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A KINEMATIC RUNNING ANALYSIS OF NCAA DIVISION I

ATHLETES WTH MEDIAL TIBIAL STRESS SYNDROME

by

Ethan L. Ostrom

A thesis

submitted in partial fulfillment

of the requirements for the degree of

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COMMITTEE APPROVAL PAGE

To the Graduate Faculty:

The members of the committee appointed to examine the thesis of Ethan L. Ostrom find it satisfactory and recommend that it be accepted.

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June 23, 2014

Ethan Ostrom
1218 Swisher Rd.
Pocatello, ID 83204

RE: Your application dated 6/20/2014 regarding study number 4121: A kinematic Running Analysis of NCAA Division I Athletes with Medial Tibial Stress Syndrome

Dear Mr. Ostrom:

I have reviewed your request for expedited approval of the new study listed above. This is to confirm that I have approved your application.

Notify the HSC of any adverse events. Serious, unexpected adverse events must be reported in writing within 10 business days.

Submit progress reports on your project in six months. You should report how many subjects have participated in the project and verify that you are following the methods and procedures outlined in your approved protocol. Then, report to the Human Subjects Committee when your project has been completed. Reporting forms are available on-line.

You may conduct your study as described in your application effective immediately. The study is subject to renewal on or before 6/23/2015, unless closed before that date.

Please note that any changes to the study as approved must be promptly reported and approved. Some changes may be approved by expedited review; others require full board review. Contact Thomas Bailey (208-282-2179; fax 208-282-4723; email: humsubj@isu.edu) if you have any questions or require further information.

Sincerely,

Ralph Baergen, PhD, MPH, CIP
Human Subjects Chair

DEDICATION

This work is dedicated to my parents Eric and Kristie Ostrom, your continued love, support, and encouragement throughout every aspect of my life has given me motivation and drive to pursue my dreams, without you I would not be where I am today. To my sister Marleigh, who has been more than just a friend through thick and thin, your support and love is greatly appreciated. And to all of my friends and family, without your support I would not be where I am today, thank you very much.

"I have no special talents. I am only passionately curious"

-Albert Einstein

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Abstract

The purpose of this study was to use videography analysis to describe the lower limb kinematics of National Collegiate Athletic Association Division I athletes suffering from Medial Tibial Stress Syndrome versus NCAA DI athletes without MTSS. Static navicular drop was recorded for 10 participants who then performed a running test while recording hip, knee, ankle angles, and angle of foot strike. Significant differences were tested using independent sample *t*-tests and two-way ANOVA. ND showed a significant difference between groups with an $\alpha<0.05$ ($t=-2.9598$, and $p=0.02366$). Two-way ANOVA for ND indicated males with MTSS had a significantly higher ND than females with MTSS ($F=7.9813$, $df=1$, $p=0.0301$). The results of this study suggest that the ND is greater in MTSS subjects, but no significant differences were shown in kinematic measurements. In conclusion this investigation showed much greater static pronation measured by the ND test in athletes with MTSS.

CHAPTER ONE

Introduction

Many athletes, from many different sports suffer from medial tibial stress syndrome (MTSS) also known in layman's terms as shin splints (Bennett, Reinking, & Rauh, 2012; Cowley & Marsden, 2013; Galbraith & Lavallee, 2009). MTSS is identified as "an overuse or repetitive stress injury of the shin area" (Galbraith & Lavallee, 2009, p. 127). MTSS causes pain on the distal two thirds of the tibia on the posteromedial border (Moen et al., 2012a). Tibial stress fracture or traction induced injuries of the musculature or deep crural fascia (DCF) have been described as some of the possible origins of pain that presents with MTSS (Bennett, Reinking, & Rauh, 2012; Raissi, Cherati, Mansoori, & Razi, 2009; Stickley, Hetzler, Kimura, & Lozanoff, 2009). Until the physiologic causes are further elucidated, scientists and doctors will continue to have difficulties treating and preventing this injury.

Many different risk factors have been associated with MTSS. Some promising areas of research have come from kinematic and biomechanic risk factor assessment. Loudon and Reiman (2012) investigated the lower extremity kinematics of runners and found that runners with MSP (Medial Shin Pain) had greater pelvic tilt, larger hip internal rotation, than runners with no MSP history. Raissi et al. (2009) showed that runners with MTSS had a significantly larger Navicular Drop (ND) than runners without MTSS. Lieberman et al., (2010) showed that runners who rear foot strike, or land on their heels first, tend to exhibit greater ground reaction force (GRF) loading rates than runners who fore foot strike, or land on their toes first. Lieberman et al. (2010) hypothesized that higher GRFs associated with rear foot striking may also be associated with injuries. Milner, Ferber, Pollard, Hamill, and Davis (2006) showed that women who had previous tibial stress fractures were also more likely to be rear foot strikers. Kinematic differences between certain athletes may lead to different kinetics and pressures exerted on the body. It is thought that if there are differences in kinetics between injured athletes and those who are not there may be observable differences in kinematic measurements between these groups of athletes. Therefore, the purpose of this study was to use videography analysis to describe the lower limb kinematics of National Collegiate Athletic Association (NCAA) Division I athletes suffering from Medial Tibial Stress Syndrome (MTSS) versus NCAA DI athletes without MTSS.

Variables, Research Questions, and Hypothesis

Variables. There are many variables that correlate with MTSS and could be potential causes of the injury. However, ND, dynamic navicular drop (dND), and previous MTSS injury are the kinematic variables that have been repeatedly shown to have a significant association with MTSS (Bennett et al., 2012; Cowley & Marsden, 2013; Moen et al., 2012a; Raissi et al., 2009; Rathleff et al., 2012; Reinking, Austin, & Hayes, 2013). This study investigated and presented some of the kinematic measurements with respect to MTSS. The first variable was the presence or absence of MTSS in the testing population. MTSS presence was defined as pain or discomfort in the posteromedial border along the distal two thirds of the tibia (Moen et al., 2012a). Participants without the described symptoms acted as the control group. The other variables measured were hip angle, knee angle, ankle angle, angle of foot strike (also known as over striding), and ND. Hip, knee, and ankle angles were measured relative to torso, thigh, shank, and foot body segments, and all measures except ND, which is a static measurement, were taken at the moment of foot strike.

Research Questions. The following research questions guided this study: (a) were there differences in hip angle, knee angle, ankle angle, or angle of foot strike between the MTSS athletes and athletic controls? and (b) Was there a difference in ND between the MTSS athletes and the athletic controls?

Hypothesis. It was hypothesized that there would be observable differences between MTSS athletes and athletic controls in these kinematic variables measured in the sagittal plane: hip angle, knee angle, ankle angle, and angle of foot strike (AFS). It was also hypothesized that athletes with MTSS would display significantly larger magnitudes of frontal plane movement in the ankle measured by ND (Bennett et al., 2012; Cowley, & Marsden, 2013; Lieberman et al., 2010; Milner et al., 2006; & Moen et al., 2012a).

Operational Definitions

All joint angles except angle of foot strike and navicular drop were measured as relative joint angles and recorded and measured in the sagittal plan. These joint angles were relative to their corresponding body segments. ND was a frontal plane measurement using methods described by Brody in 1982. An example of all the joint angle measurements taken and ND measurement methods are given in Figure 1 and 2 respectively in the methods section.

Angle of foot-strike (AFS). AFS, also considered over striding, is the angle of the hip at foot-strike in relation to a perpendicular line from the hip joint center to the ground. It was measured with a line from the knee joint marker through the thigh segment to the hip joint marker. The second line was from the hip joint marker to a point straight down to the ground (Nunan, 2007).

Ankle joint angle. Ankle joint angle is defined as the angle between shank and foot body segments. The angle was captured and measured between knee joint marker, lateral malleolus joint marker, and 5th metatarsal joint marker (Lee, Kim, Lee, Kurihara, Lee, & Kawakami, 2010). This joint angle was taken at the instant of foot strike.

Hip joint angle. The hip joint angle was measured as the angle between the shoulder joint marker, hip joint marker and knee joint marker, or in body segment terms the angle between the torso and thigh segments (Hammonds, Laudner, McCaw, & McLoda, 2012). This joint angle was taken at the instant of foot strike.

Knee joint angle. The knee joint angle was measured between the hip joint markers, knee joint marker, and ankle joint marker, or in body segment terms the posterior angle between the thigh and shank segments (Hammonds, Laudner, McCaw, & McLoda, 2012). This joint angle was taken at the instant of foot strike.

MTSS. Defined as exercise induced pain on the distal two thirds of the tibia on the posteromedial border (Moen et al., 2012a).

Navicular drop. ND is defined as the difference between the navicular tuberosity in subtalar joint neutral and the navicular tuberosity in weight bearing (Nguyen & Shultz, 2009). Navicular drop test is described by Brody (1982). This measurement was taken prior to the running test.

NCAA. The National Collegiate Athletic Association defines itself as a nonprofit organization with over 1,200 institutions across the United States and Canada that help organize 89 different sports championships in intercollegiate athletics. (ncaa.org)

Delimitations

The study's delimitations were NCAA Division I athletes currently suffering from MTSS; athletes without MTSS acted as controls. There are many other variables that have been measured and are associated risk factors with MTSS however; these variables have not been reproduced with strong evidence in the literature (Bhatt, Lauder, Finlay, Allen, & Belton, 2000; Cowley & Marsden, 2013; Loudon & Reiman, 2012; Nielsen, Nohr, Rasmussen, & Sorensen, 2013; Reinking, Austin, & Hayes, 2013). Therefore, the kinematic measurements hip, knee, and ankle joint angles in this study can be considered delimitations (Moen et al., 2012a; Raissi et al., 2009). This investigation tried to get athletes from a wide variety of sports but only ended up looking at football and track and field athletes because these were the only athletes that could be recruited to participate in this study so these can also be considered delimitations.

Assumptions

The investigator assumed that different joint angle measurements would not be from differences in sports specific movements because everyone was tested doing the same running task. It was assumed that running linearly on a treadmill would cause similar ground reaction forces as running during the athlete's competition on the field, track, or court. It was assumed that all athletes were honest in their demographic questionnaire. It was also assumed that the athletes were honest and truthful when asked to describe their level of pain on the visual analogue pain scale (0-10) during the running test. Lastly, the investigators assumed that the running test would provide sufficient time for a large amount of kinematic data collection.

Limitations

A convenience sampling procedure was used in this investigation and should be mentioned as a limitation in this study. Sample size was a significant limitation because this investigation was only able to recruit 5 athletes with MTSS and 5 athletic controls at one University. Therefore the power of statistical significance is very low for this investigation and should be considered a significant limitation. The control group was recruited based on the sex and sport played of the participants in the MTSS group. One participant in the MTSS group was a football player, but unfortunately a control participant could not be recruited from the football team due to lack of interest to participate in this study, and time constraints forced the researcher to use a track and field athlete who was a pole vaulter. This should be noted as a limitation of the present study although there were too few participants for a statistical analysis between sport groups.

Other limitations of this study include running surface, footwear, intra-participant variation of running mechanics, and generalizability of the results to other athletes (elite or recreational). Running surface was considered a limitation because many athletes who suffer from MTSS compete on courts, fields, or tracks, not on a treadmill. However, the experiment was performed indoors on a treadmill so the participants could wear minimal clothing for joint marker identification without being uncomfortable and the researchers were able to adjust temperature if necessary. Participant's choice of footwear was considered a limitation because of the many varying shoe types and support each provides. This could be worth considering as a cause of different running mechanics between participants. It has been shown by Wolf, List, Ukelo, Maiwald, and Stacoff (2009) that day to day consistency of participant's kinematics vary by three to four degrees; therefore, because the investigators only conducted one running test per participant, the variation in running mechanics has to be suggested as a possible limitation. And lastly, the ability of this study to generalize the data to recreational or elite athletes not tested on their natural performance surface (i.e. field, court, and track) was a significant limitation of this study. Experimental procedures simulated a performance environment that most accurately represents track and field mid-distance running as it is a linear event and the protocol for this procedure was a sub maximal sprint test performed on a treadmill. No other sports that were included in this study had those same exact performance requirements.

Significance

This section has discussed the limitations, delimitations, assumptions, and operational definitions. A brief background of the anatomy and physiology involved with MTSS was discussed. The purpose of this study was to use videography analysis to describe the lower limb kinematics of National Collegiate Athletic Association (NCAA) Division I athletes suffering from Medial Tibial Stress Syndrome (MTSS) versus NCAA DI athletes without MTSS. This study is significant because it could further describe the important kinematic correlates with MTSS and provide evidence through biomechanical data (i.e. joint angles) for proper lower limb movement mechanics in sports.

CHAPTER TWO

Literature Review

The purpose of this study was to use videography analysis to describe the lower limb kinematics of NCAA DI athletes suffering from MTSS versus NCAA DI athletes without MTSS. This literature review discusses relevant investigations in MTSS research. There are many different factors that may be involved with MTSS and therefore this literature review will discuss the two main theories of MTSS development as well as the lower leg anatomy, current treatment options, some biomechanical risk factors associated with MTSS, and how the literature can be applied for injury prevention strategies.

The term shin splints was developed by the American Medical Association (1966) as a non-specific descriptor of lower leg soreness or injury from repetitive running on hard surfaces. The term shin splints is vague and non-descriptive, so more recently there have been new terms that have been implemented in the literature to describe injuries of the lower leg. Medial Tibial Stress Syndrome (MTSS) is defined as diffuse lower leg pain greater than 5 centimeters upon palpitation on the posteromedial side of the tibia (Moen et al., 2012a) as opposed to widely dispersed soreness or point tenderness. The incidence of MTSS has been shown to be as high as 35% in a prospective military study, making it one of the most frequent injuries for active individuals (Yates and White, 2004). Despite its frequency in athletic and military populations there is still debate as to what causes MTSS. It is clear that there are many factors involved in the injury, none of which have been elucidated clearly enough for certainty in the primary literature.

Biomechanical risk factors and running technique have been heavily researched with respect to MTSS, and have shown more promise than physiological studies because it has been easier for researchers to clearly show relationships between MTSS occurrence and these associated biomechanical factors (Bennett et al, 2012; Raissi et al., 2009; Rathleff et al., 2011; Rathleff et al., 2012). Both physiological and biomechanical analyses of MTSS are important and necessary to increase the knowledge about this injury and improve injury treatment and prevention.

Traction Induced MTSS

There are two main theories for the cause of MTSS; the first theory is traction induced injury of musculotendinous origin. Hutchins (1913) first described shin splints (referring to MTSS) as relating to a traction induced injury involving the posterior flexor muscles of the calf. Few other studies have described the flexor digitorum longus (FDL), flexor hallicus longus (FHL), the tibialis posterior (TP), or the soleus (SOL) muscles to be involved with the traction induced injury theory (Beck & Osternig, 1994; Garth & Miller, 1989; Saxena, O'Brien, & Bunce, 1990). Connective tissue of the posterior compartment and periosteum and the Deep Crural Fascia (DCF) have also been cited as potential MTSS symptom causes (Bouche & Johnson, 2007; Michael & Holder, 1985; Stickley et al., 2009). The evidence for this theory has not shown one specific muscle repeatedly, and many of these findings do not support each other. Therefore this theory has not proven to be as reliable in the literature, although musculotendinous involvement should not be completely dismissed from MTSS discussion. For a more in depth look at the muscle traction theory one must review the anatomy of the lower leg musculature.

The musculature of the lower leg acts to support the body weight as a person walks, jogs, or runs. Therefore it is important to know the origins, insertions, and actions of these muscles for a deeper understanding of the pathologies associated with running, and specifically MTSS. Firstly the superficial posterior compartment consists of three muscles: the gastrocnemius, soleus, and plantaris muscles. The gastrocnemius originates on the medial and lateral condyles of the femur and inserts on the calcaneal tendon, also known as the Achilles tendon. The gastrocnemius acts to plantar flex the ankle, and assists in flexing the leg. The soleus muscle originates on the fibular head and tibial soleal line and also inserts on the calcaneal tendon. The soleus acts to plantar flex the ankle. The plantaris muscle originates on the lateral supracondylar line and inserts on the calcaneal tendon. It weakly assists the soleus and gastrocnemius to plantar flex the foot. These superficial muscles are the main plantar flexors of the ankle and typically are fired as a complex together to support the body and push off during running (Netter, 2011).

The deep compartment of the lower leg musculature includes the flexor hallucis longus, flexor digitorum longus, and tibialis posterior. The flexor hallucis longus (FHL) originates on the posterior fibula and interosseus membrane and inserts at the base of the distal phalanx of the great toe. The FHL acts to flex the great toe and assists in plantar flexion of the ankle. The flexor digitorum longus (FDL) originates on the posterior tibia and fibula, and inserts on the distal phalanges 2-5. The FDL acts to flex phalanges 2-5 and assists with plantar flexion of the ankle. Finally the tibialis posterior (TP) originates on the interosseus membrane, and posterior surfaces of the tibia and fibula, and inserts on the navicular, cuneiform, cuboid, and base of metatarsals 2-4. The TP acts to invert the foot and plantar flex the ankle (Netter, 2011).

The anterior compartment of the leg consists of three muscles: tibialis anterior, extensor hallucis longus, and extensor digitorum longus. The tibialis anterior (TA) originates on the lateral condyle and lateral surface of the tibia and inserts on the base of the first metatarsal. The TA acts to dorsiflex the ankle and invert the foot. The extensor hallucis longus (EHL) originates on the anterior tibia and interosseus membrane, and inserts on the dorsal aspect of the distal phalanx of the great toe. The EHL acts to extend the great toe and dorsiflex the ankle. Finally the extensor digitorum longus (EDL) originates on the anterior tibia, fibula, and interosseus membrane and inserts on the middle and distal phalanges of digits 2-5. The EDL acts to extend digits 2-5 and dorsiflex the ankle (Netter, 2011).

Finally the lateral compartment of the ankle consists of two muscles: the fibularis longus, and fibularis brevis also known as peroneus longus and peroneus brevis. The fibularis longus originates on the head and superolateral fibula and inserts on the base of the first metatarsal. It acts to evert and plantarflex the foot. The fibularis brevis originates on the inferolateral fibula and inserts on the base of the 5th metatarsal. It acts to evert and plantarflex the foot. This baseline knowledge about the musculature of the lower leg is important when considering the traction induced theory of MTSS (Netter, 2011). All of these muscles are active in some way during gait, although at different times and differing magnitudes of activation. The muscles of the lower leg must act in a coordinated and concerted effort to transmit forces through the muscles and tendons to keep the individual upright and moving and minimize injury (Reber et al, 1993; Sano et al., 2013). Any sort of miscommunication, misuse, or over exertion from any one of these muscles over long periods of time could result in pain and discomfort, and is the basis behind the MTSS muscle traction theory although a wide range of muscles and connective tissue have been cited for this theory (Beck & Osternig, 1994; Bouche & Johnson, 2007; Garth & Miller, 1989; Michael & Holder, 1985; Saxena, O'Brien, & Bunce, 1990; and Stickley et al., 2009).

Michael and Holder (1985) looked at 14 cadaveric specimens that were dissected and the origins of the soleus muscle were recorded. Ten patients were tested with muscle stimulation tests including two who were diagnosed with MTSS. EMG tests were conducted on five of these individuals in the soleus muscle using a monopolar needle electrode. The anatomical dissections of the soleus muscle in the cadaveric specimens showed some minor variations in the origins on the posterior 1/3 of the medial tibial border but was found to end approximately four inches above the medial malleolus. The fascia covering the soleus however was shown to extend past the posterior 1/3 and extends directly to the posterior medial border of the tibia through Sharpey's fibers. The dissections found that the FDL, FHL, and TP muscles originated on the lateral tibia, interosseus membrane and fibula, and were not consistent with the site of pain in MTSS. The FDL, FHL, and TP were also characterized by much thinner facial attachments than the soleus. The EMG recording of the medial soleus during passive heel eversion gave a positive EMG trace, while inversion of the heel did not, indicating that the soleus not only plantarflexes the ankle but also inverts the heel. The authors concluded that the pain was associated with the soleus muscle and fascial covering of the deep posterior compartment of the leg when the ankle is in a pronated position. This study indicates the importance of the soleus muscle with the prevalence of MTSS and could be a key player in the development of MTSS although further investigation is required.

Beck and Osternig (1994) measured the attachment sites of the soleus, FDL, TP, and the deep crural fascia on the tibia of 50 cadaveric specimens in relation to the symptoms of MTSS. The absolute measurements were recorded in millimeters and normalized relative to tibial length. Results showed that both the soleus and FDL arose on the medial border of the tibia at the site of symptoms of MTSS. The deep crural fascia was also found to attach to the tibia at the site of MTSS symptoms. The TP muscle was not found to originate on the medial border of the tibia in relation to symptoms of MTSS, and contradicts other findings (Saxena et al., 1990). They suggest that the origin of the TP could be falsely associated with the medial tibia because the inferomedial muscle fibers of the TP often lie over the tibia, however when they are cut and reflected they actually show the origin of the muscle is on the interosseous membrane and a very lateral portion of the tibia not consistent with the site of symptoms of MTSS. While this study supports the notion that the distal attachments of the soleus are consistent with the site of MTSS symptoms, the authors also note that there is a wide range of variability in the distal origins of the soleus and therefore should be further investigated.

An investigation by Garth and Miller (1989) looked at five female and 12 male athletes who presented with posteromedial shin pain were recruited along with 17 healthy athletic controls (Garth, & Miller, 1989). After physical examinations each patient's second toe was measured for range of motion using a full circle plastic goniometer. Strength was measured by having the patients flex their lesser toes while extending the great toe. If the patients could not do this properly they were characterized as having a weak FDL muscle. Results show the symptomatic athletes had greater extension of the toes but less flexion and were weaker than their healthy counterparts. Symptomatic athletes also displayed a mild claw toe deformity in a resting position indicating slightly more extension in the toes than the control group. Furthermore, being unable to maintain the extended great toe and flexion of the lesser toes for any period of time indicates intrinsic weakness or muscular dysfunction of the FDL muscle. This study indicates that there may be FDL muscular dysfunction in patients with MTSS. This intrinsic weakness may be indicated by claw toe deformity. Further investigation is needed to implicate the FDL as a main contributor to this injury, however could possibly be the cause of the pain felt in MTSS patients.

Bouche and Johnson (2007) investigated the muscle traction theory with three cadaver limbs. Strain gauges connected to the soleus, flexor digitorum longus (FDL), and tibialis posterior (TP) muscles recorded a linear relationship between the plantar flexor muscles and the tibial fascia. These results support their traction induced tibial fasciitis hypothesis and provide insight into the pathomechanics of MTSS. However, this study did not take into account where exactly the muscles of the posterior compartment inserted in the tibia. As noted in the study by Stickley et al., (2009) this is an important factor in distinguishing which anatomical sites and tissues are actually involved in the muscle traction theory.

Stickley et al. (2009) investigated the relationship between the site of MTSS pain and distal origins of the soleus, flexor digitorum longus (FDL), and tibialis posterior (TP) muscles as they have been associated with MTSS and are thought to be a factor in MTSS development (Bouche and Johnson, 2007). All of these distal attachments were measured and quantified with 16 cadavers. The researchers found that the defined attachment sites of the soleus, FDL, and TP on the most distal portion of the tibia are not consistent with the symptoms of MTSS. The pain associated with MTSS is described to be on the distal half to two thirds of the tibia (Moen et al., 2012a), but Stickley et al. (2009) describe even the most distal origin sites of the soleus, FDL, and TP are on the proximal third of the tibia. Therefore the authors concluded that the soleus, FDL, and TP were not involved with muscle traction induced injury; however, the authors did show that traction induced injury of the DCF could possibly cause the symptoms associated with MTSS because it is attached on the distal two thirds of the tibia.

The traction induced MTSS theory has not gained much support over the past few years of research however it still remains to be disproven, and therefore should continue to be present in the MTSS discussion. One of the main reasons this theory has not been given much credit is the large amount of disparity between the muscles involved in traction induced MTSS shown by these studies above. On further investigation it may present that no one particular muscle attachment is responsible for MTSS symptoms, but that a dysfunction or lack of coordination of the posterior muscles as a whole to attenuate shock forces during physical activity may be the mechanism behind MTSS injury. Further investigation is required to elucidate this theory.

Boney Overload Theory

The second theory is the tibial bending theory or what is more recently referred to as a boney overload of the tibia (Moen et al., Review 2010). This tibial bending theory was first suggested by Devas (1958). Devas proposed that when the plantar flexors of the calf muscle contract they pull on the tibia in both directions like a bow string, thus causing the tibia to bow forward. Devas theorized that stronger plantar flexor muscles can cause a greater bowing of the tibia which would cause greater stress on the tibia. According to more recent bone imaging studies patients with MTSS may have an inappropriate bone remodeling process compared to the amount of stress received by the tibia. These studies are discussed below.

Some imaging techniques have been shown to be effective in the diagnostic process for MTSS (Bhatt et al., 2000; Magnusson et al., 2001). Bhatt et al., (2000) found an increased radiographic uptake along the anterior and posterior cortices of the tibia (double strip pattern) in scintigraphy scans of patients with MTSS. Other studies have found similar results in scintigraphic scans suggesting abnormal bone metabolism in people suffering from MTSS (Anderson, Ugalde, Batt, & Gacayan, 1997; Bhatt et al., 2000; & Magnusson et al., 2001). Anderson et al., (1997) suggested that MTSS may be a type of fatigue damage to bone. Johnell, Rausing, and

Wendeberg (1982) suggest that the pain resulting from MTSS could be a cause of micro fractures along the tibia. Magnusson et al. (2001) also showed low bone mineral density (BMD) among athletes with MTSS versus athletic and non-athletic controls. The scintigraphic and bone scan results certainly point to abnormal bone physiology and could be a key factor in MTSS development; however more research is needed to solidify these findings.

In a review of bone physiology by Frost (2003), he states that bone strength is a direct result of internal and external loading forces felt by the bone. Internal forces meaning forces applied to the bone via muscle tendon units and external forces meaning impact forces (i.e. ground reaction forces or external forces applied in contact sports). The bone remodels itself based on these loads. Osteoclasts eat away the damaged cortical bone after loading and osteoblasts come in behind and rebuild the bone stronger. This natural remodeling process takes time for the bone to regrow stronger. In cases of repetitive stresses with little time for the bone to remodel itself the bone is in a catabolic state breaking down bone tissue, causing even more damage and weakness. The imaging studies by Bhatt et al. (2000) and Magnusson et al. (2001) provide evidence that there is some abnormal bone remodeling occurring in patients with MTSS and suggest that people with MTSS may have a more catabolic bone metabolism than people without MTSS.

Ozgurbuz et al. (2011) also measured athlete bone mineral density (BMD) with a DEXA scanner (Dual-Energy X- Ray Absorptiometry Scanner) but found no significant difference in BMD between athletes suffering from MTSS and healthy controls. This finding seemed inconsistent with the others, which reported bone loss (Bhatt et al., 2000; Magnusson et al., 2001). The key difference in the study by Ozgurbuz et al. (2011) was that these athletes were tested near the onset of their

MTSS symptoms, between 3 and 10 weeks. In contrast, the study by Magnusson et al. (2001) reveals that the test population who suffered from MTSS reported having symptoms for an average of 31 months. Bhatt et al. (2000) reported their patients as having symptoms of MTSS between 15-22 months. These results suggest that patients suffering from MTSS for longer periods of time begin to show abnormal bone scans and abnormal bone mineral density. This may be a strong diagnostic indicator for future researchers, but may also be important for intervening treatment options as low bone mineral density is associated with other more serious medical conditions such as stress fracture and osteoporosis. Future investigators and medical practitioners should keep in mind the timeline of their patient's symptom onset and duration, as this may be an important tool for proper diagnosis and treatment.

A study by Moen and Schmikli et al. (2012d) looked at bone marrow edema and periosteal edema with MRI scans of 52 athletes with MTSS. 43.5% of athletes showed periosteal or bone marrow edema, and bone marrow or periosteal edema was associated with significantly higher recovery rates than patients who did not show any MRI abnormalities. These results indicate there is some remodeling in patients who have edema, and that the edema could be part of the healing process. This study did not use an athletic control group however, so these results should be interpreted with caution. While edema could be a sign of healing it could also be present in athletic controls who participate in weight bearing exercise, therefore more MRI research should be performed with a case control method in athletes with MTSS.

In a follow up study by Magnusson, Ahlborg, Karlsson, Nyquist, and Karlsson (2003) researchers looked at bone mineral density scans of patients with long standing MTSS symptoms after full recovery. Patients showed a normal BMD scan and were no different compared to nonathletic healthy controls. These results suggest that decreased BMD in patients with MTSS is not an inherited condition causing MTSS but may coincide with symptoms of MTSS and subside after recovery. These results also provide evidence to support Frost's 2003 paper on bone physiology. Allowing time for the bone to fully recover while training may be an important factor for reducing the amount of bone loss and reduce the risks associated with low bone mineral density.

These investigations offer evidence of the bone overload theory, as they show some abnormal balance between bone reabsorption and bone growth. One case study by Moen et al. (2011) treated two patients with Sodium Alendronate, a biphosphonate medication used to treat osteopenia. Both patients recovered fully from MTSS symptoms within 10-11 weeks with altered activity and the Sodium Alendronate medication. Although this is a case study and more research is needed on this topic it is an interesting finding, and may provide useful when treating MTSS. These studies suggest there may be abnormal bone remodeling in patients with MTSS and support the boney overload theory.

These studies provide valuable insights to show a more complete picture of bone pathology in patients with MTSS. All of these studies show that bone remodeling is occurring within patients suffering from MTSS although it may only be in conjunction with MTSS symptoms and not a preexisting condition that causes MTSS. Therefore, imaging techniques like the DEXA scanning and scintigraphy are useful tools in the analysis of MTSS pathology. When combined with the use of histological and physiological analysis of bone, connective tissue, and muscle, researchers will be better able to paint an entire picture of this complex injury. Future research should focus on methods that provide random sampling and cause and effect relationships between variables.

Both the boney overload hypothesis and the muscle traction hypothesis need further research to provide more details about this injury. The underlying anatomy and physiology is a very important area of research for this injury because until scientists know what is happening at a physiological level they will not be able to prescribe the most accurate treatments or preventative measures for people suffering from this injury. Therefore further cause and effect relationship studies should be conducted on these theories at a physiological and histological level.

Treatment Options

In a prospective case study by Krenner (2002), a subject presented with pain along the distal portion of the tibia with exercise, and the practitioner diagnosed her with MTSS. The practitioner used chiropractic adjustments to realign the patient in order to reinstitute proper mechanics, and acupuncture to release endogenous endorphins to the affected area. The practitioner also prescribed the use of orthoses and NSAIDs (Non-Steroidal Anti-inflammatory Drugs) to the patient. The patient returned to training, with pain as her guide after two weeks. The practitioner used a common multifaceted treatment approach for the patient (Krenner, 2002). While acupuncture and chiropractic adjustments are less common in treating MTSS, rest, ice, and NSAIDs are a very common prescription for MTSS (Cosca & Navazio, 2007).

A study conducted by Moen and Holtslag et al. (2012b) investigated treatment options in an athletic population. Participants were randomly placed into three treatment groups: (a) one group performed a graded running program (b) the second group performed a graded running program and calf stretching and strengthening program, and (c) the third group performed the graded running program with sports compression stockings. Outcome measures were defined as the amount of time, in days, to complete the graded running program with a four or less on the Visual Analogue Pain Scale (VAS- from 0-10). Researchers found no significant differences in time to complete the graded running program within each of the three groups; there was also no significant difference in patient satisfaction for the running program. These results suggest that compression stockings and stretching and strengthening exercises do not significantly decrease time to recovery. However, the researchers were measuring how long it took to complete a graded running program, not time to full recovery. The participants were allowed to complete the graded running program if their symptoms were at a four or less on the VAS. This outcome measure surely incorporates how the patients' MTSS was affecting them, but it also takes into consideration the patients' pain tolerance and fitness level. Fitness level would include nutritional habits and lifestyle variables as well. Although these variables were not explicitly measured, they should be taken into consideration. People may have different levels of pain tolerance, and fitness improvement has been widely accepted as partially dependent on nutrition and lifestyle choices such as smoking (Sharma, Golby, Greeves, & Spears, 2011). Therefore compression stockings, stretching, and strengthening exercises are still viable treatment options in combination with others (Loudon & Dolphino, 2010).

A study by Loudon and Dolphino (2010) investigated the use of off the shelf foot orthoses and a calf stretching protocol in 23 patients with MTSS. Results showed that 65.2% of the patients in the study showed significant improvement on the VAS pain scale (0-10). Significant improvement was defined as >50% reduction in symptoms. The authors state that orthoses were used to reduce the effects of poor biomechanics, while the stretching protocol was used to increase the passive range of motion of the talocrural joint, to relieve stresses from improper mechanics. It can be speculated that decreased range of dorsiflexion might cause more traction on the posterior musculature of the leg. Therefore, a stretching protocol would be useful for patients with MTSS. Although these treatments are not complete, it does show their treatment options could be viable as part of a larger, more complete treatment program, and stretching and foot orthoses are effective when used on their own, however it is not known if adding other treatment options on top of that would be more or less effective.

A study by Rompe, Cacchio, Furia, and Maffulli (2010) looked at extracorporeal shock wave therapy as a feasible treatment option for patients with MTSS. Shock wave therapy (SWT) is focused shock waves that are sent through a machine to the affected site of injury through ultrasound gel placed on the skin over the affected site. The investigators used a cohort retrospective study design to investigate the effects of SWT in conjunction with an at-home treatment plan that included stretching and strengthening exercises for 47 participants versus a control group who were only prescribed the at home treatment program (Rompe et al., 2010). The researchers considered a 1 (completely recovered) or 2 (significant improvement) rating by the patients on a Likert scale (1-6) a successful outcome. The SWT treatment group was treated three times (weeks 2, 3, and 4) after the start of the home treatment plan. Primary outcome measures were taken at four months after the home training program began, and secondary outcome measures were also taken at one and 15 months. The SWT treatment group showed a significantly higher number of completely recovered (1) or significant improvement (2) scores on the Likert scale, as opposed to the control group at one, four, and 15 months after treatment began. These results suggest that SWT could be an effective treatment option for patients with MTSS, especially those who do not respond to other treatment options. According to the authors this was the first study that investigated SWT as a realistic treatment option for MTSS.

More recently Moen and Rayer et al. (2012c) conducted a study of patients with

MTSS that compared SWT treatment and a graded running program (n=22) with a control group that was only treated with a graded running program (n=20). The results from this study were somewhat different than the study by Rompe et al. (2010) when analyzing patient recovery time. The differing results between studies could be attributed to altered definitions of successful outcome measures. Rompe et al. (2010) defined successful recovery as 1 (completely recovered) or 2 (significant improvement) on a Likert scale (1-6), whereas the study by Moen, and Rayer et al. (2012c) defined successful recovery as being able to complete the graded running program with a four or less on a VAS pain scale (0-10). While recovery time and outcome measures were different in these two studies both results suggest that SWT is a viable and effective treatment option for MTSS since both studies' patients recovered and were able to return to previous activity. Therefore, SWT should be considered by practitioners when conventional treatments listed above are not effective for patients suffering from MTSS. SWT shows promise but more research is needed because it is a relatively new treatment method.

Current literature shows a wide variety of treatment options including, rest, NSAIDs, stretching and strengthening exercises, orthoses, graded running programs, SWT, and biphosphonates. None of these options have been shown to be better than another, signifying the importance for future research in this arena. Researchers should conduct randomized control studies that can provide further insight into cause and effect relationships between treatment options. This will help identify which ones are worth the time to prescribe to patients. Until that time, practitioners should try incorporating multiple treatment options to maximize the effects. The varied research design from these treatment studies has not allowed any conclusive evidence for any of these treatment options. Successful treatment doesn’t give an exact mechanism of injury, but it does provide some type of idea of what is wrong with the patients, and is therefore useful when trying to elucidate the causes of MTSS.

Kinetic, Kinematic, and Biomechanical Risk Factors

Biomechanical analysis has also been an important tool for investigating MTSS. It has been highly investigated that the individuals who develop MTSS present with certain biomechanical risk factors that may contribute to the injury. Some biomechanical risk factors associated with MTSS include: over pronation, limited hip internal rotation, increased BMI, low physical fitness, smoking habits, increased plantar flexion, muscle strength imbalance between inverters and everters, previous history of MTSS or stress fracture, less running experience, and orthotic use (Hubbard, Carpenter, & Cordova, 2009; Moen et al., 2012a; Raissi, Cherati, Mansoori, & Razi 2009; Sharma, Golby, Greeves, & Spears 2011; Tweed, Campbell, & Avil, 2008; Yagi, Muneta, & Sekiya 2013;Yates & White 2004; and Yuksel at al., 2011). Over pronation is the most commonly cited risk factor in prospective and comparative studies (Moen et al., 2012a; Raissi et al., 2009; Sharma et al., 2011; Tweed et al., 2008; Yates & White 2004) and should be kept in mind when investigating MTSS or writing an exercise protocol for MTSS prevention.

In 1982 Brody described the navicular drop (ND) test as a static test to measure the degree of foot pronation in injured runners. The ND test measures medial longitudinal arch deformation in weight bearing versus non-weight bearing and therefore can be related to foot function. The ND test is important because it quantifies the amount of pronation seen in the foot (Brody, 1982). Pronation of the foot is normal in gait, however larger pronation values, as measured by Brody's method is considered a risk factor for MTSS (Bennett et al., 2012; Brody, 1982; Moen, 2012a; Rassi et al., 2009; Rathleff et al., 2012).

Gehlsen and Seger (1980) looked at the angular displacement of the calcaneus from the midline of the lower leg in patients who had previous MTSS symptoms but were not feeling their symptoms during the test. These methods are very similar to measuring pronation, just in the hind foot. They found that individuals who had previous MTSS had a greater angular displacement from the midline of the lower leg to the calcaneus compared to the healthy control group. A second study with the same methods and testing procedures as Gehlsen and Seger (1980) found the same results (Viitalsalo & Kvist, 1983). These studies and Brody's were three of the first to investigate magnitude of mid foot and rear foot pronation as biomechanical risk factors associated with MTSS. Gehlsen and Seger hypothesized that greater pronation of the foot would cause a higher magnitude of eccentric contraction of the posterior musculature in the leg. Eccentric exercise is known to cause greater muscle damage than isometric or concentric exercise (Kanda et al., 2013; Parr, Yarrow, Garbo, & Borsa, 2009) and could be a contributing factor to the development of MTSS according to Gehlsen and Seger (1980).

Madeley, Munteanu, and Bonanno (2007) showed that subjects with MTSS did a significantly lower number of heel raises than a healthy control group suggesting that there may be a higher fatigue rate in the plantar flexors of the leg than in healthy people. Higher levels of foot pronation may be linked to greater fatigability. A study by Cowley and Marsden (2011) looked at the amount of foot pronation before and after a half marathon and showed a significant increase in ND after finishing the half marathon compared to before the start of the race. Similarly Gheluwe and Madsen (1997) showed that rear foot pronation significantly increases after a run to exhaustion. Gehlsen and Seger's hypothesis may have even more validity when taking these three studies into consideration, as fatigability certainly affects muscle contraction and therefore affects the muscles ability to attenuate shock during exercise. This shock may in fact increase the load on the tibia, and cause some of the symptoms of MTSS. The bone imaging studies cited previously certainly suggest this as a possibility and support the boney overload theory suggested by Moen et al., (2009). More studies are needed to further elucidate these hypotheses.

Yuksel and colleagues (2011) looked at muscle strength imbalance between MTSS patients and healthy controls of the inverter and everter muscles of the ankle. The investigators used isokinetic concentric muscle strength tests with an angular velocity of 30 degrees per second and 120 degrees per second to assess the inverter and everter muscle strength as well as the ratio of inversion strength to eversion strength. The investigators found a higher strength ratio in control groups than MTSS patients. They also found the everter muscles stronger in the MTSS patients and a lower inversion strength than healthy controls. The results of this study suggest that a strength dysbalance between the inverters and everters of the ankle could contribute to MTSS. The results support other investigations that have shown higher degrees of pronation in MTSS patients because the inverter muscles are weak. The inverter muscles of the ankle are the muscles that act to oppose the pronation movement, and if there is an imbalance between inverter and everter muscles this could contribute to higher degrees of pronation and higher risk of developing MTSS.

Rathleff et al. (2012) used reflective markers placed on the bare foot during a running task to measure navicular drop in dynamic conditions. The researchers evaluated ND characteristics in patients with MTSS in both static and dynamic conditions. The researchers found no differences between static ND groups, however there was a significantly larger dynamic navicular drop (dND) and larger dND velocity (2.4mm/sec) compared to controls. The researchers also found that patients with

MTSS had a 3% longer ND phase and a 4.2% longer stance phase than healthy controls.

Rathleff, Samani, Olesen, Kersting, and Madeline (2011) compared the variability of dynamic navicular height (dNH) as well as the surface electromyography (EMG) signal from the tibialis anterior (TA) and soleus between patients with MTSS and healthy controls. dNH is similar to dND however it is just taking into account the lowest point of the navicular tuberosity during the stance phase of gait. Patients with MTSS showed less variability in dNH than controls but their dNH on average was 1.5mm lower than healthy controls, meaning that the MTSS group showed less variability in midfoot kinematics but had an overall larger amount of pronation of the midfoot during stance. The study also showed that patients with MTSS had a higher variability in muscle activation in the soleus and TA muscles than their healthy controls. The healthy controls also showed a greater magnitude of EMG in both soleus and TA muscles than the MTSS counterparts. The researchers suggest that the greater variability and lower magnitude of EMG may relate to a less predictable muscle firing pattern that could result from a lower level of coordination and muscle strength. A prospective study using EMG should be used to determine whether muscle coordination is a legitimate risk factor in the development of MTSS.

A study by Li in 1990 showed that impact impulses during running are linearly related to heel strike velocities and that shank angle and knee flexion angle are responsible for the shape and direction of the impulse while running. These findings suggest that kinematics have a direct effect on the forces felt by the runner.

In a study by Lieberman et al., (2010) the researchers examined the running mechanics in habitually shod runners versus habitually unshod runners. The investigators found that habitually unshod runners showed a fore foot strike pattern, while habitually shod runners showed either a mid-foot strike pattern or a rear foot strike pattern. The habitually unshod runners who showed a fore foot strike pattern also showed very low loading rates on the ground reaction forces recorded by a force plate compared to a very high loading rate in habitually shod runners who showed a rear foot strike pattern. The habitually unshod fore foot strike runners also showed greater ankle dorsiflexion and knee flexion during the impact period of running compared to habitually shod rear foot strikers. These researchers discuss the fact that a more plantar flexed ankle and extended knee associated with rear foot striking may lead to injury due to larger impact forces and loading rates.

A Study by Milner et al., (2006) supports this discussion and results by Li (1990) and Lieberman et al., (2010). Milner et al., (2006) showed that female runners who exhibited a rear foot strike pattern and had previous tibial stress fractures showed larger impact forces and average loading rates than the control group. All three of these studies results seem to show that particular kinematics in the sagittal plane associated with rear foot striking is related to higher ground reaction forces and loading rates, which are also linked with higher rates of injury. Rear foot striking is also related to specific lower extremity joint angles, and could be an important factor in developing other injuries like MTSS.

These studies show that kinematic and kinetic measurements are a legitimate risk factors relating to MTSS, and that improper running mechanics, muscle weakness, and fatigue are all risk factors that have been shown to increase the risk of developing MTSS or other related injuries (Gheluwe and Madsen, 1997; Li, 1990; Lieberman et al., 2010; Madeley, Munteanu, & Bonanno, 2007; Milner et al., 2006). Special consideration and detail has been given to ND as a measure of pronation and have had reproducible results in the literature (Raissi et al., 2009; Rathleff et al., 2012). It may be that people suffering from MTSS not only show larger values for dND, and velocity of dND but other variations in gait patterns like larger plantarflexion and knee extension in runners with higher GRF found by Lieberman et al., (2010), and Milner et al., (2006).

Conclusion

This literature review has shown some of the underlying physiological conditions involved with MTSS, along with the anatomy thought to be involved with MTSS. Some treatment options for MTSS have been discussed, including conventional and non-conventional approaches gleaned from primary research, without much evidence favoring one treatment option over another. The biomechanical, kinetic, and kinematic risk factors thought to be most involved with MTSS development have been discussed and certain risk factors have been reproduced with good certainty in the literature. Many of the aforementioned studies have looked at MTSS and running kinematics with respect to frontal plane measurements such as ND however, the largest changes in joint angles occur in the sagittal plane during running. It is known that a weakness or imbalance in the kinematic chain may have an effect on more distal portions of the kinematic chain. Few studies have investigated running mechanics and kinematics in the sagittal plane. Therefore the purpose of this study was to use videography analysis to describe the lower limb kinematics of National Collegiate Athletic Association (NCAA) Division I (DI) athletes suffering from MTSS compared to NCAA DI athletes without MTSS. The thought is that if these athletes have differences in running kinematics, there may be different muscle activation or coordination that may be contributing to their condition.

CHAPTER THREE

Methods

The purpose of this study was to use videography analysis to describe the lower limb kinematics of NCAA DI athletes suffering from MTSS versus NCAA DI athletes without MTSS. This section will discuss (a) research design, (b) participants, (c) instrumentation, (d) procedures, and (e) data analysis.

Research Design

This study employed a descriptive quantitative approach. Basic descriptive statistics were used to summarize the data and two sample independent t-tests were used to analyze differences in mean angles between groups. This method was used because joint angles must be measured and recorded with quantitative data to be valid and accurate (Baumgartner & Hensley, 2013; Nunan, 2007). The researchers investigated whether or not there was a difference between athletes who had MTSS and athletes who did not have MTSS in these variables: hip angle, knee angle, ankle angle, angle of foot strike, and ND during a running task. This descriptive quantitative research design was used because it is the most accurate way to measure the variables of interest and answer the research questions (Baumgartner & Hensley, 2013; Nunan, 2007).

Sampling and Participants

This study used a convenience and purposive sampling procedure whereby the researcher sampled from a specific segment of the population because the researcher had access to the individuals in this study and the research questions were specific for this athletic population with MTSS; those inclusion criteria are listed below (Baumgartner & Hensley, 2013). Participants were selected based on the following inclusion criteria: (a) Current NCAA DI athletes 18 years and older, (b) the patients must be currently experiencing tibial pain and (c) the participants pain symptoms must present along the posterior medial border on the distal two-thirds of the tibia for greater than 5cm upon physician palpitation (Moen et al., 2012a). For the purpose of this study MTSS was diagnosed by a sports medicine physician. The participants who had MTSS were cleared to participate by the sports medicine doctor. Participants were recruited from NCAA DI teams from one University with consent from athletes and coaches. Participants with MTSS were matched with a control group of NCAA DI athletes for sex and sport played as best as possible however not all control participants played the same sport. This was discussed in the limitations section in Chapter 1. Participants were excluded from this study if the pain symptoms were not consistent with MTSS. The demographic information recorded is shown below in Table 1.

Table 1

Participant Demographic Information

Subject	**Gender**	**Age**	**MTSS**	**Sport**	**Position**
1	Female	22	Yes	Track & Field	Pole Vault
2	Male	22	Yes	Track & Field	Short Sprints
3	Female	21	Yes	Track & Field	Hurdles
4	Male	20	Yes	Track & Field	Pole Vault
5	Male	22	Yes	Football	Wide Receiver
6	Male	20	No	Track & Field	Pole Vault
7	Female	21	No	Track & Field	Pole Vault
8	Male	21	No	Track & Field	Short Sprints
9	Female	20	No	Track & Field	Hurdles
10	Male	21	No	Track & Field	Pole Vault

Instrumentation

A Cannon XL2 digital video camcorder was used to record the running motion of participants. Digital video cameras have been shown to be both reliable and valid for motion capture and analysis of human movement (Rathleff et al., 2012). Joint markers will be used to track joint centers and body segments for easier identification, and calculation of the relative joint angles (Loudon & Reiman, 2012; Rathleff et al., 2012). Dartfish video analysis software was used to analyze the digital video. Dartfish has been shown to be reliable when identifying and analyzing joint angles (Melton, Mullineaux, Mattacola, Mair, & Uhl, 2011). Participants completed all running trials on a SportsArt Fitness 6320 treadmill. Treadmills have been shown to be valid tools when performing running tests on subjects with MTSS and are considered a safe means of testing athletes with MTSS (Moen et al., 2012a, 2012b, 2012c, & 2012d). Microsoft excel and R were used to record and sort joint angles and navicular drop test data as well as provide basic statistical tools and statistical analysis and to display data within the paper (graphs, tables, bar charts etc.).

Procedures

Approval for all procedures was obtained from the Human Subjects Committee (HSC) at Idaho State University (see preliminary page iv). Once approval was granted by the HSC a pilot study was completed with one male and one female participant to evaluate the proposed study methods. The pilot study indicated the procedures were safe and sufficient for obtaining the joint angle measurements required, therefore no adjustments were made to the procedure. Participants were informed of the purpose and requirements of the study before agreeing to participate. Then the MTSS participants were examined by the team physician for proper diagnosis of injury. All participants were asked for their written consent before participating in this study.

Before obtaining the joint angles during the running test, participants were shown a visual analogue scale for pain (VAS) from 0-10 (0- no pain, 10- worst pain ever felt) previously described by Moen et al., (2012b). Participants were shown the VAS during the running test and instructed that if symptom pain presents with a four or higher on the pain scale (0-10), the running test must be stopped and will continue at a later date. No participants experienced a pain level of four on the pain scale so stopping the test was not necessary. The video camera was placed perpendicular to the sagittal plane 3 meters away from the treadmill and marked on the floor to make sure exact placement and distance for every trial was accurate, and that enough room was given to capture all joint angles. The Cannon XL2 camcorder was set with a frame rate of 60 frames per second (fps) in order to capture the precise moment of foot contact with the ground.

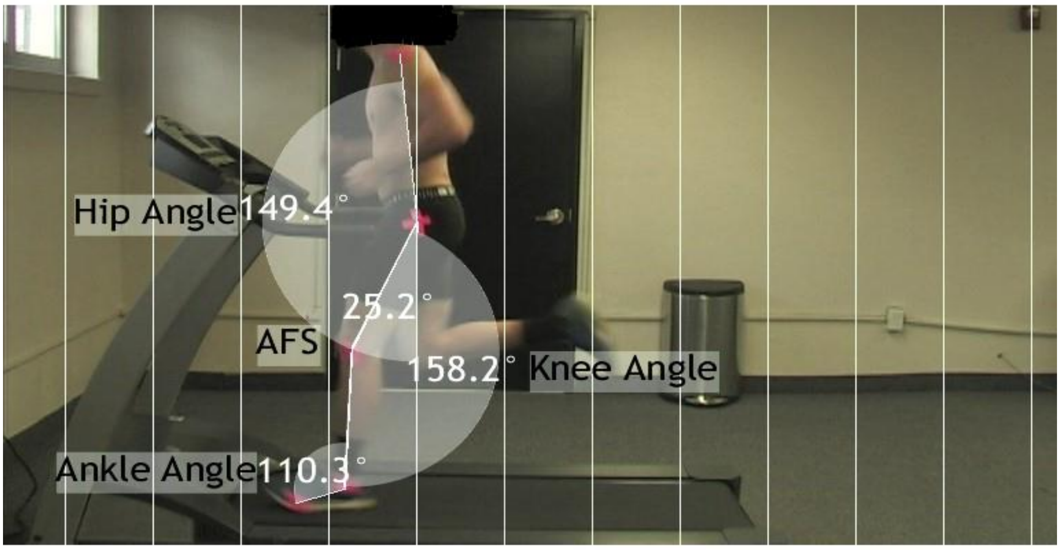


Figure 1. *Joint angle measurements for hip, knee, ankle, and AFS.*

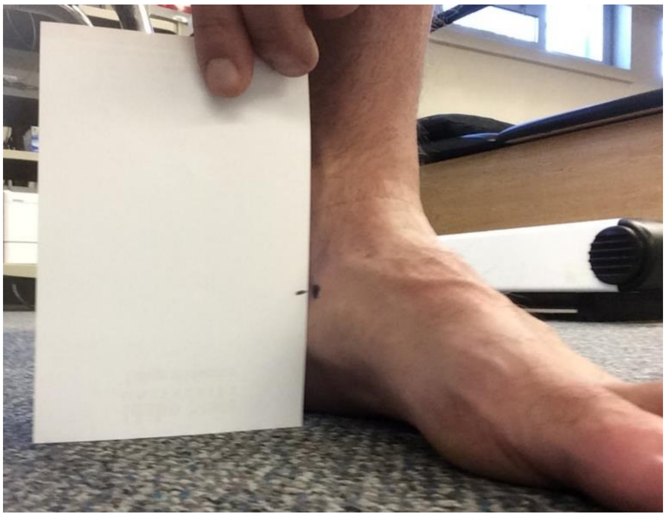
The kinematic measurements researchers analyzed were: hip, knee, and ankle angles at foot strike, navicular drop (ND), and angle of foot strike (AFS) also known as over striding. In order to find the joint angles necessary for this study reflective markers were placed on the left side of the body at the joint centers of the shoulder, hip, knee, and ankle. The last marker was placed on the shoe of the participant at approximately the fifth metatarsal phalangeal joint. This last marker provided the researcher with the foot segment for proper ankle angle measurements. Figure 1 above shows the placement of joint markers in pink crosses, and angle measurements in degrees for each joint angle captured.

All measurements were relative to the body segments except for angle of foot strike. Angle of foot strike was measured from the thigh segment and hip joint to a perpendicular point on the ground. The hip joint angle was measured as the angle between the lines formed by the shoulder joint marker, the hip joint marker, and the hip joint marker and the knee joint marker, respectively, or the angle between the torso and thigh body segments (Hammonds, Laudner, McCaw, & McLoda, 2012). The knee angle was measured as the angle between the thigh and shank body segments (Hammonds, Laudner, McCaw, & McLoda, 2012). The ankle angle was measured between the shank and foot segments. Larger ankle angles indicate greater plantar flexion and smaller ankle angles indicate greater dorsiflexion (Lee, Kim, Lee, Kurihara, Lee, & Kawakami, 2010). Angle of foot-strike (AFS) also considered over striding, is the angle between the thigh segment and hip at foot-strike in relation to a perpendicular line from the hip joint center to the ground (Nunan, 2007). All angles were recorded at the moment the foot contacted the ground.

Investigators obtained measurements for the navicular drop test to for the degree of static pronation in the ankle (Brody, 1982). The measurement for static navicular drop, previously described by Brody (1982) was taken just before participants began their warm up. A marker was placed on the navicular tuberosity. A 3x5 card was placed next to the subject's foot and marked at the level of the navicular tuberosity mark while the subject was in subtalar joint neutral. The 3x5 card was marked again at the level of the navicular tuberosity mark when the participant went into a full weight bearing position. The difference between the two marks on the 3x5 card were measured in millimeters and recorded. This measurement was only performed and recorded once for each subject. An example of the methods used are shown in Figure 2 below.

a.

b.



c.

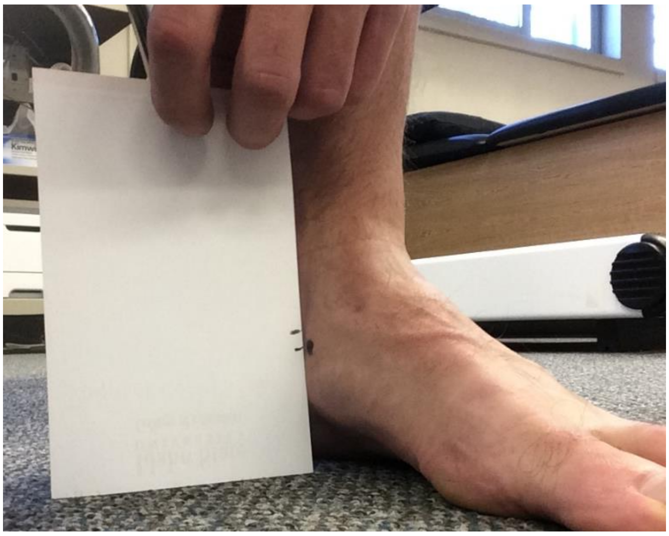


Figure 2. Methods for measuring static navicular drop described by Brody (1982). (a) Mark placed on the navicular tuberosity, (b) mark on the 3x5 card at the level of the mark on the navicular tuberosity while the subject is in subtalar joint neutral, and (c) a second mark on the 3x5 card corresponding to the same mark on the navicular tuberosity while the subject is standing in a full weight bearing position. The ND is the difference between the two marks measured in millimeters.

Participants were instructed to wear their normal running shoes and dress in minimal clothing such as short shorts or spandex and a tank top or sleeveless shirt for easier joint marker placement and joint center identification. Once participants were in the lab, they completed a questionnaire designed by the researcher to gather basic demographic information shown in Appendix A. The participant's duration of MTSS symptoms was also noted by the researcher at this time. As a warm up participants walked for two minutes, and then jogged for four minutes at a pace deemed comfortable by the participant. Next, participants ran at a pace of 10 MPH (approximately 4.47 m/sec) for one minute. The investigator recorded the participant during the one minute run. The angles from each foot strike over the entire one minute were used to obtain average joint angles. Participants then performed a four minute cool down consisting of jogging and walking. The described running test procedures have been modified from Moen et al., (2012a) to accommodate the research questions and participants.

After participants ran on the treadmill, the video was analyzed using Dartfish software. Motion capture tracking was used to trace joint markers on the subjects and the investigator manually adjusted the cursor to the proper joint center location when necessary. Sagittal plane joint angles were recorded on an excel spreadsheet. An example of hip joint angle data collected for participant 1 is illustrated in Table 6 (Appendix C).

Data Analysis

Basic descriptive statistics and two sample independent t-tests were used to analyze the data points. Two sample independent t-tests were used to test the difference between athletes with MTSS and athletes without MTSS for each measured variable. (Baumgartner & Hensley, 2013). Means were calculated for each subject's following joint angles: hip, knee, ankle, angle of foot strike shown in Figure 1. The static measurement navicular drop was also recorded on each subject's excel spreadsheet (Figure 2 a-c). Average joint angles and standard deviations were calculated for each subject shown in Table 2 of the results section. These averages were then used in subsequent calculations for an independent sample t-test. In order for the researcher to be comfortable assuming a normal distribution of joint angles the number of samples taken must be greater than 30 ($n \geq 30$). The number of foot strikes for each individual varied from 88-96 during the one minute running task, therefore the researcher was comfortable assuming the averages of each subject's joint angle measurements met the assumptions of an independent sample t-test shown by a normal distribution of angles throughout the test. An example of the approximate normally distributed angles is shown in Figure 3 for participant 1's hip angles.

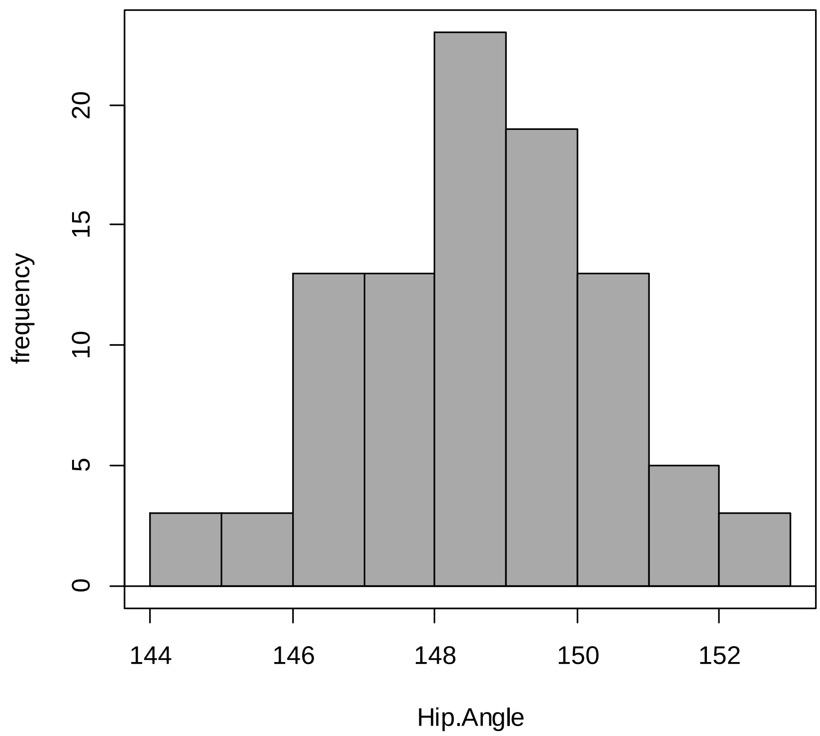


Figure 3. Histogram of hip angle for participant 1 shows a normal distribution, therefore our assumptions are met for an independent sample *t*-test.

The variation between individual sample size (n= 88-96) measurements represents the number of times an individual's left foot struck the ground during one full minute of running on the treadmill. Participant 1's left foot struck the ground 95 times during one minute of filming at 10 miles per hour, therefore 95 measurements were used to calculate average joint angles for participant 1 (Table 6, Appendix D). These same measurements were used to create the distribution of hip angles for participant 1 shown in Figure 3. The sample sizes varied among subjects because of differences in stride length and stride frequency.

Conclusion

This chapter has reviewed the research design, sampling and participants, instrumentation, procedures, and data analysis. This study used the instruments, procedures, and purposive sampling procedure to analyze individual athletes' stride differences by assessing relative joint angles at ground contact and static ND. These measurements were used to test for statistically significant differences between MTSS groups. The running task procedure described in the methods section was modified from Moen et al., (2012a) and the static ND test described by Brody (1982). These procedures were sufficient in data collection and analysis with statistical tests.

CHAPTER FOUR

Results

The purpose of this study was to use videography analysis to describe the lower limb kinematics of NCAA DI athletes suffering from MTSS versus NCAA DI athletes without MTSS. This section discusses the results of the current investigation, as well as the statistical tools used in further detail. As mentioned in the introduction and literature review chapters, researchers have investigated frontal plane kinematics, in particular the frontal plane movements of the ankle and foot in both static and dynamic conditions with respect to MTSS (Moen & Bongers et al., 2012; Rathleff et al., 2011; Rathleff et al., 2012). For this reason the investigator took a static measurement of pronation to elucidate frontal plane movement of the ankle and foot to add to the current literature. However, the main objective of this study was to investigate the kinematics of running from a sagittal plane view (lateral view) because there are large ranges of motion in the sagittal plane at the hip, knee, and ankle joints in running but it has not been as thoroughly investigated as frontal plane movements with regards to MTSS. This section will present the statistical analysis in further detail and present the relevant findings of the investigation.

MTSS and control group averages were calculated for each joint angle using each subject's joint angle averages. Table 2 shows all subjects joint angle averages, ND measurement, as well as gender, and the group category: MTSS, or control. An independent two-sample *t*-test was then used to compare joint angle measurements between groups. The following hypothesis was used to evaluate each of the joint angles:

H_0: $\mu_{MTSS} = \mu_{NoMTSS}$

H_a: $\mu_{MTSS} \neq \mu_{NoMTSS}$.

An α=0.05 was used for the two tailed *t*-tests. Average joint angle breakdown for each group are shown in Table 3 along with standard deviation, *t*- values, p- values, and degrees of freedom. Table 3 also shows the r^2 = 0.86, not listed is the adjusted r^2 (r^2_{Adj}= 0.784) for gender and MTSS versus ND. The r^2 of .86 shows a large measure of effect for ND.

Table 2.
Subjects sex, group, average joint angles with standard deviations, and ND in millimeters. Angles are in degrees.

Sex	**Hip mean (SD)**	**Knee mean (SD)**	**Ankle mean (SD)**	**AFS mean (SD)**	**ND**
MTSS Group					
Female	148.73 (1.78)	159.71 (3.12)	117.08 (3.33)	30.28 (0.93)	7mm
Male	147.98 (1.82)	163.71 (2.5)	104.17 (2.66)	28.31 (1.17)	14mm
Female	158.72 (2.18)	164.57 (3)	104.41 (2.5)	26.22 (1.4)	9mm
Male	153.63 (1.9)	160.12 (2.5)	110.81 (3.1)	24.29 (1.03)	16mm
Male	148 (1.77)	157.48 (4.21)	121.51 (3.4)	26.62 (1.03)	14mm
Control Group					
Male	150.11 (1.84)	156.6 (15.3)	110.21 (10.9)	27.08 (1.1)	5mm
Female	150.67 (1.83)	158.72 (10.69)	119.21 (4.02)	29.61 (1.13)	5mm
Male	150.82 (1.69)	165.53 (3.65)	109.31 (4.35)	28.68 (1.2)	9mm
Female	158.40 (2.07)	165.29 (3.64)	114.93 (5)	21.07 (1.5)	8mm
Male	154.53 (2.73)	162.99 (5.81)	112.63 (3.03)	21.04 (1.95)	4mm

Table 3.
*Mean and standard deviation, t value, p value, degrees of freedom, and r^2 of independent sample t-test for joint angles and navicular drop. *Indicates statistical significance with α< 0.05.*

Angle	**MTSS Mean (SD)**	**Athletic Control Mean (SD)**	***t*-value**	**p-value**	***df***	**r^2**
Hip Angle	151.41 (4.18)	152.91 (3.54)	0.5666	0.5877	7.416	
Knee Angle	161.12 (2.95)	160.42 (4)	0.2327	0.824	5.79	
Ankle Angle	111.6 (7.68)	113.26 (3.98)	0.4296	0.6825	6.009	
AFS	27.14 (2.26)	25.5 (4.15)	-0.779	0.4648	6.183	
ND	12 (3.81)	6.2 (2.17)	-2.96	0.024*	6.35	.86

Hip Angle

The average hip angle and standard deviation for the MTSS group was mean m=151.41 and SD=4.18 while the control group mean m=152.91 and SD=3.54. The two sample *t*-test with *df*=7.416 showed t= 0.5666, p=0.5877 with a 95% confidence interval (-4.67 - 7.66) indicating no difference between hip angle at foot strike.

Knee Angle

The average knee angle and standard deviation for the MTSS group was mean m=161.12 and SD= 2.95, while the control group showed mean m=160.42 and SD=4. The two sample *t*-test with *df*=5.79 showed t= 0.2327, p=0.824 with a 95% confidence interval (-8.16 – 6.75). This showed no significant differences between the MTSS group and control group for knee angle at foot strike.

Ankle Angle

The average ankle angle and standard deviation for the MTSS group was mean m=111.6 and SD=7.675, while the control group had mean m=113.26 and SD=3.98. The two sample *t*-test with *df*=6.00 showed t= 0.4296, p=0.6825 with a 95% confidence interval (-7.8 – 11.12). This showed no significant differences between the MTSS group and control group for ankle angles at foot strike.

Angle of Foot Strike

The average AFS and standard deviation for the MTSS group was mean m=27.14 and SD=2.26 while the control group showed a mean m=25.5 and SD=4.15. The two sample *t*-test with *df*=6.18 showed t= -0.779, p=0.4648 with a 955 confidence interval (-6.78 – 3.49). This showed no significant differences between the MTSS group and the control group for AFS. A bar graph of joint angles versus group is depicted in Figure 4 for a graphical display of these joint angles.

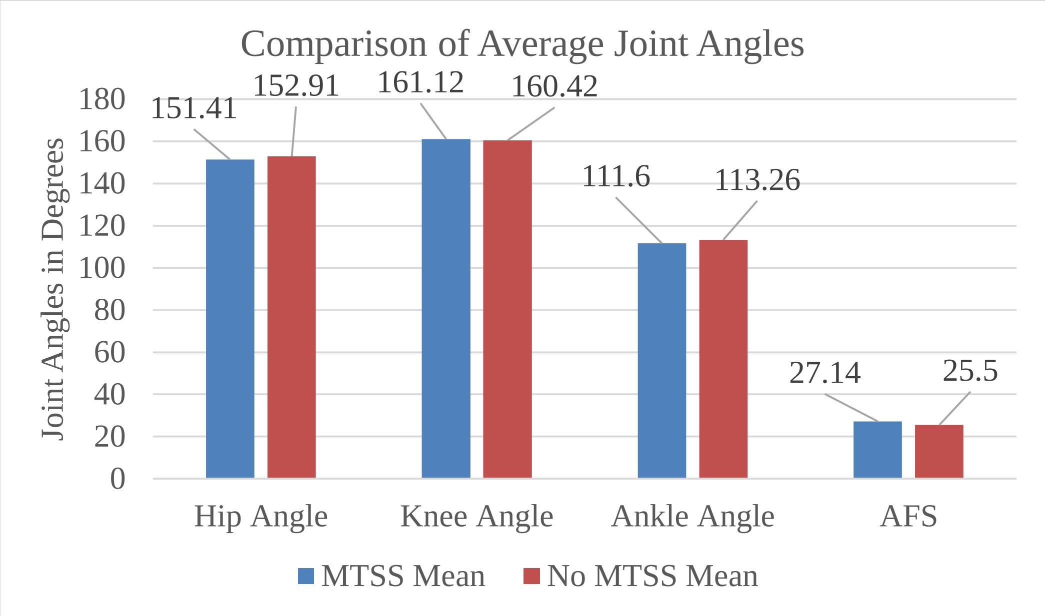


Figure 4. Comparison of average joint angles in degrees between MTSS group and controls.

Navicular Drop

The ND mean and standard deviation for the MTSS group was: mean m=12 and SD=3.81 while the control group mean m=6.2 and SD=2.17. The two sample *t*-test with *df*=6.347 showed t= -2.9598, and p=0.02366 with a 95% confidence interval (-10.532 - -1.068). This is the only value that reached statistical significance between MTSS and control groups (see Table 3). Figure 5 shows a box plot of the ND averages for MTSS versus controls. The boxes for MTSS participants and controls are not overlapping on the y axis, indicating the significant difference between group averages for ND. The bars extending away from the boxes in either direction indicate the ranges of ND measured for each group.

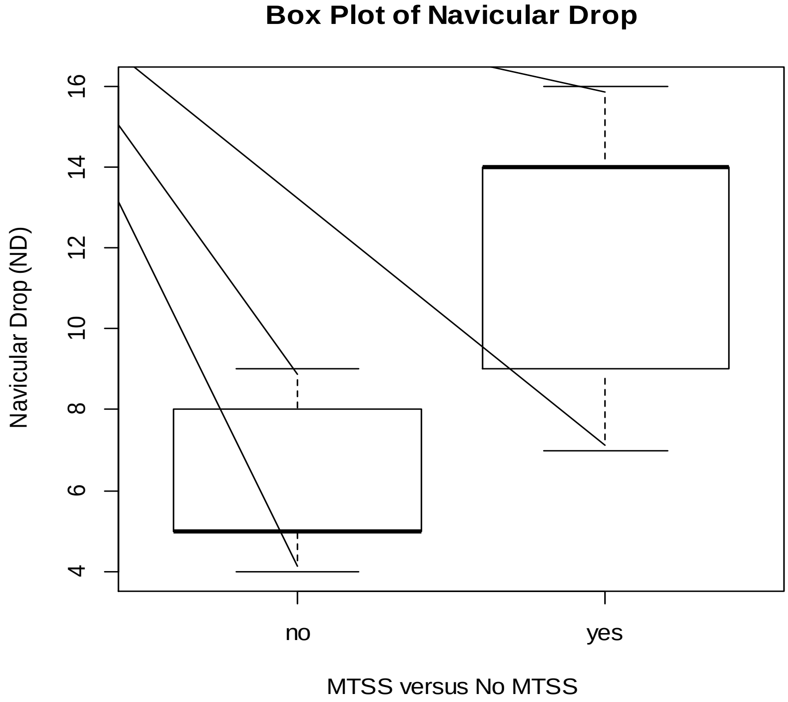


Figure 5. Box plot of navicular drop for MTSS group versus control group. MTSS group m= 12mm (SD= 3.81), control group m= 6.2mm, (SD= 2.17).Y axis in millimeters.

Because the independent sample *t*-test was shown to be significant for the ND measurement, a two-way ANOVA was conducted to determine if there was a relationship between navicular drop, sex, and MTSS. The null hypothesis for the two way ANOVA was there is no difference between sex and MTSS level for ND. The alternative hypothesis was there is a difference between sex and MTSS level for ND. Table 4 below shows the statistical summary of the two-way ANOVA.

Table 4.
*ANOVA table for the interaction between MTSS, sex, ND. * p< 0.05, **p<0.01*

Two-way ANOVA: Sex v. MTSS				
Response: ND				
	Sum Sq	*df*	F value	p value
Sex	22.817	1	5.9094	0.051099
MTSS	84.1	1	21.7813	0.003442**
Sex: MTSS	30.817	1	7.9813	0.030151*
Residuals	23.167	6		

A significant relationship between ND and MTSS occurrence was found (F=21.781, *df*=1, p=0.003). This showed that there was a significant interaction between ND and MTSS occurrence, the higher the ND the greater the likelihood of developing MTSS. Secondarily, two-way ANOVA showed a significant interaction between subjects' sex and MTSS group for the ND measurement (F= 7.9813, *df*=1, p=0.03). Females without MTSS showed an average ND= 6.5mm, while males without MTSS had an average ND=6mm. Females with MTSS had an average ND=8mm, but males with MTSS had an average ND= 14.67mm. These results indicate that being male and having a greater magnitude of ND has a high association with MTSS occurrence. The averages for ND can be seen for both groups in Table 5.

Table 5.
Average Navicular Drop in millimeters for sex and MTSS or control group.

	Athletic Control	MTSS
Female	6.5mm	8mm
Male	6mm	14.67mm

The results of this study suggest there is a significant difference in the magnitude of ND between athletes who have MTSS and athletic controls. It should be expressed again that this study's sample size is a significant limitation to this study, and future studies should investigate a bigger population of MTSS patients. Despite this limitation these findings support other prospective and introspective studies that have investigated the occurrence of ND and MTSS (Moen & Bongers et al., 2012; Raissi et al., 2009; Rathleff et al., 2011; Rathleff et al., 2012; Sharma et al., 2011; Yates & White, 2004). No significant findings were shown for the other kinematic joint angle measurements. Further investigations should include the ND test in MTSS studies, as it is a cheap and quick measurement that is easy and provides good risk factor assessment for athletic individuals.

CHAPTER FIVE

Discussion

The purpose of this study was to use videography to describe lower limb kinematics in NCAA DI athletes with MTSS versus NCAA DI athletes without MTSS. The results of this investigation showed no significant differences in kinematic joint angles between groups; however a statistically significant difference was found for ND test between groups, with the MTSS group showing higher magnitudes of ND than athletic controls. Furthermore, men in the MTSS group had much higher ND magnitudes than women in the MTSS group, but the women still had greater ND than the athletic controls. These results support other findings in relation to pronation and prevalence of MTSS (Moen and Bongers et al., 2012a; Raissi et al., 2009; Sharma et al., 2011; Tweed et al., 2008; and Yates & White 2004), although the pain symptoms have yet to be correlated strongly with abnormal bone remodeling or muscle traction induced pain.

The kinematic chain is important for considering the mechanism of injury in physical activity Nicola and Jewison, (2012). Athletes will have a greater risk of injury and possibly decreased performance if there is muscle weakness, imbalance, or poor coordination in any of the muscles involved with the movement in sports (Nicola and Jewison, 2012; Reber, et al., 1994, Sano et al., 2013; Yuksel et al., 2011). Therefore it is imperative that coaches, athletic trainers, physical therapists, teachers, and sports medicine clinicians have an in depth understanding of the kinematic chain, and can apply this knowledge when creating a training program. Properly training an athlete is crucial for increasing performance and reducing the risk of injury especially with regard to volume and intensity of training (Nielsen et al., 2013). Understanding how elite athletes perform may provide some clues for correct mechanics, reduce the amount of injuries, and possibly improved performance, even if skill level and athletic potential are much lower in beginning and intermediate competition levels.

Multiple studies have suggested that the kinematic chain is important in running with regards to the development of injuries (Leiberman et al., 2010; Li, 1990; Milner et al., 2006; Nicola & Jewison, 2012) and the findings of this investigation indicate that some are more important than others with respect to the development of MTSS. The results of the current study showed no significant differences in joint angles at ground contact. These findings do not support other research studies that have indicated kinematic joint angles are related to ground reaction forces and increased injury rates (Li, 1990; Lieberman et al., 2010; Milner et al., 2006; Nicola & Jewison, 2012); however it should be noted that this investigation did not measure ground reaction forces. Figure 4 shows the comparison between average joint angles for the MTSS group and controls that were not significantly different, but it should be noted that the small sample size may not reflect the population. It should also be mentioned that joint angle measurements are not a direct measurement of motor program firing patterns, but reflects, in part, some form of the motor firing pattern during a running task. Furthermore EMG utilization in future research may elucidate these findings.

This study's results are consistent with other researchers' findings indicating the static navicular drop measurement for the degree of pronation in the ankle joint and the prevalence of MTSS. Other prospective biomechanical risk factor studies have found similar results (Moen et al., 2012; Rassi et al., 2009; Rathleff et al., 2011) Increased pronation has been shown in multiple studies to be an intrinsic risk factor for the development of MTSS. Excessive pronation can lead to an overuse of the plantar flexors and has been hypothesized to increase eccentric loading of the posterior musculature of the leg (Viitasalo & Kvist, 1983). Eccentric loading has been shown to cause delayed onset muscle soreness (DOMS) and reduced strength immediately after eccentric exercise and up to 24 hours after eccentric exercise (Vila-cha et al., 2012). Eccentric contractions have not been correlated directly with over pronation but have been suggested mechanisms relating, in part, to excessive pronation (Ghelsen and Seger, 1980). Viitasalo and Kvist (1983) stated that this continuous eccentric activity may reduce the muscle's ability to attenuate shock absorption because of muscle soreness and fatigue. As a result the mechanical forces are transmitted to the tibia inappropriately. If the stresses of excessive pronation keep occurring with physical activity, and the posterior chain muscles of the leg cannot attenuate the shock appropriately, this may result in continuous boney overload and abnormal bone remodeling as shown in imaging studies by Moen et al. (2012), Magnusson et al. (2001), and Ogurbutz et al. (2011). This eccentric loading could cause a traction induced injury on the soleus, flexor digitorum longus, or the deep crural fascia as well (Beck & Osternig, 1994; Garth & Miller, 1989; Michael & Holder, 1985; Stickley et al., 2009), but more investigation is needed to identify whether the pain symptoms are coming from muscle traction or bone overload.

In order to properly attenuate the forces felt from over ground running it is important to have the proper coordination of muscle activation. If the neuromuscular firing patterns are miss timed or improperly activated it may reduce the muscles ability to attenuate shock forces and cause injuries over time (Reber et al., 1993). Leiberman et al., (2010) found that heel striking increases impact transients in habitually shod runners while their habitually barefoot counterparts' forefoot strike and show a much lower rate of loading during impact. The authors hypothesized that the greater rate of loading in heel strikers may in fact increase the risk of injury.

Reber et al., (1993) used fine wire electrodes to measure EMG profiles of the gastrocnemius, soleus, peroneus brevis, tibialis posterior, and tibialis anterior during three speeds of running. They also used a high speed camera to synchronize the EMG profiles to different phases of running deemed heel strike and toe off. Their results show that the posterior muscles of the leg have the greatest firing rate during mid-stance because they concluded the muscles are being used to contract eccentrically to counter the dorsiflexion motion as their body weight shifts over the toe. The findings by Reber et al., (1993) counter the previously thought purpose of the posterior muscles of the leg which were supposedly used to push off during the toe off phase of gate. This study suggests that the posterior muscles of the leg are used instead to keep us from falling over, because they are maximally activated during mid-stance and not toe off. These authors suggest that as running pace increases or the duration of the run gets longer the more susceptible to fatigue and injury the runners become, and improper activation timing or strength and endurance of the posterior muscles may have exacerbating effects relating to injuries.

The study by Lieberman et al., (2010) brings up another question important for running and injury prevention: if the subjects who were heel strikers changed to a midfoot or forefoot strike pattern when running, would they see a decrease in impact loading rates? More importantly would they see a reduced risk of injury? A study done by Sharma et al., (2014) investigated the effectiveness of a gait retraining exercise protocol on subjects with increased risk of developing MTSS. The investigators used a foot balance score to illustrate peak lateral to medial balance of the foot during stance. This measurement is similar to pronation measurements or eversion measurements. The foot balance score targeted specific subjects who were at risk for developing MTSS. One hundred sixty-six participants were deemed at risk for developing MTSS based on their baseline plantar pressure variables, so 83 were randomly assigned to the gait retraining treatment group and 83 were assigned to the control group.

Biofeedback was given immediately after a walking task for the gait retraining subjects as well as neuromuscular coordination exercises to perform 3 times a week. The subjects were monitored and corrected about form and technique during the walking tasks as well as the exercises in the first weeks of gait retraining. Results showed the subjects in the gait retraining group had lowered their risk of developing MTSS by 75% compared to the control group based on a reduced foot plantar pressure score from their baseline measurements. This study was performed with male military recruits, therefore it is difficult to predict how other populations would respond to gait retraining. However these results suggest that using gait retraining may help reduce the risk of MTSS development and should be investigated further.

To expand the discussion of Reber et al., (1993) and Sharma et al., (2014) and elaborate on the type of muscle contractions occurring in the lower leg during locomotion a study done by Sano et al., (2013) investigated the stretch shortening cycle of elite Kenyan distance runners compared to physically active controls. The investigators wanted to determine if there were any biomechanical differences that characterized the Kenyan's elite level performance. The investigation employed EMG and ultrasonography methods in the musculature of the lower leg to visualize muscle activation patterns and the muscle tendon unit length changes in both groups during a hopping exercise. EMG was recorded for the tibialis anterior, medial gastrocnemius, and soleus muscles and ultrasonography was used to visualize the muscle tendon unit length changes in the medial gastrocnemius. The elite Kenyan runners displayed different EMG profiles and different muscle tendon unit length changes than their physically active counterparts. Specifically, the Kenyans EMG showed greater pre-activation of the TA, soleus, and medial gastrocnemius slightly before ground contact while the controls showed less pre-activation. The Kenyans also displayed smaller muscle tendon unit length changes during ground contact than the control group. The Kenyans had less muscle fascicle length changes and more tendinous structure length changes than the control group indicating the Kenyans were taking advantage of free energy storage and return of the tendinous structures compared to the controls.

Many other animal model studies have shown the prevalence and use of elastic recoil as an effective use of tendinous structures allowing animals to reduce energy demand while maintaining power output or increasing power output during locomotion. (Dawson & Taylor 1973; Morgan, Proske, & Warren, 1978; Roberts, Marsh, Weyand, & Taylor, 1997). These studies together indicate the importance of biomechanical variables in locomotion with respect to performance. Using muscles isometrically has been shown to use significantly less metabolic energy at the same muscular force than concentric contractions (Ryschon et al., 1997). Thus isometric contractions could help attenuate impact forces better than eccentric or concentric contractions with less energy consumption reducing fatigue and could possibly reduce risk of injury.

It is fair to note that elite athletes and animal models may not be directly comparable to other populations because of the genetic predispositions to be able to withstand higher workloads and increased force production. However, the altered firing patterns of the Kenyan runners suggests that there is a neuromuscular factor that could be learned and applied to other populations even if those populations are not genetically suited for elite performance. The way the Kenyans fire their muscles not only helps them increase performance but also reduces the risk of injury because of the increased force output and reduced energy demand on the muscle that allows the tendinous structures to store and return free elastic energy. The types of muscle contractions and neuromuscular activation patterns occurring in the lower leg should be investigated in MTSS patients. It would also be worthwhile to further investigate gait retraining as it may be the only permanent preventative solution for MTSS.

Practical Application

The results of this study support the findings of other investigations suggesting that over pronating may be a factor in the development of MTSS. The ND test is a quick and easy test to determine the magnitude of pronation in athletes. The ND test could be used as part of a more extensive yet easy pre-screening method to determine risk factors for MTSS by coaches, athletic trainers, and sports medicine clinicians. If an athlete falls into an at-risk category such as larger magnitudes of pronation they could be placed under a modified training program that focuses on injury prevention exercises and gait retraining protocols instead of the normal training load. The gait retraining protocol should focus on teaching the athlete to fire all the muscles before striking the ground thus pre-activating the muscles. This will allow the muscle tendon unit to store and return elastic energy from the external forces felt at ground contact.

Other strength and conditioning exercises should be used in conjunction with the gait retraining to better facilitate a training adaptation. Exercises used in the gait retraining study by Sharma et al., (2014) are of particular interest because they have been shown to work. Expansion of these exercises should be investigated as well as other exercises and modalities. Overall coaching, sports medicine clinicians, and athletic trainers need to focus their efforts more on using indicators and risk factors to place athletes in modified activity for preventative measures instead of treating athletes once they have gotten injured.

Suggestions for Future Research

Future research should focus on describing the types of contractions that occur in athletes with MTSS who display higher levels of pronation using methods similar to Sano et al. (2013). EMG and ultrasonography along with videography should be used to determine whether or not MTSS patients are contracting the muscles in the posterior compartment of the leg eccentrically as a brake, concentrically as a motor, or isometrically as a strut during a running or hopping task.

Secondarily, investigations should focus on identifying biomechanical risk factors further to give coaches and trainers a better idea of indicators that could be used to classify someone who is at-risk. Finally investigations should look at gait retraining as an intervention and prevention method for individuals who have MTSS or are at risk for developing MTSS. Adding to the current literature about gait retraining would be valuable for coaching applications.

In conclusion this investigation found significant differences between athletes with MTSS and athletic controls in navicular drop. Increased pronation has been implicated in other MTSS cases as one of the most common biomechanical risk factors and many studies have prescribed treatment options with this in mind (Loudon & Dolphino, 2010; Sharma et al., 2014). While treatment of the symptoms is important, future efforts should be made to prevent MTSS from happening at all. Therefore coaches and athletic trainers should be conscious of increased pronation as a risk factor for the development of MTSS. Athletes should be screened for this risk factor before starting training, and at risk individuals should be put through a gait retraining protocol with proper instruction and guidance (as in Sharma et al., 2014) to reduce the prevalence of MTSS in athletic populations.

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Appendix A

Demographic Information

Name: ________________________________

Age: ______

Sex: Male/ Female

Sport: ______________________________

Duration of Medial Tibial Stress Syndrome symptoms in weeks: ____________

Please describe the location and type of pain felt (i.e. throbbing, aching etc.):

Appendix B

Visual Analogue Pain Scale (VAS)

0	1	2	3	4	5	6	7	8	9	10

No Pain Moderate Pain Worst Pain Ever Felt

Appendix C

Table 6.

Subject 1: 95 joint angle measurements from each foot strike during one minute of filming. The 2nd to last row is the average joint angle, and the last row is standard deviation.

Hip Angle	Knee Angle	Ankle Angle	AFS
149.4	160	109.5	29.7
149.9	164	114.6	28.1
147.9	160.8	116.2	30.3
147.9	162.9	112.9	30.7
148	165.5	114.5	30
149.6	161.8	116.2	29.7
149.3	164	116	29.7
148.2	163.4	115.2	30.5
147	161.4	115.9	30.9
148.7	164.1	116.5	29.3
150	161.5	114.5	31
150.4	164.5	115.9	29.9
146.6	159.4	114.9	31.5
150.5	160.3	113.5	31.1
152.4	160.4	111	30.6
150.9	163.5	115.2	30.5
149	160.4	113.3	30.4
150.4	167.8	115.3	28.5
148.7	158.4	116	31
150.8	165.5	114.3	31.3
146.6	160.4	116.2	31.7
149.8	161.3	116.3	30.6
149.8	160.5	112.6	30.6
149.7	161.2	111.5	31.3
148.1	162.6	117.3	30.9
148.1	158.3	116.4	32.4
149	156.2	116.7	33.1
150	164.3	114.6	30.3
149.6	163.7	118.8	28.9
147.3	156.9	114.9	30.5
151.7	166.2	114.4	30.2
150	159.5	113.2	29.2
152.1	164.5	111.9	28.3
148.4	157.3	114.5	29.5
147.3	163.6	112.6	29.8
149.7	159.6	111.7	29.7
150.1	159.3	112.5	30.2

150	156.7	116.2	28.9
148.4	161.4	115.5	30.8
151.8	160.6	116.5	30.1
149.1	160.7	116.3	30.1
150.8	162.9	116	29.5
147.6	159	115.1	29.6
147.9	158	113.6	30.6
146.2	159.2	117.5	31
152.4	161.1	119.1	28.9
151.8	162.2	111.3	28.9
148.7	158.1	111.7	29.5
148	160.4	112.8	29.9
148.1	155.5	114.2	31.1
147	158.5	117.2	29.9
149.9	160.4	115.7	31.2
149.2	159.8	124.9	30.4
151.6	158.8	117.9	29.9
148.3	157.7	116	30.9
148.8	159.5	120.2	30.1
145.6	155.4	120.4	31
146.6	153.4	117.5	30.7
146.8	159.2	120.3	30.4
150.2	160.4	123.2	30
148.9	160.9	122.9	29.2
149.5	157	118.6	30.1
149	161.3	117.4	30.1
147.8	157.2	121.8	30.5
150	163.3	121.5	29.9
148.2	155.1	116.8	31.1
146.2	157.3	123.2	32
148.8	161.6	121.7	29.7
148.5	156.9	118.8	30
149.3	159.6	115.8	31.1
146.6	156.9	119.6	30.2
148.7	161.6	119.2	30.1
147.4	157.5	121.3	30.3
148.8	160.5	121.3	28.3
145	155.5	119.5	31.2
145.4	156	119.6	31.8
146	153.4	117.2	30.9
144.4	155	120.7	30.9
150.5	160.6	118.8	28.2
150.7	160.2	119	30
150.4	158.3	118	29.4
150.9	159.4	121	29.1

151.5	161.9	117.7	29.4
149	155.2	116	30.2
150.1	160.8	117.7	29.5
147.9	155.2	119.5	29.5
148.1	155.4	121.3	30.6
146.6	154.6	121.5	31.3
146.5	154.4	121.2	31
144.4	156.3	119.9	31.8
146.9	159.7	122.7	30.8
148.1	160	123.8	31.4
148	160.3	120.3	30.1
146.5	157.2	120.7	31.4
147.2	152.8	119.9	30.3
148.732	159.714	117.079	30.281
1.784	3.12	3.332	0.925