditions. Further, it can be concluded that different athletic footwear affects navicular drop. The greatest navicular drop occurred in the barefoot condition and the least amount of deformation was seen while wearing football boots. However, the lower navicular drop that occurred while wearing football boots lasted for a longer period of time, with a "plateau" that started approximately in the midstance period and went through to the terminal stance period. Footwear also appears to change the function of the foot by not allowing full recovery, possibly through limited midfoot resupination, prior to toe-off. This in turn, does not allow the foot to become a fully rigid structure necessary for propulsion.

It could also be concluded that foot type, specifically the abnormal pes planus foot, affects foot function, with a greater navicular drop seen for those subjects. Pes cavus did not appear to affect foot function, but due to the small sample size, definitive conclusions cannot be drawn and more studies are warranted.

Finally, unlike the previous studies in this thesis, the statistical differences seen between the static and dynamic conditions were not substantiated by the correlational analysis. A correlation between the static and dynamic measurement of this study was found to be statistically significant, indicating that the foot may function similarly between the two conditions. However, the gait timing curves indicate there is a great deal going on within the foot during movement and therefore one must also consider the timing of the movements of various segments when looking at whole foot function.

Based upon the results of this study, it appeared that additional research needs to be conducted. First of all, verification of the marker placement and the effects of shoe integrity will need to be addressed. Further, a more accurate picture of actual anatomical structures must be obtained in order to fully assess foot function during movement. The use of a dynamic fluoroscopic x-ray procedure would provide pictures of the anatomical structures through the stance period of gait. Additionally, it would have the added advantage of obtaining the images while wearing various types of footwear, so the effects of footwear can be studied in further detail.

It also appeared that in order to get a better picture of dynamic foot function, a study needs to be conducted looking at rearfoot motion in relationship to navicular drop and midfoot pronation, as well as the effects of the shoes on this motion. The majority of existing studies have addressed rearfoot motion through measurement of the subtalar joint in static and dynamic conditions. Therefore, an additional study utilizing the ProReflex® motion analysis system, looking at subtalar joint motion and navicular drop will be conducted while wearing the various types of footwear.

Chapter 9

ProReflex® Analysis of Subtalar Joint Function and Navicular Drop

9.1 INTRODUCTION

The subtalar joint consists of the articulation between the talus and the calcaneus in the hind foot. The predominant motion at this joint is pronation/supination with components of eversion/inversion and dorsiflexion/plantar flexion (Engsberg, et. al., 1988).

It is believed that changes in subtalar joint position are transmitted via the talus to the navicular at the midtarsal joint articulation and consequently, changes in navicular height are related to changes in position of the calcaneus as well as in the midtarsal joint (Sell, et. al., 1994). It is also theorized that the navicular drop test addresses the plantar-flexion component of talar motion and therefore, can be used to assess the amount of subtalar pronation (Brody, 1982; Picciano, et. al. 1993). This test has been widely accepted as a static foot measurement used to infer dynamic foot function in the medical and clinical settings.

Excessive pronation or overpronation has often been implicated in the development of many lower-extremity overuse injuries. Overpronation has been associated with too much movement of the rearfoot during the foot-ground contact of running (Clarke, et. al., 1984; Luethi, et. al, 1987; and Nigg, et. al., 1987). Further, many studies have also found that footwear contributes to this overpronation (Clarke, et. al, 1984, Hamill, et. al. 1992; Luethi, et. al., 1987; Nigg, et. al., 1987, and Stacoff, et. al., 1990). Among the various reasons given for overpronation in the running shoe literature are a weak heel counter and a high torsional stiffness of the shoe sole. Another factor that is commonly reported is an increased velocity of initial pronation after heel strike when wearing footwear due the increased torque about the joint generated at heel-strike.

Some existing studies have reported a lower incidence of injury among barefoot runners as opposed to those who wear running shoes and that this is primarily due to less rearfoot pronation seen among barefoot runners (Stacoff, et. al., 1988; 1989; 1991). In contrast, the results of the previous studies covered in this paper indicate that there is a greater amount of navicular drop occurring during dynamic barefoot gait. Given the implied relationship between pronation and navicular drop outlined above, this might suggest that more, not less pronation should be observe in barefoot gait in these subjects. Based upon these results, it appeared essential to address the movement of the subtalar joint in relationship to navicular drop, as well as the effects of footwear upon these measurements.

Therefore the purpose of this study was to use the ProRelex® Motion Analysis System to: 1) determine if there is a relationship between subtalar joint movement and navicular drop, 2) determine if football boots and running shoes affect the motion of the subtalar joint when compared to the unshod condition, and 3) determine the timing of the hindfoot motion as it relates to the entire stance phase.

9.2 SUBJECTS

Twelve healthy volunteers (male; aged 21.5±3.0 years; mass, 74.3±9.3 kg; height, 1.79±0.69 m) recruited from the School of Biomedical Sciences at the University of Leeds acted as subjects for this study. The subjects were all football players at varying levels of abilities, and each played at least one game of football a week. All had acted as subjects in at least one previous study and were familiar with the testing procedures. Visual foot examination and goniometric measurements of the subtalar joint revealed 4 subjects with pes planus and 1 subject with pes cavus feet, although all subjects had functionally healthy feet.

9.3 EQUIPMENT AND SETUP

For this study, the ProReflex® system was used. This system consisted of two ProReflex® 250 cameras, a Macintosh computer with MacReflex 3.41f17 PPC software (Qualysis©, 1997), and a monitor to check the setup of the cameras. Reflective markers, 3 mm in diameter, were attached to the navicular tuberosity, medial calcaneal tuberosity, the joint space of the head of the first metatarsal of the right foot, the posterior-inferior protuberance of the calcaneus, and the subtalar joint space. Additional markers, 10 mm in diameter, were attached to the posterior side of the lower leg at the upper junction of the gastrocnemius-soleus complex and at the upper narrow portion of the Achilles tendon. (Figure 9.1).

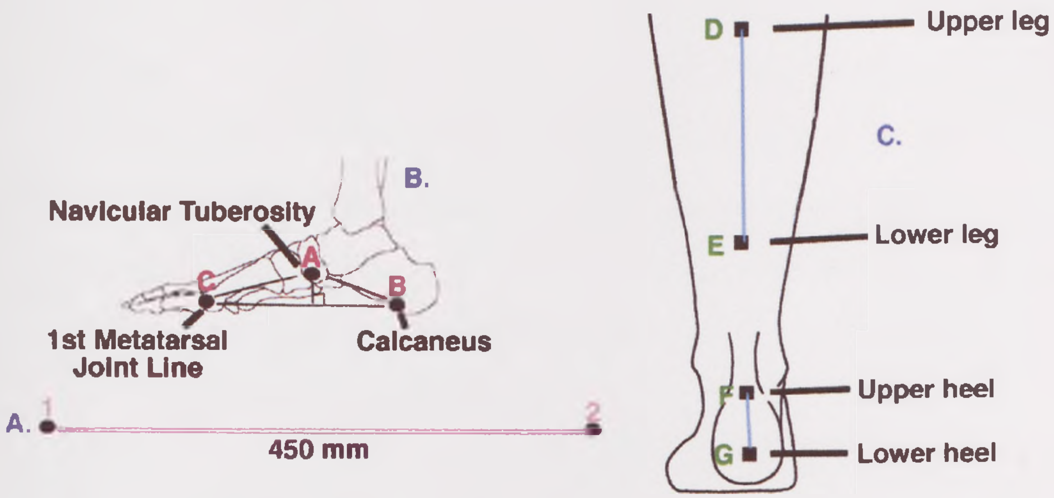


Figure 9.1. Marker Placement. A. Scale, B. Medial foot, C. Posterior lower leg

One ProReflex® camera was set up 700 mm from the platform walking area at a right angle to the sagittal plane. This camera was positioned to detect the markers on the navicular tuberosity, medial calcaneal tuberosity, and the joint space of the first metatarsal. The second camera was set up 500 mm directly behind the walking area and positioned to detect the markers on the posterior-inferior protuberance of the calcaneus, the subtalar joint space, the upper narrow portion of the Achilles tendon, and the upper junction of the gastroc-soleus complex. The entire walking surface was covered with a 25 mm thick artificial turf to allow for penetration of the studs of the football boots.

A scaling bar was constructed and 10 mm markers were placed on each end, 450 mm apart. This bar was used with each subject to provide reference points for scaling the data (Figure 9.1).

Data were collected for a period of 3 seconds, and digitized measurements were obtained at a rate of 120 frames per second.

9.4 METHODS

Initially, static navicular drop, utilizing the Brody method was obtained for each of the subjects.

After static navicular drop was obtained, goniometric measurements were taken of the subtalar joint. These measurements were taken in accordance with the guidelines outlined in the handbook: <u>Joint Motion, Methods of Measuring and Recording</u>, by the American Academy of Orthopaedic Surgeons (1965).

Using a cotton-tipped applicator, the skin was then prepped with a Tincture of Benzoin solution and reflective markers were attached to the anatomical points on the foot and leg with double-sided adhesive tape.

Initially, the subject was instructed to walk normally in front of the cameras and the foot-strike position was noted. The scaling frame was placed in the position where the right foot struck the camera visual field. The ProReflex® system was then activated and data were collected for the scaling frame. The position of the frame was then marked on the walking area with masking tape to provide a guideline for the subject to aim for during the data collection process.

After the foot-strike area was identified, the subject was instructed to stand on the marked area and static data were collected. The subject was then instructed to walk normally in front of the cameras, and data were collected for the first step. The subjects were allowed to practice until the right foot landed in the appropriate spot in front of the camera without altering their usual walking pattern. The walking data were collected while the subject was barefoot. Five clear trials were recorded. A clear trial was determined to be one that the seven markers (3 foot and 4 leg/heel) were captured by each camera as indicated by the camera's LED display. However, even though the cameras showed that a total of seven markers were captured throughout the full movement, subsequent analysis revealed that each trial did have a few missed frames (≤15). Therefore, the software's "fill-in" command was used to smooth the data for the missed frames. If there were more than four consecutive frames missing, the entire trial was eliminated from analysis.

Once the barefoot trials were recorded, the same methods were repeated with the subjects wearing different types of footwear: moulded stud football boots (Mitre, Hoddle Pro-Fit P.U., style #F1204), and sports trainers (Mitre, Daytona Senior, style #SS99). To allow for viewing of the markers placed on the foot, each of the right shoes had windows of approximately 30 mm x 30 mm, cut out over the three marker points at the calcaneus, navicular tuberosity, and head of the first metatarsal. An additional hole, approximately 20 mm x 50 mm was cut in the heel of the shoe to allow for viewing of the posterior markers placed on the lower calcaneus and subtalar joint. Before each series of trials was conducted, the markers were rechecked for clear visibility and placement over the original ink spots on the skin. The subjects wore the same type of footwear on each foot during the data collection process, although data was collected for the right foot only.

9.5 DATA ANALYSIS

Each of the cameras provided 2 dimensional data for the markers seen in Figure 9.1. Camera one provided information to allow for calculation of dynamic navicular drop and the following calculations were made to obtain a numerical value for navicular height in millimeters:

Step 1: Calculating the linear scale(S) in millimeters.

$$S = \frac{\sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}}{450}$$

Where x_1 and y_1 = marker 1, x and y coordinates

Where x_2 and y_2 = marker 2, x and y coordinates

Step 2: Calculating the angle scale (σ_s) in degrees.

$$\sigma_s = \tan^{-1}\left(((y_2 - y_1) + (x_2 - x_1))\right)$$

Step 3: Calculating the length from navicular tuberosity to head of first metatarsal (L_{ac}).

$$L_{ac} = \left(\sqrt{(x_c - x_a)^2 + (y_c - y_a)^2}\right) \div S$$

Where x_a and y_a = navicular tuberosity x and y coordinates

and where y_c and y_c = First metatarsal joint line x and y coordinates

Step 4: Calculating angle of line to the horizontal A-C (σ_{ach}).

$$\sigma_{ac} = \left(\tan^{-1}((y_c - y_a) \div (x_c - x_a))\right) - \sigma_r$$

Step 5: Calculating angle of line to the horizontal B-C (σ_{bch}).

$$\sigma_{bch} = \left(\tan^{-1}((y_c - y_a) \div (x_c - x_a))\right) - \sigma_r$$

Step 6: Calculating angle between line A-C and B-C (σ_{abc}).

$$\sigma_{abc} = \sigma_{ac} - \sigma_{bch}$$

Step 7: Calculating navicular height (h_n).

$$h_n = (\sin \sigma_{abc})\,(L_{ab})$$

Once the navicular height was determined for each frame, the highest and lowest measurements were found. The difference between these two measurements was determined to be dynamic navicular drop. The mean navicular drop from the five trials, both walking and running, was then calculated.

The second camera provided information for the markers shown in Figure 9.1 for calculation of the subtalar joint angle. The following calculations were used to determine the subtalar joint angle:

Step 1. Calculating upper leg angle (σ_{de}) in degrees.

$$\sigma_{de} = \tan^{-1}((y_d - y_e) \div (x_d - x_e))$$

Where x_d and y_d = upper leg x and y coordinates and

where x_e and y_e = lower leg c and y coordinates

Step 2. Calculating heel angle (σ_{fg}) in degrees.

$$\sigma_{fg} = \tan^{-1}((y_f - y_g) \div (x_f - x_g))$$

Where x_f and y_f = Upper heel x and y coordinates and

where x_g and y_g = Lower heel x and y coordinates

Step 3. Calculating subtalar joint angle (σ_{STJ}) in degrees.

$$\sigma_{STJ} = 180^\circ + (\sigma_{de} - \sigma_{fg})$$

Once the subtalar joint angle was calculated, each trial was plotted. The frame number which corresponded with the heel strike was found and the heel strike subtalar angle obtained. Following heel strike, all trials exhibited a large pronation curve. The value that was found at the apex of the pronation curve was also determined. The difference between these two values was then calculated and this number was determined to be amount of initial pronation. In order to determine the velocity at which this initial pronation occurred, the length of time occurring between heel-strike and the apex of the initial pronation curve needed to be calculated. This was done by determining the number of frames from heel strike to the apex of the initial pronation curve and dividing by the frame rate (120 Hz). The resulting pronation velocity being expressed in degrees/second. Next, the length of time from the end of the initial pronation apex until heel-off was determined. Again, this was done by finding the number of frames and dividing the frame rate (120 Hz). Finally, the length of time from heel strike to maximum navicular drop was determined. As before, the number of frames was found and then divided by the frame rate (120 Hz). The means of the five trials were then calculated for each of the subjects.

The results were compared utilizing an ANOVA for correlated means to see if there were any differences (p<0.05) between the static weight-bearing navicular drop and dynamic navicular drop during walking and running conditions. Further analysis utilizing a post hoc t- test was undertaken to see where, if any, the differences occurred. Further, in instances where it was theorized that a correlation might exist, a Pearson correlation coefficient was used to determine if a relationship existed between two sets of data.

9.6 RESULTS

Twelve subjects were tested in each of the three dynamic testing conditions: barefoot, football boots, and sports trainers. Once data had been calculated, two subjects were eliminated from further analysis due to incomplete data collection as defined from the criteria previously set. The data from the remaining ten subjects were utilized for analysis.

Initially, pronation velocity was calculated for each of the trials in each condition. The mean values can be seen in Table 9.1. Individual subject results can be found in Appendix H. Once individual values were obtained, an ANOVA for correlated means was conducted. No statistical differences were observed in the pronation velocity between different conditions (F=1.55, p=0.24). However, the overall mean values for all of the individuals show that the pronation velocity for the barefoot, football boot, and sports trainer conditions was 21.63±11.73, 24.92±12.38, and 25.24±12.26 degrees/second, respectively. As these results indicate, a large standard deviation was seen in each of the conditions.

Next, the timing of the motion for each condition was addressed to see if footwear affected the length of time spent in each phase. This was broken down into four categories: 1) heel-strike to initial maximum pronation; 2) maximum pronation to heel-off; 3) time between heel-strike and heel-off; and 4) time from heel-strike to maximum navicular drop. The mean results for each testing condition in each category can be seen in Table 9.1. Individual subject results can be found in Appendix H. No statistical differences were found between conditions for the first three categories (f=1.85, p=0.18; f=0.043, p=0.95; f=0.102, p=0.90) respectively. However, in the latter category, statistical differences were seen between conditions, (f=3.85, p=0.03). A post hoc t-test revealed that these differences occurred between the sports trainer condition and barefoot condition (t=-2.74, p=0.02), as well as between the sports trainer and football boot condition (t=-3.92, p=0.01). No differences were seen between the barefoot and football boot condition (t=1.19, p=0.26).

Table 9.1. Mean±SD values for each of the evaluation categories for each testing condition.

	Barefoot	Football Boots	Sports Trainers
Pronation velocity (deg/sec)	21.63±11.73	24.92±12.38	25.24±12.36
Time from heel-strike to maximum pronation (sec)	0.13±0.03	0.11±0.02	0.12±0.03
Time from maximum initial pronation to heel-off (sec)	0.28±0.07	0.27±0.13	0.28±0.12
Total time from heel-strike to heel-off (sec)	0.41±0.09	0.38±0.14	0.40±0.14
Time to maximum navicular drop (sec)	0.55±0.13*	0.49±0.15†	0.65±0.11*†

* Significant differences between barefoot and sports trainer conditions.
† Significant differences between football boots and sports trainer conditions.

Finally, analysis was carried out to see if there was a correlation between maximum subtalar joint pronation and maximum navicular drop. The mean values obtained for each subjects in the barefoot, football boot, and sports trainer conditions can be found in Table 9.2. Overall, a very low correlation (r=0.03) was found between the two measurements. The correlational analysis for Individual categories can be seen in Table 9.3. Analysis was then carried out on pronation velocity and maximum

Table 9.2. Mean±SD Maximum Navicular Drop and Maximum Pronation Measurements for the Three Testing Conditions.

Testing Condition	Maximum Pronation (degrees)	Navicular Drop (millimeters)
Barefoot	9.89±2.16	5.03±1.41*
Football Boots	9.49±1.85	3.11±0.62*†
Turf Trainers	9.37±2.05	4.25±1.31†

* Statistical differences in navicular drop between barefoot and football boot conditions.
† Statistical diferences in navicular drop between football boot and sports trainer conditions.

navicular drop to see if there was a correlation between the two. Again, overall, a very low correlation was found between the two (r=0.06). The correlational analysis for individual categories can be seen in Table 9.4. The correlation coefficient values for both the maximum navicular drop/maximum STJ pronation and the maximum navicular drop/pronation velocity were not considered statistically significant for a sample of this size.

Table 9.3. Correlational Analysis Results for Maximum Navicular Drop and Maximum Subtalar Joint Pronation Between Conditions.

Condition	r value	Correlation classification
Barefoot	-0.05	Very low negative
Football Boots	0.56	Modest
Sports Trainers	0.35	Low
Combined	**0.03**	**Very low**

Table 9.4. Correlational Analysis Results for Maximum Navicular Drop and Subtalar Joint Pronation Velocity Between Conditions.

Condition	r value	Correlation classification
Barefoot	0.17	Very low
Football Boots	0.35	Low
Sports Trainers	0.17	Very low
Combined	**0.06**	**Very low**

Additional analysis was carried out to see if there were differences in navicular drop with each condition. An ANOVA for correlated means revealed that there were statistical differences between the barefoot, football boot, and sports trainer condition ($F=6.82$, $p=0.00$). A post hoc t-test showed that these differences occurred between the football boot and barefoot conditions ($t=3.85$, $p= 0.00$) as well as the football boot and sports trainer conditions ($t=-3.02$, $p=0.01$). No statistical differences were seen between the barefoot and sports trainer conditions ($t=1.98$, $p=0.05$). However, the mean navicular drop values were slightly higher for the barefoot condition (5.03±1.41 mm) than those values obtained for the sports trainer (4.25±1.31 mm) and the football boot (3.11±0.62 mm) conditions.

Analysis was then carried out to see if there were differences in maximum subtalar joint pronation values between each condition. An ANOVA for correlated means showed no statistical differences between the subtalar joint pronation values and the barefoot, football boot, and sports trainer conditions ($f=0.177$, $p=0.84$).

9.7 DISCUSSION

Data were collected utilizing two 2-dimensional camera systems, each looking at a different motion. This was done because it was difficult to set up a three-dimensional system that could identify all of the points during the movement without losing several markers due to an obscured view caused by the follow-through leg. Cornwall and McPoil (1995) demonstrated that there are minimal differences between two-dimensional and three-dimensional recording of rearfoot motion as long as the analysis of the 2-dimensional rearfoot motion does extend beyond 60% of the stance phase of walking. Since this study was addressing the heel strike to toe-off phase of stance, this should not be considered a limitation. Additionally, the three previous chapters in this thesis demonstrate that two-dimensional analysis is adequate for obtaining dynamic navicular drop values.

Due to the fact that windows were cut into the shoe to allow access to viewing the calcaneus, metatarsal head, and the navicular tuberosity on the medial foot, it was also necessary to cut a window in the posterior heel of the shoe to allow for marker placement over the anatomical points of the subtalar joint. Reinschmidt, et. al., (1992) found that markers placed on the skin, compared to those placed on the shoe, provided better information regarding foot movement and position of the calcaneus during movement. He also found that the effect of the windows on the heel movement was minimal. Therefore, it can be concluded that the window cut out over the posterior heel of the shoes in this study did not compromise the integrity of the shoe and should not be considered a limitation. However, the effect of the medial shoe cut-outs on shoe integrity and foot function will be addressed in Chapter 10.

The movements of the subtalar joint were broken down into three periods for analysis: the time from heel strike to initial maximum pronation; the time from which maximum initial pronation had been reached to heel-off; and the total time between heel-strike and heel-off. Figures 9.2A, 9.2B, and 9.2C demonstrate a typical subtalar joint motion curve through the stance phase of the walking gait cyclefor each of the testing conditions. Each of the three analysis phases can be identified on the curves. As seen on the curve on Figure 9.2A, heel strike occurred at 0.18 seconds into the movement, followed by a rapid period of pronation lasting 0.13 seconds, as indicated by the sharp upward movement of the line. This was then followed by a "plateau" period in which occurred from the time that initial maximum pronation was reached through the moment of heel-off, lasting about 0.24 seconds. Following heel-off, the foot starts to supinate and the curve moves downward. The total period from heel-strike to heel-off is simply determined by adding the length of time of the initial pronation phase to the plateau phase.

Figure 9.2. Subtalar Joint Motion During the Stance Phase Throughout the Walking Gait Cycle

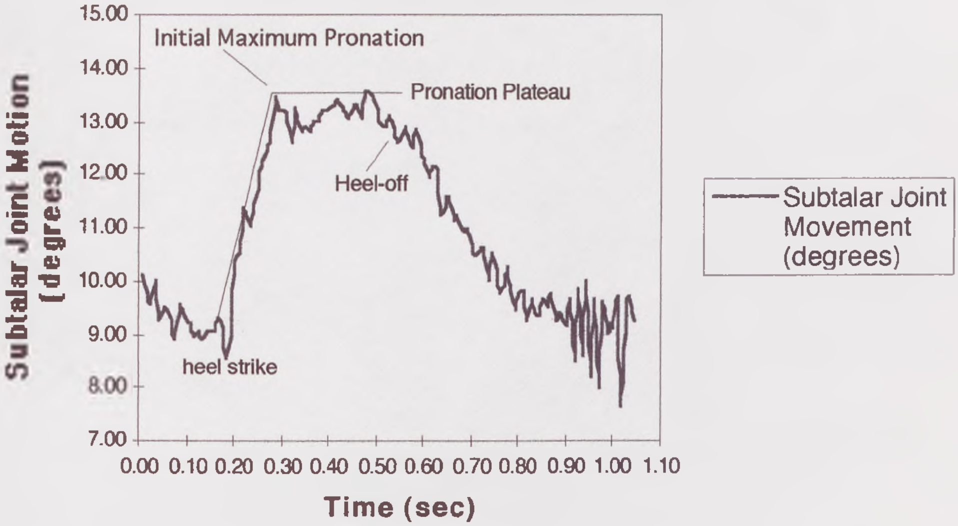
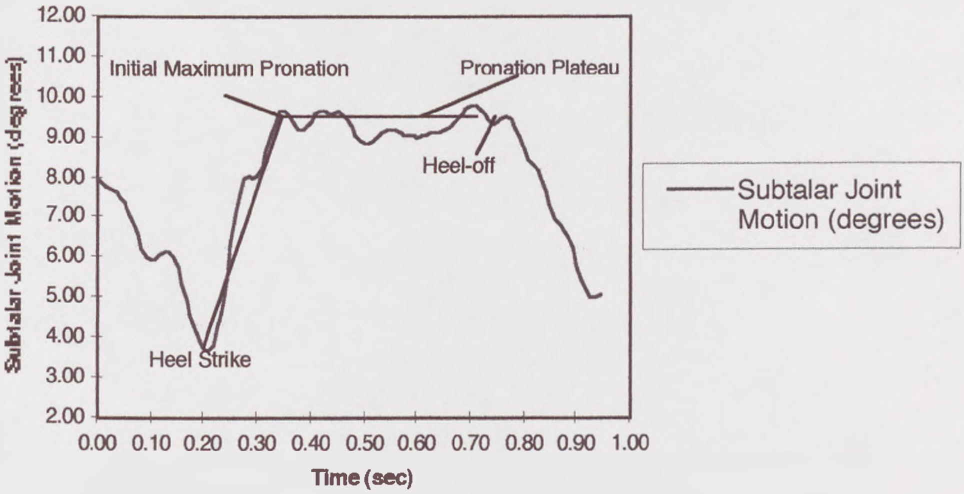


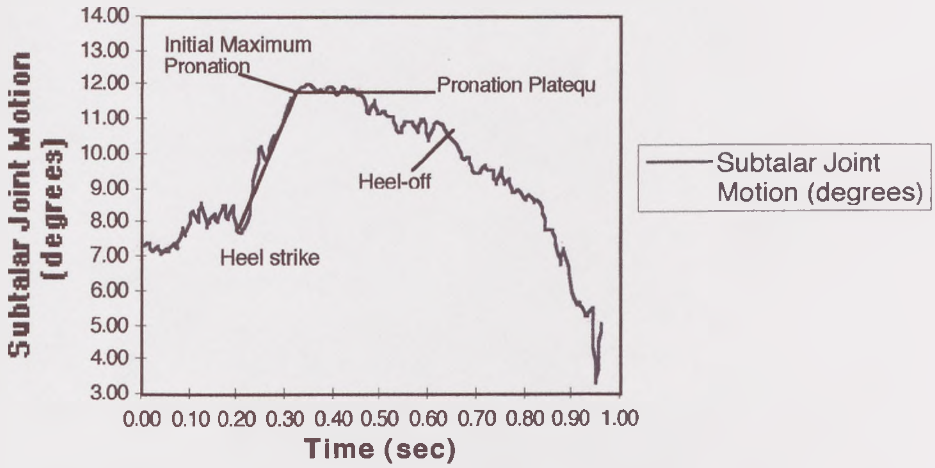
Figure 9.2B. Subtalar Joint Motion During the Stance Phase Throughout the Walking Gait Cycle While Wearing Football Boots



A fourth category utilized in analysis was determined by the navicular height curve demonstrated in Figures 9.3A, 9.3B, and 9.3C. In addition to the navicular drop values, the length of time from heel strike to maximum navicular drop was also determined. As can be seen in Figure 9.3A, this period of time was about 0.48 seconds.

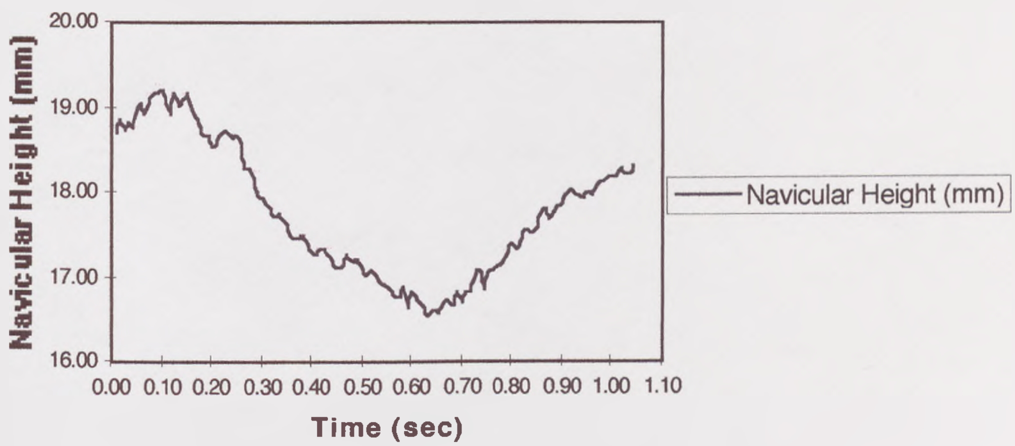
With these categories in mind, the analysis could be carried out looking at various timing and movements of the subtalar joint and midfoot, to see how footwear affects the

Figure 9.2C. Subtalar Joint Motion During the Stance Phase Throughout the Walking Gait Cycle While Wearing Sports Trainers



results, and to see if there were correlations between navicular drop (midfoot pronation) and subtalar joint pronation (hindfoot pronation).

Figure 9.3A. Typical Navicular Height Curve Throughout the Stance Phase of a Walking Cait Cycle While Barefoot



The timing of the subtalar movements that occurred within the various categories appeared to be fairly consistent between conditions with no statistical differences found. Therefore, it could be concluded that the footwear does not affect the length of time

Figure 9.3B. Typical Navicular Height Curve Throughout the Stance Phase of a Walking Gait Cycle While Wearing Football Boots

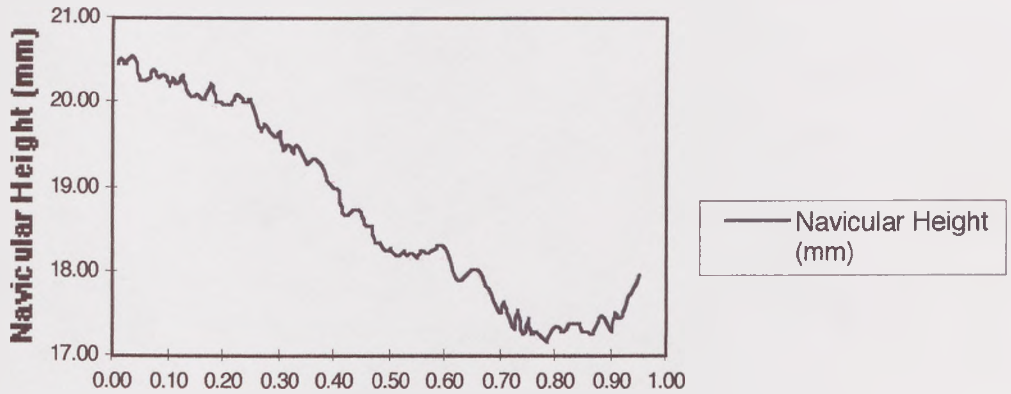
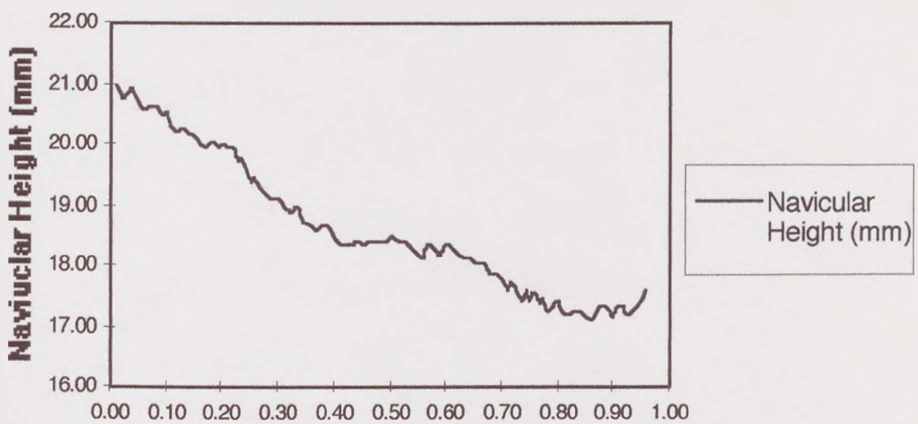


Figure 9.3C. Typical Navicular Height Curve Throughout the Stance Phase of a Walking Gait While Wearing Sports Trainers



involved during each period from heel-strike to heel-off and that the total time from heel-strike to heel-off remains similar regardless whether the individual is barefoot or wearing footwear. However, statistical differences were seen between conditions in the timing from heel strike to maximum navicular drop. These differences occurred between the sports trainer and barefoot condition and the sports trainers and football boot condition. The time to maximum navicular drop was least in the football boot condition (0.49±0.15

seconds), followed by the barefoot condition (0.55±0.13 seconds) and then the sports trainer condition (0.65±0.11 seconds). In all of the conditions, it appeared that maximum navicular drop occurred after heel-off, but prior to toe-off. These results also indicate that there is a possibility of the midfoot acting independently of the rearfoot motion. The subtalar joint movement curves (Figure 9.2a, 9.2B, and 9.2C) indicated that the rearfoot, that is, the subtalar joint, begins to supinate while the midfoot is still pronating.

Pronation velocity following heel strike was chosen as a parameter for investigation because it has been suggested as an important variable in assessing injury (Clarke, et. al, 1984; Hamill, et. al., 1992; Luethi, et. al., 1987; Stacoff, et. al., 1991). Luethi, et. al., (1987) explains that these injuries can occur when the excessive initial joint motion results in fast eccentric loading of the muscles, tendons and supporting ligaments. No statistical differences were seen in the pronation velocity between the barefoot, football boot, and sports trainer conditions. However, a large standard deviation was seen in each of the three conditions, probably due to the small sample size. Disregarding these large standard deviations, differences were clearly seen between the barefoot and shod conditions with the slowest pronation velocity reported in the barefoot condition (21.63 degrees/second) , followed by the football boots (24.92 degrees/second) and sports trainers (25.24 degrees/second). Stacoff, et. al., (1990) found that right after touchdown, there is a very rapid pronation period that is increased when wearing shoes. He goes on to explain that a stiff shoe can force the foot into faster pronation. This would explain the results seen in this study. It would appear that the shoes force the foot into pronation at a rapid rate. This rapid pronation can lead to a change in the timing relationship between the motions of the subtalar joint and other structures involved in the kinetic chain which could lead to dysfunction within the lower extremities (Hamill, et. al., 1992). Stacoff, et. al., (1989) explained that in barefoot running, the forefoot goes into eversion independent of the rearfoot, which remains stable. The result is a torsional movement and a small pronation of the rearfoot. He goes on to claim that the situation differs with sports shoes since forefoot and rearfoot are additionally connected by the material of the shoe so that a stiff shoe sole can lead to an increased torsional stiffness of the foot and shoe combined. This may decrease the torsion between the forefoot and rearfoot and increase the pronation.

Although it appears that a firmer midsole can increase initial pronation velocity, many researchers have suggested that a softer midsole shoe can affect rearfoot motion by increasing the amount of pronation (Bates, 1989; Cavanagh, 1982; Hamill, et. al., 1992; Nigg, et. al., 1990; Stacoff, et. al., 1988,1989, 1991). Conversely, the results of this study found no statistical differences between the amount of rearfoot pronation in the barefoot, football boot, and sports trainer conditions. This casts doubt on this theory but may have been due to the small sample size involved in this study and would warrant further investigation at a later date.

The previous chapter of this thesis found that there were statistical differences between navicular drop and the barefoot and shod conditions. In the current study, these same differences were found, with the football boot condition reporting a lower navicular drop measurement which was significantly different from both the barefoot and sports trainer conditions. These lower navicular drop values seen in the football boot condition could be explained by the works of Robbins and Hanna (1987), who report that a stiffer shoe changes the foot to a rigid structure in which the bony structures are unable to yield on normal loading. Although the navicular drop values reported in this study for the sports trainers were slightly less than those seen in the barefoot condition, as in the previous chapter, no statistical differences were seen between the two. Using the arguments of Robbins and Hanna, one would expect to see statistical differences with the sports trainers. The results of this study could indicate that this particular sports trainer does not have a midsole that is stiff enough to significantly change the function of the foot.

Since one of the primary purposes of this study was to determine if there was a relationship between dynamic subtalar joint pronation and navicular drop, analysis was carried out to see if a correlation between the two existed. Initially, the values obtained for maximum subtalar joint pronation were compared against the maximum navicular drop values. The results indicated that overall there was a very low correlation ($r=0.03$), the closest relationship between maximum subtalar joint values and maximum navicular drop was found while wearing football boots. However, this modest correlation (r=0.55) was not significant for this sample size. Next, analysis was carried out to see if there was a correlation between the pronation velocity and maximum navicular drop as it might be expected that more rapid pronation could generate a greater amount of navicular drop. Again, analysis revealed a very low correlation overall (r=0.06). While none of these were statistically significant, individual conditions revealed a very low correlation in the barefoot and sports trainer conditions, and a low correlation was found while wearing football boots. The contention has frequently been that movements of the subtalar and transverse tarsal joints are interdependent and that action in both joints occurs simultaneously (Manter, 1941). However, Manter also compares the action of the talus as a "screw-like" motion which causes the head of the talus to be carried forward into pronation, pushing the navicular bone into pronation and that the motion of one cannot be carried out without the motion of the other. While this might be the case, the results of this study indicate that even though both structures are showing some degree of pronation, the amount of subtalar pronation does not seem to be related to the amount of navicular movement. This also appears to be true with the velocity of subtalar pronation in that velocity does not seem to have a relationship to the amount of navicular drop. Both of these results indicate that there is little or no correlation between subtalar motion and navicular motion, however, because both structures are pronating to some extent, the overall picture of foot movement is not quite so simple.

Many studies which have positively related navicular drop pronation to pronation of the subtalar joint or rearfoot motion have been conducted with static measurements (Cavanagh, et. al., 1997; Cobey, et. al., 1981; Duckworth, et. al., 1983; McPoil, et. al., 1996; Mueller, et. al., 1993; Picciano, et. al., 1993). However, controversy remains about the effectiveness of static measurements in predicting dynamic foot function. The results of this study indicate that the navicular drop measurement cannot be used to predict the amount of rearfoot subtalar pronation. This concurs with the findings of a running study by Nigg, et. al., (1993) in which he found that a functional relationship between arch height and foot eversion or internal leg rotation did not exist. Further, in gait studies by Kernozek, et. al., (1990), and Knutzen, et. al., (1994), it was found that arch height, as determined by pre-testing static measurements, was not a good predictor of maximum pronation, but was a good predictor of total rearfoot motion. At this time, it appears that there is limited information regarding the relationship between arch height and subtalar joint motion during dynamic activity within the literature. The literature does reveal that there are many other factors influencing rearfoot and midfoot motion and perhaps one of the most prevalent factors is foot placement angle. Kernozek, et. al., (1990) reported that foot placement angle was a better predictor of maximum pronation than arch height. While this was not addressed in the methods and subsequent analysis, the effects of foot placement angle should have been lessened by having the foot strike guide marked prior to data collection.

9.8 CONCLUSIONS

The results of this study indicate that footwear does not seem to affect the length of time between heel-strike and heel-off during walking gait. However, it appears there are differences in the length of time from heel-strike to the point at which maximum navicular drop is reached between barefoot, football boots, and sports trainer conditions. The sports trainers seemed to affect this length of time the most, with maximum navicular drop occurring later in the stance phase. Additionally, in all of the conditions, maximum navicular drop occurred after heel-off at a time when the subtalar joint had already started to supinate. It could be concluded that there was a possibility of the midfoot acting somewhat independently of the rearfoot. While it appeared that the navicular drop and subtalar joint pronation began at the same time, as the heel began to lift off of the ground during gait, the midfoot continued pronating and the navicular drop occurred slightly later.

Analysis of subtalar pronation velocity revealed that there were no statistical differences between each of the conditions. However, a large standard deviation was seen among the subjects. Disregarding this large deviation, differences were seen between the barefoot and both shod conditions. The small sample size could explain these results and therefore, additional studies utilizing a larger sample size would be warranted at a later date.

Analysis of the amount subtalar pronation and each of the conditions also revealed no differences. Additional correlation analysis was carried out to see if there were relationships between maximum subtalar pronation and maximum navicular drop as well as maximum subtalar pronation velocity and maximum navicular drop. Again, no correlations were found between the two, suggesting that there was no relationship between subtalar joint pronation and navicular drop. However, it must be noted that there was some degree of pronation at both structures so there may still be a relationship and further investigation would be warranted.

Finally, the results of this and those of the previous chapter indicate that differences were found between navicular drop and the testing conditions. The navicular drop of the football boot condition were lower than those for the barefoot and sports trainer conditions. Therefore it could be concluded that the football boots interfere with midfoot pronation, limiting the amount of motion that occurs within this area.

The results of this study appear to indicate that the timing of the foot motion is more important than the amount of angular and linear displacement, or the amount of angular velocity. Comparison of the subtalar joint curve with the navicular drop curve might lead to these conclusions. One cannot deny that there is a certain degree of pronation occurring simultaneously at both the subtalar joint and at the navicular bone, but it is possible that there is a "chain-reaction" of movements with pronation beginning at the subtalar joint/rearfoot, continuing on to the midfoot/navicular bone, and then on to the forefoot. Therefore, the relationship between displacement measurements may be negligible when determining the effect of the amount of pronation on the risk of injury. The timing variations that occur within the subtalar joint and distal kinetic chain could lead to dysfunction of the other structures, specifically, muscles, tendons, and ligaments, which have to compensate for these variations. A weakness or abnormality among any of these soft-tissue structures could lead to a breakdown, which could lead to injury.

Chapter 10

A Fluoroscopic Analysis of the Effects of Football Boots on the Structure and Function of the Midfoot During Dynamic Motion

10.1 INTRODUCTION

Most studies which have attempted to investigate the role of bone structure, ligaments and muscles of the foot have been limited to static loading conditions, which as mentioned previously, are not valid predictors of dynamic foot function. Dynamic foot function needs to be assessed in detail in order to gain a thorough understanding of the intricate interactions of the bones, muscles, and ligaments during activity, specifically gait. Further, since most dynamic activity occurs when the athlete is wearing some type of footwear, and footwear appears to change the way the foot functions (potentially leading to injury), dynamic foot function needs to be assessed while wearing footwear. Because the shoe covers the foot, analysis of foot function is difficult.

In Chapter 8, an attempt was made to address this issue. The results of that study indicate that the foot appears to function differently while wearing different types of athletic footwear. Stacoff, et. al., (1991) also tried to address this issue during his analysis of subtalar joint motion while wearing shoes by cutting windows in the shoe to allow for measurement. However, the results of these studies could be considered questionable because the integrity of the shoe has been altered. Another limitation could be the fact that the measurements obtained may have been prone to human error in identifying anatomical landmarks underneath soft tissue, which has a tendency to move and deform.

Traditional radiographic evaluation, or x-rays, provide information regarding the body's skeletal structure. Utilizing this technology, Shereff, et. al., (1990) conducted a study comparing non-weight-bearing films and weight-bearing films in order to obtain additional information concerning the bony and soft-tissue structures under physiologic loading conditions. They were able to see differences between the two conditions, but were unable to draw any definitive conclusions regarding foot function. Morag, et. al., (1994) attempted to address the foot-shoe interface issue using traditional x-rays but again, these x-rays were static measurements taken in the non-weight-bearing and weight-bearing positions, making inferences to dynamic foot function difficult. More recently, studies by Perlman, et. al., (1996) and Wearing, et. al., (1998), have used videofluoroscopy to assess different components of foot function during pathological gait with some degree of success. Videofluoroscopy combines videography/cinematography with x-ray to capture a moving image of the skeletal structure during dynamic activity.

Most radiographic techniques have the advantage of capturing dense images (such as bone), while viewing through extraneous objects or tissue. This ability makes it ideal for obtaining clear views of skeletal structure while wearing various kinds of footwear, as seen in the study by Morag, et. al., (1994). Utilizing fluoroscopy, one should be able to obtain clear views of the foot during activity, while wearing different types of footwear. Consequently, fluoroscopy may provide a safe, non-invasive, alternative method of quantifying dynamic foot function not only during barefoot gait, but also while wearing footwear. Additionally, it may also provide validation of other motion recording techniques which rely on skin-mounted markers as estimates of the location of skeletal landmarks.

The primary purpose of this project was to use x-ray fluoroscopy to: 1) evaluate the movement of the skeletal structure of the midfoot during dynamic motion; 2) to verify the marker placement used in the previous ProReflex® studies in relationship to anatomical landmarks; and 3) to determine what effects, if any, cutting windows in the shoes has on the structural integrity of the shoe and if it affects foot function.

10.2 SUBJECTS

Twelve healthy volunteer subjects (age, 25.4±2.8 years; mass, 78.2±10.1 kg; height, 1.796±0.55 m) who met the selection criteria (Table 10.1) were used for this study. These subjects were recruited from a pool of football players within the Centre for Studies in Physical Education and Sports Sciences, the Department of Biomedical Sciences, the University of Leeds Football Club, and local club teams. All subjects had previously participated in the ProReflex® footwear study covered in Chapter 8. The study was approved by the Ethical Committee of the Leeds Health Authority. All subjects signed an informed consent document in accordance with the guidelines set by this committee.

Table 10.1. Criteria for Subject Selection.

Inclusion criteria:	Exclusion criteria:
Male, aged 18 - 28 Football player (must play at least one game per week) Wear shoe size 8, 9 or 10 boot Injury, pain, and symptom-free Normal gait (i.e. absence of limping, overpronation, or oversupination) Presence of metatarsal arch, transverse arch, and medial longitudinal arch Normal functioning medial longitudinal arch in non-weight-bearing and weight-bearing positions Normal position of os calcis (0° ± 5°) during weight-bearing	History of recent injury to foot/ankle/lower leg Abnormalities of gait Abnormal arches (i.e., flat-foot, rigid high arch) Abnormal foot appearance (i.e., bunions, overlapping toes) Shoe size of <8 or >10 Abnormal position of os calcis (pronation >5°, supination >5°)

10.3 EQUIPMENT AND SETUP

In order to collect the appropriate dynamic (walking) data when utilizing the fluoroscope, a special x-ray table was constructed. This table was .55 m wide, .85 m high and 1.55 m long. The subject was required to stand on top of the table to take one full step along its length, passing by the lens of the fluoroscope while it collected the x-ray data.

The data was collected utilizing a Phillips Diagnost 4® C-arm fluoroscope (Figure 10.1).

10.4 METHODS

Once consent was obtained, each subject completed a short injury history form and then underwent a visual gait analysis followed by a foot/ankle physical evaluation in which the static navicular drop measurement was obtained and goniometric

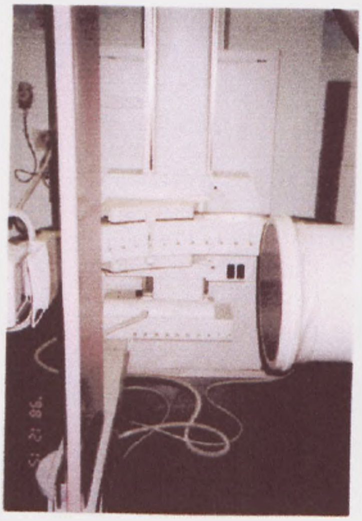


Figure 10.1 Phillips Diagnost 4®
C-arm Fluoroscope
1A. Frontal view
1B. Lateral view

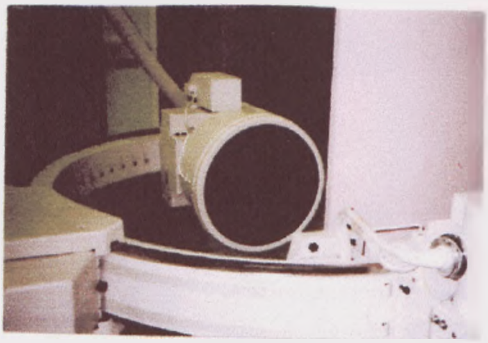


Figure 1A.

Figure 1B.

measurements were taken of the subtalar joint. Additionally, height and mass information were recorded for each subject. This part of the study was conducted in the Biomechanics Laboratory at the Centre for Studies in Physical Education and Sports Science at the University of Leeds. If, at any time during the preliminary evaluation process, a candidate did not meet all of the selection criteria, he was dismissed from further study.

Once the subject had met the selection criteria, he was invited to participate in the second part of the study, conducted at the Department of Radiology, Leeds General Infirmary. This phase of the research involved the use of x-ray fluoroscopy, which allowed information to be collected during movement while barefoot and while wearing footwear.

The subject was required to stand on top of the specially-constructed table to take one full step along its length, passing by the lens of the fluoroscope as it was collecting the x-ray data. The fluoroscope was in the "off" position between trials and prior to data collection. The subject was given the opportunity to practice the gait cycle until he was comfortable with the setup. Once the subject was comfortable with the procedures, data was collected for 15 trials. These 15 trials were conducted as follows:

1 exposure while barefoot with radiographic markers placed on the foot; non-weight-bearing
1 exposure while barefoot with radiographic markers placed on the foot; weight-bearing

3 exposures while barefoot with radiographic markers placed on the foot-walking
1 exposure while wearing molded stud football boots with holes cut out, with radiographic markers placed on the foot; non weight-bearing
1 exposure while wearing molded stud football boots with holes cut out, with radiographic markers placed on the foot; weight-bearing
3 exposures while wearing molded stud football boots with holes cut out, with radiographic markers placed on the foot; walking
1 exposure while wearing molded stud football boots with radiographic markers placed on the boot; non weight-bearing
1 exposure while wearing molded stud football boots with radiographic markers placed on the boot; weight-bearing
3 exposures while wearing molded stud football boots with radiographic markers placed on the boot; non weight-bearing

Each exposure lasted approximately 2 seconds with a total maximum exposure of 30 seconds. The fluoroscopic procedures were conducted by radiographers Tracey Thorne and Karen Wainford and supervised by radiologist Prof. Wayne Gibbon at Leeds General Infirmary. The total radiation exposure incurred by the subjects in this study was the equivalent of approximately 1 chest x-ray and was considered to be within the low-dose range according to the guidelines set up by the NHS radiation protection services (Chris Taylor, Radiation Protection Advisor, personal communication, 1999).

10.5 DATA ANALYSIS

The fluoroscope data were collected at a rate of 8 frames per second and recorded directly onto a high resolution standard video tape. Hard copies of the fluoroscope images were also produced for each of the subjects as a back-up. This video data was analyzed in the Biomechanics lab utilizing a manual digitizing process. Each set of data was digitized twice, first the true anatomical landmarks were digitized, followed by digitizing of the radiographic markers that had been placed on the foot or shoe prior to testing. Utilizing the mathematical equations outlined in the "Chapter 6-Data Analysis" section, linear measurements were obtained for navicular drop in relation to the ground and shoe in each of the testing conditions and an average of the three trials was calculated for each of the conditions. To allow for scaling of the data, drawing pins were placed in the studs of the shoes at a distance of 105 mm for size 8 boots, 108 mm for size 9 boots, and 111 mm for size 10 boots.

Once this information was obtained, each set of data were compared within the various testing conditions for each subject with further analysis looking at the between subject differences with each of the testing conditions. Analysis was carried out using a two-way ANOVA for correlated means with a significance level of $p<0.05$. A post hoc Tukey test was also used to see where, if any, differences exist.

10.6 RESULTS

After digitizing the anatomical landmarks, the average static navicular drop for all of the subjects was found to be: barefoot, 2.66 ±1.50 mm; football boots with holes, 2.51 ±1.77 mm; and intact football boots, 2.37 ±1.33 mm. When the marker points were digitized, the average static navicular drop for all of the subjects was found to be: barefoot, 2.78±1.44 mm; football boots with holes, 1.65±1.31 mm; and intact football boots, 2.35±1.33 mm. Navicular drop results can be seen in Table 10.2. Individual subject results can be foun in Appendix I. These results indicate that there was no statistical differences in static navicular drop between the three conditions (f=0.076, p=0.93). However, the static results were statistically different from the values obtained

Table 10.2. Mean±SD Navicular Drop Measurements for Anatomical Landmarks and Markers in Static and Dynamic Condition.

	Anatomical Landmarks:			Markers:		
	Barefoot (mm)	Football Boots, w/holes (mm)	Football Boots, intact (mm)	Barefoot (mm)	Football Boots, w/holes (mm)	Football Boots, intact (mm)
Static Navicular Drop	2.66 ±1.50*	2.51 ±1.77*	2.37 ±1.33*	2.78 ±1.44*	1.65 ±1.31*	2.35 ±1.33*
Dynamic Navicular Drop	6.38 ±1.24*	5.10 ±1.47*	5.58 ±0.90*†	5.42 ±1.24*	3.35 ±1.10*	2.29 ±0.64*†

* Statistical differences were found between static and dynamic navicular drop in all conditions.
† Significant differences were found between anatomical landmarks and marker placement on outside of shoe.

for dynamic navicular drop (f=91.12, p=0.00). When the anatomical landmarks were digitized, the average dynamic navicular drop for all of the subjects was found to be: barefoot, 6.38 ± 1.24 mm; football boots with holes, 5.10 ± 1.47 mm; and intact football boots, 5.58 ± 0.90 mm. The navicular drop for the digitized markers for all of the subjects was found to be: barefoot, 5.42±1.24 mm; football boots with holes, 3.35±1.10 mm; and intact football boots, 2.29±0.64 mm.

The results of the fluoroscopy and subsequent digitization indicated that there was no statistical difference between anatomical landmarks and marker placement (f=3.66, p=0.06). However, there was a statistical difference between the anatomical landmarks and the markers placed on the outside of the shoe as in the case of the intact football boot (f=37.09. p=0.00). Further analysis was carried out comparing the results of navicular drop obtained for each of the subjects from the study covered in chapter 8 with the results obtained for the digitized marker points from the barefoot and modified boots conditions in this study (Table 10.3). Again, no statistical differences were found between the two in both the barefoot (f=2.04, p=0.16) and the modified boot conditions (f=0.44, p=0.617).

In order to determine the effects of altering the boots by cutting holes over the anatomical landmarks to allow for viewing of the markers, a comparison was made between the two football boot conditions. After digitizing the anatomical landmarks and comparing the navicular drop values for these two conditions, no statistical differences were found (f=1.58, p=0.221).

Next, analysis was carried out to see if there were differences in dynamic navicular drop between the barefoot and shod conditions. An ANOVA revealed that there were statistical differences between the conditions (f=3.35, p=0.04). A post hoc Tukey test was then undertaken, and these differences were found between the barefoot and both shod conditions. No differences were found between the two shod conditions.

Table 10.3. Dynamic Navicular Drop Results from ProReflex® Footwear Study and Fluoroscopy Study.

	ProReflex®-Footwear Study		Fluoroscopy Study	
	Barefoot (mm)	Football Boots with holes (mm)	Barefoot (mm)	Football Boots with holes (mm)
MEAN±SD	5.64±1.28	4.69±1.42	6.38±1.24	5.17±1.40

10.7 DISCUSSION

Fluoroscopy has long been used as a diagnostic tool for physicians when instant images are required, such as tracking of the gastro-intestinal tract, or for use during surgeries for pin placement in fracture repairs, location of foreign bodies, implantation of pacemakers, biopsies, and catheterizations (Health Devices, 1990). Because it is one of the few imaging modalities that affords a real-time view of dynamic processes, combined with the advantage of low radiation dosages, fluoroscopy is becoming a beneficial method of evaluating skeletal function in the areas of sports medicine and biomechanics as seen in the studies of Cholewicki, et. al., (1991), Perlman, et. al., (1996), and Wearing, et. al., (1998). Further, when comparing image quality between normal x-rays and fluoroscopy, the distortion levels compared favourably. Wearing, et. al. (1998) reported an intraclass correlation coefficient of 0.99 for radiographic images and 0.97 for the fluoroscopic images. Tapiovaara (1997) reported image quality was slightly less for the fluoroscope images, especially around the edges of the viewing field, but that the anatomical structures could still be seen and identified. Suileiman, et. al., (1997) reported that when the fluoroscope radiation dosages were increased, the image quality did improve and that little or no “ghosting” of the images were seen. It must be noted that even the “high” radiation doses on the fluoroscope are still substantially lower than those seen for regular radiographic images (Chris Taylor, 1999). While still in the developmental stages, dynamic fluoroscopy has the potential to become a valuable, safe, and inexpensive tool in the evaluation and diagnosis of musculoskeletal injuries.

The results found in this preliminary study revealed a wealth of information regarding foot function while walking. While dynamic foot fluoroscopy has been used on individuals with symptomatic conditions (Perlman, et. al., 1996; Wearing, et. al., 1998), this study was used to evaluate foot function on healthy individuals. Further, analysis was carried out to evaluate the effects of footwear on dynamic foot function. The methodology utilized in this study offers the added advantage providing static images in the non-weight-bearing and weight-bearing positions, as would be seen if one were to obtain lateral views of traditional radiographic films. Figures 10.2A and 10.2B shows the images obtained for the barefoot condition in the non-weight-bearing and weight-bearing positions, Figures 10.2C and 10.2D shows the same images while the subject was wearing football boots with the holes cut out, and Figures 10.2E and 10.2F shows the images while the subject was wearing intact football boots. In addition to the anatomical points clearly seen on the images, radiographic markers were also placed over the anatomical landmarks prior to testing so that comparisons could be made.

As can be clearly seen on all of the images, changes can be seen between the non-weight-bearing and weight-bearing exposures; the navicular bone changes position and the distance between the calcaneus and head of the first metatarsal increases, indicating that the shape of the medial longitudinal arch changes. The average static navicular drop for all of the subjects in all of the conditions was 2.66 ± 1.50 mm. There were no statistical differences found in the static navicular drop between any of the conditions. The fact that there was a difference between non-weight-bearing and weight-bearing static navicular drop is not surprising and was in fact, expected. However, what was surprising was that the navicular drop values were so low when compared to the static navicular drop values reported by Brody (1982), Hamill, et. al. (1989), McPoil, et. al. (1996), and the results reported earlier within this document. One possible explanation was the fact that the subjects were not seated in the non-weight-bearing views, but rather, were instructed to transfer their weight to the opposite leg while the exposure was taken.

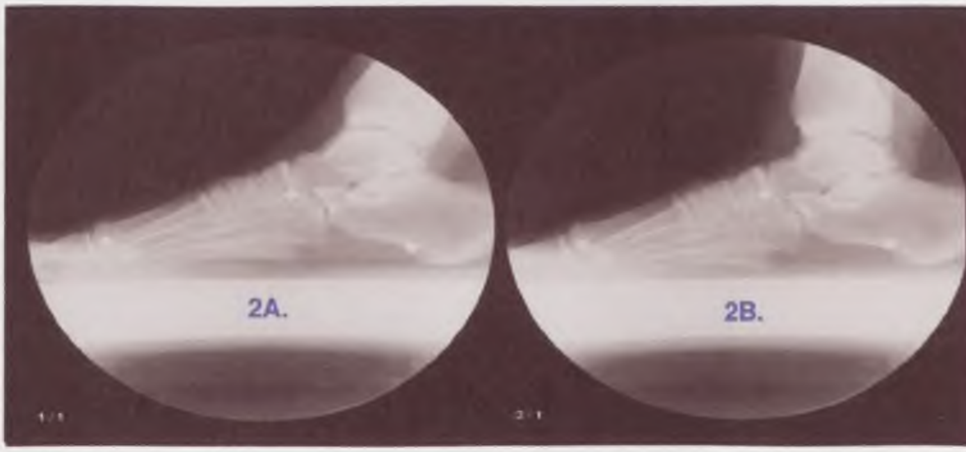


Figure 10.2A and B Static views while barefoot.
2A. Non-weight-bearing, 2B. Weight-bearing

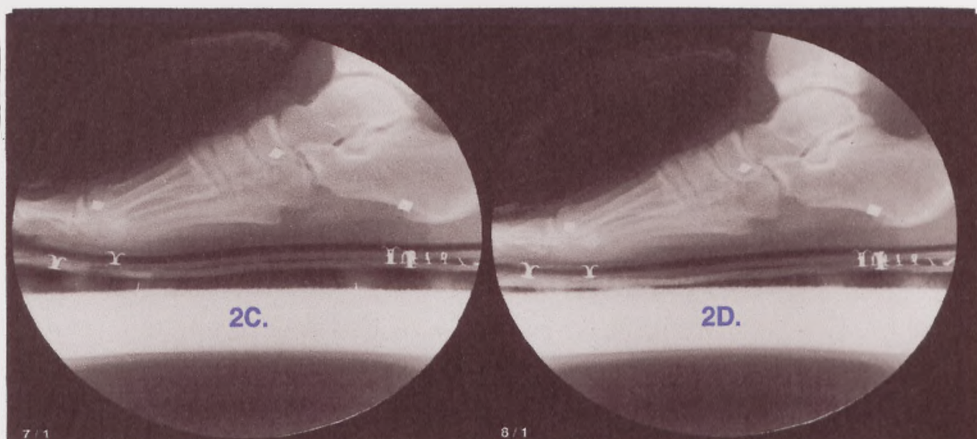


Figure 10.2C and D Static views while wearing football boots with holes cut out. 2C. Non-weight-bearing, 2D. Weight-bearing

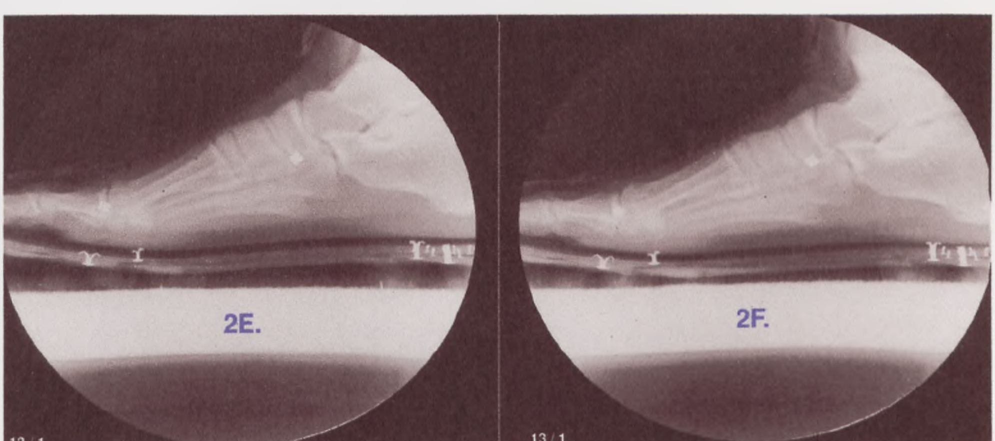


Figure 10.2E and F Static views while wearing intact football boots.
2E. Non-weight-bearing, 2F. Weight-bearing

After the static images had been taken, 3 dynamic images were obtained while the subjects were barefoot, while wearing football boots with holes cut out, and while wearing intact football boots and the average navicular drop was calculated for each of the three conditions to provide a single value. The dynamic images were collected at a rate of 8 frames per second, and films were provided for each of the frames. The walking speed was determined by number of frames obtained for the entire step as seen on the images of the right foot. Overall, the gait speed varied from 1 to 1.875 seconds (8 to 15 frames) for all of the subjects with the average speed of 1.25 seconds (10 frames). A step frequency of about 0.55 seconds can be considered "typical" for adult men (Norkin and Levangie, 1992), indicating that the step frequency was much slower in this study. This could have been caused by the fact that the subjects had to be careful about foot placement for each step and could have altered their speed accordingly. Another factor could have been due to the height of the walkway platform and the subjects' innate fear of falling.

The walking sequences can be clearly seen in Figures 10.3, 10.4, and 10.5. As in the static views, changes can be seen in the position of the navicular bone and the length between the calcaneus and head of the first metatarsal, indicating changes to the medial longitudinal arch. Additionally, one can see that these changes are greatest in the latter portion of the stance phase in the period just prior to heel lift, also referred to as the early terminal-stance phase. In Figures 10.3 and 10.4, this is seen in image 7, while in Figure 10.5, this is seen in image 8. This trend was also seen in the study by Wearing, et. al. (1998) who found that the calcaneal-first metatarsal angle increased during the midstance and early terminal-stance periods of gait. This suggests a lowering of the navicular bone combined with an elongation of the medial longitudinal arch throughout the midstance and early terminal stance phases of the walking gait cycle. In his study, Perlman, et. al., (1996), proposed that this may represent the pathological gait of the "late pronator". However, since the current study utilized healthy, non-symptomatic subjects, it can be concluded that this can be considered normal motion of the arch during dynamic conditions.

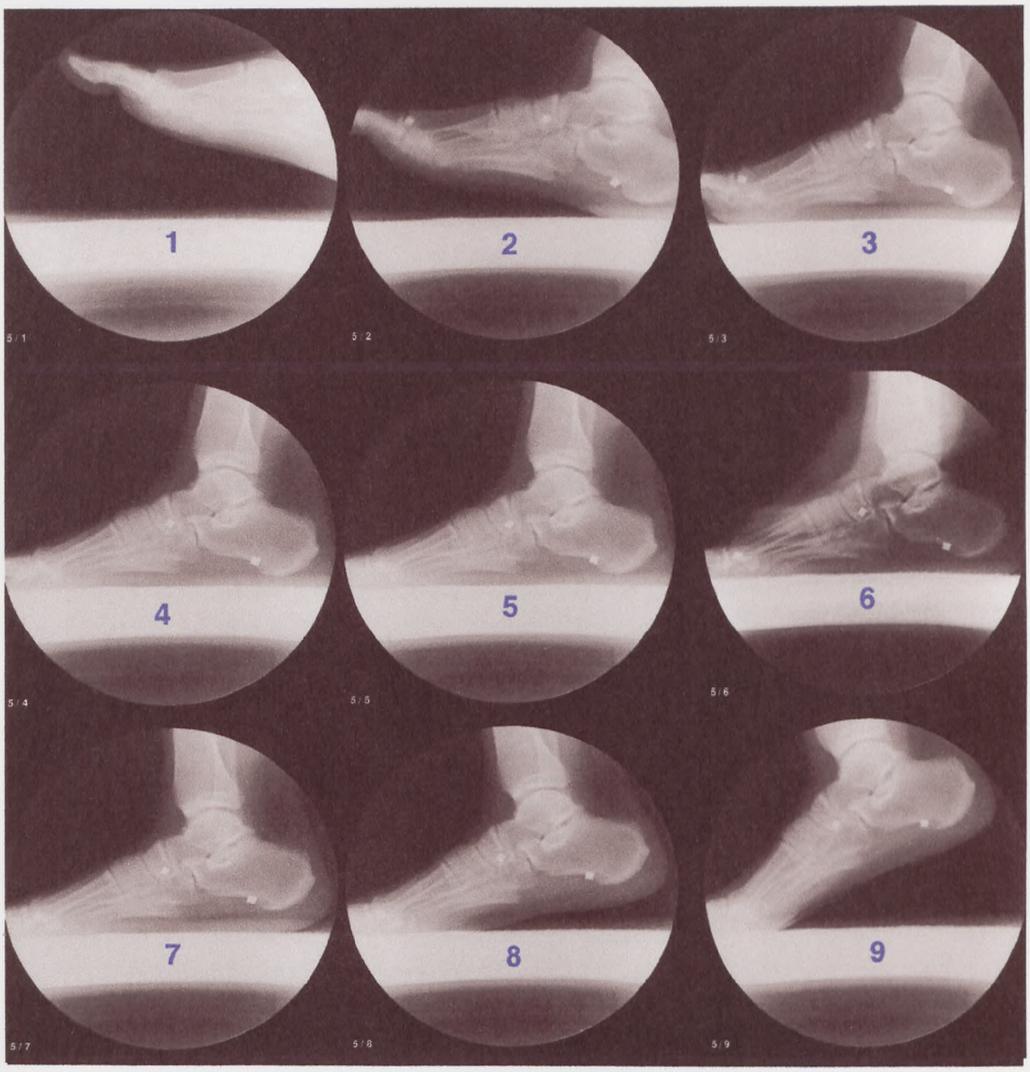


Figure 10.3 Barefoot Walking Sequence

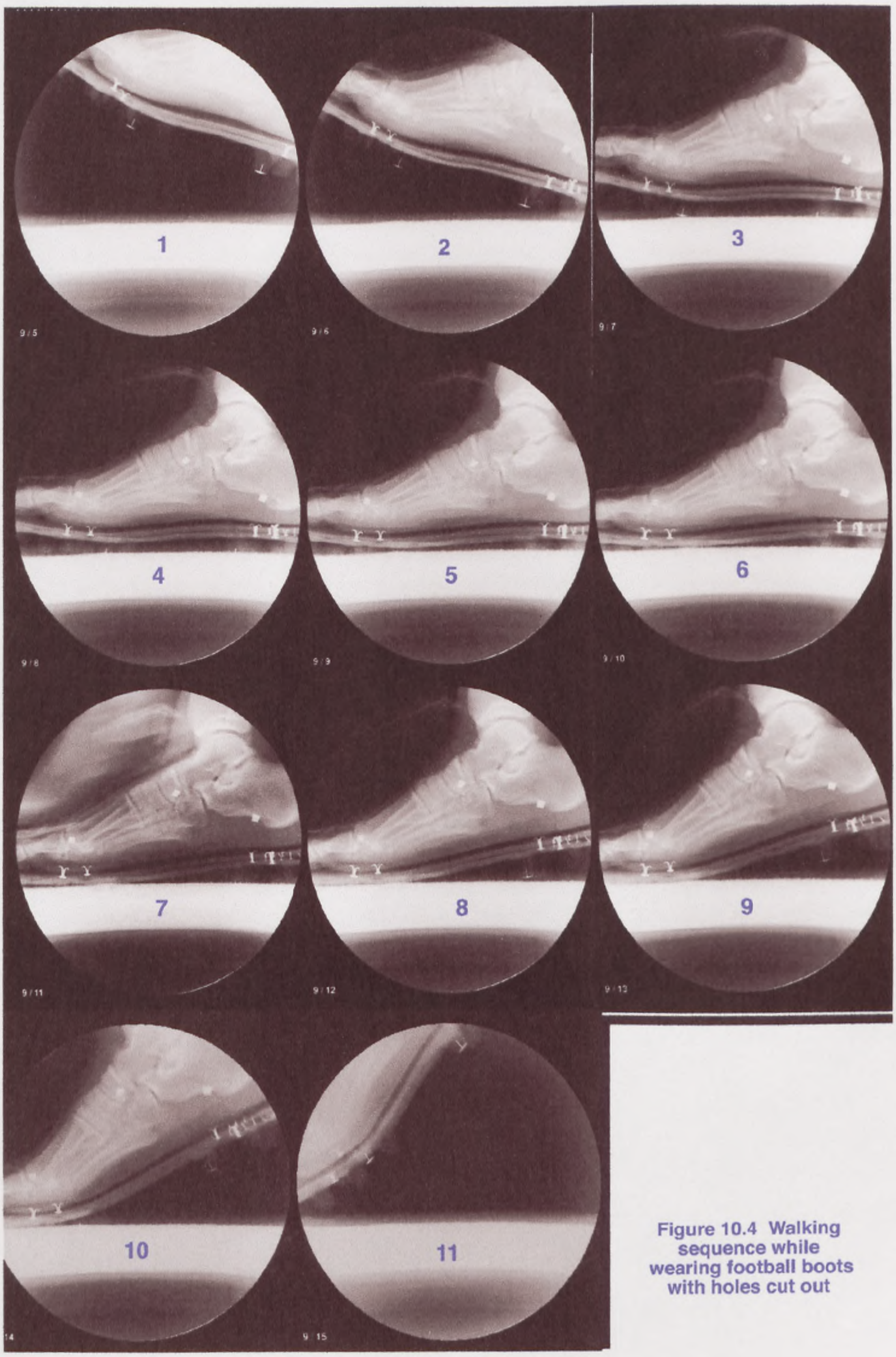


Figure 10.4 Walking sequence while wearing football boots with holes cut out

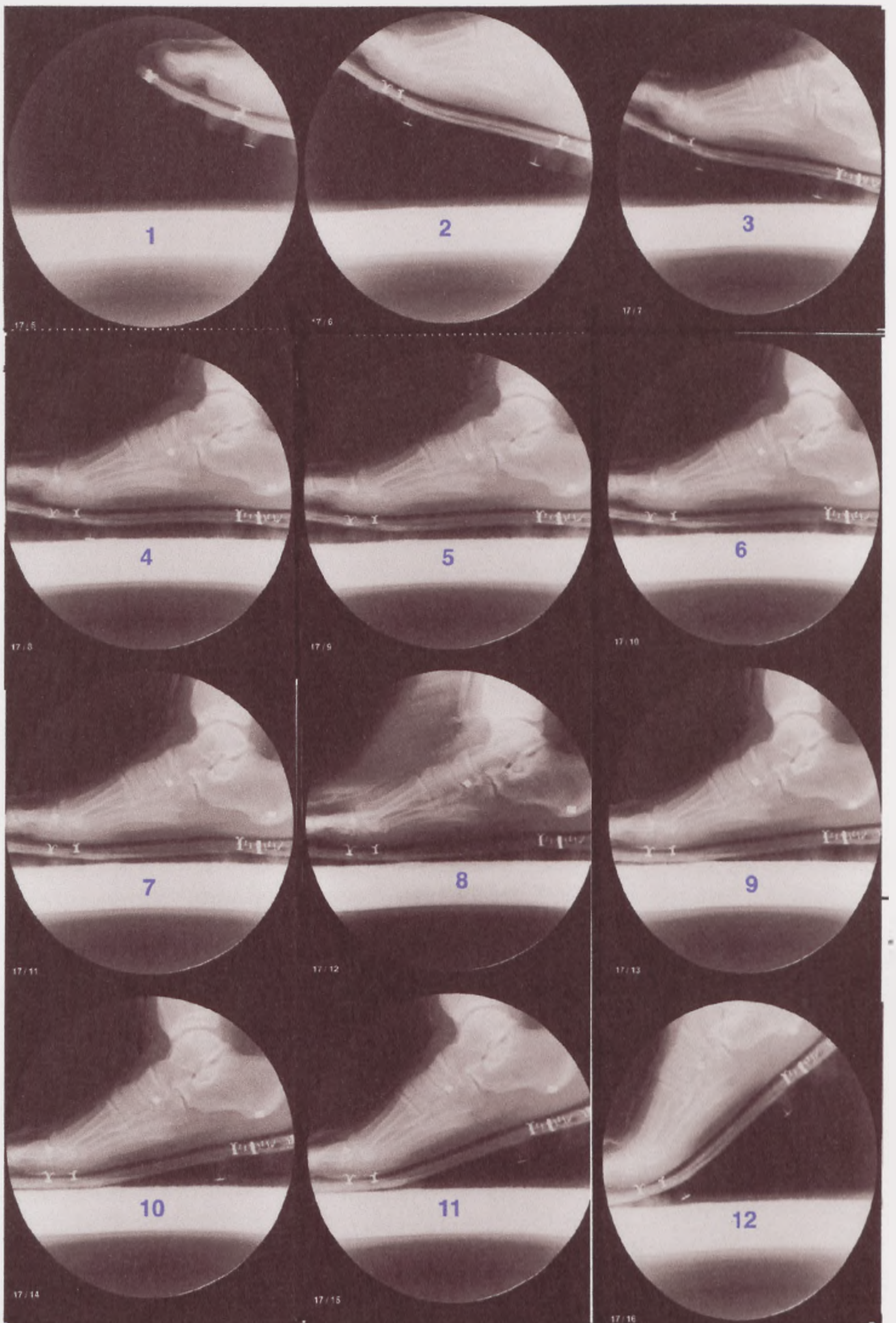


Figure 10.5 Walking sequence while wearing intact football boots

Dynamic navicular drop was determined to be statistically different between the barefoot and both shod conditions, with the navicular drop being less for the shod conditions. This was also seen in chapter 8 when looking at the effects of footwear on dynamic navicular drop. Encouragingly, no statistical differences were seen between the football boots with the holes cut out and the intact football boots. This is an important finding due to the fact that there were statistical differences between anatomical landmarks and markers placed on the exterior of the shoe, suggesting that while the foot moved within the shoe, there was limited movement of the exterior of the shoe itself. Based upon these results, one can conclude that the structural integrity of the shoe is not dramatically altered when the holes are cut out to allow for viewing of markers placed over anatomical landmarks as required for kinematic data collection.

Recently, there has been great debate over the validity of motion recording techniques such as videography and cinematography in assessing kinematic parameters of the lower extremities due to the use of skin-mounted markers as estimates of the location of anatomical landmarks (Maslen and Ackland, 1994; Reinschmidt, et. al., 1992). The results of this study found no statistical differences between the true anatomical landmarks and the markers placed on the skin prior to imaging. Sell, et. al., (1994) and Picciano, et. al., (1993) both addressed the reliability for assessing measurement techniques of the foot. In both of these studies, it was found that testers who are trained in measurement techniques and have extensive experience in palpating and identifying anatomical landmarks are more likely to have consistent and reliable results when compared to non-trained testers. While there were problems with marker placement and reliability in the studies of Maslen and Ackland (1994) and Reinschmidt, et. al. (1992), the results of the current study could be due to the fact that the primary investigator for this study has been trained in identifying anatomical landmarks and anomalies through palpation of the skin.

Since no statistical differences were found between the anatomical landmark and marker locations, additional analysis was carried out to see how the navicular drop results of this study compared to those obtained for the subjects when they participated in the footwear study in chapter 8. Again, no statistical differences were found between the two sets of results. Based upon this information, it can be concluded that the ProReflex® method utilized in the previous chapters can be an accurate, non-invasive method for assessing dynamic navicular drop in healthy individuals.

While the fluoroscopy method offered a great deal of valuable information, some additional problems not previously addressed were encountered during the data collection process. For example, when looking at the individual subject results for the barefoot and the modified football boot conditions from fluoroscopy (Table 10.4) a great deal of variation was seen, as noted by the large standard deviations reported. It is felt that a greater number of trials are needed to get a more accurate picture of foot function. However, many of these variations could be due to the manual digitization process required to get the coordinates for the mathematical calculations. Therefore, for future research, it is recommended that each sequence be digitized more than once. However, since the fluoroscope data were collected at a rate of 8 frames per seconds and the video data were collected at a rate of 25 frames per second, each fluoroscope image was captured in approximately 4 video frames and each video frame was digitized. This did allow for some smoothing of the coordinates.

10.8 CONCLUSIONS

This study provided valuable anatomical information and verified existing kinematic studies regarding dynamic foot function. While the fluoroscopy technique used in this study might be valuable for biomechanical analysis, it may also provide an alternative diagnostic tool for physicians looking at the skeletal structure and function of rheumatoid arthritis and diabetic populations. Further research looking at these diverse populations would be warranted.

The current investigation found no differences between the anatomical landmarks and the markers placed on the skin. Further, it was found that the structural integrity of the shoe was not dramatically altered when holes are cut out. Based upon this information, it can be concluded that the ProReflex® method utilized in the previous chapters can be an accurate, non-invasive, laboratory-based method for assessing dynamic navicular drop in healthy individuals.

Fluoroscopic x-ray is a viable method for providing an actual, real-time view of the skeletal structures of the foot during dynamic gait. The results of this study, as those reported in the previous chapters within this document, indicate that maximum navicular drop occurs at the latter portion of the stance phase, just prior to heel lift. Since this study was conducted with a healthy population, it can be concluded that this is a normal function of the foot during gait.

Chapter 11

Discussion

11.1 Defining the Problem

Lower extremity injuries appear to be a problem in the sport of football (Ekstrand and Gillquist, 1983a, 1983b; Ekstrand, et. al., 1983; Engstrom, et. al., 1990, 1991; Nielsen and Yde, 1989; Schmidt-Olsen, et. al., 1991). The injury questionnaire study revealed that nearly 92% of college and university football players sustained a lower-extremity injury during a single football season. Nearly 73% of these injuries were classified as acute injuries, while the remaining 27% were considered chronic. Of these chronic injuries, nearly 86% were caused by repetitive-stress or overuse mechanisms. While not necessarily as serious as the acute injuries, overuse injuries are still a considerable problem in the sport of football in that some degree of pain and discomfort is involved which can and will impair performance.

The game of football requires a great deal of running, jogging, and sprinting, (Withers, et. al., 1982) and the injury questionnaire revealed that there are many similarities in the types of overuse injuries seen among runners and football players. However, the distribution of these injuries differs between the two. In running, nearly 40% of all overuse injuries involve the knee and surrounding structures, with the shin and lower leg involved in about 25% of the injuries (Clement, et. al., 1981). The results of the injury study revealed that 57% of the overuse injuries seen among football players affected the shin and lower leg, with 24% of the injuries affecting the knee and surrounding structures, and the remaining 19% of the injuries affecting the foot and ankle.

It is generally accepted that because football is a contact sport, injuries are bound to occur. However, according to the injury questionnaire study, nearly one-fourth of these injuries are overuse in nature. The causes for overuse injuries has been attributed to many factors: equipment (including footwear), playing surfaces, over-training, lack of conditioning, training methods, and individual anatomical anomalies (Ekstrand, et. al., 1983a, 1983b; Ekstrand and Gillquist, 1983a, 1983b; Ekstrand and Nigg, 1989; Inklaar, 1994; McMaster and Maarten, 1978; Nielsen and Yde, 1989). While many of these factors can be addressed through proper maintenance of facilities, or though education of coaches and athletes (conditioning, over-training, and training methods), the intrinsic anatomical deficiencies and footwear were identified as areas that needed further investigation.

Since intrinsic anomalies are as varied as the individuals involved, it was felt that rather than addressing individual anatomical problems, that the issue of footwear should be investigated in further detail. In contrast to other sport shoes on the market, the current approach in football boot design is still the "one type is appropriate for all" and athlete-specific boots are not currently available for individuals with various foot anomalies such as pes cavus and pes planus conditions. Current football boot design might also increase the risk for development of overuse injuries in the "normal" populations as well.

11.2 Methodological Aspects

Once it became apparent that overuse injuries to the lower-extremities appeared to be a significant problem, and footwear was identified as one of the key contributors to this problem, a technique needed to be developed to assess foot function in a normal foot and then to see if the same analysis could be carried out while the subjects were either wearing football boots or while the subjects underwent a similar loading pattern without necessarily wearing shoes.

11.2.1 Static Measurements

Initially, static measurements were obtained through the use of footprint collection and navicular drop measurements under two different loading conditions. The data were collected in a normal barefoot condition while the subject was non-weight-bearing and weight-bearing. The procedure was repeated except the subjects' heel and forefoot were elevated to a height of a standard stud of a football boot.

Although the footprint collection has been utilized frequently for predicting arch height, and therefore foot function, (Cavanagh, 1985, 1987; Cavanagh and Rodgers, 1987; Clarke, 1933; Clarke, 1980; Freychat, 1996; Henning, 1984; Irwin, 1937; Jung, 1982), the footprint results found in this study were considered inconclusive due to the inability to differentiate between soft tissue deformation and changes in underlying skeletal structure.

Navicular drop was selected as a criterion for measurement because the height of the arch is believed to be functionally significant for the mechanics of the foot (Brody, 1982; Donatelli, et. al., 1999; McPoil, et. al., 1996; Mueller, et. al., 1993; Nachbauer, et. al., 1992; Picciano, et. al., 1993). The Brody method (1982) was used for this measurement because of its accepted use in the clinical setting as a static measurement used to predict dynamic foot function. It has also been used for assessing subtalar joint position (Sell, et. al, 1994), and as a method for classifying foot type (Hawes, et. al., 1992). While no differences were found between the unloaded barefoot condition and that while the forefoot and heel were elevated, it was still felt that it could be a valuable measurement tool.

11.2.2 Dynamic Measurements

Due to the fact that no differences in navicular drop were seen under static loading conditions, a dynamic method of testing was developed utilizing a single-camera ProReflex® motion analysis system. This system was used to measure navicular drop during dynamic motion, which in the case of this study, was the first step of a walking gait. This procedure had the added benefit of being able to collect dynamic data while wearing various types of modified footwear.

Through the use of multi-day, multiple trial repeatability testing, it was determined that the ProReflex® method for collecting 2-dimensional data was a simple option for dynamic foot evaluation and that repeatable, consistent linear measurements were obtained under various loading conditions. Further testing utilizing this method revealed that while statistical differences were found between walking and running conditions, there was a statistically significant relationship between the two conditions. Based upon these results and the fact that the fluoroscope x-ray equipment used for additional verification research for this thesis would only accommodate a walking gait, it was decided that the walking gait would be used for all analysis.

Subsequent x-ray fluoroscopic evaluation of the walking gait during various loading conditions revealed that there were no statistical differences between the navicular drop measurements of those shoes that had holes cut out and the intact shoes of identical make, model, and size. It was therefore concluded that cutting holes in the shoes to allow for viewing of the markers, which was required with the ProReflex® method, did not affect the integrity of the shoe and that the results were not affected. The fluoroscope study also revealed no statistical differences between markers placed on the skin and the underlying anatomical landmarks. Since the ProReflex® method relied on external marker placement, the fluoroscope results indicated that skin movement was not a limiting factor which would have adversely affected the results obtained through ProReflex® testing.

Once analysis had been carried out and data collected for dynamic navicular drop measurements, it was felt that because there has been an implied relationship between static navicular drop and subtalar joint motion that further analysis was needed to determine if this was true in the case of dynamic motion. Again, the ProReflex® motion analysis system was used. This time, an additional camera was set up to obtain 2-dimensional data for the subtalar joint while at the same time, data were collected for navicular drop.

11.3 Discussion

As previously mentioned, static navicular drop measurements are widely accepted for use in the clinical setting to predict dynamic foot function. The results of the studies within this thesis have revealed that this may not necessarily be the case. In the studies of chapters, 6, 7, and 8, statistical differences were found between static and dynamic navicular drop measurements. It might be expected that the static measurements would be greater than the dynamic measurements because the static measure was taken relative to the floor and the dynamic measure was taken relative to a line connecting the calcaneus to the joint line of the first metatarsal head. However, both methods isolate the navicular bone and provide a measurement of its movement regardless of the initial reference point. The only real difference between the two measurements is that the dynamic method eliminates the effect of the fat pad and soft tissue compression on the sole of the foot (Ker, et., al., 1987, 1989). While the studies of chapters 6, 7, and 8 all revealed statistical differences, the correlational analysis of chapters 6 and 7 differed from those of chapter 8. The results of chapters 6 and 7 both revealed that there was not a statistically significant correlation between static and dynamic navicular drop, suggesting that dynamic foot function cannot be predicted from static navicular drop measurements. Conversely, the results of chapter 8 found that there was a statistically significant correlation between static and dynamic navicular drop measurements. This study utilized a greater number of subjects and therefore, the results could be considered to have a greater value than those of the other two studies. Based upon this information, it could be concluded that the foot may function similarly between static and dynamic loading conditions. However, further analysis of the dynamic navicular drop information revealed that there were many other things occurring during dynamic activity and that these motions cannot be explained by a simple static measurement. Hamill, et. al.(1989) concluded that "measures of a static lower extremity evaluation were generally ineffective in accounting for observed variability in the dynamic variables describing gait."

An advantage to using the ProReflex® motion analysis system for assessing dynamic navicular drop is that the timing of the movement can be easily tracked and specific motions can be identified in relation to the entire movement. Figure 9.3 demonstrates the changes in navicular height throughout the walking gait, from the period just prior to heel-strike all the way through to toe-off. For that particular subject, maximum navicular drop occurred about 0.48 seconds after heel strike. In all of the subjects, maximum navicular drop occurred late in the stance phase or during terminal stance, rather than during the middle of the midstance phase as would have been expected. Brody's navicular drop measurements are taken at the equivalent of the middle of midstance and the weight is on both feet, rather than a single foot, as seen during gait. This casts doubt on the use of static measurements to predict dynamic foot function. The maximum navicular drop was followed by a quick recovery period in which the transverse tarsal joint is supposed to become fully locked and the foot becomes a rigid structure to allow for propulsion of the body.

When looking at the effects of footwear on the navicular drop timing curve, some differences were seen (Figure 8.2). The graph indicates that the navicular drop curves were similar for the barefoot and sports trainer conditions, but the sports trainer condition exhibited a shorter recovery period. The navicular drop curves for the football boots and turf trainers were also similar, but the maximum values were less than those seen in the other two conditions. Again, the shorter recovery time was seen with the football boots and turf trainers. Also, the maximum navicular drop that was reached in these two conditions, while less than the other conditions, seemed to exhibit a "plateauing" effect, staying at or near maximum values for a longer period of time. The curves demonstrate that shoes do seem to impair foot function, particularly during the recovery period. It could be concluded from these results that, due to the shortened recovery period seen while wearing footwear, the foot does not recover fully, that is, the calcaneo-cuboid and talo-navicular joint axes are still partially parallel and the midtarsal joint is still partially flexible, and therefore does not become a fully rigid structure for propulsion. Because of this, the soft tissues of the foot and lower leg must compensate in order for propulsion to occur. This could lead to injury of the lower extremity. It could also be argued that the lower navicular drop measurements seen with the turf trainers and football boots could be a result of the calcaneo-cuboid and talo-navicular joint axes not becoming fully parallel and unlocking the midtarsal joint fully, thereby not allowing the foot to become a flexible and accommodating structure that can absorb impact forces and adapt to varying surfaces. This too, could lead to an increased injury risk to the lower extremities.

As noted in the above paragraph, differences in navicular drop were seen between conditions. These differences were seen in all of the footwear-related studies carried out for this thesis (Chapters 6, 8, 9, and 10). Due to the stud placement and limited midfoot support, it was expected to see the greatest navicular drop while wearing football boots. However, this was not the case. Even though all of the shod conditions resulted in a lower navicular drop than the barefoot condition, the only one that was statistically different from the barefoot condition was the football boot condition which exhibited the lowest navicular drop measurement of all conditions. This was surprising because existing research has found that there is greater pronation while wearing shoes than while barefoot (Bates, et. al., 1978; Cavanagh, et. al., 1984; Clarke, et. al., 1984; Stacoff, et. al., 1988). The lower navicular drop values obtained for the footwear conditions of this study could be explained by Robbins and Hanna (1987) who describe the foot of the normally shod individual as "rigid" in which the main arches of the foot are unable to yield on normal loading. Further, the higher value obtained for the barefoot condition could be explained by Rasch and Burke (1978) who observed that during locomotion in barefoot subjects, the medial longitudinal arch changes from highly arched during the swing phase to completely flat during the stance phase.

The majority of existing studies looking at footwear effects on pronation have been conducted looking at rearfoot motion at the subtalar joint (Bates, et. al., 1978; Cavanagh, et. al., 1984; Clarke, et. al., 1984; Stacoff, et. al., 1988). There has also been many studies which have positively related static navicular drop to pronation of the subtalar joint (Cavanagh, et. al., 1997; Cobey, et. al., 1981; Duckworth, et. al., 1985; McPoil, et. al., 1996; Mueller, et. al., 1993; Picciano, et. al., 1993). Controversy remains about the effectiveness of static measurements in predicting dynamic foot function (Hamill, et. al., 1989). Therefore, it was felt that dynamic subtalar joint motion should also be assessed in relationship to navicular drop and footwear.

The results of the study indicated that there was not a relationship between the amount of subtalar pronation or initial pronation velocity and navicular drop measurements. It could be concluded from these results that there is no relationship between dynamic subtalar joint motion and navicular drop. While this might be the case, because both structures are pronating to some extent, the overall picture of foot movement is not quite so simple.

Again, since the ProReflex® was used to obtain data, the movement was tracked and individual motion segments were identified (Figure 11.1). The timing of the subtalar movements was consistent between footwear conditions and no differences were found. This lead to the conclusion that the time from heel-strike to heel-off remains similar whether the individual is barefoot or wearing footwear.

Figure 11.1 Navicular Height Timing Curve Compared to Subtalar Joint Timing Curve

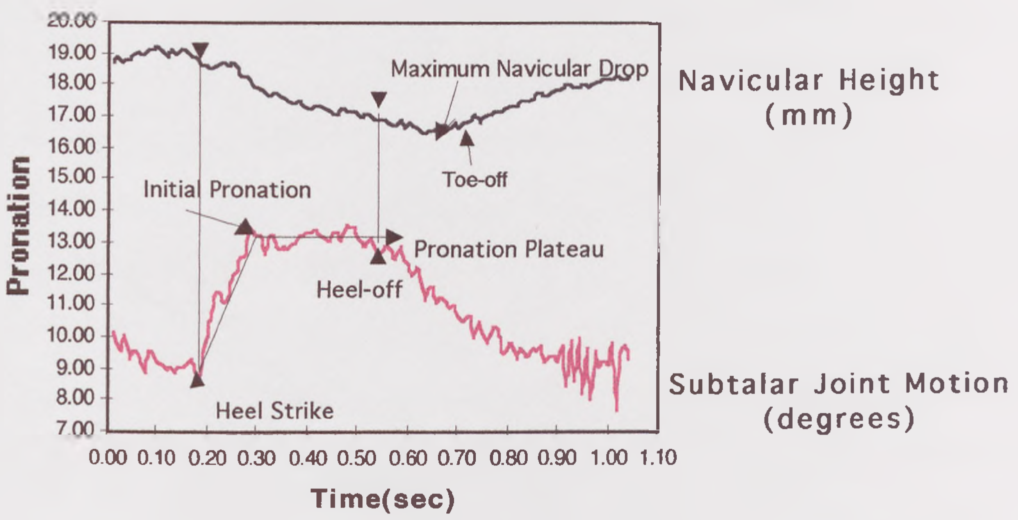


Figure 11.1 also shows that maximum navicular drop occurred after heel-off, but prior to toe-off. This was seen in all of the conditions, indicating that there is a possibility of the midfoot acting independently of rearfoot motion. One cannot deny that there is a certain degree of pronation occurring simultaneously at both the subtalar joint and at the navicular bone. However, the curve indicates that the rearfoot is starting to supinate while the midfoot is still pronating. It is possible that there is a "chain-reaction" of movements with pronation beginning at the subtalar joint, continuing on to the midfoot, and then on to the forefoot. Manter, (1941), compared the action of the talus as a "screw-like" motion which causes the head of the talus to be carried forward into pronation, thereby pushing the navicular bone into pronation. Nigg and Segesser (1991) illustrate the relative

movements of the forefoot with respect to the rearfoot (Figure 11.2) explaining that this twisting motion, or torsion, occurs primarily at the midtarsal joint. These observations could be applied to the results seen in this study.

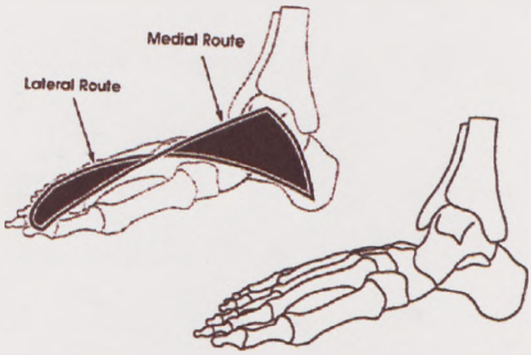


Figure 11.2. Relative movement of the forefoot with respect to the rearfoot (Nigg and Segesser, (1991).

Fluoroscopic x-ray evaluation offered information regarding the skeletal structure of the foot during dynamic walking gait. The images obtained, although captured at a much slower rate than that of the ProReflex® studies (8 frames vs. 120 frames per second), still allowed viewing of the foot throughout the stance phase of gait. Figures 10.3, 10.4, 10.5 demonstrates a typical sagittal view of the stance phase of walking gait for a single subject. As can be seen, changes in navicular bone position occur throughout the movement. Specifically, the navicular bone rotates downward, reaching its maximum drop level at terminal stance, while at the same time the distance between the calcaneus and head of the first metatarsal increases, indicating that the shape of the medial longitudinal arch changes throughout the stance phase of gait.

11.4 Conclusions and Summary

Section 1.2.1 of Chapter 1 listed the specific aims of this thesis. While each of these aims was addressed in detail in the previous sections, a summary of these aims and their results follows:

1. *To review the current literature and provide an overview of types and causes of lower-extremity overuse injuries.*

A review of literature revealed that overuse injuries account for one-fourth to one-third of the injuries that occur in football. The causes for overuse injuries has been attributed to equipment (including footwear), playing surfaces, over-training, lack of conditioning, training methods, and individual anatomical anomalies. Overuse injuries to the lower extremities generally involve the shin and lower leg region.

2. *To determine the frequency and type of lower-extremity overuse injuries associated with university football players and determine if gender differences exist.*

In the injury questionnaire study, nearly 92% of college and university football players sustained a lower-extremity injury during a single football season. Seventy three percent of these injuries were classified as acute injuries, while the remaining 27% were considered chronic. Of these chronic injuries, nearly 86% were caused by repetitive-stress or overuse mechanisms. Fifty seven percent of the overuse injuries affected the shin and lower leg, with 24% of the injuries affecting the knee and surrounding structures, and the remaining 19% of the injuries affecting the foot and ankle. No gender differences were seen when comparing athletes who practiced an average of 9 to 15 hours per week.

3. *To review the current literature and provide an overview of foot anatomical structure, the general mechanics of gait, and the specific foot mechanics occurring during gait.*

A review of literature revealed that when contact is made with the ground in walking, the foot must be flexible as it adapts to the contact surface, semi-rigid as it absorbs and transmits the force of impact, and rigid as it propels the body forward. Pronation and supination movements in the foot are important in determining the extent to which the foot will behave as a flexible or rigid body.

At heel strike, the foot is slightly supinated. After contact is made with the supporting surface, the foot is forced into pronation, where the primary activity is at the subtalar joint. As pronation takes place, the calcaneo-cuboid and talo-navicular joint axis become parallel, unlocking the midtarsal joint and creating flexibility in the forefoot. These actions allow the foot to become a flexible and accommodating structure that can absorb impact forces and adapt to varying surfaces.

As the body moves over the foot into the midstance position, supination is initiated in the foot. The calcaneus inverts and pushes the talus into dorsiflexion and abduction. At the midtarsal joint, the calcaneo-cuboid and the talo-navicular joint axes are forced into a nonparallel relationship to each other, locking the transverse tarsal joint and creating rigidity in the forefoot.

4. To analyze static navicular drop in weight-bearing and non-weight-bearing subtalar-neutral positions under various loading conditions.

Initially, static measurements were obtained through the use of footprint collection and navicular drop measurements under two different loading conditions. The footprint results found in Chapter 5 were considered inconclusive due to the inability to differentiate between soft tissue deformation and changes in underlying skeletal structure. No differences were found in navicular drop measurements between the regular barefoot loading condition and that while the forefoot and heel were elevated.

5. To develop a repeatable method to analyze dynamic navicular drop during gait.

The Pro-Reflex® motion analysis system was used to study motion of the navicular bone and subtalar joint during the first step of a walking gait. A repeatability study and subsequent fluoroscopic verification revealed that this methodology was a simple option for dynamic foot evaluation, and that repeatable, consistent linear measurements were obtained for dynamic navicular drop during various loading conditions.

6. To determine if there is a relationship between static and dynamic navicular drop measurements.

The results of the studies within this thesis cast doubt upon the use of static foot measurements to predict dynamic foot function. While a statistically significant correlation was found between static and dynamic barefoot navicular drop when using a larger sample size, the timing of the movements indicated that there were additional factors that must be considered when looking at dynamic foot function.

7. To determine if foot function differs between walking and running gait.

There were statistical differences in navicular drop between running and walking conditions, however there was also a statistically significant correlation between the two, indicating that the midfoot may function similarly during the stance/support phase of both walking and running. The speed and timing of the movement occurred much faster during a running gait.

8. To determine the effects of various type of footwear on dynamic navicular drop.

The greatest dynamic navicular drop was seen in the barefoot condition, and the least amount of deformation was seen while wearing football boots. As shown on the footwear navicular drop curve (Figure 11.2), a shorter recovery period was seen in all of the shod conditions. Footwear appeared to change the function of the foot by not allowing a full recovery, possibly through limited midfoot resupination, prior to toe-off. The lower navicular drop measurements that occurred while wearing football boots and turf trainers lasted for a longer period of time, with a "plateau" that started approximately in the middle of midstance and went through the terminal stance period. It might be possible that the calcaneo-cuboid and talo-navicular joint axes are not unlocking the midtarsal joint fully, thereby not allowing the foot to become a flexible structure that can absorb impact forces.

9. To determine the timing of various foot segmental movements during gait.

The results of the studies within this thesis demonstrate that maximum navicular drop occurred during the terminal stance period of the stance phase, regardless of foot loading condition. From the comparison of the motion curves of the navicular drop and subtalar joint it appeared that the timing of foot motion is more important than the amount of linear or angular displacement. The maximum navicular drop occurred after heel-off, as the subtalar joint was starting to resupinate. The timing variations that were seen within the subtalar joint and midfoot could lead to dysfunction of other structures, specifically the soft tissues, which would have to compensate for the altered movement patterns. A weakness or abnormality could lead to a breakdown, which in turn, could lead to injury.

10. To determine if a relationship exists between navicular drop and subtalar joint pronation.

There were no statistical relationships between subtalar joint motion and navicular drop, however the motion curves of Figure 11.3 showed that a certain degree of pronation was occurring simultaneously. This lead to the conclusion that the midfoot acts somewhat independently of the rearfoot or that there is a chain-reaction of movements taking place which start in the rearfoot and continue through the midfoot and then on to the forefoot. Therefore, the relationship between displacement measurements may be negligible when determining the effect of the amount of pronation on the risk of injury.

11. To evaluate the skeletal movement of the midfoot during dynamic movement.

Fluoroscopic x-ray evaluation offered information regarding the skeletal structure of the foot during dynamic walking gait. The images obtained, allowed viewing of the foot throughout the stance phase of gait. Changes in navicular bone position occur throughout the movement with the navicular bone rotating downward, reaching its maximum drop level at terminal stance. The medial longitudinal arch is lengthening simultaneously with a change in distance between the calcaneus and the head of the first metatarsal.

11.5 Future Applications of the Research

With the increased interest in football worldwide, many athletes are suffering from overuse or repetitive stress injuries directly related to football participation. These athletes present themselves to the sports medicine professionals trying to find the underlying cause of their injuries. Armed with the information from this study, those sports medicine professionals might have a better understanding of the fundamental biomechanics and the problems associated with the current design of the football boot.

As stated above, it appears that the changes in timing of the segmental movements within the foot, as seen with footwear, may cause many of the problems associated with overuse injuries to the lower extremities. Additionally, footwear seems to restrict the normal movement of the foot, especially at the midtarsal joint. One recommendation for future footwear design is to address the construction of the shoe sole at the anatomical region of the transverse tarsal joint in such a way that the torsional movement would not be restricted by the shoe. Ideally, this could be accomplished by constructing the rearfoot, midfoot, and forefoot independently of each other to allow for torsional movements. However, this method is not feasible in a mass-marketing society and could only be done on an individual basis with custom-made shoes. A more realistic suggestion might be to introduce a shoe "break" similar to that found in the metatarsal region of the forefoot at the midtarsal joint. Yet another practical suggestion might be to introduce a longitudinal "S" shaped break along the length of the sole of the shoe to accommodate the chain-reaction of the foot structures.

It has been well-established that there are fewer overuse injuries among barefoot runners (Luethi, et. al., 1987; Robbins, et. al., 1987, 1990; Stacoff, et. al., 1989, 1990). From this information it could be concluded that footwear restricts normal motion, or changes normal mechanics to such an extent that breakdown of the structures occur, which leads to the development of overuse injuries. Ideally, future athletic footwear should be designed to allow the foot to function like a bare, unshod foot, while at the same time protect it from excessive trauma caused by man-made surfaces and temperature extremes. Football boots need the added protection from trauma caused by contact with the ball, and yet, must not interfere with overall performance.

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APPENDIX A

ANATOMICAL TERMINOLOGY

A great variation in terminology in regards to body position, joint motion, and movements currently exists in the field of biomechanics and medicine, leading to confusion between the disciplines. Therefore, in order to allow for a greater understanding, the following definitions and terms will be used in the context of this thesis. All positional terms are in reference to the universally accepted anatomical position, in which a person stands, looking forward, with the palms of the hands facing forward. In this position, joints are often referred to as being in a neutral position.

Glossary of Positional Terms

Anterior - toward the front or in front.

Deep - away from the body surface or skin

Distal - away from the trunk or root of the limb

Inferior - below

Lateral - away from the midline

Medial - towards the midline

Posterior - toward the rear or behind

Proximal - close to the trunk or root of the limb

Superficial - close to the surface of the body or skin

Superior - above

DESCRIPTION OF MOTION

Types of Motion

Rotary (angular) motion - movement of a segment around a fixed axis in a curved path. While not necessarily accurate, most joint motions are commonly described as if they were pure rotary movements.

Translatory (linear) motion - movement of a segment in a straight line. *Gliding* is a type of translatory motion in which one flat joint surface translates along another flat joint surface.

Curvilinear motion - a combination of rotary and translatory motions which results in rotation of a rigid object through space. Contrary to popular belief, it is the most common form of motion produced at the joints since all joint axis shift slightly during movement.

General plane motion - a special case of curvilinear motion. Occurs when an object rotates about an axis while the axis is translated in space by motion of an adjacent segment.

Location of Motion/Planes of the body

Rarely do movements of one body segment with respect to another take place in a single plane. Motion in any one of these planes means that a body segment is being rotated about its axis or translated in such a way that the segment is moving through a path that is parallel to one of the three cardinal planes. This system provides a simple way of describing movement at a given joint.

Transverse (horizontal) plane - an imaginary line dividing the body into upper and lower halves. Movements in this plane occur parallel to the ground. Rotary motions in this plane occur around a vertical or longitudinal axis of motion. In three dimension, it corresponds to the x-coordinate.

Coronal (frontal) plane - an imaginary line dividing the body into front and back halves. Movements in this plane occur in side-to-side motion. Rotary motion in this plane occurs around an anterior-posterior (A-P) axis. In three dimension, it corresponds to the y-coordinate.

Sagittal (median) plane - an imaginary line dividing the body into right and left halves. Movements in this plane occur in forward and backward motions. Rotary motion in this plane occur around the coronal axis. In three-dimension, it corresponds to the z-coordinate.

Direction of Movement

Flexion - the bending of adjacent body segments in the sagittal plane so that their two anterior/posterior surfaces are brought together.

Extension - the moving apart or straightening of two opposing surfaces in a sagittal plane. Also refers to movement beyond the neutral position in the direction opposite of flexion.

Plantar Flexion - moving the dorsal surface of the foot away from the anterior surface of the leg, i.e., pointing the toe downwards.

Dorsiflexion - bringing the dorsum of the foot towards the front of the leg.

Abduction - the movement of a body segment in a coronal plane that it moves away from the midline of the body. In the toes, movement occurs in relation to the midline of the third digit.

Adduction - the movement of a body segment in a coronal plane such that it moves towards the midline of the body. In the toes, movement occurs in relation to the midline of the third digit.

Internal (medial) rotation - rotation of a limb segment about its longitudinal axis toward the midline of the body.

External (lateral) rotation - rotation of a limb segment about its longitudinal axis away from the midline of the body.

Supination - movement of the foot where the sole of the forefoot faces medially, it is always accompanied by adduction of the forefoot.

Pronation - movement of the foot which causes the sole of the forefoot to face laterally, is always accompanied by abduction of the forefoot.

Inversion - a combination of supination and adduction of the forefoot and plantar flexion of the ankle joint resulting in movement of the whole foot to bring the sole to face medially.

Eversion - a combination of pronation and abduction of the forefoot in conjunction with dorsiflexion of the ankle joint resulting in movement of the whole foot so that the sole comes to face laterally.

APPENDIX B--INJURY QUESTIONNAIRE

GENERAL BACKGROUND INFORMATION

Part I

Does your institution have a varsity soccer program?

Yes No

If no, you do not need to complete this questionnaire

If yes, is it: _______male _______female (check all that apply)

What is your institution's classification/division: (circle one)

NCAA-I NCAA-II NCAA-III NAIA-I NAIA-II

Part IIa

MALE:

Number of male varsity soccer athletes? _______________

(if you do not have a men's soccer program, skip to part IIb)

Percentage of time the following playing surfaces are used for practices and scrimmages: (check one for each category)

Natural turf (i.e. grass):

Never [ ] 1 - 25% [ ] 26 - 50% [ ] 51 - 75% [ ] 76 - 100% [ ]

Artificial turf:

Never [ ] 1 - 25% [ ] 26 - 50% [ ] 51 - 75% [ ] 76 - 100% [ ]

Indoor turf:

Never [ ] 1 - 25% [ ] 26 - 50% [ ] 51 - 75% [ ] 76 - 100% [ ]

Percentage of time the following playing surfaces are used for games: (check one for each category)

Natural turf (i.e. grass):

Never [ ] 1 - 25% [ ] 26 - 50% [ ] 51 - 75% [ ] 76 - 100% [ ]

Artificial turf:

Never [ ] 1 - 25% [ ] 26 - 50% [ ] 51 - 75% [ ] 76 - 100% [ ]

Indoor turf:

Never [ ] 1 - 25% [ ] 26 - 50% [ ] 51 - 75% [ ] 76 - 100% [ ]

Number of hours spent per week at practice: (check one)

1 - 3 [ ] 3 - 6 [ ] 6 - 9 [ ] 9 - 12 [ ] 12 - 15 [ ] 15+ [ ]

Number of scrimmages played during practice, per week: (check one)

0 [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 [ ] 6 [ ] >6 [ ]

Part IIa - Continued

Average number of games, played per week: (check one)

1 - 2 [ ] 3 - 4 [ ] 5 - 6 [ ] more than 6 [ ]

Length of season, in months: (check one)

1 - 2 [ ] 2 - 3 [ ] 3 - 4 [ ] 4 - 5 [ ] 5 - 6 [ ] 6+ [ ]

Part IIb

FEMALE:

Number of female varsity soccer athletes: ________________

(if you do not have a women's soccer program, skip to Part III)

Percentage of time the following playing surfaces are used for practices and scrimmages: (check one for each category)

Natural turf (i.e. grass):

Never [ ] 1 - 25% [ ] 26 - 50% [ ] 51 - 75% [ ] 76 - 100% [ ]

Artificial turf:

Never [ ] 1 - 25% [ ] 26 - 50% [ ] 51 - 75% [ ] 76 - 100% [ ]

Indoor turf:

Never [ ] 1 - 25% [ ] 26 - 50% [ ] 51 - 75% [ ] 76 - 100% [ ]

Percentage of time the following playing surfaces are used for games: (check one for each category)

Natural turf (i.e. grass):

Never [ ] 1 - 25% [ ] 26 - 50% [ ] 51 - 75% [ ] 76 - 100% [ ]

Artificial turf:

Never [ ] 1 - 25% [ ] 26 - 50% [ ] 51 - 75% [ ] 76 - 100% [ ]

Indoor turf:

Never [ ] 1 - 25% [ ] 26 - 50% [ ] 51 - 75% [ ] 76 - 100% [ ]

Number of hours spent per week at practice: (check one)

1 - 3 [ ] 3 - 6 [ ] 6 - 9 [ ] 9 - 12 [ ] 12 - 15 [ ] 15+ [ ]

Number of scrimmages played during practice, per week: (check one)

0 [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5 [ ] 6 [ ] >6 [ ]

Average number of games played per week: (check one)

1 - 2 [ ] 3 - 4 [ ] 5 - 6 [ ] >6 [ ]

Length of season, in months: (check one)

1 - 2 [ ] 2 - 3 [ ] 3 - 4 [ ] 4 - 5 [ ] 5 - 6 [ ] 6+ [ ]

Part III

INJURY HISTORY
(please limit your responses to the soccer teams only)

How many lower-extremity acute injuries did you see during the 1997 soccer season?

____________________male ____________________female

How many lower-extremity chronic injuries did you see during the 1997 soccer season?

____________________male ____________________female

Of these chronic injuries, how many were a result of repetitive-stress or overuse?

____________________male ____________________female

Please list below, the number of the lower extremity, chronic, repetitive-stress/overuse injuries seen in your soccer athletes during the 1997 season:

	male	female
Achilles Tendinitis	__________	__________
Compartment Syndrome	__________	__________
Extensor tendon inflammation	__________	__________
Flexor tendon inflammation	__________	__________
Illio-Tibial band Syndrome	__________	__________
Patellar Tendinitis	__________	__________
Peroneal Tendinitis	__________	__________
Plantar Fasciitis	__________	__________
Shin splints	__________	__________
Stress Fracture	__________	__________
Tibialis Anterior Tendinitis	__________	__________
Tibialis Posterior Tendinitis	__________	__________
Other:	__________	__________
If other, please list:		
	__________	__________
	__________	__________
	__________	__________
	__________	__________

-Thank you for your time in completing this questionnaire. Please return the completed form in the self-addressed stamped envelope by December 15, 1997-

Appendix C- Foot Evaluation Form

FOOT EVALUATION FORM

(Adapted from Hoppenfeld's *Physical Examination of the Spine and Extremities,* [1976])

* *

NAME____ SUBJECT NO.________

SEX_______ AGE_______ HEIGHT_________ WEIGHT________

STREET SHOE SIZE___________ TRAINER SHOE SIZE___________

ORTHOTICS/PRESCRIPTION INSERTS? NO YES

PREVIOUS FOOT INJURY? NO YES

If YES, please explain____

Date of Injury________________

Are you presently having any pain or symptoms? NO YES

If yes, exclude from study.

* *

FOOT EVALUATION

VISUAL INSPECTION

		NORMAL	ABNORMAL
Shoe - wear pattern		_____	_____
If abnormal, what is seen?			
Broken medial counter	_____		
Excessive wear	_____		
Oblique marks	_____		
Other			

____

BAREFOOT AND STANDING

		NORMAL	ABNORMAL
Gait		_____	_____
AROM			
Walk on toes		_____	_____
Walk on heels		_____	_____
Walk on lateral border		_____	_____
Walk on medial border		_____	_____
Toes		_____	_____
If abnormal, what is seen?			
Overlapping	_____		
Hallux valgus	_____		
Arches			
Metatarsal Arch		_____	_____
Transverse Tarsal Arch		_____	_____
Medial Longitudinal Arch		_____	_____
If abnormal, what is seen?			
Pes Planus	_____		
Pes Cavus	_____		

Position of Os Calcis

Normal (0° ± 5°) ______

Abnormal

Pronation >5° ______

Supination >5° ______

Position of Medial Prominence of Talar Head ______ ______

NON WEIGHT-BEARING, SITTING ON TABLE, LEGS EXTENDED AND SUPPORTED BY TABLETOP, TIBIA IN FIXED POSITION, FEET EXTENDED OVER EDGE OF TABLE

Calluses ______ ______

If abnormal, location?________________________________

Resting Position of Foot

Normal (few degrees of plantar flexion and inversion) ______

Abnormal (dorsiflexion and eversion) ______

AROM

Toes turned in ______ ______

Toes turned out ______ ______

Toes extended ______ ______

Toes flexed ______ ______

**** If subject is unable to perform any of the RANGE OF MOTION or GAIT tests pain-free, he/she should be excluded from the study.**

MARK THE NAVICULAR TUBERCLE _ _ _ _ _

MARK THE MEDIAL AND LATERAL FOOT AT THE LEVELS OF THE METARSAL HEADS AND _ _ _ _ _
THE TRANSVERSE TARSAL ARCH _ _ _ _ _

* *

APPENDIX D
Individual Subject Results From Chapter 6

Navicular drop measurements for individual subjects.

Subject	Static (mm)	Barefoot (mm)	Turf Trainers (mm)	Football Boots (mm)	Sports Trainers (mm)
1-day 1	11	4.59±0.36	5.75±0.57	5.44±0.26	5.51±0.38
1-day 2	11	4.76±0.48	5.27±0.65	5.63±0.81	5.41±0.64
1-day 3	12	4.39±0.46	5.04±0.37	5.05±0.48	4.68±0.32
1-day 4	12	4.48±0.31	5.25±0.43	5.18±0.76	5.00±0.38
mean ±SD	**11.5±0.58**	**4.55±0.42**	**5.33±0.56**	**5.33±0.64**	**5.36±0.49**
2-day 1	9	6.27±0.50	4.75±0.37	4.11±0.30	5.43±0.23
2-day 2	8	6.47±0.30	4.33±0.47	4.40±0.28	5.27±0.69
2-day 3	9	6.45±0.41	4.51±0.45	4.16±0.34	5.57±0.30
2-day 4	9	6.20±0.36	4.31±0.42	4.17±0.19	5.38±0.25
mean ±SD	**8.75±0.6**	**6.35±0.34**	**4.48±0.45**	**4.21±0.30**	**5.41±0.42**
3-day 1	11	9.60±0.60	7.51±0.40	6.42±0.27	8.67±0.45
3-day 2	11	9.39±0.51	7.30±0.38	6.19±0.42	8.68±0.78
3-day 3	10	9.60±0.35	7.24±0.22	6.17±0.21	8.72±0.30
3-day 4	9	9.43±0.57	7.35±0.38	6.52±0.61	8.32±0.34
mean ±SD	**10.25±0.96**	**9.50±0.51**	**7.35±0.35**	**6.33±0.42**	**8.60±0.51**
4-day 1	7	6.05±0.68	4.31±0.60	3.88±0.22	4.31±0.28
4-day 2	7	6.56±0.65	4.05±0.86	3.82±0.31	4.37±0.38
4-day 3	6	6.47±0.58	4.38±0.34	3.82±0.35	4.50±0.21
4-day 4	8	6.21±0.46	4.56±0.43	3.69±0.36	4.32±0.35
mean ±SD	**7.0±0.82**	**6.32±0.61**	**4.33±0.60**	**3.80±0.31**	**4.37±0.31**
Combined Means ±SD	**9.34±1.86**	**6.70±1.86**	**5.36±1.30**	**4.91±1.08**	**5.95±1.66**

Appendix E

SUBJECT INFORMATION SHEET and CONSENT FORM

MACREFLEX® ANALYSIS OF NAVICULAR DROP DURING DYNAMIC MOVEMENT

INVESTIGATORS:

Karla M. Bruntzel, MA, ATC; Postgraduate Student; Centre for Studies in Physical Education and Sports Science

Neil Messenger, PhD; Lecturer; Centre for Studies in Physical Education and Sports Science

AIM OF THE STUDY

The purpose of this project is to use the MacReflex® to evaluate navicular height and the height of the medial longitudinal arch while walking and to see if various types of footwear affect the skeletal movement and structure of the normal foot. In addition to increasing the body of knowledge in this area, this study is also designed to provide data to fulfill the requirements of a research degree for the principle investigator.

PROCEDURES

You will first need to complete a short injury history form and then undergo a foot/ankle physical evaluation, followed by visual gait analysis. Additionally, height and weight information will be obtained. From this evaluation, your foot type will be determined for future reference.

After the evaluation has been complete, reflective markers will be placed on your foot over the navicular tuberosity, calcaneus, and head of the first metatarsal. A static measurement of arch height will also be recorded at this time.

Once the static measurement has been obtained, the MacReflex® data will be collected. You will be instructed to walk in front of the camera on a platform that is slightly raised from the ground (approximately 10 cm). Five trials will be conducted in each of the shod conditions as follows:

5 trials barefoot
5 trials turf trainers
5 trials football boots
5 trials sports trainers

The shoes will have windows cut out over the three marker points so that data can be collected.

CONFIDENTIALITY

The data collected will become the property of the researchers involved and the Centre for Studies in Physical Education and Sports Science. All written data will be stored in compliance with the Data Protection Act and will be kept confidential. Additionally, no reference to the subject by name will appear in any documents, manuscripts or publications authored by the researchers.

QUESTIONS

The researchers will gladly answer any question(s) that you might have regarding any component of the project. Your participation is strictly voluntary, and at any time, you are free to withdraw your consent and discontinue participation in the project/activity without any prejudice.

If you should have any questions please contact:

Karla Bruntzel, MA, ATC
Centre for Studies in Physical Education and Sports Science
0113 233 5080
e-mail: phskmb@leeds.ac.uk

CONSENT FORM

PROREFLEX® ANALYSIS OF NAVICULAR DROP DURING DYNAMIC MOVEMENT

		Please delete as applicable
1.	I have read the Subject Information Sheet.	Yes/No
2.	I have had the opportunity to ask questions and discuss the research study.	Yes/No
3.	I am satisfied with the answers to my questions.	Yes/No
4.	I have received enough information about this study.	Yes/No
5.	I have spoken to Ms. Karla Bruntzel.	Yes/No
6.	I understand that I am free to withdraw from the study at any time without giving a reason and without affecting my future care.	Yes/No
7.	I agree to take part in this research study.	Yes/No

Signature..

Name (block capitals)... Date................

Signature of witness...

Name (block capitals)... Date................

Appendix F
Individual Subject Results From Chapter 7

Navicular drop measurements for individual subjects.

Subject	Static (mm)	Walking (mm)	Running (mm)
1-m	12.0	8.77 ±1.22	9.26 ±0.54
2-f	11.0	4.48 ±0.86	6.04 ±1.36
3-m	15.0	6.11 ±0.53	7.10 ±1.46
4-f	5.0	3.28 ±0.69	5.08 ±0.46
5-f	9.0	9.07 ±0.77	10.51 ±1.41
6-m	11.5	5.13 ±0.71	6.40 ±0.33
7-m	19.0	7.76 ±0.57	9.30 ±0.49
8-f	4.0	9.24 ±1.05	6.31 ±0.31
9-f	9.0	6.20 ±1.17	9.82 ±2.51
10-m	9.5	5.47 ±0.32	6.48 ±0.39
11-f	13.0	8.51 ±1.52	9.91 ±1.27
12-m	10.0	5.41 ±1.29	7.77 ±0.35

Appendix G
Individual Subject Results From Chapter 8

Navicular Drop (mm) for All Subjects in all Testing Conditions

SUBJECT NUMBER	TESTING CONDITIONS: Static	Barefoot	Turf Trainers	Football Boots	Sports Trainers
subject 1	8	4.32±0.96	4.76±0.26	4.42±0.30	5.60±0.26
subject 2†	11	5.32±0.46	6.72±0.25	5.96±0.46	6.75±0.39
subject 3*	11	9.57±0.41	7.75±0.29	6.51±0.32	8.29±0.43
subject 4	9	4.58±0.30	5.59±0.20	5.35±0.25	5.38±0.32
subject 5†	7	5.56±0.24	4.35±0.47	4.00±0.29	4.71±0.33
subject 6*	13	6.66±0.36	5.76±0.38	7.53±0.38	6.75±0.45
subject 7	5	4.66±0.38	6.34±0.37	5.43±0.29	6.36±0.45
subject 8	7	4.14±0.40	5.37±0.61	5.11±0.27	5.94±0.16
subject 9	7	4.79±0.30	5.27±0.28	4.35±0.15	6.57±0.27
subject 10	10	5.20±0.43	4.56±0.32	4.20±0.59	6.55±0.26
subject 11	7	3.30±0.25	3.62±0.43	2.79±0.24	3.69±0.30
subject 12	9	8.08±0.67	3.97±0.57	4.97±0.75	5.79±0.47
subject 13	8	4.87±0.26	6.43±0.38	4.49±0.33	5.12±0.38
subject 14	6	4.41±0.29	5.59±0.53	5.63±0.50	5.63±0.37
subject 15*	8	5.02±0.57	2.34±0.70	2.85±0.46	2.83±0.34
subject 16*	14	5.69±0.61	5.88±0.40	4.71±0.32	6.97±0.59
subject 17	8	6.43±0.62	4.03±0.61	4.90±0.66	4.27±0.24
subject 18*	16	9.04±0.76	6.59±0.52	6.10±0.50	5.30±0.10
subject 19	12	4.97±0.21	5.51±0.24	5.86±0.70	6.29±0.35
subject 20	11	6.29±0.32	6.05±0.65	4.82±0.33	5.08±0.20
subject 21	9	4.61±0.55	6.03±0.76	3.95±0.38	5.28±0.70
subject 22	5	6.53±0.56	6.16±0.56	8.09±0.82	6.80±0.16
subject 23	6	6.23±0.48	3.30±0.15	2.31±0.20	5.07±0.30
subject 24	9	6.22±0.44	4.78±0.47	4.12±0.27	5.35±0.29
subject 25*	11	8.78±0.85	4.32±0.59	3.25±0.75	7.09±0.39
subject 26*	7	5.60±0.72	5.00±0.61	4.36±0.19	4.06±0.46
Mean±SD	9.00±2.76	5.80±1.58	5.23±1.21	4.85±1.36	5.67±1.19

* Indicates subject with pes planus foot.

† Indicates subject with pes cavus foot.

Appendix H

Individual Subject Results From Chapter 9

Pronation velocity from heel strike to maximum pronation.

Subject	Barefoot (deg/sec)	Football Boots (deg/sec)	Sports Trainers (deg/sec)
1	27.45	34.10	27.33
2	11.45	19.45	26.00
3	27.91	16.09	17.38
4	5.33	16.21	11.38
5	37.15	42.67	52.18
6	16.45	26.82	28.50
7	15.00	13.82	13.07
8	14.06	14.67	18.00
9	19.38	17.50	20.23
10	42.14	47.56	38.00
Mean±SD	21.63±11.73	24.92±12.38	25.24±12.36

Mean time from heel-strike to maximum pronation (seconds) in each condition.

Subjects	Barefoot	Football Boots	Sports Trainers
1	0.11	0.10	0.09
2	0.09	0.08	0.09
3	0.11	0.11	0.08
4	0.18	0.14	0.16
5	0.13	0.12	0.11
6	0.11	0.11	0.10
7	0.15	0.11	0.15
8	0.16	0.12	0.15
9	0.13	0.12	0.13
10	0.14	0.09	0.10
Mean±SD	**0.13±0.03**	**0.11±0.02**	**0.12±0.03**

Mean time from maximum initial pronation to heel-off (seconds) in each condition.

Subjects	Barefoot	Football Boots	Sports Trainers
1	0.29	0.44	0.36
2	0.19	0.18	0.16
3	0.24	0.22	0.19
4	0.35	0.38	0.40
5	0.17	0.15	0.18
6	0.27	0.14	0.14
7	0.33	0.20	0.25
8	0.40	0.52	0.49
9	0.31	0.20	0.28
10	0.25	0.25	0.36
Mean±SD	**0.28±0.07**	**0.27±0.13**	**0.28±0.12**

Mean total time from heel-strike to heel-off (seconds) in each condition.

Subjects	Barefoot	Football Boots	Sports Trainers
1	0.40	0.54	0.45
2	0.28	0.26	0.24
3	0.35	0.33	0.27
4	0.53	0.52	0.56
5	0.30	0.27	0.29
6	0.38	0.35	0.24
7	0.48	0.31	0.36
8	0.56	0.64	0.64
9	0.44	0.32	0.41
10	0.9	0.34	0.46
Mean±SD	**0.41±0.09**	**0.38±0.14**	**0.40±0.14**

Mean time to maximum navicular drop (seconds) in all conditions.

Subjects	Barefoot	Football Boots	Sports Trainers
1	0.45	0.59	0.68
2	0.32	0.30	0.52
3	0.67	0.71	0.65
4	0.75	0.40	0.74
5	0.42	0.38	0.44
6	0.60	0.39	0.56
7	0.63	0.42	0.73
8	0.62	0.65	0.70
9	0.51	0.66	0.80
10	0.51	0.36	0.65
Mean±SD	**0.55±0.13**	**0.49±0.15**	**0.65±0.11**

Maximum Navicular Drop and Maximum Pronation Measurements for the Barefoot Condition.

Subject	Maximum Pronation (degrees)	Navicular Drop (millimeters)
1	13.61	4.08
2	8.91	2.86
3	8.25	5.48
4	7.18	6.56
5	11.07	3.00
6	8.98	6.49
7	8.50	6.42
8	9.81	4.92
9	13.41	4.35
10	9.14	6.10
Mean±SD	**9.89±2.16**	**5.03±1.41**

Maximum Navicular Drop and Maximum Pronation Measurements for the Football Boot Condition.

Subject	Maximum Pronation (degrees)	Navicular Drop (millimeters)
1	11.38	3.58
2	7.92	2.76
3	8.50	2.98
4	6.78	2.35
5	12.36	3.55
6	10.69	3.15
7	9.05	4.38
8	8.93	2.43
9	11.38	3.34
10	7.87	2.63
Mean±SD	**9.49±1.85**	**3.11±0.62**

Maximum Navicular Drop and Maximum Pronation Measurements for the Sports Trainer Condition.

Subject	Maximum Pronation (degrees)	Navicular Drop (millimeters)
1	10.34	3.76
2	8.1	2.97
3	7.62	4.17
4	5.95	3.03
5	11.63	3.78
6	12.27	6.66
7	8.29	5.46
8	9.68	2.60
9	11.54	4.41
10	8.31	8.31
Mean±SD	**9.37±2.05**	**4.25±1.31**

Appendix I

FLUOROSCOPE STUDY
SUBJECT INFORMATION SHEET and CONSENT FORM

TITLE: The Effects of Football Boots on the Structure and Function of the Midfoot During Dynamic Motion

INVESTIGATORS:
Karla M. Bruntzel, MA, ATC; Postgraduate Student; Centre for Studies in Physical Education and Sports Science
Prof. Wayne Gibbon; Radiologist; Radiology Department-LGI
Neil Messenger, PhD; Lecturer; Centre for Studies in Physical Education and Sports Science
Tracey Thorne; Radiographer; Radiology Department-LGI
Karen Wainford; Radiographer; Radiology Department-LGI

AIM OF THE STUDY
You are invited to take part in a cooperative research project with the Radiology Department of the Leeds General Infirmary, and the Centre for Studies in Physical Education and Sports Science at the University of Leeds. The purpose of this project is to use x-rays to evaluate the movement of the bones of the midfoot/arch area while running and to see if stud placement on a football boot affects skeletal movement and structure of the normal foot. In addition to increasing the body of knowledge in this area, this study is also designed to provide data to fulfill the requirements of a research degree for the principle investigator.

PROCEDURES
In order to see if you meet the selection criteria set for this study, you will first need to complete a short injury history form and then undergo a foot/ankle physical evaluation, followed by visual gait analysis. Additionally, height and weight information will be obtained. If you are found to have any foot/ankle/gait abnormalities or have a history of foot and ankle disorders, you will excluded from further study. This part of the study will be conducted by Karla Bruntzel, a Certified Athletic Trainer, in the Biomechanics Laboratory at the Centre for Studies in Physical Education and Sports Science at the University of Leeds.

If you meet the selection criteria, you will then be invited to participate in the second part of the study, which will be conducted at the Department of Radiology, Leeds General Infirmary. As stated earlier, this phase of the research will involve the use of x-ray fluoroscopy, which allows information to be collected during movement and while wearing footwear. In this way, we can determine what is happening within the foot, and how the footwear affects the structures of the foot.

In order to collect the appropriate dynamic (walking) data when utilizing the fluoroscope, a special x-ray table have been constructed. This table is .55 m wide, .85 m high and 1.55 m long. You will be required stand on top of the table to take one full step along its length, passing by the lens of the fluoroscope while it is collecting the x-ray data. The fluoroscope will be in the "off" position between trials and you will be given the opportunity to practice the gait cycle until you become comfortable with the setup before data collection begins. A total of 12 trials will be conducted and the data collection will be as follows:

1 exposure while barefoot with radiographic skin markers placed on the foot (needed for reference points) - standing
3 exposures while barefoot - walking
1 exposure while wearing regular trainers with holes cut and radiographic skin markers placed on the foot - standing
3 exposures while wearing normal trainers - walking

1 exposure while wearing football boots with holes cut and radiographic skin markers placed on the foot - standing
3 exposures while wearing molded stud football boots - walking

Each exposure will last approximately 2 seconds with a total maximum exposure of 30 seconds.

RISKS
This project involves the use of x-ray fluoroscopy and exposure to low-levels of radiation. The fluoroscopic procedures will be conducted by qualified radiographers and overseen by a radiologist. The total radiation exposure for this study is equivalent to approximately 1 chest x-ray and is considered to be within the low-dose range according to the guidelines set up by the NHS radiation protection services. Other risks involved are those associated with the procedures for collecting the fluoroscope data. Because of the height of the table from the ground, there is a risk of falling off of the table and injuring oneself. However, precautions, in the form of support tables, will be in place to lessen this risk. In the case of injury, there are no indemnity arrangement in place, beyond those previously set up by the NHS Trust to cover its employees for negligence only.

PAYMENT
The researchers recognize the time commitment required of you and in exchange for the your participation in the fluoroscopic data collection, you will be paid £10.

CONFIDENTIALITY
The data collected will become the property of the researchers involved, the Radiology Department, and the Centre for Studies in Physical Education and Sports Science. All written data will be stored in compliance with the Data Protection Act and will be kept confidential. The x-rays will be catalogued and titled by subject number, age, and gender with no reference to the subject's name. Written documents that have the subjects name listed will be kept separate from the x-ray data. Additionally, no reference to the subject by name will appear in any documents, manuscripts or publications authored by the researchers.

QUESTIONS
The researchers will gladly answer any question(s) that you might have regarding any component of the project. Your participation is strictly voluntary, and at any time, you are free to withdraw your consent and discontinue participation in the project/activity without any prejudice. If you choose to withdraw from the project, the outcome of the study will not be compromised. While there are no specific benefits to you, the subject, the information collected from this study can and will increase the body of knowledge in the area of foot mechanics and footwear research.

If you should have any questions please contact:

Karla Bruntzel, MA, ATC
Centre for Studies in Physical Education and Sports Science
0113 233 5080
e-mail: phskmb@leeds.ac.uk

CONSENT FORM

THE EFFECTS OF FOOTBALL BOOTS ON THE STRUCTURE AND FUNCTION OF THE MIDFOOT DURING DYNAMIC MOTION

		Please delete as applicable
1.	I have read the Subject Information Sheet.	Yes/No
2.	I have had the opportunity to ask questions and discuss the research study.	Yes/No
3.	I am satisfied with the answers to my questions.	Yes/No
4.	I understand and accept the risks involved with this study.	Yes/No
5.	I have received enough information about this study.	Yes/No
6.	I have spoken to Ms. Karla Bruntzel.	Yes/No
7.	I understand that I am free to withdraw from the study at any time without giving a reason and without affecting my future care.	Yes/No
8.	I agree to take part in this research study.	Yes/No

Signature...

Name (block capitals)... Date.................

Signature of witness...

Name (block capitals)... Date.................

Appendix J

Individual Subject Results From Chapter 10

Static Navicular Drop Measurements.

	Anatomical Landmarks:			Markers:		
	Barefoot (mm)	Football Boots, w/holes (mm)	Football Boots, intact (mm)	Barefoot (mm)	Football Boots, w/holes (mm)	Football Boots, intact (mm)
Subject 1	0.63	2.17	3.97	0.78	0.94	N/A
Subject 2	0.95	1.54	0.73	0.14	0.09	N/A
Subject 3	1.38	1.42	3.64	2.98	0.50	N/A
Subject 4	1.69	3.95	1.57	1.15	1.89	1.10
Subject 5	5.17	2.26	2.24	4.56	1.94	2.88
Subject 6	3.51	3.11	1.91	3.34	0.84	2.37
Subject 7	2.84	2.23	1.49	2.92	0.48	1.53
Subject 8	2.19	3.62	4.35	3.92	3.62	4.35
Subject 9	4.10	7.08	3.88	4.24	4.52	4.12
Subject 10	4.62	0.73	0.68	4.24	1.43	2.95
Subject 11	1.46	0.73	3.55	2.46	1.30	1.05
Subject 12	3.41	1.41	0.98	2.57	2.26	0.76
MEAN±SD	2.66 ±1.50	2.51 ±1.77	2.37 ±1.33	2.78 ±1.44	1.65 ±1.31	2.35 ±1.33

Dynamic Navicular Drop Measurements.

	Anatomical Landmarks:			Markers:		
	Barefoot (mm)	Football Boots, w/holes (mm)	Football Boots, intact (mm)	Barefoot (mm)	Football Boots, w/holes (mm)	Football Boots, intact (mm)
Subject 1	4.41	4.40	5.64	7.77	2.59	N/A
Subject 2	6.77	5.13	6.41	4.66	4.06	N/A
Subject 3	6.46	3.61	5.26	5.93	3.59	N/A
Subject 4	5.12	5.97	5.83	4.89	2.74	3.68
Subject 5	8.75	3.12	7.12	4.91	4.92	2.88
Subject 6	6.21	3.68	4.22	5.42	2.51	1.68
Subject 7	5.65	6.03	6.00	5.75	2.96	2.09
Subject 8	6.55	7.97	5.38	7.51	5.53	1.94
Subject 9	7.37	5.73	6.85	5.12	3.38	2.29
Subject 10	7.77	6.90	4.79	5.46	3.69	1.91
Subject 11	4.93	3.79	4.95	3.70	1.62	1.71
Subject 12	6.55	4.92	4.53	3.87	2.59	2.41
MEAN±SD	6.38 ±1.24	5.10 ±1.47	5.58 ±0.90	5.42 ±1.24	3.35 ±1.10	2.29 ±0.64

Dynamic Navicular Drop Results from ProReflex® Footwear Study and Fluoroscopy Study.

	ProReflex®-Footwear Study		Fluoroscopy Study	
	Barefoot (mm)	Football Boots with holes (mm)	Barefoot (mm)	Football Boots with holes (mm)
Subject 1	4.79±0.30	4.35±0.15	4.41±0.69	4.40±0.79
Subject 2	4.32±0.96	4.42±0.30	6.77±2.44	5.13±0.68
Subject 3	6.29±0.32	4.82±0.33	6.46±2.49	3.61±1.66
Subject 4	4.66±0.38	5.43±0.29	5.12±2.83	5.97±2.87
Subject 5	6.22±0.44	4.12±0.27	8.75±3.47	6.70±0.69
Subject 6	6.53±0.56	8.09±0.82	6.21±1.24	3.68±1.19
Subject 7	6.23±0.48	2.31±0.20	5.65±0.68	6.30±1.56
Subject 8	4.14±0.40	5.11±0.27	6.55±1.66	7.97±0.94
Subject 9	8.78±0.85	3.25±0.75	7.37±1.75	5.73±0.89
Subject 10	5.20±0.43	4.20±0.59	7.77±1.76	3.79±0.66
Subject 11	5.60±0.72	4.36±0.19	4.93±1.57	3.79±0.66
Subject 12	4.97±0.21	5.86±0.70	6.58±1.73	4.92±0.89
MEAN±SD	5.64±1.28	4.69±1.42	6.38±1.24	5.17±1.40