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# ASSESSMENT OF FIFTH METATARSAL ETIOLOGY

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# ASSESSMENT OF
# FIFTH METATARSAL FRACTURE ETIOLOGY

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A Thesis
Presented to
the Graduate School of
Clemson University

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In Partial Fulfillment
of the Requirement for the Degree
Master of Science
Bioengineering

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by
Daniel Reed
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Accepted by:
Dr. Martine Laberge, Committee Chair
Dr. Lisa Benson
Dr. Larry Bowman MD

## ABSTRACT

The fifth metatarsal “Jones Fracture” is a fracture that occurs 3.5cm distal to the tuberosity. It is an injury that is common in athletes, especially those who participate in sports with a lot of lateral movement. The Jones Fracture is known for its difficulty to heal due to non-union and re-fracture. There has been much research recently regarding in-shoe pressure distributions and their relation to shoe type, movement, and shoe surface interaction. However, only the forces along the bottom of the foot have been investigated. Literature and the direction of fracture seem to implicate a force on the lateral portion of the foot is the cause of the fracture though the exact causal forces are still largely unknown.

Until now technology has limited researchers in the investigation of the forces distributed along the lateral portion of the foot. SensorTech is a moldable ultra-high molecular weight polyethylene sensor that is capable of reading those forces. Its wireless application will also allow for forces to be read while an athlete performs a series of maneuvers without being encumbered. In order to best utilize this new technology the variables applicable to the jones fracture needed to be determined. To accomplish this, a survey was sent to the head athletic trainers of all of the Division 1 Football Bowl Subdivision and Football Championship Subdivision’s Universities. The survey addressed shoe types worn, number of fractures incurred, what movement was being performed, surface being played on, how it was treated, and what the return to play time was.

The information gleaned from the survey was used to design a study in which athletes will be run through a series of maneuvers and while the forces along the fifth metatarsal are recorded. The survey revealed that Division 1 Bowl Subdivision athletes are significantly more likely to receive a fracture. Lateral cuts were also found to cause significantly more fractures than any other movement. Possible contributors were found to be Nike cleats (in one of the two years) and artificial turf. Those factors are all addressed in the study design in order to provide definitive results of how each factor affects the forces. This information could lead to the development of a method of Jones Fracture prevention.

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# CHAPTER I

# INTRODUCTION

The "Jones Fracture" is a fracture of the fifth metatarsal that occurs at the metaphyseal-diaphyseal junction, more specifically located 1.5 cm distal to the tuberosity of the fifth metatarsal[37]. The injury is common in athletes and can occur as an acute or a stress injury. The fracture presents itself at the point where the primarily cancellous bone transitions into the cortical bone found throughout the diaphysis of the bone.

The purpose of this paper is to further investigate the etiology of the Jones Fracture. In order to gain a comprehensive look at possible factors implicated in current literature as well as those suspected by medical experts to lead to the fracture, a survey was conducted. The survey was sent to the head athletic trainers of Division 1 Football Bowl Subdivision and Division 1 Football Championship Subdivision. Results gleaned from the survey require further testing in order to pinpoint the exact forces responsible. New technology capable of measuring forces along the lateral portion of the fifth metatarsal will allow for that to happen. Using the information gleaned from the survey a methodology was developed for a study of the forces all along the fifth metatarsal of athletes performing different athletic maneuvers. This study not only provides a comprehensive look at the current state of Jones Fracture in Division 1 football but it provides the basis to design a methodology for testing athletes. That testing will provide the first detailed measurement of forces along the lateral portion of the foot under several different circumstances.  This data has the potential to revolutionize the way shoes are made and hopefully prevent more Jones Fractures from occurring.

# CHAPTER II.

# LITERATURE REVIEW: ANATOMY AND ETIOLOGY OF JONES FRACTURE

## 2.1 Anatomy of the foot and fifth metatarsal

*Skeletal Structure*

The foot has a complex skeletal structure, comprised of several short and long bones. The tibia and fibula extend to the talus to form the very stable ankle joint, a mortise and tenon joint. The talus is connected to the calcaneus, or heel, via the subtalar joint. This joint allows the foot to move from side to side, while the ankle joint provides the foot with the mobility to move up and down[78]. Below the talus, there are the five tarsal bones that work together as a group. The tarsal bones are connected to five metatarsals, via tarsal-metatarsal joints. The metatarsals are the long, thin bones that run down through the middle of the foot; these bones are numbered one through five, where "one" is the bone medial to the body connecting to the "big toe". Thus, it is the outermost metatarsal bone that will be discussed in this paper. The last set of bones in the foot is comprised of the phalanges, which are connected to the metatarsals by metatarsophalangeal joints; these joints form the ball of the foot. The big toe, or the hallux, is very important for motor functions, and the first metatarsophalangeal joint can be a problematic area of the foot[78].

*Tendons, Ligaments, and Muscles*

Tendons are soft tissues that connect bone to muscle; ligaments are very similar to tendons, but function to connect bone to bone. Both tissues are comprised primarily of collagen fibers, bound together in a tough, rope-like structure. The thickness of the soft tissues is directly correlated with the strength of the ligament or tendon. The Achilles tendon is a very thick tendon, found just above the heel on the lateral aspect of the leg. It runs from the calf muscles to the heel bone to facilitate the general up-and-down movement of the entire body. The posterior tibial tendon connects the underside of the foot to smaller calf muscles and functions to support the arch and control inward foot movement; the raising of the foot is done by the anterior tibial tendon. Two tendons run along the outside of the ankle (lateral malleolus) and function to turn the foot outward. Tendons also run along the bottom and top of the foot across the toes to bend the toes down or straighten them, respectively[78].

There is a collection of many tiny ligaments that is responsible for holding the bones of the foot together. The majority of these ligaments form a section of each joint capsule that can be found around joints of the foot. Joint capsules are watertight sacs that form around every joint in the body; they are comprised of the ligaments around the joints and the soft tissue found in the spaces between bones and ligaments[78].

The contraction of muscles in the lower legs is responsible for the majority of movement in the foot, via connecting tendons. These connections to lower leg muscles provide the ability to perform our daily motor functions, such as walking, running, and jumping. Similar to ligaments, there are many tiny muscles throughout the foot. These muscles are not as intricate as those found in the hand, but are critical in influencing movement of the toes and can present many problems if they are damaged[78].

*Nerves and Blood Vessels*

The tibial nerve runs along the inside of the ankle bone (medial malleolus), entering the sole of the foot to act as the primary nerve in the foot. This nerve is responsible for sensation to the toes and bottom of the foot; it also controls the muscles on the bottom of the foot. To provide sensation to the top and outside edge of the foot, several other nerves run throughout the top and outside edge of the foot[78].

The posterior tibial artery runs along the tibial nerve and is the main blood supply for the foot. Other arteries enter at various positions in the foot to provide blood to the remainder of the foot. The largest of these secondary arteries is the dorsalis pedis, which runs along the top of the foot. The lack of sufficient vascularity in the tight region of the fifth metatarsal has been suggested to seriously hinder the ability of the body to heal Jones fractures[69, 70, 78].

*Anatomy of the Fifth Metatarsal*

The fifth metatarsal consists of the head, neck, shaft or diaphysis, tuberosity or styloid process, and base. Its features are similar to those in other metatarsals, but its tuberosity is unique to the fifth metatarsal. The metaphysis tapers into the tubular diaphysis of the metatarsal; at the junction between the two portions is where acute and stress fractures within 1.5 cm of the tuberosity occur. The fifth metatarsal articulates with the cuboid proximally and the fourth metatarsal medially. There are three soft tissue attachments to the fifth metatarsal. The lateral band of plantar fascia inserts on the proximal tip of the metatarsal. The peroneus brevis tendon inserts in a "fan-like"[72] pattern across the tuberosity, while the peroneus tertius tendon inserts farther down on the shaft of the fifth metatarsal.

## 2.2 Terminology

The term "Jones" fracture was coined in 1902 by Sir Robert Jones after he sustained a fracture during a Maypole dance; thus, the fracture has alternatively been called "dancer's fracture"[37]. A combination load comprised of stressed inversion and plantarflexion often results in a fracture of this portion of the fifth metatarsal. Jones described the fracture himself as follows: "I trod on the outer side of my foot, my heel at the moment being off the ground[37]". Although Jones successfully treated his own injury conservatively, over the past few decades there has been controversy regarding the best possible way in which to treat this fracture; both surgical and non-surgical techniques have been analyzed. There is typically a high incidence of non-union or delayed union following Jones fractures, conditions in which the two bone fragments never fully rejoin following injury or do not rejoin within a clinically acceptable time frame, respectively.[16] The goal of treatment, operative or non-operative, is to avoid cases of non-union, delayed union, and re-fractures. Different methods of treatment will be discussed later in this paper. The Jones fracture is common among elite and recreational athletes, so it is critical that the fracture site be healed as quickly and effectively as possible.

The mechanism of injury has been described by many sources, and there are several different opinions in the literature as to how the fracture most frequently occurs. Because the ligaments surrounding the fifth metatarsal are so strong, it becomes easier to break the bone than dislocate it[37]. Due to the mechanical laws governing areas of stress concentration, it can be assumed that stresses accumulate at the point where the fifth metatarsal narrows, distal to the tuberosity. Given the geometry of the fifth metatarsal, this area is prone to Jones fracture injury when exposed to high levels of strain. The mechanism for fracture has been described as indirect, usually by a sudden inversion accompanied by weightbearing[11], often occurring after a fall, misstep, or jump. Cross-breaking strain directed anteriorly to the base of the metatarsal while the body is raised leads to adductive forces[10]. These forces, directed laterally to the metatarsal base while the foot is in plantar flexion and inversion is the most commonly described combination of forces encountered during Jones fracture[16, 72, 63]. One research group described Jones fractures as resulting from the foot failing to go into inversion, resulting in large vertical and mediolateral ground reaction forces[40]. It is known that the fracture results from very high loads concentrated near the base of the fifth metatarsal and that sudden movements encourage fracture propagation from the lateral to medial portion of the metatarsal, where the fourth and fifth metatarsals articulate[16]. However, there is not a universal consensus regarding which specific forces are actually responsible for the injury.

Signs and symptoms[37] for Jones fractures include slight swelling over the base of the fifth metatarsal and pain at the point of fracture. No deformity is present, and the bone does not yield upon manipulation. Long periods of immobilization may be necessary, and symptoms may linger for several months after fracture or surgery[16, 43]. Poor blood supply has been cited as a primary reason for slow and complicated healing of this fracture[11, 69, 70]. The nutrient artery is disrupted during fracture, and this artery has been cited as one of the critical factors in bone healing[70]. Mechanical predisposition to overloading has been suggested as another primary factor in the complicated, delayed healing rate of Jones fractures[43].

## 2.3 Epidemiology

There have been several studies conducted to analyze the epidemiology of acute and stress Jones fractures. First, anatomical variations in the foot and metatarsals have been correlated with particular incidences of fractures; people with rigid, cavus feet are more prone to Jones fractures than people with normal arches[64]. Acute Jones fractures tend to occur in non-athletes or in people who have compromised bone health due to cartilage or bone disease. However, some athletes who sustain very high forces during practice or competition are also subject to acute Jones fractures. The proportion of males and females who sustain acute Jones fractures is roughly equal[64]. Stress fractures tend to occur in athletes who are in intense training and are repeatedly executing pivoting or jumping movements with which high forces are associated[64]. Studies suggest that a higher percentage of females sustain Jones stress fractures[9]; this is most likely related to the presence of nutritional deficiency or hormonal imbalance more frequently seen in females than in males[77]. Although Jones fractures of both types have been seen in nearly every age group, the majority of stress fractures occur in younger patients who are actively participating in sports or other physically demanding activities. Acute fractures seem to occur more frequently in older age groups. The majority of Jones fractures reported in athletes occurs in basketball and football. Twisting, falling, and direct blows represent the three most common maneuvers resulting in Jones fracture[56]. Military trainees frequently get “march fractures”, or stress fractures of the second and third metatarsals, while athletes tend to experience predominantly lateral forces that produce Jones fractures.

## 2.4 Classification

There are other injuries to the fifth metatarsal that are commonly misdiagnosed as Jones fractures. The most common of these is the avulsion fracture occurring at the tuberosity of the fifth metatarsal. Although the fracture is in a similar region of the foot, the fracture occurs much closer to the tarsal-metatarsal junction than the Jones fracture. Avulsion fractures of the fifth metatarsal are the most commonly occurring fractures in the bone.

There has been confusion in the literature regarding the term “Jones fracture” and whether it represents both acute and stress fractures in the proximal diaphysis region of the foot, or just the acute fracture. A “Jones fracture” corresponds to the *region* of the metatarsal to which injury occurs. The injury can be acute or sub-acute, and there are distinct differences between presentation, treatment, and clinical management of acute and stress fractures.

## 2.5 Stress fractures of the proximal diaphysis

In 1997, Weinfeld et al[77] described the general pathophysiology and diagnoses of fifth metatarsal fractures. Stress fractures result primarily from alternating tensile and compressive forces transmitted to the bone through ligaments, tendons, and muscles. By themselves, these forces would not be significant enough to cause fracture, but after excessive repetition they often result in fatigue injuries. The group cites athletes, dancers, runners, and military personnel as being most at-risk for fatigue fractures in the metatarsals. Of these, athletes have the highest rate of incidence of Jones fractures. The fifth metatarsal is the most mobile of the metatarsals in the sagittal plane, but is limited by strong ligaments and muscle in adduction and abduction; high pressure on the plantar aspect of the foot places even more stress on the proximal end of the fifth metatarsal. For this reason, patients with cavus feet (very high arches), genu varum (bow-leggedness), or chronic ankle instability are at much higher risk for fifth metatarsal stress fractures. In addition, stress fractures are common in patients with neuropathic disorders, such as Charcot-Marie-Tooth (hereditary sensorimotor neuropathy) and diabetes, as patients with these disorders have decreased protective sensation in their feet. In these individuals, deformities or fractures are common occurrences.

Matheson et al[47] described the occurrence of stress fractures in a study of 320 athletes. Of all the stress fractures present, fractures of the metatarsal represented 8.8%. Of these, 16.6% were bilateral stress fractures, suggesting that perhaps certain anatomical or physiological characteristics in these athletes increased their propensity for fatigue fractures. From injury reports, it was determined that running was the most common activity when fracture occurred. Interestingly, mileage logged did not appear to have an effect on the rate of incidence of stress fractures. Other common activities during which fractures occurred include fitness classes, basketball, and racquet sports. Radiographs were only conducted in 43.4% of patients with initial injury complaints; of these, only

9.8% were abnormal. This indicates that there is a delay of conclusive radiographic evidence following initial symptoms of stress fractures. In general, females sustained fractures an average of three or four years earlier than men for each bone analyzed, again suggesting that various hormonal and nutritional factors are associated with the incidence of stress fractures.

Brudvig[9] and Meurman[48] studied the incidence of stress fractures in 339 and 827 military trainees, respectively. The two groups reported 28.3%[9] and 16.4%[48] of fractures as metatarsal fractures. In the second study, it was specified that only 2.9% of metatarsal fractures were in the fifth metatarsal (4 fractures), and that these occurred during running (2), Cooper fitness test (1), and unspecified activities (1). Females had a higher rate of incidence for these stress fractures, and Caucasians had higher rates of incidence than other ethnic groups. As age of trainees increased, a higher proportion of stress fractures were noted[9].

Preventative practices to avoid Jones stress fractures have been explored, and insole and shoe design are two areas in which modifications have been apparent. Schwellnus et al[67] asked 237 randomly selected military trainees to wear neoprene shock-absorbing insoles during nine weeks of basic training. Of these trainees, 84.6% said they wore the insoles every day. In terms of comfort, 74.8% of them found the insoles "comfortable" (the second-highest comfort rating), while 21.7% found them "very comfortable" (the highest comfort rating). There were 1151 trainees in the control group, and incidence of injury was recorded for both groups. In the group who wore insoles, the incidence of injury was 22.8%; for the control group, the incidence was 31.9%. The overwhelming majority of these were overuse injuries, suggesting that insoles did lower the overall incidence of stress injury.

In 1997, Frey et al[26] discussed the overall goals of footwear design in terms of user satisfaction and injury prevention. The goal of footwear, particularly in athletes, is to attenuate shock and control joint motion. The ground reaction forces runners experience while running is two or three times their body weight, and basketball players can experience up to five times their body weight when landing off of a jump. Most recently, advances in midsole design and competition have led to shoes that are able to provide additional cushioning, shock absorption and attenuation, lift, and control. As a shoe ages, it provides less shock absorption and foot support. Because of this decrease in performance, age of shoes has been positively correlated with incidence of injury. Higher-priced shoes often advertise themselves as better able to absorb shock and prevent injury. Interestingly, no correlation was found between price of shoe and incidence of injury[26]

## 2.6 Biomechanical evaluation of fifth metatarsal

*Metatarsal Strains Under Various Loading Conditions*

Many studies have conducted from 1958 to 2004 to determine the stresses and strains present in the metatarsals due to various cyclic loading conditions. In 1959, Lease et al[45] examined the fatigue life of 51 intact human metatarsals using a flexure fatigue machine and recorded bone diameter (midpoint) for each specimen. There was no gross pathology seen in any of the specimens, and each was loaded to failure with a 10 to 15 pound load to simulate different body sizes. With regard to age, there was no positive correlation between age of specimen and fatigue life. Also, there was no correlation between diameter of specimen and fatigue life. It was determined that metatarsals two and three had the longest fatigue life under wet conditions; metatarsals four and five have the greatest fatigue life under dry conditions. It is believed that the wet condition more closely simulates in vivo conditions. Finally, the comminuted and oblique fractures found in the specimens were similar to those occurring in clinical settings.

Thirty-one years later, Gross et al[28] recorded the forefoot stresses in 21 male distance runners using eight discrete piezoelectric vertical stress transducers. The group recorded peak stress in each metatarsal and toe and the maximum values for bending moment, axial force, shear force, and bending strain for each metatarsal. The highest average peak stresses were found under the hallux and second and third metatarsals. The average peak stress on the fifth metatarsal (322.5 kPa) was only 60.4% of the average peak stress on the second metatarsal (533.7 kPA), the metatarsal experiencing the highest peak stress. Shear forces and bending strains were the greatest for the second metatarsal, and the first metatarsal experienced the largest axial force. The first metatarsal has the lowest length to diameter ratio, making it the most robust metatarsal for resisting bending. The second and third metatarsals are the least resistant, which explains why these two are generally the location for the majority of stress fractures in athletes and military trainees. The fifth metatarsal is moderately resistant to strain, leading to the lower number of stress fractures in this region, when compared to the second and third metatarsals.

Roca et al[62] used a photoelastic model of the fifth metatarsal to determine where the majority of stresses occur in the bone. The model included elements to simulate tendon and muscle forces during walking. After testing, the model was viewed through polarized light, and resulting interference patterns were used to determine how loads were distributed throughout the bone. It was determined that the fifth metatarsal is stressed during walking and experiences the highest stresses when the hindfoot is carried in valgus by the peroneus brevis tendon as the heel rises. Although the bone is functionally adapted to stress, repetitive high forces present in the outer cortical area during contraction of the peroneus brevis may ultimately lead to fatigue failure of the bone.

In 1997, Arangio et al[6] used finite element analysis in conjunction with beam theory to determine stresses in the fifth metatarsal. Each cross section of bone was loaded to give rise to shear and normal forces, bending moments, and torsion. From the analysis, the stress at every point along the fifth metatarsal was determined, as were the principal stress and local maximum stress on the outer boundaries of each cross-section. Results suggest that the weakest portion of the metatarsal is located approximately 3.38cm distal to base of the fifth metatarsal, which corresponds almost exactly to the point at which Jones fractures occur and slightly proximal to the point where the majority of stress fractures of the proximal diaphysis occur. From radiographic analysis, the group also determined that a fulcrum effect occurring over the base of the fourth metatarsal articulation contributed to additional weakness in that region. Improvements to the current model include modifications to account for muscle forces, bone density, and dynamic loading.

Arangio et al[5] conducted a second study in 1998 to analyze shear and normal stresses throughout the second, third, fourth, and fifth metatarsals under various loading conditions. The stresses were determined mathematically using mechanics of solids theory. The group utilized computer assisted tomography (CAT) scanning to produce anatomical data of a 20 year-old male fifth metatarsal at 5 mm increments. Maximum tensile stress resulted from nearly horizontal loading and occurred in the cross section located 3.5 mm from the proximal end, again corresponding to the general region in which Jones fractures and stress fractures occur. Jones fractures are the result of a horizontal force progressing in a lateral to medial direction, as this is the loading position in which the bone experiences the greatest stress. Researchers suggest that increasing muscle strength, endurance, and proprioception and repairing loose lateral ankle ligaments may aid in preventing stress injuries in the third through fifth metatarsals.

Following the previous studies of stress in the metatarsals, Donahue et al[19] analyzed the stresses in the second and fifth metatarsals, where the majority of military and athlete stress fractures, respectively, occur. The group used a dynamic gait simulator to load fifteen cadaveric feet, approximating the peak strain during the stance phase of gait under three conditions: 1) normal walking; 2) walking with fatigue of auxiliary plantar flexors; and 3) walking after a plantar fasciotomy. It was determined that the peak axial strain is significantly greater in the second metatarsal than in the fifth. Accordingly, the fatigue life of the fifth metatarsal is estimated to be 51 times greater than in the second metatarsal[12]. The higher strains in the second metatarsal support the clinical findings that stress fractures of the second metatarsal are far more common than those in the fifth metatarsal. Simulated muscle fatigue greatly increased the peak strain in the second metatarsal and decreased peak strain in the fifth, and walking following plantar fasciotomy caused a large increase in the peak tensile strain for both bones. Fatigue of toe flexors does not seem to be a factor in the pathogenesis of stress fractures in the fifth metatarsal, as tensile stress was reduced during muscle fatigue. However, loss of function of the plantar fascia increases peak tensile strain in the fifth metatarsal, thus creating the propensity for fifth metatarsal stress fractures.

In 2000, Donahue et al[20] sought to further clarify the relative frequency of second and fifth metatarsal stress fractures by evaluating bone strain and microcracks at locations where stress fractures occur frequently. It has been suggested that microcracks on the surface of bones are the result of strain microdamage and lead to stress fractures. Bone strain was again measured using a dynamic gait simulator, and the microcrack and surface densities were measured. Two main findings were reported from this study. First, neither microcrack, nor surface density, was significantly related to age in either metatarsal. Second, there was no significant difference in microcrack or surface density in either metatarsal. In conclusion, it is clear that discrepancies between microcrack and surface densities in the second and fifth metatarsals do not account for the difference in injury frequency in the two bones.

Vashishth et al[75] analyzed the fatigue characteristics of cortical bone under combined axial and torsional loads using cylindrical dumbbell bovine bone specimens.

The group placed the specimens under a varying combination of axial and torsional loads and measured the cycles to failure for each condition. As would be expected, the combination of axial and torsional loads reduces the fatigue life of each specimen. The fatigue life was noticeably reduced when the maximum shear stress was greater than 59% of the maximum normal stress. The oblique fractures incurred during testing are representative of axial-torsional loading conditions and suggest that high torsional loads greatly reduce fatigue life in cortical bone.

In 2002, Milgrom et al[49] evaluated in vivo metatarsal strains during cyclic overloading by implanting strain-gauged staples in the tibia and the second metatarsal. The subjects performed various walking, jogging, and callisthenic exercises and simultaneously measured peak axial strain and strain rates in both bones. Microstrain levels in compression were five to nine times greater in the metatarsal than in the tibia; microstrain levels in tension were approximately twice as large in the metatarsal than they were in the tibia. Comparative microstrain levels are reported in Table 2. The combination of tensile and compressive strains during moderate activity can induce fatigue failure in the metatarsal, but typically not in the tibia. The higher levels of strain occur in the metatarsal before an intermediate bone remodeling response can be initiated, thus leading to stress fractures in a relatively short period of time.

Table 2.1. Comparison of metatarsal strain to tibial strain during various activities[49].

| **Activity** | **Compression Value Factor*** | **Tension Value Factor*** |
|---|---|---|
| Broad Jump | 9.1 | 2.5 |
| Vertical one leg jump | 5.7 | 1.8 |
| Vertical two leg jump | 5.8 | 2.2 |

*Value factors expressed as follows: metatarsal strain = tibial strain * Factor

Most recently, Vertullo et al[76] examined torsional strains in the proximal fifth metatarsal with respect to possible implications for management of Jones fractures and proximal diaphysis stress fractures. Specifically, the points on the fifth metatarsal to which the peroneus brevis and peroneus tertius tendons attach suggest that forces produced may result in torsional loads to the proximal region of the metatarsal where Jones and stress fractures occur. Following fracture, intramedullary screw fixation may not provide adequate resistance to rotation between the proximal and distal fragments. To analyze the forces present, cadaver feet were loaded to simulate axial and tendon forces, and principal and shear strains were measured through stacked rosette strain gauges placed in the locations where acute and stress fractures typically occur. The shear strains and their accompanying directions suggest that the fracture sites are prone to rotation during normal locomotion. Although intramedullary screw fixation has proven to be a relatively safe and effective technique for fracture fixation, an ideal device would resist torsion in addition to controlling tension and bending in the fifth metatarsal.

*Relevance of Biomechanical Evaluation to Clinical Studies*

The combination of research regarding strain in the metatarsals and efficacy of various fracture fixation devices strongly correlates to the incidence and treatment of Jones fractures found in clinical studies. For the metatarsals, no correlation was found between age or diameter and fatigue life, which explains why Jones fractures can occur in people of different ages and sizes. In addition, strain in the second and third metatarsals is much higher than in the fifth metatarsals, which correlates to the lower incidence of Jones fractures than march fractures. Also, the majority of Jones fractures result from a horizontal force that would not normally be experienced during normal walking or running activities, which again justifies the higher incidence of march fractures during repetitive walking and running exercises. The combination of anatomical characteristics and combination loading on the fifth metatarsal during particular movements make Jones fractures a frequent problem during many irregular movements. The fulcrum effect at the point of articulation with the fourth metatarsal, bending and torsional moments created by the tendons, and large forces experienced in the area when the heel rises make this area prone to fractures. It was determined that increased muscle strength, endurance, and proprioception helped to prevent injury.

## 2.7 Factors in shoe-surface interactions affecting injury

The interaction between shoe and playing surface has been shown to have an effect on various factors that could ultimately lead to injury. During athletic maneuvers, torque is developed between the shoe and the playing surface, as well as between the shoe and the foot. Torque on the foot of a player can place unreasonable stress on bones, ligaments, muscles, and tendons, thus leading to injury. Frictional and traction properties between shoe and playing surface can affect player safety and performance. Finally, playing conditions, including type of surface and climate during play, can also significantly affect safety and performance. An optimal balance must be found among shoe type, surface conditions, and other factors.

Beginning in the mid-1970's, a series of studies were conducted to determine the effects that playing surface, shoe type, and a couple of other factors had on the peak torque developed during athletic movements. In 1975, Bonstingl et al[7] investigated the effects of shoe type, playing surface, weight supported, and stance position on torque developed at the shoe-surface interface. Although the torque developed at this interface has been suggested as a factor in many knee injuries, it is reasonable to assume that the same torque may be responsible for many foot injuries, as well. Their testing apparatus utilized the impact of a weighted pendulum jerking a metal leg to simulate the sudden torque generated during athletic movements. Eleven different shoe types, four playing surfaces, two player weights, and two stance positions were tested. Several conclusions were drawn after the testing was completed. First, every shoe type but one developed 70% more torque in a foot-stance position (weight towards the back of the foot) than a toe-stance position (weight towards the ball of the foot). Also, as would be expected, the torque developed increased significantly as player weight increased. Conventional, ¾" football cleats generated much greater torque than any shoe; this adds to the performance capability of the shoe but may decrease player safety in doing so. Conventional cleats on natural grass surfaces generate the highest torque of any shoe-surface combination. Of the remaining ten types of shoe, eight developed higher torques on synthetic surfaces than on natural grass. It was determined that total effective cleat surface area, defined by the relative number of cleats in contact with the ground. In non-cleated shoes, torque was developed due to friction between the outsole of the shoe and the playing surface. Altering outsole composition or design did not seem to have an effect on the torque developed. Careful consideration must be given to each of the above parameters when choosing a shoe for each individual athlete.

In 1986, Andreasson et al[2] revisited this issue and examined the torque and friction generated by different sport shoes on an artificial surface. The group constructed an apparatus to simultaneously measure the torque and frictional resistance developed when a shoe slides along a surface. Twenty-five different shoes were tested at speeds ranging from 1 to 5 m/s. According to the results, frictional force is independent of speed in the range tested. Through analyzing results and an equation for torque balance, it was determined that the amount of material around the heel of the shoe should be increased to balance with the material around the toe of the shoe. The ultimate goal is to provide a more balanced shoe for the athlete. It has been suggested that altering sole material may inadvertently affect the balance and performance of the shoe, and this should be carefully considered in the design of athletic shoes.

Livesay et al[46] examined similar relationships in their 2006 study. Again driven by the increasing frequency of knee injuries, the group focused on measuring the torque versus applied rotation developed on five different playing surfaces (Astroturf™, Fieldturf™ tray, Outdoor Astroplay™, Astroplay™ tray, and grass) using two types of shoes (grass and turf) with a compressive load of 333 N. Torque versus rotation curves indicated three primary regions: 1) initial steep rise in torque developed as rotation was induced, 2) linear region from about $5^{o}$ of rotation to $15^{o}$ of rotation, and 3) a region where the shoe starts slipping. Peak torque generated was lowest on grass surface for both grass and turf shoes. For the grass shoe, the highest torque was generated on Fieldturf™ tray, and the torque generated on Astroturf™ was lower than the torques developed on the other three surfaces. For the turf shoe, the highest torque was generated on Astroturf™, and the torques developed on the other three synthetics surfaces were also high. Rotational stiffness varied with different shoe types and different surfaces, but in general was highest in the initial degrees of rotation on the Astroturf™ surface and lowest in the linear region on grass surface. In each shoe-surface combination, the rotational stiffness was the greatest in the initial region of the torque versus rotation curves. In general, the differences among rotational stiffness in the different shoe-surface combinations were greater than the differences among peak torques. From this study, it becomes evident that monitoring rotational stiffness may be critical in the evaluation of new shoe designs.

Several studies have also been conducted to examine cleat-surface friction, or traction, defined as the 'resistance to movement when one surface slides on another[8]', between these different interfaces. In 1975, Bowers et al[8] analyzed the performance of three different cleat types on unused and five year-old turf with and against surface grain. The group designed a system to methodically test these parameters and came up with several significant conclusions. As turf ages, the friction properties between the shoe and the surface change. With some shoes, the friction increases as turf ages; with others, the friction decreases as turf ages. The coefficients for friction on wet ground were lower than those on dry ground. Inconsistency of the friction properties occurred on old turf, but was not found on new turf. From the study, it can be concluded that loss of friction qualities due to aging of turf is detrimental to player performance but may not have a significant impact on player safety.

Rheinstein et al[61] conducted a study in 1978 to analyze the effects of outsole composition, hardness of basketball shoes, and playing surfaces on traction properties. The outsoles were made of elastomer material or polyurethane, which had different durometer hardness ratings. Clean hardwood, dusty hardwood, and clean artificial flooring were tested. A pendulum system was developed to test dynamic torque, traction forces, and static drag. Two player weights, 177 and 147 pounds, were used during testing. One observation from the results indicated that the maximum torque increased as the hardness of both types of outsoles increased on dusty floors, but decreased as the hardness increased on clean hardwood and artificial floors. The group made no statistically significant conclusions regarding impact of weight, outsole composition and hardness, or playing surface but suggested that using a wider range of testing weight might provide more insight into this area of investigation.

Nearly twenty years later, another study was conducted to again evaluate the interrelationships among shoe type and surface conditions. Heidt et al[30] tested three different shoes, manufactured by Apex, Nike, and Reebok, on synthetic and natural turf using a pneumatic actuator designed to measure peak rotational torque and shear translation force for each combination. Results for wet versus dry surface performance indicated that rotational torque was significantly higher on dry surfaces but that there was not a statistically significant difference between shear forces on wet and dry surfaces. Spatting is a method whereby an athlete's leg is taped from lower calf down through to the mid-foot area, over the shoe. Incorporating this variable into the study led to an overall reduction in both rotational torque and shear force during sliding. With regard to grass versus artificial turf, no statistically significant difference was found across all shoe types in torque or shear forces.

The most recent relevant study was completed in 2003 by Cawley et al[13]. The group utilized another specially designed pneumatic testing device to quantify the differences among shoe types, surfaces, and physiologic loads with regard to rotational torque and translational resistance. Several of the same researchers were involved in the previous study[30], and the primary modification was to alter the load with which the factors were tested; loads of 40 and 220 pounds were used in the current study versus just 25 pounds in the previous. It was determined that increasing loads significantly increased the frictional resistance between shoe and artificial turf. Also, turf shoes exhibited the most frictional resistance of any shoe for artificial turf. Cleated shoes resulted in the highest frictional and torsional resistance on grass, and these measurements were higher than those generated when cleated shoes were tested on artificial turf. The differences found among shoe types and different surfaces that were not significant in the previous study became significant when the load was increased from laboratory testing levels to physiological levels. The resulting increase in frictional resistance is nonlinear with respect to increases in physiological loads, and this is a critical factor that must be accounted for during shoe design and playing surface design and maintenance.

In 2002, Orchard[54] conducted a literature review and survey analysis to determine the effect of environmental conditions on the occurrence of athletic injury. He summarized that increased surface hardness leads to increased shoe-surface traction, which could lead to a higher incidence of injuries. Although many relationships have been described among these factors in previous studies, few have analyzed what environmental elements could produce these changes in playing conditions. Orchard concluded that environmental and seasonal factors affect ground hardness and shoe-surface traction properties and ultimately lead to more injuries. He found the following significant relationships after sorting through published incident reports and other literature: 1) injuries are more common early in the season for sports played outdoor during the fall and winter, but not for sports played indoor or during the summer; 2) there has been a greater injury incidence in football played in warm, dry weather conditions; and 3) football injuries occur more frequently on artificial turf than on natural turf. The changes in shoe-surface traction are affected by the changes inherent between seasons and playing surfaces. Shoe-surface traction increases with the following factors: ground hardness, dryness, grass cover, root density, length of cleats, and speed of athletic pursuit. Weather or other environmental conditions that increase any number of the above factors will most likely increase traction; this change increases player performance, but can negatively influence player safety and ultimately result in more injuries.

## 2.8 In-foot plantar pressure distribution and forces on metatarsals

Forces experienced along the plantar portion of the foot are highly dependent on individual bone anatomy. However, there are some consistent trends that have been observed regarding the pressure distribution during walking. In 1979, Stokes et al[71] looked specifically at the forces experienced in the forefoot during the "push-off" phase of gait, which can exceed body weight by around 20%. Researchers measured the length of each metatarsal and the angle of each with the ground. From these measurements and output from the force plate, the group was able to calculate the axial, bending, and shear forces experienced in each metatarsal. The fifth metatarsal experienced the lowest forces of the five metatarsals in each type of force. The greatest forces were experienced early in the push-off phase of gait. The axial and shear forces were 102 N and 71 N, respectively; the bending moment was 18 N*m. There is a correlation between the size of the bone and the forces experienced. The load in the metatarsals during the first half of forefoot contact time comes from the ground reaction forces, while the second half is primarily due to metatarsophalangeal joint forces.

Recently, much research has been focused on the in-shoe pressure distribution on different surfaces, in different shoes, and during different movements. Hennig and Milani[31] studied the in-shoe pressure distributions at eight locations on the foot during running, wearing nineteen different running shoes. The two sensors most directly correlating to the fifth metatarsal were located under the tuberosity and under the metatarsal head region, though there were only three sensors across the forefoot. The lateral portion (under the tuberosity) experienced the greatest loads of the mid-foot, though it was much lower than any other portion of the foot (8.8% of the total load of the foot). The sensor under the fifth metatarsal head experienced the lowest pressures of the forefoot (12% of total load of the foot), which makes the need for extensive use of insoles in preventing Jones stress fractures questionable. Loads were significantly higher in the mid-foot during running than in standing or walking, indicating possible arch collapse under higher loads. Shoe type was found to significantly influence the way that the pressure was distributed through the foot.

Santos et al[65] looked at the dynamic in-shoe pressure distribution in professional football players in 2001. They compared the football boot versus the trainer shoes to see what the effect was on the pressure distribution during a normal walking pace. The study focused on the maximum and mean forces along the plantar aspect of the foot for the two types of shoes. The maximum pressure was 35% higher in the football boot than the trainer, and the mean pressure was also 27.6% higher in the football boots. This study also proves the effect of shoes on the pressure distribution in the foot, though a smaller surface area in the football boot could have caused some of the difference.

Guettler et al[29] (2006) recently studied the forces acting on the fifth metatarsal during certain basketball maneuvers (jump, $180^{o}$ direction change, $180^{o}$ pivot) and what effect medial arch support had on the forces. They wore "standard basketball shoes" and then shoes with an arch supporting orthosis. The study looked only at the plantar aspect of the fifth metatarsal using Tekscan technology. The study proposed foot shape, fifth metatarsal anatomy, muscular forces, and footwear all play roles in the potential establishment of a stress fracture in the fifth metatarsal. It was determined that the basketball maneuvers place significant pressures on the fifth metatarsal. Medial arch support provided some reduction of the forces on the fifth metatarsal. The paper also cites the limits of reading only plantar pressure when such a "complex interplay of forces" is occurring.

Ford et al[25] looked at the in-shoe loading patterns encountered on natural grass compared to synthetic turf in 2005. The study used a Pedar Novel pressure-sensing insole to find the pressure at nine different regions of the foot throughout the back and forth slalom course the football players ran. The turf conditions had the highest central forefoot and lesser toes pressures (646 kPa and 429.3 kPa respectively), compared to 533.3 kPa and 348.1 kPa on grass. The grass however had the higher percentage of load in the medial forefoot and the lateral mid-foot (30.2% and 4.1%, respectively, to the 27.2% and 3.4% of turf). This study established the significant effect playing surface has on how the foot is loaded during activity.

Chen et al[14] performed a study in order to find the relationship between plantar pressure distribution and the comfort of an insole in 1994. Four insoles were used in both running and walking tests; the pressure was read along the plantar aspect of the foot by an EMED pressure measuring device. The insoles were then ranked in order of comfort level. Walking exhibited higher pressures mid-foot and lower pressures in the medial forefoot and hallux wearing the most comfortable insert compared to the least. That pressure change caused an even pressure distribution on the plantar surface. It also shifted the center of force laterally for more comfort. A 1999 study by Mueller et al[52] also points to the powerful potential the knowledge of plantar pressure distributions can and should have on shoe and insert design.

In 2007 Yu et al[80] investigated the effect of medial arch supporting orthotics on fifth metatarsal loading and ankle inversion angle. The angle of ankle inversion and pressure distributions are recorded during a simulated lay-up with a single leg landing and a shuttle sprint with a $180^{o}$ turn in the middle wearing the same Nike shoes and $1^{st}$ Step Foot Orthosis. A Novel pressure-sensing insole was used in the shoes. Three-dimensional coordinates were obtained by placing reflective markers on the leg and were recorded using a Motus real-time 3-D videographic system in order to calculate ankle joint angles. The maximum ankle inversion angle, plantar force, and pressure on the fifth metatarsal head were all significantly increased when foot orthoses were used. The increased pressure on the fifth metatarsal makes an argument against general medial arch support orthotics; they force the foot into a cavus position, which is anatomically prone to Jones fractures.

## CHAPTER III

## A SURVEY OF THE OCCURRENCES, ACTIVITY AT TIME OF FRACTURE, EQUIPMENT, TREATMENT, AND RESULTS OF FIFTH METATARSAL JONES FRACTURES AT NCAA DIVISION ONE FOOTBALL PROGRAMS

### 3.1 Abstract

**Purpose:** To investigate the possible causes and incidences of Jones Fractures in Division 1 college football. **Study Design:** Cross-sectional study. **Methods:** A survey was email to the head athletic trainers of Division 1 Bowl Subdivision and Division 1 Championship Subdivision football programs. **Results:** Of the 81 responses there were 40 fractures occurring in the 2006-2007 season and 26 fractures in the 2007-2008 season. 42 (51.9%) of the responses were from D1 Bowl Subdivision (BS) schools and the other 39 (48.1%) were D1 Championship Subdivision (CS). D1 BS accounted for significantly more of the fractures with 67.5% of the 2006-2007 season and 76.9% of the 2007-2008 seasons. Nike shoes showed a significant increase in fractures in 06-07 with 67.5% of the fractures despite only having 53.1% or the responses. There was a very significant correlation of fracture to the lateral cut maneuver 87% for 06-07 season and 67% of the 07-08 season. 18.3% of fractures were still treated non-surgically despite current literature indicating the need for surgical treatment for athletes.

**Conclusion:** This data can be used as guidelines for further research into the exact forces causing the Jones Fracture and potentially lead to a method of prevention.

## 3.2 Background

The Jones Fracture is a fracture of the fifth metatarsal that occurs at the base of the bone and was coined by Sir Robert Jones in 1902 after he incurred the fifth metatarsal fracture while dancing. The fracture occurs at the metaphyseal-diaphyseal junction and is located 1.5 cm distal to the tuberosity of the fifth metatarsal. The fracture presents itself at the point where the primarily cancellous bone at the end of the shaft transitions into the cortical bone found throughout the long portion of the bone.[13] Both stress fractures and acute fractures can be termed a Jones fracture, as the term refers to the region of bone in which the fracture occurs rather than the cause.

The location of the Jones Fracture and the vasculature of the fifth metatarsal are responsible for the notorious problems with its ability to heal. The location of the Jones Fracture causes an the arterial blood supply to the bone to be interrupted.[20] It can be treated surgically or non-operatively though surgical treatment has become the most promising method for athletes due to it's ability to provide a faster return to play time.[15,12,7,9,21] Intramedullary (IM) screw fixation is what is typically being referred to by the term surgical technique and it is not without it's problems. The anatomical shape and vasculature make IM screw fixation difficult.[20] Other considerations include the close proximity of the screw head to the sural nerve which can lead to pain[8].

There is some discrepancy with regard to exactly what motion is the most common cause of the fracture. It is clear, however, that the fifth metatarsal is more likely to fracture than to dislocate due to the strength of the ligaments surrounding it.[13] Arangio et al used finite element analysis along with beam theory in order to find the stresses occurring in the fifth metatarsal in 1997. They were able to provide a stress distribution along the entire length of the bone including local maximum stresses along the outer edge of the bone. The distributions found the most susceptible portion of the bone at 3.38cm distal to the base of the metatarsal, which corresponds to the region where Jones Fractures occur.[4] In a 1998 study by Arangio et al, the shear and normal stresses found in the second through fifth metatarsals of a 20 year old male were calculated using mechanics of solids theory. The maximal tensile stresses were calculated to occur from nearly horizontal loading at 3.5mm from the proximal end of the fifth metatarsal. This again corresponds to the general area of the Jones Fracture.[3]

As would be expected from the implication of horizontal forces above, the majority of Jones fractures reported in athletes occurs in basketball and football which involve significant amounts of horizontal movements. Twisting, falling, and direct blows represent the three most common maneuvers resulting in Jones fracture[16]. Although Jones fractures of both types can occur in nearly every age group, the majority of stress fractures occur in younger patients who are actively participating in sports or other activities involving repeated pivoting and high forces.[18] Acute fractures seem to occur more frequently in older age groups. Stress fractures from marching type motions as in military recruits tend to occur in the second and third metatarsals while the lateral loadings of athletes tend to result in Jones Fracture.[16, 18]

The forces experienced by the foot during athletics are also affected by the particular athletic movement, shoe type, and surface on which the movement is occurring. Recent studies on in-shoe pressure distributions have found that the lateral movements do show significant increases of pressure on the plantar surface of the fifth metatarsal.[22, 17] The limitation of these studies is the inability to measure the forces being encountered by the lateral aspect of the foot where, as discussed previously, the main cause of Jones Fractures seem to originate. There have also been many studies investigating the affect of shoe type on the in-shoe pressure distribution experienced by the foot. The consensus is that shoe type does have a significant affect on forces experienced by the foot in both normal gait and athletic type lateral maneuvers.[11,5,1] Santos et al even found that football cleats in particular showed a significantly higher force distribution in comparison to training shoes.[19] The interface between the shoe and playing surface has been proven to be another significant factor in affecting the forces acting on the foot.[10,5,14,2] In particular the artificial surfaces have been shown to provide the highest vaues.[6,14,5]

All of the factors mentioned above were attempted to be addressed in our survey. Football was chosen due its repetitive lateral movement and high loadings due to large athletes, as well as its history as one of the leading sports for Jones Fractures. The treatment method was investigated as well as its respective time to heal. The type of shoe, movement being made at time of injury, and surface being played on were also investigated.

## 3.3 Materials and Methods

*Procedure*

An email (see Appendix A) was sent to the head athletic trainers of the NCAA Division 1 Football Bowl Subdivision and Division 1 Football Championship Subdivision schools (n=236). A hyperlink to the survey posted on www.surveymonkey.com was in the email. There was one reminder email sent during the 52 day collection period. The email stated the need for the survey and the informed consent which would be accepted upon clicking the link.

*Survey*

The survey was comprised of four different sections and addressed the issues indicated in the literature review as mentioned in the background. Section one, "Background Information", addressed the general information confirming that their school had football, what division they were in as well as what types of shoes were worn by their players. The questions were multiple choice with the option of writing in the shoe brand (if other than the main choices) and what style of shoe. Section two "Injuries 2006-2007 season" addressed the Jones Fractures occurring in that season. The number of Jones Fractures occurring, time of year they occurred, surface they occurred on, and the maneuver being performed at the time of fracture were all investigated. All questions were multiple choice or indicating the number of fractures that occurred for each answer. Section three, "Injuries 2007-2008 season" was identical to section two but regarding the 2007-2008 season. Section four, "Treatment", addressed how the fractures where treated, what the return to play criteria was and how long the recovery was before return to play. These questions were also multiple choice or gave the ability to indicate the number of fractures that applied to the given answer.

*Statistical Analysis*

All of the proportions tested were analyzed using the hypothesis test of a proportion with a 95% confidence level.

### 3.4 Results and Discussion

Of the 236 schools, 81 (34.3%) fully completed and returned the survey. The following tables are broken up into four sections as in the survey. The first column contains the question that was asked. The second column contains the answer options that were presented for that question. Column three and four contain the total number of responses with its correlating answer and the percentage of the total responses that answer accrued, respectively.

**Table 3.1 Survey results returned from Football Bowl Subdivision and Championship Subdivision Trainers.**

| Question | Answer | Response Count | Response % |
|---|---|---|---|
| 1. Does your university have varsity football? | Yes | 80 | 100% |
| | No | 0 | 0% |

| | | | |
|---|---|---|---|
| 2. In which division does your school participate? | Football Bowl Subdivision (Division I) | 42 | 51.9% |
| | NCAA Football Championship Subdivision (Division I-AA) | 39 | 48.1% |
| 3. Do your football players wear one brand of shoes or different brands? | We all wear the same brand | 68 | 84.0% |
| | Players may have different shoes | 13 | 16% |
| 4. During the 2006-2007 season, which brand of shoes do your athletes use? | Nike | 54 | 66.7% |
| | Reebok | 5 | 6.2% |
| | Adidas | 24 | 29.6% |
| | Under Armour | 8 | 9.9% |
| | New Balance | 6 | 7.4% |
| | Unavailable | 2 | 2.5% |
| | Other | 1 | |
| 7. During the 2007-2008 season, which brand of shoes did your athletes use? | Same as 06-07 season | 46 | 56.8% |
| | Nike | 20 | 24.7% |
| | Reebok | 0 | 0% |
| | Adidas | 12 | 14.8% |
| | Under Armour | 4 | 4.9% |
| | New Balance | 2 | 2.5% |
| | Unavailable | 1 | 1.2% |
| | Other | 1 | |

**Table 3.2 Injuries 2006-2007 season**

| Questions | Answer | Response Count | Response % |
|---|---|---|---|

| | | | |
|---|---|---|---|
| 1. During the 2006-2007 football seasons, how many 5th metatarsal fractures did you have at your university? | None | 50 | 61.7% |
| | One | 25 | 30.9% |
| | Two | 4 | 4.9% |
| | Three | 1 | 1.2% |
| | Four | 1 | 1.2% |
| | Five or More | 0 | 0% |
| | ***TOTAL FRACTURES*** | ***40*** | |
| 2. When did they occur? Please indicate how many of these fractures occurred during the following circumstances. | Spring or Preseason | 15 | 37.5% |
| | Fall practice sessions | 13 | 32.5% |
| | Game | 8 | 20% |
| | Non-team related | 4 | 10% |
| 3. How many occurred on the following surfaces? Please indicate the number with each choice. | Natural Grass | 13 | 33.3% |
| | Artificial Turf | 19 | 48.7% |
| | Other | 7 | 17.9% |
| 4. To the best of your knowledge, what movement were the athletes making when they sustained these fractures? Please indicate the number with each choice. | Acceleration | 4 | 10.3% |
| | Deceleration | 0 | 0% |
| | Cut/Lateral move towards the direction of injury | 14 | 35.9% |
| | Cut/Lateral move away from the direction of injury | 13 | 33.3% |
| | Contact | 0 | 0% |
| | Unsure | 8 | 20.5% |

**Table 3.3 Injuries 2007-2008 season**

| Questions | Answer | Response Count | Response % |
|---|---|---|---|

| | | | |
|---|---|---|---|
| 1. During the 2007-2008 football seasons, how many 5th metatarsal fractures did you have at your university? | None | 59 | 74.7% |
| | One | 16 | 20.3% |
| | Two | 2 | 2.5% |
| | Three | 2 | 2.5% |
| | Four | 0 | 0% |
| | Five or More | 0 | 0% |
| | ***TOTAL FRACTURES*** | ***26*** | |
| 2. When did they occur? Please indicate how many of these fractures occurred during the following circumstances. | Spring or Preseason | 12 | 44.4% |
| | Fall practice sessions | 10 | 37.0% |
| | Game | 4 | 14.8% |
| | Non-team related | 1 | 3.7% |
| 3. How many occurred on the following surfaces? Please indicate the number with each choice. | Natural Grass | 11 | 40.7% |
| | Artificial Turf | 13 | 48.1% |
| | Other | 3 | 11.1% |
| 4. To the best of your knowledge, what movement were the athletes making when they sustained these fractures? Please indicate the number with each choice. | Acceleration | 4 | 14.8% |
| | Deceleration | 2 | 7.4% |
| | Cut/Lateral move towards the direction of injury | 8 | 29.6% |
| | Cut/Lateral move away from the direction of injury | 6 | 22.2% |
| | Contact | 1 | 3.7% |
| | Unsure | 6 | 22.2% |

**Table 3.4 Treatment**

| Question | Answer | Response Count | Response % |
|---|---|---|---|
| 1. Regarding your fifth metatarsal fractures mentioned above, how were they managed? Please indicate the number with each choice | Non-operative | 11 | 18.33% |

| | | | |
|---|---|---|---|
| number with each choice. | | | |
| | Surgical | 49 | 81.66% |
| 2. Of those surgically repaired, how were they done? (Indicate Number) | Canulated Intramedullary Screw | 39 | 84.8% |
| | Non-canulated Intramedullary Screw | 0 | 0% |
| | Variable Thread Pitch Compression Screw (Acutrak) | 3 | 6.5% |
| | Headless Compression Screw | 3 | 6.5% |
| | Other | 1 | 2.2% |
| 3. What is your Return-To-Play criteria? | Athlete is pain-free | 2 | 4.3% |
| | X-ray evidence of bony union | 6 | 12.8% |
| | Both | 39 | 83% |
| 4. Of the athletes treated surgically, how long were they held out of competition? (Indicate Number) | <2 weeks | 0 | 0% |
| | 2-4 weeks | 4 | 3.1% |
| | 4-6 weeks | 23 | 36.0% |
| | >6 weeks | 39 | 60.9% |
| 5. Of the athletes treated non-operatively, how long were they held out of competition? (Indicate Number) | <8 weeks | 7 | 33.3% |
| | 8-12 weeks | 6 | 28.6% |
| | 12-16 weeks | 3 | 14.3% |
| | 16-20 weeks | 3 | 14.3% |
| | >20 weeks | 2 | 9.5% |

For the 2006-2007 academic year, 61.7% of the schools reported no fractures and 38.3% of schools had at least one Jones Fracture. For the 2007-2008 season the percentage of schools with at least one fracture was 25.3%. These relatively high percentages of schools encountering at least one Jones Fracture supports the research implicating football as one of the sports with the highest incidences of the fracture as well as establishing the sports need for a better understanding of the causes associated with it. By filtering the responses it was found that of the 81 responses, 42 (51.9%) were Division 1 Football **Bowl** Subdivision and 39 (48.1%) were Division 1 Football **Championship** Subdivision. Despite this near even distribution, Division 1 schools accounted for 67.5% (27) of the total fractures for the 2006-2007 season and 76.9% (20) of the total fractures for the 2007-2008 season (Figure 3.1).

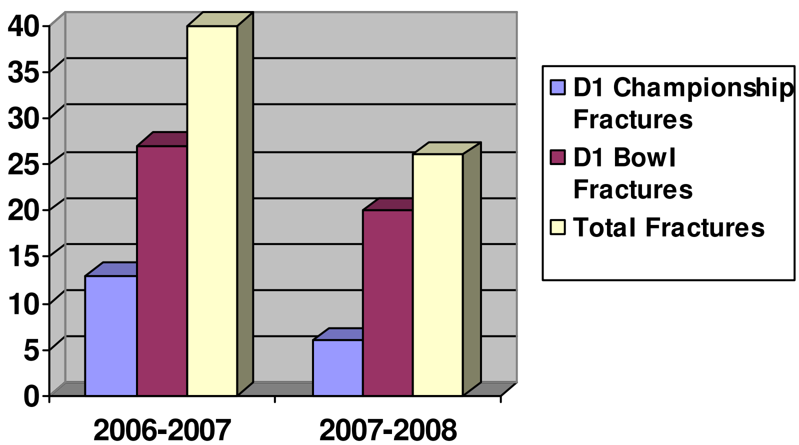


**Figure 3.1 Number of fractures by subdivision.**

This is a statistically significant increase (p=.024 for 06-07, p=.0054 for 07-08) in the percentage of the total fractures that would be expected for both seasons. Division 1 Bowl Subdivision as a general rule is composed of more elite and therefore bigger, stronger, faster athletes. This means that the forces being applied to the fifth metatarsal would be higher in the D1 Bowl Subdivision than the Championship Subdivision, thereby possibly explaining the large difference in proportion of Jones Fractures. This seems to contradict the thought that better training and strengthening can prevent the fracture.[3]

Maneuver has a very noticeable affect on whether or not there is a fracture. Due to the potential for misinterpretation of which type of lateral cut being described in the answers the two descriptions will be lumped into one category for lateral cut.

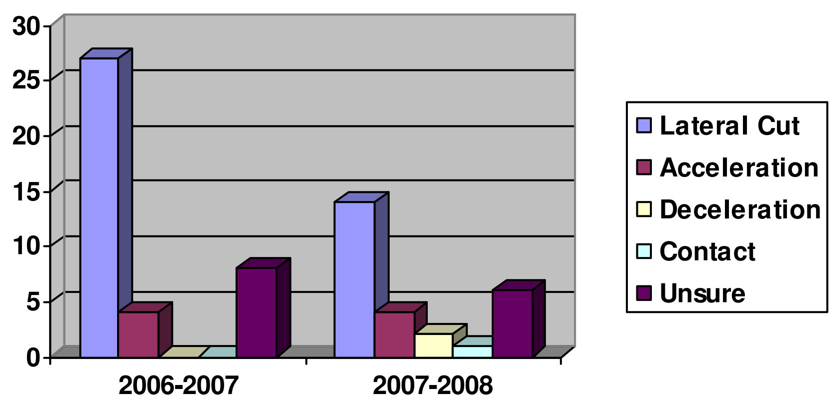


**Figure 3.2 Number of fractures by maneuver**

The lateral cut accounted for 87% of the known maneuvers in 2006-2007 and 67% of the known maneuvers in 2007-2008. The lateral cut shows a statistically significant increase ($p=5.5 \times 10^{-21}$ for 06-07 and $p=3.63 \times 10^{-8}$ for 07-08) for both the 2006-2007 and 2007-2008 seasons in the cause of fracture from the other maneuvers. This strongly supports the literature which also implicated the lateral loadings in the cause of fracture .[3,18] It is also interesting to note that out of the 66 fractures for both years only one of them was caused by contact.

Nike is by far the most popular brand of shoe with 66.7% of schools wearing them in 06-07. By again filtering the responses based on those who answered that they all where the same brand of shoe and said that they wear Nike (53.1%), the results of teams that wear Nike wear able to be analyzed.

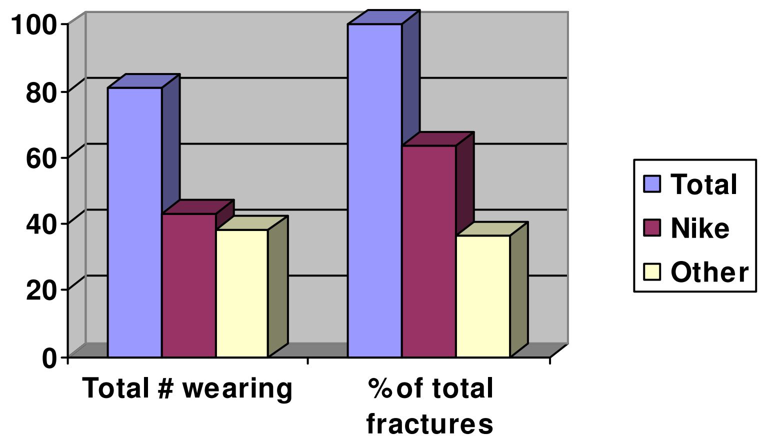


**Table 3.3 Number of fractures as a function of shoe brand for 2006-2007.**

The percentage of fractures with Nike in 06-07 (27 of the total 40) 67.5% is significantly higher (p=.034) than the 53.1% of the fractures it should claim based on the percentage of schools that are accounted for. There is however ever a statistically insignificant (p=.135) but noticeably lower percentage of the fractures (42.3%) that should be associated with Nike in 07-08. The other shoe brands showed no significant ties to fracture.

The significance of playing surface on fracture can not be determined due to the fact that the survey responses are not tagged to the specific school that responded. Therefore there is impossible of knowing the percentage of time that the players were playing on artificial turf rather than grass. It is worth noting however that artificial turf accounts for the most fractures both years. The higher numbers become statistically significant in 06-07 if the artificial turf is being played on 40% of the time or less and 34% of the time or less for 07-08. The fewer number of artificial turf stadiums compared to turf would seem to infer that the increase is in fact significant, but the lack of knowledge of who replied makes it impossible to say with certainty.

In light of recent literature on fifth metatarsal Jones Fracture treatment it is very surprising that 18.3% of fractures are still treated non-surgically. Type of surgical treatment seems to be uniform, with 84.8% of the surgical treatment being cannulated IM screw fixation. Also surprising is that the majority return to play time for the fractures treated surgically fall outside of expected range with >6 weeks. The range was set based on the literature and professional opinion with most of the responses expected to be between 3 and 4 weeks. The return to play for the non-surgically treated was also a little outside the expected range determined from the literature with the majority falling <8 weeks. There was no correlation of division to the type of treatment or the return to play criteria and time. This shows that the standard of care is uniform between the two divisions. When the responses are grouped based on what season the fracture occurred in two distinct groups can be made. In season is defined by fall practice and game and out of season is described as spring practice or preseason and non-team related. It is interesting that the return to play time is significantly lower for those surgically repaired fractures occurring "in season" 56.7% in <6 weeks compared to the 40% in <6 weeks for out of season. Non-surgically repaired fractures occurring in season do not show a statistically different return to play time. A faster return to play time would be expected due the more pressing need to get the player back on the field compared to the off-season where it would be more beneficial to make sure the injury heals as fully as possible.

## 3.5 Conclusion

This survey shows the significant impact Jones Fractures can have on Division 1 football. The surprising use of non-surgical treatment may indicate that the sports medicine community is not convinced of which method is best or a resistance to change. The results provide a very good guide for future research involving pressure distributions on the fifth metatarsal. The different areas implicated by this survey include using Division 1 Bowl Series athletes performing maneuvers that focus on lateral cuts. It would also potentially benefit from analyzing Nike shoes as well as looking at the difference between forces encountered on artificial turf versus grass. This could confirm the suspicion that artificial turf causes significantly more fractures. If all of the forces acting on the fifth metatarsal throughout maneuvers under the above circumstances the exact cause of fracture and a thereby a method of prevention could be developed.

## REFERENCE


1. Andreasson G, Lindenberger U, Renstrom P, et al: Torque developed at simulated sliding between sport shoes and an artificial turf. *Am J Sports Med 14*(3): 225-230,1986

2. Arangio G: Transverse proximal diaphysial fracture of the fifth metatarsal: a review of 12 cases. *Foot Ankle 13*(9): 547-549,1992

3. Arangio GA, Beam H, Kowalczyk G, et al: Analysis of stress in the metatarsals. *Foot & Ankle Surgery 4*: 123-124-128,1998

4. Arangio GA, Xiao D, Salathe EP: Biomechanical study of stress in the fifth metatarsal. *Clin Biomech (Bristol, Avon) 12*(3): 160-164,1997

5. Bonstingl RW, Morehouse CA, Niebel BW: Torques developed by different types of shoes on various playing surfaces. *Med Sci Sports 7*(2): 127-131,1975

6. Cawley PW, Heidt RS,Jr, Scranton PE,Jr, et al: Physiologic axial load, frictional resistance, and the football shoe-surface interface. *Foot Ankle Int 24*(7): 551-556,2003

7. Clapper MF, O'Brien TJ, Lyons PM: Fractures of the fifth metatarsal. Analysis of a fracture registry. *Clin Orthop Relat Res (315)*(315): 238-241,1995

8. Donley BG, McCollum MJ, Murphy GA, et al: Risk of sural nerve injury with intramedullary screw fixation of fifth metatarsal fractures: a cadaver study. *Foot Ankle Int 20*(3): 182-184,1999

9. Fernandez Fairen M, Guillen J, Busto JM, et al: Fractures of the fifth metatarsal in basketball players. *Knee Surg Sports Traumatol Arthrosc 7*(6): 373-377,1999

10. Ford KR, Manson NA, Evans BJ, et al: Comparison of in-shoe foot loading patterns on natural grass and synthetic turf. *J Sci Med Sport 9*(6): 433-440,2006

11. Hennig E, Milani T: In-shoe pressure distribution for running in various types of footwear. *Journal of Applied Biomechanics 11*: 299-300-310,1995

12. Holubec KD, Karlin JM, Scurran BL: Retrospective study of fifth metatarsal fractures. *J Am Podiatr Med Assoc 83*(4): 215-222,1993

13. Jones R: I. Fracture of the Base of the Fifth Metatarsal Bone by Indirect Violence. *Ann Surg 35*(6): 697-700.2,1902

14. Livesay GA, Reda DR, Nauman EA: Peak torque and rotational stiffness developed at the shoe-surface interface: the effect of shoe type and playing surface. *Am J Sports Med 34*(3): 415-422,2006

15. Mindrebo N, Shelbourne KD, Van Meter CD, et al: Outpatient percutaneous screw fixation of the acute Jones fracture. *Am J Sports Med 21*(5): 720-723,1993

16. Petrisor BA, Ekrol I, Court-Brown C: The epidemiology of metatarsal fractures. *Foot Ankle Int 27*(3): 172-174,2006

17. Porter DA, Duncan M, Meyer SJ: Fifth metatarsal Jones fracture fixation with a 4.5-mm cannulated stainless steel screw in the competitive and recreational athlete: a clinical and radiographic evaluation. *Am J Sports Med 33*(5): 726-733,2005

18. Sammarco GJ: The Jones fracture. *Instr Course Lect 42*: 201-205,1993

19. Santos D, Carline T, Flynn L, et al: Distribution of in-shoe dynamic plantar foot pressures in professional football players. *The Foot 11*: 10-11-14,2001

20. Smith JW, Arnoczky SP, Hersh A: The intraosseous blood supply of the fifth metatarsal: implications for proximal fracture healing. *Foot Ankle 13*(3): 143-152,1992

21. Wright RW, Fischer DA, Shively RA, et al: Refracture of proximal fifth metatarsal (Jones) fracture after intramedullary screw fixation in athletes. *Am J Sports Med 28*(5): 732-736,2000

22. Yu B, Preston JJ, Queen RM, et al: Effects of wearing foot orthosis with medial arch support on the fifth metatarsal loading and ankle inversion angle in selected basketball tasks. *J Orthop Sports Phys Ther 37*(4): 186-191,2007

# CHAPTER IV

# METHODOLOGY DEVELOPMENT FOR IN SITU FORCE MEASUREMENTS ON FIFTH METATARSAL

## 4.1 Introduction

There is still much to be learned about the biomechanics of the foot and more specifically the fifth metatarsal during athletic maneuvers. The forces acting along the lateral aspect of the foot have yet to be recorded during any type of movement or in any shoe. It is the lateral aspect of the foot that appears to be where the forces that cause the Jones Fracture occur. Without it, it is impossible to know exactly how the fracture is occurring and go about finding ways to prevent it from occurring.

Technology has been the limiting factor in the ability to examine the forces on every portion of the foot. The complex shape of the foot and the deformation that occurs during movement requires not only a moldable sensor that can follow the shape of the side of the foot but can also flex without giving false measurements. Due to the small size of the fifth metatarsal and the complexity of the forces that interplay on it, the sensor must also be able to provide a large number of readings over a very small area in order to pinpoint where the pressure concentrations are occurring. Research has also shown the importance the athletic maneuver as well as the type of shoe and shoe-surface interface play on the forces incurred by the fifth metatarsal. The sensor must therefore also be capable of being worn inside of a shoe and free to move while providing simultaneous readings.

The two main products available today are Fuji film and Tekscan. The film is only capable of showing the maximum load on the sheet at any point as opposed to a time progression of pressure readings during a particular maneuver. It is also subject to creasing which ruins the reading. Tekscan does provide a detailed pressure distribution as well as time progression of the forces. However, Tekscan sheets must be flat to provide accurate readings and is therefore incapable of providing readings on anything but the plantar surface of the foot. SensorTech may hold the solution to these problems. It is made of a formable ultra-high molecular weight poly-ethylene UHMWPE in “smart” sheets that can be made into any shape. It can withstand overloads beyond the point of permanent deformation while still providing accurate readings. It is waterproof and has no electronics. It also has wireless capabilities which make it very conducive for use in the shoe during maneuvers.[83]

Using the survey data in conjunction with the literature available a comprehensive study was designed. The study addresses the implicated causes from the survey as well as prior research by pressure reading along all aspects of the fifth metatarsal under several different situations. The athletes should be Division 1 Bowl Subdivision athletes due to their ability to apply the largest forces on the foot indicated in the survey. The athletes will be run through an obstacle course that requires them to perform the maneuvers that appear to be the most likely to be responsible for the forces leading to the Jones Fracture. The athletes will also run the same course in different types of shoes as well as on different surfaces. Not only will the following testing method provide a detailed progression of forces along the fifth metatarsal throughout a particular maneuver for each athlete but also the precise point in time of each maneuver that the maximum forces occur through averaging the body of the results. The point in time of maximum forces for each maneuver should be compared to the visual data from the high speed camera to see if shoe deformation is contributing to this peak force and how. It will also be able to show exactly where on the fifth metatarsal the maximum forces are occurring. There are numerous comparisons to be investigated such as affect of shoe type, body weight, speed, height, surface, foot size. Which of these factors provide the most significant affect is yet to be seen. These results as whole should provide the information necessary to begin to formulate a method for prevention.

## 4.2. Materials and Methods

*Course Setup*

The course is designed to look at seven different specific maneuvers occurring on the athlete's right foot. The course (see Fig.4.1) will be laid out with 15 orange cones and water soluble spray paint on the ground.

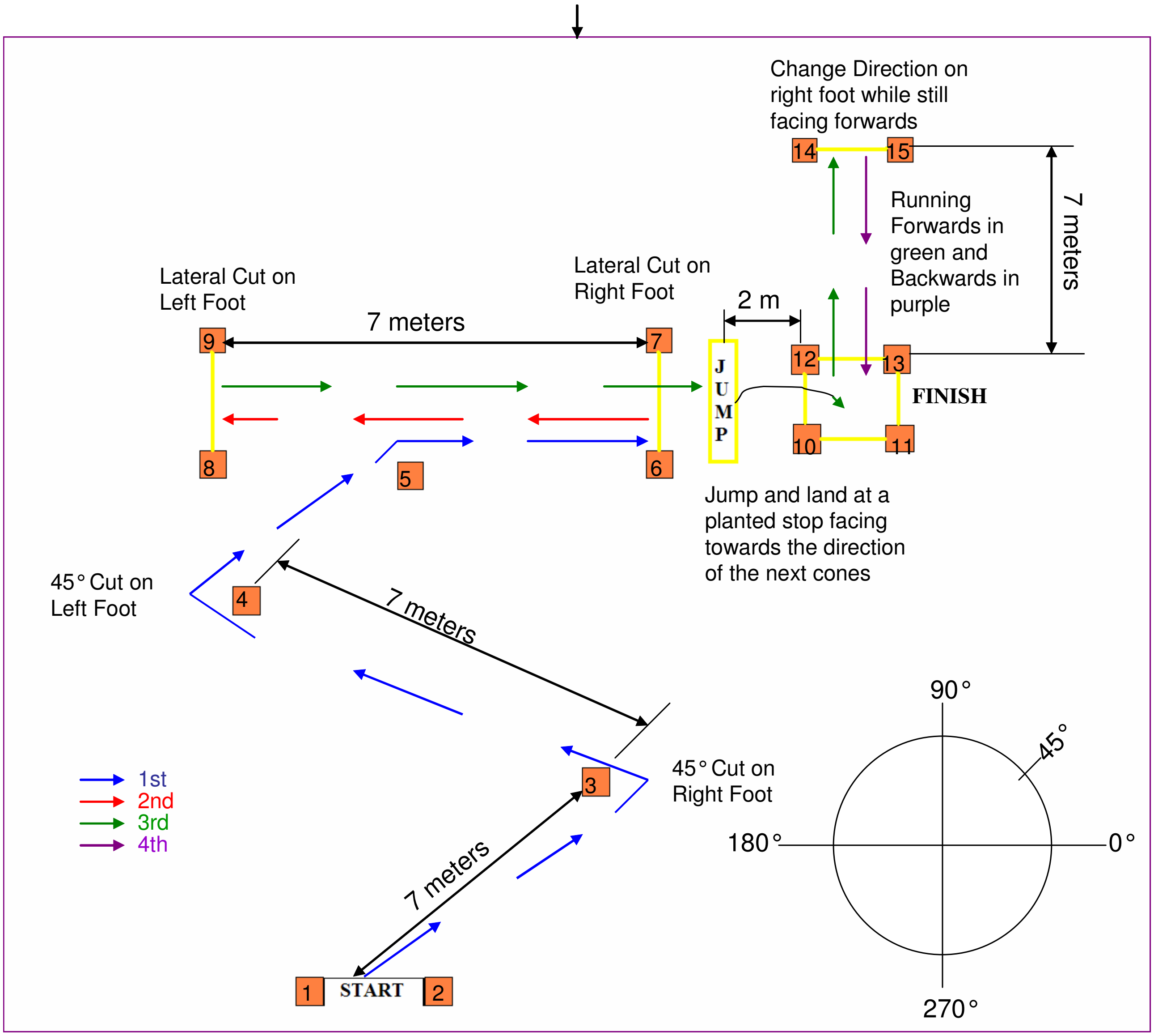


Figure 4.1 : Obstacle course.

There will be two orange cones at the start point as well as the word "START" spray painted between the cones. Cone 3 will be 7 meters away at a 45° angle along with arrows spray painted on the ground to and around the cone. Cone 4 for will be 7 meters away from Cone 3 at 135° with spray painted arrows between them an around the cone. Cone 5 will be only 3 meters away at 45° with arrows between and around the cone to 0°

towards Cones 6 and 7. A line will be painted between Cones 6 and 7 as well as arrows going to the line painted between Cones 8 and 9 at 180°. The arrows will touch the line and then point back and through Cones 6 and 7 at 0°. Approximately 1 meter behind the line between Cones 6 and 7 will be a rectangle painted with the word "JUMP" in it. A one square meter box is located 2 meters in front formed by Cones 10, 11, 12, and 13 as well as spray painted lines connecting them. Cones 14 and 15 will be 7 meters away from the top edge of the box at 90° with arrows pointing to the line painted between them. There will also be arrows pointing back towards the box from the line at 270°. Outside the box at 0° will be the word "FINISH" painted on the ground.

A high speed camera will provide important information regarding shoe performance. In order to provide this information the sampling rate of the camera must equal that of the SensorTech sensor or the data acquisition system (whichever is the limiting factor). Digital high-speed cameras are capable of several hundred thousand frames per second. A high resolution is needed since the frame of the camera will need to cover a larger area. This is because each athlete will not plant his foot in the same area and the researcher will have to zoom in on the foot to see a detailed deformation. Depending on the number availability of high speed cameras, they should be placed in the following locations which will be discussed in order of importance based on the survey results and literature studies. The most probable causal maneuver is located between Cones 6 and 7. The next camera location should be at Cone 3 followed by between Cones 8 and 9 and then Cone 4. Least important but still interesting to see would be to locate one camera focused on the box. The ideal location for the testing will be on the Clemson University football practice field where both grass and artificial turf are available beside each other.

Equiptment list: "SensorTech sensor sock" - 4

Data acquisition system

High-speed camera – As many as can be afforded

Extension Cords – 1 per camera and 1 for data acquisition system

Orange Cones – 30

Yellow spray paint cans – 2

Medical scale with height measurement system – 1

Clip board for recording height, weight, shoe size – 1

Nike Speed TD cleats – size 8, 9, 10, 11, 12, 13, 14

Nike Turf Shoes LT 21 – size 8, 9, 10, 11, 12, 13, 14

Adidas Scorch Competition– size 8, 9, 10, 11, 12, 13, 14

Adidas Scorch 8 FT low – size 8, 9, 10, 11, 12, 13, 14

Stopwatch – 2

Table – 1

Water Jug – 2

Towels - 20

*Data Aquisition*

These instructions should provide us with the forces incurred during seven different maneuvers relative to the right foot. The first maneuver is a 90° cut that would be considered “away from the site of injury” followed by the second maneuver at Cone 4 that would be considered a “90° cut towards the site of injury”. The third maneuver occurs at the line between Cones 6 and 7, and “lateral cut away from the site of injury”. Maneuver four occurs at the line between Cones 8 and 9, and is a “lateral cut towards the site of injury”. Landing in the box made by Cones 10-13 is the fifth maneuver which is a “jump stop”. The acceleration out of that box is sixth maneuver or “acceleration”. The sudden deceleration at the line between Cones 14 and 15 is the seventh and final maneuver or “deceleration”. The forces encountered by the time progression sampling of the sensor paired with the high speed camera will allow for the forces measured to be correlated to the type and phase of the maneuver being conducted.

The sensor being used for this study is the SensorTech “smart sheet”. If the sensor can be formed thin enough to not provide its own resistive force to deformation of the shoe during the study, than it should be formed to shape of the lateral portion of the shoe surrounding the fifth metatarsal. If the sensor is found to provide resistance than the sheet will need to be cut into three or four strips so as to allow for the deformation while still measuring the forces all around the fifth metatarsal. The sensor will be incorporated into a sock so that it will always be oriented around the fifth metatarsal. The athlete will put on the sensor sock followed by the Adidas cleat and will lace the shoe tightly to comfort.

*Calibration*

The sensor must be calibrated prior to conducting the study with the athletes. This includes setting the tensile force to which the shoes should be laced. This should be determined by measuring what force is required to tighten the shoes to the point where there is minimum slipping between the foot and shoe while still being comfortable. A strain gauge should be attached to the laces each time the athletes lace up in order to ensure consistency. The sensor will need to be calibrated to remove the preloading achieved by the tightness of the shoe.

The course should also be run several times by non-athlete (preferably 4 or 5 people) several times and the data analyzed. This will allow for the study to be optimized based on what movements are actually showing the higher forces. Maneuvers other than the ones listed above should also be performed in order to confirm that they do not provide the same high level of lateral forces. The maneuvers should also be conducted on a force plate in order to shoe the correlation between shear and axial forces and the forces encountered on the lateral portion of the foot. The affect of body angle during the cut should also be investigated for a correlation to the forces on the sensor. This can be achieved using a camera in conjunction with the sensor data and measuring the angle of the lower leg.

*Testing*

Each participant's height and weight will be measured and recorded along with their shoe size. Following this the test group will all be walked through the course prior to the study as a group and then individually before their respective test. The athletes will be told to run the course as fast as they are capable while still performing the required tasks. After leaving the start line the athlete must make a 90° cut at Cone 3 with their right foot, exploding towards Cone 4. At Cone 5 another 90° cut will be performed, this time with the left foot and exploding towards Cone 5. The athlete will round Cone 5 however they want, while maintaining speed towards the line between Cones 6 and 7. The athlete will plant their right foot on the line and change direction towards the line between Cones 8 and 9. At this line the left foot will be used to plant on the line, change direction, and head back through Cones 6 and 7. They will run through the line at Cones 6 and 7 to the rectangle labeled "JUMP" where they will jump using one foot and land in the box formed by Cones 10-13. They must turn their body in the air so that when they land they are facing the line between Cones 14 and 15. Allowing their body to come to a full stop in the square, they will then accelerate towards the line between Cones 14 and 15 where they will quickly change direction (keeping their body facing forwards) by running backwards back to the box. The data acquisition system (Labview) will then be started simultaneously with the high speed camera. The player will then be asked to run the course as quickly as possible. When the athlete crosses the start line a stop watch should be started; stopping when the athlete crosses the finish line.

Upon completion of the walk through for the group and individually the athlete will conduct the course on grass with the sensors in place. In order to account for the affect of the shoe found in the survey on the loading of the fifth metatarsal the athlete will then put on the Nike speed td's and run the course again. In order to address the likely indication that artificial turf increases the probability of fracture the athlete will then move to an exact replica of the course that is setup on an artificial turf and run the course. The athlete will then change shoes back into the Adidas cleats and run the course one final time. The Adidas cleat was chosen due to its lack of significant difference in fracture proportions found in the survey.

## 4.3. Conclusion

The use of Division 1 Bowl Subdivision athletes should allow for the highest possible forces on the fifth metatarsal to be measured according to the survey. The setup of the course addresses all of the maneuvers listed in the survey while focusing on the lateral cuts that where shown to cause significantly more fractures. Not only does it focus on the lateral cut but it will also be able to show which direction of lateral cut causes the highest pressures on the fifth metatarsal. It will also show whether a 45° lateral cut has higher forces than the 90° lateral cut. The results of this survey will also provide a much deeper look into the affect the shoe has on the pressure distribution through the fifth metatarsal. It will do so by not only comparing the numbers between two different shoe brands but it will also allow for the readings to be compared to visually what the shoe is doing at that moment from the high speed camera. The SensorTech sensor being wireless and very small will allow for the athlete to perform the maneuvers as they naturally would. Artificial turf will also be able to be compared with grass directly with all other variables being the same. This large amount of new data will hopefully be able to lead to the development of some way to prevent the fracture all together.

### 4.4. Recommendations

In order to glean the maximum information possible from this study there are a couple of extra materials and information that would be good to have. Due to the anatomy of the fifth metatarsal and the fact that the curvature is unique to the individual, an x-ray of each athlete foot prior to the study would be very beneficial. This would allow the researcher to investigate the effect of bone anatomy on pressure distributions and determine if in fact some athletes are anatomically predisposed to fracture. It could also allow for another variable to allow the grouping of patients and hopefully provide a more cohesive data trend. It would also be advisable to have a high speed camera positioned over each location a maneuver is taking place in order to visualize what is happening to the shoe and the foot throughout the maneuver. This can then be correlated to the peaks in pressure and give a better idea of what parts of the shoe performance need to be addressed. Ideally the sensor could be molded to cover the entire foot in order to show the complete transfer of forces throughout all of the maneuvers. If this is not achievable, then as many locations along the foot as possible should measured. If it is determined, by the coaches or researchers, that the athletes will not be able to learn and execute the coarse in a short amount of time a new coarse such as the one described above can be developed with help from the strength and conditioning coaches.

The innovative technology used in this study indicates that the research regarding all of the forces acting on the foot for both the Jones Fracture and the forces in general are just beginning. This study addresses most of the maneuvers thought to be responsible for the Jones Fracture in football players including the most probable shoe types and surfaces. This leaves many different variables left to be investigated not only for football but for other sports with high incidences of Jones Fractures such as basketball and soccer. It would be beneficial to run a similar study with sport specific maneuvers, shoes, and surfaces for that sport. This technology should also be used to investigate the affect shoe inserts or orthotics have on the force distributions along the lateral portion of the foot. This technology could prove invaluable to shoe manufacturers with its ability to give quantifiable feedback of how a shoe design affects the pressure distribution on any portion of the foot during any maneuver.

Once a preventative design of an orthotic or shoe is designed the same study can be performed and the data compared to the original study. This will provide verification of the efficacy of the design.

# Appendix (Survey Email)

Dear Head Athletic Trainer,

**Due to the limited response on our last survey and the great potential the survey has for understanding and preventing Jones Fractures, we implore those of you who did not respond to please do so. It will take no longer than 5 to 10 minutes of your time while providing much needed information regarding Jones Fractures in athletes. If you have already taken the survey, thanks again and sorry for the repeat.**

Attached below is a survey for the occurrence, mechanism & treatment of $5^{th}$ metatarsal fractures among college football players. This survey hopes to put together information regarding any contributing factors, mechanism of injury, treatment, rehab and return to play. This comprehensive data is currently lacking in the medical literature and this joint collaboration between Anmed Health Primary Care Sports Medicine, Blue Ridge Orthopedics and Clemson University Department of Bioengineering hopes to fill that void.

It should take no longer than 5 to 10 minutes of your time. If you could please fill-out the online survey within the next 2 weeks, it would be most helpful.

The Institutional Review Committees of Anmed Health and the Greenville Hospital System have reviewed this study for the protection of the rights of human participants in research studies, in accordance with federal and state regulations. However, before you choose to be a research participant, it is important that you read the following information and ask as many questions as necessary to be sure that you understand what your participation will involve. This survey has been sent to every NCAA Division 1 and 1AA school's head athletic trainer. All you will be asked to do is answer a few questions to the best of your knowledge. **This survey is completely anonymous with no connection between your program and the responses.** Any questions regarding this survey can be sent to any of the email addresses provided above.

## CONSENT TO PARTICIPATE

I choose to participate in this study. I have read all of the above or it has been read to me. I have been given the opportunity to ask questions about this study and my questions have been answered to my satisfaction. By clicking the link below to take the survey you have agreed to the terms and conditions of this study.

http://www.surveymonkey.com/s.aspx?sm=UmNPsV6EcTuqwutRbFvaqg_3d_3d

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# REFERENCES


1. Acker JH, Drez D,Jr: Nonoperative treatment of stress fractures of the proximal shaft of the fifth metatarsal (Jones' fracture). *Foot Ankle 7*(3): 152-155, 1986.

2. Andreasson G, Lindenberger U, Renstrom P, et al: Torque developed at simulated sliding between sport shoes and an artificial turf. *Am J Sports Med 14*(3): 225-230, 1986.

3. Arangio G: Transverse proximal diaphysial fracture of the fifth metatarsal: a review of 12 cases. *Foot Ankle 13*(9): 547-549, 1992.

4. Arangio GA: Proximal diaphyseal fractures of the fifth metatarsal (Jones' fracture): two cases treated by cross-pinning with review of 106 cases. *Foot Ankle 3*(5): 293-296, 1983.

5. Arangio GA, Beam H, Kowalczyk G, et al: Analysis of stress in the metatarsals. *Foot & Ankle Surgery 4*: 123-124-128, 1998.

6. Arangio GA, Xiao D, Salathe EP: Biomechanical study of stress in the fifth metatarsal. *Clin Biomech (Bristol, Avon) 12*(3): 160-164, 1997.

7. Bonstingl RW, Morehouse CA, Niebel BW: Torques developed by different types of shoes on various playing surfaces. *Med Sci Sports 7*(2): 127-131, 1975.

8. Bowers KD,Jr, Martin RB: Cleat-surface friction on new and old AstroTurf. *Med Sci Sports 7*(2): 132-135, 1975.

9. Brudvig TJ, Gudger TD, Obermeyer L: Stress fractures in 295 trainees: a one-year study of incidence as related to age, sex, and race. *Mil Med 148*(8): 666-667, 1983.

10. Byrd T: Jones fracture: relearning an old injury. *South Med J 85*(7): 748-750, 1992.

11. Carp L: Fracture of the Fifth Metatarsal Bone: with Special Reference to Delayed Union. *Ann Surg 86*(2): 308-320, 1927.

12. Carter DR, Caler WE, Spengler DM, et al: Fatigue behavior of adult cortical bone: the influence of mean strain and strain range. *Acta Orthop Scand 52*(5): 481-490, 1981.

13. Cawley PW, Heidt RS,Jr, Scranton PE,Jr, et al: Physiologic axial load, frictional resistance, and the football shoe-surface interface. *Foot Ankle Int 24*(7): 551-556, 2003.

14. Chen H, Nigg B, de Koning J: Relationship between plantar pressure distribution under the foot and insole comfort. *Clin Biomech (Bristol, Avon) 9*: 335-336-341, 1994.

15. Clapper MF, O'Brien TJ, Lyons PM: Fractures of the fifth metatarsal. Analysis of a fracture registry. *Clin Orthop Relat Res (315)*(315): 238-241, 1995.

16. Dameron TB,Jr: Fractures of the Proximal Fifth Metatarsal: Selecting the Best Treatment Option. *J Am Acad Orthop Surg 3*(2): 110-114, 1995.

17. Dameron TB,Jr: Fractures and anatomical variations of the proximal portion of the fifth metatarsal. *J Bone Joint Surg Am 57*(6): 788-792, 1975.

18. DeLee JC, Evans JP, Julian J: Stress fracture of the fifth metatarsal. *Am J Sports Med 11*(5): 349-353, 1983.

19. Donahue SW, Sharkey NA: Strains in the metatarsals during the stance phase of gait: implications for stress fractures. *J Bone Joint Surg Am 81*(9): 1236-1244, 1999.

20. Donahue SW, Sharkey NA, Modanlou KA, et al: Bone strain and microcracks at stress fracture sites in human metatarsals. *Bone 27*(6): 827-833, 2000.

21. Donley BG, McCollum MJ, Murphy GA, et al: Risk of sural nerve injury with intramedullary screw fixation of fifth metatarsal fractures: a cadaver study. *Foot Ankle Int 20*(3): 182-184, 1999.

22. Ebraheim NA, Haman SP, Lu J, et al: Anatomical and radiological considerations of the fifth metatarsal bone. *Foot Ankle Int 21*(3): 212-215, 2000.

23. EDWARDS EA: Anatomy of the small arteries of the foot and toes. *Acta Anat (Basel) 41*: 81-96, 1960.

24. Fernandez Fairen M, Guillen J, Busto JM, et al: Fractures of the fifth metatarsal in basketball players. *Knee Surg Sports Traumatol Arthrosc 7*(6): 373-377, 1999.

25. Ford KR, Manson NA, Evans BJ, et al: Comparison of in-shoe foot loading patterns on natural grass and synthetic turf. *J Sci Med Sport 9*(6): 433-440, 2006.

26. Frey C: Footwear and stress fractures. *Clin Sports Med 16*(2): 249-257, 1997.

27. Glasgow MT, Naranja RJ,Jr, Glasgow SG, et al: Analysis of failed surgical management of fractures of the base of the fifth metatarsal distal to the tuberosity: the Jones fracture. *Foot Ankle Int 17*(8): 449-457, 1996.

28. Gross TS, Bunch RP: A mechanical model of metatarsal stress fracture during distance running. *Am J Sports Med 17*(5): 669-674, 1989.

29. Guettler JH, Ruskan GJ, Bytomski JR, et al: Fifth metatarsal stress fractures in elite basketball players: evaluation of forces acting on the fifth metatarsal. *Am J Orthop 35*(11): 532-536, 2006.

30. Heidt RS,Jr, Dormer SG, Cawley PW, et al: Differences in friction and torsional resistance in athletic shoe-turf surface interfaces. *Am J Sports Med 24*(6): 834-842, 1996.

31. Hennig E, Milani T: In-shoe pressure distribution for running in various types of footwear. *Journal of Applied Biomechanics 11*: 299-300-310, 1995.

32. Hens J, Martens M: Surgical treatment of Jones fractures. *Arch Orthop Trauma Surg 109*(5): 277-279, 1990.

33. Holubec KD, Karlin JM, Scurran BL: Retrospective study of fifth metatarsal fractures. *J Am Podiatr Med Assoc 83*(4): 215-222, 1993.

34. Horst F, Gilbert BJ, Glisson RR, et al: Torque resistance after fixation of Jones fractures with intramedullary screws. *Foot Ankle Int 25*(12): 914-919, 2004.

35. Hulkko A, Orava S, Nikula P: Stress fracture of the fifth metatarsal in athletes. *Ann Chir Gynaecol 74*(5): 233-238, 1985.

36. Husain ZS, DeFronzo DJ: A comparison of bicortical and intramedullary screw fixations of Jones' fractures. *J Foot Ankle Surg 41*(3): 146-153, 2002.

37. Jones R: I. Fracture of the Base of the Fifth Metatarsal Bone by Indirect Violence. *Ann Surg 35*(6): 697-700.2, 1902.

38. Josefsson PO, Karlsson M, Redlund-Johnell I, et al: Closed treatment of Jones fracture. Good results in 40 cases after 11-26 years. *Acta Orthop Scand 65*(5): 545-547, 1994.

39. Josefsson PO, Karlsson M, Redlund-Johnell I, et al: Jones fracture. Surgical versus nonsurgical treatment. *Clin Orthop Relat Res (299)*(299): 252-255,1994.

40. Kavanaugh JH, Brower TD, Mann RV: The Jones fracture revisited. *J Bone Joint Surg Am 60*(6): 776-782, 1978.

41. Kelly IP, Glisson RR, Fink C, et al: Intramedullary screw fixation of Jones fractures. *Foot Ankle Int 22*(7): 585-589, 2001.

42. Khan W, Agarwal M, Warren-Smith C: Management of fractures of the base of the fifth metatarsal distal to the tuberosity. *The Foot 15*: 141-142-145, 2005.

43. Landorf KB: Clarifying proximal diaphyseal fifth metatarsal fractures. The acute fracture versus the stress fracture. *J Am Podiatr Med Assoc 89*(8): 398-404, 1999.

44. Larson CM, Almekinders LC, Taft TN, et al: Intramedullary screw fixation of Jones fractures. Analysis of failure. *Am J Sports Med 30*(1): 55-60, 2002.

45. LEASE GO, EVANS FG: Strength of human metatarsal bones under repetitive loading. *J Appl Physiol 14*(1): 49-51, 1959.

46. Livesay GA, Reda DR, Nauman EA: Peak torque and rotational stiffness developed at the shoe-surface interface: the effect of shoe type and playing surface. *Am J Sports Med 34*(3): 415-422, 2006.

47. Matheson GO, Clement DB, McKenzie DC, et al: Stress fractures in athletes. A study of 320 cases. *Am J Sports Med 15*(1): 46-58, 1987.

48. Meurman KO: Less common stress fractures in the foot. *Br J Radiol 54*(637): 1-7,1981.

49. Milgrom C, Finestone A, Sharkey N, et al: Metatarsal strains are sufficient to cause fatigue fracture during cyclic overloading. *Foot Ankle Int 23*(3): 230-235,2002.

50. Mindrebo N, Shelbourne KD, Van Meter CD, et al: Outpatient percutaneous screw fixation of the acute Jones fracture. *Am J Sports Med 21*(5): 720-723,1993.

51. Mologne TS, Lundeen JM, Clapper MF, et al: Early screw fixation versus casting in the treatment of acute Jones fractures. *Am J Sports Med 33*(7): 970-975,2005.

52. Mueller MJ: Application of plantar pressure assessment in footwear and insert design. *J Orthop Sports Phys Ther 29*(12): 747-755,1999.

53. Murakami T: On the position and course of the deep plantar arteries, with special reference to the so-called plantar metatarsal arteries. *Okajimas Folia Anat Jpn 48*(5): 295-322,1971.

54. Orchard J: Is there a relationship between ground and climatic conditions and injuries in football? *Sports Med 32*(7): 419-432,2002.

55. Panagis JS, Gelberman RH, Taleisnik J, et al: The arterial anatomy of the human carpus. Part II: The intraosseous vascularity. *J Hand Surg [Am] 8*(4): 375-382,1983.

56. Petrisor BA, Ekrol I, Court-Brown C: The epidemiology of metatarsal fractures. *Foot Ankle Int 27*(3): 172-174,2006

57. Pietropaoli MP, Wnorowski DC, Werner FW, et al: Intramedullary screw fixation of Jones fractures: a biomechanical study. *Foot Ankle Int 20*(9): 560-563,1999

58. Porter DA, Duncan M, Meyer SJ: Fifth metatarsal Jones fracture fixation with a 4.5-mm cannulated stainless steel screw in the competitive and recreational athlete: a clinical and radiographic evaluation. *Am J Sports Med 33*(5): 726-733,2005

59. Portland G, Kelikian A, Kodros S: Acute surgical management of Jones' fractures. *Foot Ankle Int 24*(11): 829-833,2003

60. Reese K, Litsky A, Kaeding C, et al: Cannulated screw fixation of Jones fractures: a clinical and biomechanical study. *Am J Sports Med 32*(7): 1736-1742,2004.

61. Rheinstein DJ, Morehouse CA, Niebel BW: Effects on traction of outsole composition and hardnesses of basketball shoes and three types of playing surfaces. *Med Sci Sports 10*(4): 282-288,1978.

62. Roca J, Roure F, Fernandez Fairen M, et al: Stress fractures of the fifth metatarsal. *Acta Orthop Belg 46*(5): 630-636,1980.

63. Rosenberg GA, Sferra JJ: Treatment strategies for acute fractures and nonunions of the proximal fifth metatarsal. *J Am Acad Orthop Surg 8*(5): 332-338,2000.

64. Sammarco GJ: The Jones fracture. *Instr Course Lect 42*: 201-205,1993.

65. Santos D, Carline T, Flynn L, et al: Distribution of in-shoe dynamic plantar foot pressures in professional football players. *The Foot 11*: 10-11-14,2001.

66. Sarimo J, Rantanen J, Orava S, et al: Tension-band wiring for fractures of the fifth metatarsal located in the junction of the proximal metaphysis and diaphysis. *Am J Sports Med 34*(3): 476-480,2006.

67. Schwellnus MP, Jordaan G, Noakes TD: Prevention of common overuse injuries by the use of shock absorbing insoles. A prospective study. *Am J Sports Med 18*(6): 636-641,1990.

68. Shah SN, Knoblich GO, Lindsey DP, et al: Intramedullary screw fixation of proximal fifth metatarsal fractures: a biomechanical study. *Foot Ankle Int 22*(7): 581-584,2001

69. Shereff MJ, Yang QM, Kummer FJ, et al: Vascular anatomy of the fifth metatarsal. *Foot Ankle 11*(6): 350-353,1991.

70. Smith JW, Arnoczky SP, Hersh A: The intraosseous blood supply of the fifth metatarsal: implications for proximal fracture healing. *Foot Ankle 13*(3): 143-152,1992.

71. Stokes IA, Hutton WC, Stott JR: Forces acting on the metatarsals during normal walking. *J Anat 129*(Pt 3): 579-590,1979.

72. Strayer SM, Reece SG, Petrizzi MJ: Fractures of the proximal fifth metatarsal. *Am Fam Physician 59*(9): 2516-2522, 1999.

73. Torg JS, Balduini FC, Zelko RR, et al: Fractures of the base of the fifth metatarsal distal to the tuberosity. Classification and guidelines for non-surgical and surgical management. *J Bone Joint Surg Am 66*(2): 209-214, 1984.

74. Traina SM, McElhinney JP: Tips of the trade #38. The Herbert screw in closed reduction and internal fixation of the Jones fracture. *Orthop Rev 20*(8): 713, 716-7, 1991.

75. Vashishth D, Tanner KE, Bonfield W: Fatigue of cortical bone under combined axial-torsional loading. *J Orthop Res 19*(3): 414-420, 2001.

76. Vertullo CJ, Glisson RR, Nunley JA: Torsional strains in the proximal fifth metatarsal: implications for Jones and stress fracture management. *Foot Ankle Int 25*(9): 650-656, 2004.

77. Weinfeld SB, Haddad SL, Myerson MS: Metatarsal stress fractures. *Clin Sports Med 16*(2): 319-338,1997.

78. Wheeless C, Nunley JA, Urbaniak J: in *Wheeless's Textbook of Orthopaedics.* 2008

79. Wright RW, Fischer DA, Shively RA, et al: Refracture of proximal fifth metatarsal (Jones) fracture after intramedullary screw fixation in athletes. *Am J Sports Med 28*(5): 732-736, 2000.

80. Yu B, Preston JJ, Queen RM, et al: Effects of wearing foot orthosis with medial arch support on the fifth metatarsal loading and ankle inversion angle in selected basketball tasks. *J Orthop Sports Phys Ther 37*(4): 186-191,2007.

81. Zelko RR, Torg JS, Rachun A: Proximal diaphyseal fractures of the fifth metatarsal--treatment of the fractures and their complications in athletes. *Am J Sports Med 7*(2): 95-101,1979.

82. Zogby RG, Baker BE: A review of nonoperative treatment of Jones' fracture. *Am J Sports Med 15*(4): 304-307,1987.