2016

Predisposing Risk Factors Associated With Stress Fracture Development In Division I Cross Country Runners

Kaci Griffin
University of Mississippi

PREDISPOSING RISK FACTORS ASSOCIATED WITH STRESS FRACTURE DEVELOPMENT IN DIVISION I CROSS COUNTRY RUNNERS

A Thesis

presented in partial fulfillment of the requirements

for the degree of Master of Science

in the Department of Nutrition and Hospitality Management

The University of Mississippi

by

KACI L. GRIFFIN

May 2016

ABSTRACT

The purpose of this study was to explore potential factors that could be associated with increased stress fracture development in division one collegiate cross country runners. Participants for this study consisted of 42 collegiate cross country runners at the University of Mississippi. A nutritional assessment consisting of a 3-day food record and measurements of whole body, lumbar spine and hip bone mineral densities using a Dual-Energy X-ray Absorptiometry (DXA) was conducted on each athlete. Each athlete was also asked to answer a demographic questionnaire with questions regarding ethnicity, hometown, smoking status, vitamin/mineral intake, previous stress fracture history, birth control usage and menstrual status. Athletes were also asked to submit their training log to assess weekly and monthly running mileage.

This study found that of the 40% of females and 35% of males reporting a history of stress fracture, all females and males did not meet the recommended daily energy intake, adequate intake for calcium or adequate intake for vitamin D required for their amount of training. Chi-Square Test for Independence found statistical significance in the associations of caloric intake, calcium intake, and vitamin D intake with stress fracture development. No statistical significance was shown between lumbar spine or femoral neck BMD on stress fracture development. Pearson correlation found statistically significant associations with lumbar spine BMD and age of menarche, daily calcium intake and daily vitamin D intake, femur neck BMD and daily caloric intake, and calcium on number of cycles per year as well as vitamin D on number of cycles per year. Other meaningful statistics noted that when data on the lumbar spine was evaluated, 31% of participants were identified as having osteopenia and 4.8% with osteoporosis. More specifically, 31.8% of males and 30% of females suffered from osteopenia. Training in relation to stress fracture development could not be assessed statistically. All female and male training mileage proved to be constant. Results warrant a need for future longitudinal studies.

ACKNOWLEDGEMENTS

I would like to thank my Thesis Committee composed of Dr. Melinda Valliant, Dr. Martha Bass, and Dr. Kathy Knight for their help in making my thesis. Without their wisdom and guidance not only on my thesis, but throughout graduate school, I may not have gotten to this point.

I would also like to thank the entire Ole Miss track & field/cross country team for their participation and support of my thesis. Without the help of this team, none of this thesis would have been possible. It has been a true privilege to work with and study this team over the past two years.

Lastly, I would like to thank the entire Department of Nutrition and Hospitality Management and the School of Applied Sciences at the University of Mississippi for giving me the opportunity to serve as a Master's of Science candidate. It has been an honor to call Ole Miss home.

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

First introduced in 1880 at Harvard University as an autumn training event for track and field distance runners, collegiate cross country running has skyrocketed in popularity over the last decade. Adolescents begin all-terrain competitive running at a very young age and by early twenties, hit the peak in their running careers. Runners are consistently increasing their training and workload while decreasing other pivotal factors such as optimal carbohydrate, protein, fat intake and recovery. With this situation, it is likely that an athlete's bone health can suffer. A decline in bone health predisposes athletes to numerous forms of overuse injuries. The most common overuse injury, stress fractures, was first cited in case studies of soldiers in the 19th and early 20th centuries. By the mid-1900s, nonmilitary populations developed such fractures with increasing frequency. Individuals participating in repetitive weight-bearing activities such as running and marching are the most frequently reported cases of stress fracture (Jones et al, 2002). Overuse injuries of the shin and lower leg are increasingly common in recreational and competitive runners. Consistent loading while running unmasks the bone to internal forces of stress. Previous research has determined that if the degree of weight or strain placed on the bone reaches an appropriate threshold, microcracks may develop (Barrack, 2014). Despite ongoing damage, the bone has the ability to repair itself if provided with adequate nutrients and sufficient recovery. However, if not repaired, these microcracks develop into larger cracks leading to more drastic bone injury such as stress fractures.

One retrospective study had found that 8.3% to 52% of runners have had a history of stress fracture, although whereas the incidence in a 12-month prospective study of track and field athletes the incidence was 21.1% (Warden, Burr & Brukner, 2006). When expressed as a percentage of all injuries, stress fractures have been reported to represent between 0.5% and 20% of all injuries sustained by athletic populations (Warden, Burr & Brukner, 2006). Prevention is key and the only way to prevent this type of injury is to recognize the predisposing risk factors. In their 2007 consensus statement, the American College of Sports Medicine stated that the recognition of risk factors associated with stress fractures is of paramount importance. It is imperative to note that stress fractures are not the result of one individual cause but of multiple causes. Results from studies of female or female and male athletes are contradictory regarding the associations of stress fractures with age, lower bone mineral density or lean body mass, late age at menarche, use of oral contraceptives, low body weight, disordered eating, and low calcium and dairy product intake. Individual studies have reported leg length discrepancy, low dietary fat intake, and a history of stress fracture to be risk factors, but confirmation in other investigations is needed (Kelsey et al, 2007). Nutritional deficits additionally compromise bone and increase the susceptibility to fractures (Bennell, 1996). Athletes represent an important population to evaluate for dietary and activity factors related to bone growth and development because they are often of high school or college age and at least 90% of peak bone mass is attained by age 18 (Tenforde et al, 2010).

Not only does low bone mineral density put athletes at an increased risk for stress fractures and future bone health diseases, failure to achieve peak bone mass in early adult years may hasten the onset of osteoporosis (Winters-Stone & Snow, 2004). Unfortunately, no symptoms correlate with bone loss making it nearly impossible to determine bone status without bone density measurement. A positive correlation between low bone mass and stress fractures was noted in Fredericson's study on 12 female distance runners (2003). In this study, 9 of 12 female distance runners experienced stress fractures along with osteopenia or osteoporosis. Given the strong correlation between distance running and stress fractures, there is much research on the risk factor reduction. Cross country runners, typically females, are on the negative end of the spectrum when it comes to consuming adequate daily amounts of these two key nutrients. Normal healthy bones turn over calcium constantly, replacing lost calcium with new calcium received from dietary intake (Moyer, 2013). There is good evidence that calcium, vitamin D, and protein help promote bone growth in children, teens, and young adults. High milk intake has also been correlated with greater BMD and lower risk of fractures for later in life (Nieves et al, 2010). Good dietary practices in correlation with adequate calcium and vitamin D intake present promise when maintaining healthy bones.

Research of bone health has increased over the past few decades. While there has been an increase in information and knowledge on the female athlete triad - disordered eating, amenorrhea and osteoporosis - there has been a lack of research the interaction of these factors in the male athlete. The interaction between stress fracture incidence and training hours has received significantly less attention over the past few decades as well. In 2012, Wentz and colleagues found that hours of training per week were negatively correlated with total-body and lumbar-spine BMD (2012). Prior to this study, the only known prospective study calculating incidence of stress fractures in terms of training hours was published by Bennell and colleagues in the late 1990's.

When examining the risk factors, it appears that cross country runners are at an increased risk for development of this injury. Therefore, an evaluation of risk factors common in cross country runners would be an appropriate step in determining future prevention measures. Also, early exposure of risk factors for stress fractures can lead to early treatment which in turn may boost athlete performance and overall health.

Statement of the Problem

The purpose of this study is to explore potential risk factors that could be associated with increased stress fracture development in a NCAA Division I collegiate cross country team. At the beginning of the cross country season in the fall of 2015, a dual-energy x-ray absorptiometry (DXA) scan including whole body, lumbar spine, left hip bone mineral density and body fat percentage was performed on each athlete. Each athlete was also asked to complete prospective 3-day nutritional assessment of total dietary intake. Data on training was also collected on each athlete via flotrack.com running logs.

Research Questions

This study addressed the following research questions:

1. Are collegiate cross country runners at an increased risk for stress fracture development based on bone mineral density?
2. Are collegiate cross country runners at an increased risk for stress fracture development based on miles ran per month?
3. Are collegiate cross country runners at an increased risk for stress fracture development based on caloric intake?
4. Are collegiate cross country runners at an increased risk for stress fracture development based on calcium intake?

5. Are collegiate cross country runners at an increased risk for stress fracture development based on vitamin D intake?

Definition of Terms

For clarity of understanding and use of the working definition by the researcher, the subsequent terms are defined as follows:

Amenorrhea is the absence of menstruation.

Eumenorrhea is normal menstruation.

Oligomenorrhea is infrequent menstruation.

Osteopenia is abnormally low bone density clinically defined as a T-score value of -1.0 to -2.5.

Osteoporosis is a skeletal disease characterized by low bone density with a subsequent increase in bone fragility and susceptibility to fractures. It is clinically defined as a T-score value of less than -2.5.

Osteogenesis is the process of laying down new bone material by cells. It is synonymous with bone tissue formation.

Female athlete triad is the combination of disordered eating, menstrual irregularity, and osteoporosis/osteopenia in physically active girls and women.

Dual-Energy X-ray Absorptiometry or bone densitometry is an enhanced form of x-ray technology that is used to measure bone loss.

Trabecular bone, also known as cancellous bone is found at the ends of long bones. It is spongy and makes up the bulk of the interior of most bones, including the vertebrae. Its main function is to protect organs, support the body, provide levels for movement, and store minerals.

Cortical bone, also known as compact bone and forms the cortex, or outer shell, of most bones. It is much denser than trabecular bone and contributes 80% of the weight of the human skeleton.

Assumptions and Limitations

There are several concealed assumptions and limitations in this study that should not be overlooked when analyzing the research. First, it was assumed that all 3-day nutritional assessments were accurate and there were no misconceptions or perceptions about what they should or should not be eating. Second, it was assumed that training logs accurately measured training hours completed on a weekly basis. However, terrain and incline gradient were not measured only training time. Third, it was assumed that the DXA scan was calibrated prior to each usage with the most up to date software available. Limitations to the study included the lack in ethnic diversity with 95.3% Caucasian and only 4.7% African American. The study was also limited to one NCAA Division I cross country team competing in the Southeastern Conference. However, it is possible that several other variables that were not looked could have changed the results of this study and/or future research.

CHAPTER 2

LITERATURE REVIEW

This chapter reviews risk factors and health concerns in relation to stress fracture development in collegiate cross country runners. Current literature suggests that the development of bone stress injury involves genetic, hormonal, metabolic, biomechanical, musculoskeletal, training, and nutrition components collectively (Barrack, 2014). Specifically, this chapter will focus on energy availability, vitamin D, calcium, bone mineral density, menstrual history, osteoporosis/osteopenia, exercise, training, dietary practices, female athlete triad, and biomechanical factors.

Energy Availability

The remodeling of bone to adapt to mechanical loads depends on energy availability (Loucks, 2007). Energy availability, defined behaviorally as dietary energy intake minus exercise energy expenditure, is the amount of dietary energy remaining after exercise training for these other metabolic processes (Loucks, 2007). Many marathon runners and other endurance athletes reduce energy availability either (1) intentionally to modify body size and composition for improving performance; (2) compulsively in a psychopathological pattern of disordered eating; or (3) inadvertently because there is no strong biological drive to match energy intake to activity-induced energy expenditure (Loucks, 2007). Decreases in leptin, estradiol and insulin-like growth factor-11 and an increase in cortisol have been attributed to inadequate calorie intake relative to exercise energy expenditure sustained over a period of weeks or months (Barrack, 2014). These disruptions in hormone levels present an imbalance in bone turnover that disturbs newly formed bone development and reduces ability to repair previous microdamage (Meyer, 2007). The uncoupling of bone formation and resorption can be seen with restricted energy availability of as little as 30 kcal/kg of lean body mass/d (Pepper, Arkuthota & McCarty, 2006).Research complied by Ihle and Loucks (2004) on female military recruits demonstrated that restricted energy availability in young exercising women negatively altered bone turnover, as indicated by reduced levels of bone formation markers (plasma osteocalcin and serum type I procollagen car- boxy-terminal propeptide) and elevated levels of a marker for bone resorption (urinary N-terminal telopeptide). This finding indicates that deficient caloric intake may potentiate stress fracture development by altering the skeleton's susceptibility to developing microdamage and its ability to repair such damage. Other studies, as referenced by Burrows et al (2003) have suggested that low energy intake can alter luteinising hormone pulsatile activity and decrease BMD levels. Despite not finding a direct relation between energy intake and BMD at any site, femoral neck BMD was significantly associated with magnesium and zinc intake, with higher magnesium and lower zinc intakes related to higher femoral neck BMD values. If the micronutrients are examined looked at individually, low levels of magnesium could downregulate parathyroid hormone secretion, decreasing calcium uptake and altering the bone remodeling process (Burrows et al, 2003).

Calcium

Dietary deficiencies, in particular dietary calcium, may contribute to the development of stress fractures by influencing bone density and bone remodeling (Bennell et al, 1999). Calcium, one of the main nutrients required for bone growth. Normal healthy bones turn over calcium constantly, replacing calcium lost with new calcium received from dietary intake intake (Moyer, 2013). Calcium is found in various forms of dairy products such as milks and cheese and it can also be found in leafy greens, seafood, and some beans. Calcium intake has been established as a determinate of bone metabolism, especially essential to childhood bone growth and the fulfillment of peak bone density (Weaver, 2002). Lappe and colleagues (2008) reported five primary reasons why these two dietary components have a strong correlation with decreased injury risk. (1) Women less than thirty years of age have not achieved peak bone mass and have the potential to gain bone, which requires that they be in positive calcium balance; (2) intense training stimulates bone formation increasing calcium demands; (3) microfracture repair through remodeling requires calcium for bone formation; (4) substantial cutaneous calcium losses can occur during training; and (5) calcium and vitamin D intake in young women is typically less than optimal. However, the recommended daily allowance for calcium differs across the life span and may not adequately address the specific needs of physically active individuals or female athletes with menstrual disturbances (Bennell et al, 1999). Wentz et. al (2012) hypothesized through his study that female runners who had a higher calcium intake and whose dairy intake throughout the adolescent years was high would be less prone to developing stress fractures. The study compared female runners with a history of stress fractures with matched runners with no history of stress fracture to determine whether there were differences in dairy intake during their adolescent years and current dietary calcium intake. Forty-four stress fractures were identified in the 27 subjects with 8 of the subjects having multiple stress fractures. Statistical analysis revealed an increased risk for stress fracture in women with longer running history, higher percentage of hard-ground running, low dietary calcium intake, and lower total body bone mineral density. Myburgh et al (1990) found shin soreness, an early stage of stress fracture development and low bone density, common in both males and female athletes is also associated with low dietary calcium intake.

Nieves and colleagues (2010) formulated original research to identify nutrients, foods, and dietary patterns associated with stress fracture risk and changes in bone density among young female distance runners. This two year prospective cohort study assessed the dietary variables via food frequency questionnaire of 125 competitive female distance runners. Higher intakes of calcium per day were each related to a reduced rate of stress fracture. Every additional cup of skim milk consumed per day was associated with a 62% reduced fracture risk; every additional serving of dairy products consumed per day warranted a 40% reduction in risk. Focusing on bone mineral density, calcium intake was positively related to annual gains in bone mineral density of the hip and total body. For every standard deviation increase in calcium intake, women gained an additional 0.16% in spine bone mineral density annually and 0.26% in hip bone mineral density. Skim milk, total milk intake, and number of dairy servings per day also predicted significant gains in hip bone mineral density and whole-body bone mineral count. Overall, women who consumed less than 800mg of calcium per day had approximately six times the stress fracture rate of women whose intake was greater than 1,500mg of calcium and more than twice the rate for women whose intake was between 800 and 1,500 mg. In a study on 25 athletes at the University of Cape Town Sports Injury Clinic, the authors found that athletes with stress fractures had lower intakes of dietary calcium and histories of lower intakes of dairy products than did control subjects and that there was a significant positive correlation between calcium intake and bone mineral density in the weight-bearing bones. Mean calcium intake levels of injured subjects were only 87% of the recommended levels. Researchers concluded that satisfactory calcium intake during developmental years is necessary for adequate skeletal expansion, while sufficient calcium intake during adult years is necessary for bone conservation (Snow, 2002). Using data from the third National Health and Nutrition Examination Survey(NHANES III) of 3,251 non-Hispanic, white women greater than 20 years of age, Kalkwarf and colleagues (2003) noted that among women aged 20 to 49 years, bone mineral content was 5.6% lower than those who consumed less than one serving of milk per week than those who consumed greater than one serving per day during childhood. These statistics also suggest that low milk intake during adolescence was associated with a 3% reduction in hip bone mineral content and bone mineral density. For this review, the key result was the determination that low milk intake during childhood was associated with a two-fold greater risk of fracture. Related to these results, Teegarden and colleagues (1999) also hypothesized that higher milk intake during adolescence is associated with greater total body, spine, and radial bone mineral measures during development of peak bone mass. Limited research is available on the potential effects of calcium lost in sweat; however, some research warrants consideration when it comes to consistent and extensive outdoor training. Calcium lost in sweat following moderate-intensity exercise is believed to place an individual in what is called a "negative calcium balance." Negative calcium balance is parallel to gradual loss of bone mass and has the potential to increase the risk of developing osteoporosis or bone damage.

Vitamin D

Vitamin D is a secosteriod hormone that is primarily obtained via cutaneous synthesis following exposure to ultraviolet B. Vitamin D can also be acquired in smalled quantities from fatty fish, eggs, fortified foods, and dietary supplements (Lewis, 2013). According to the National Institutes of Health, the average adult American diet only contains 150-300 IU of Vitamin D per day. Recommended dietary allowance of Vitamin D for adults is 600-800 IU per day, but higher levels may be optimal (Price et al, 2012). The key importance of vitamin D is its calciotropic properties (regulation of calcium in the blood and bone), acting on the kidney, intestines, and bone. It is necessary for adequate bone health through regulation of the expression of genes that enhance calcium absorption and bone deposition. Reduced vitamin D status promotes secretion of parathyroid hormone (PTH), which may increase bone resorption, resulting in diminished bone density (Moran, 2013). Vitamin D deficiency is known to contribute to decreased bone mineral density and increased fracture prevalence (Lewis et al, 2013 and Tenforde, 2010). Despite this discovery, there is very limited research available on the role of vitamin D alone in stress fracture development and prevention in athletes. Ruohola et al (2006) found that low baseline 25 (OH) D predicted stress fracture in Finnish male military recruits. In the final multivariate analysis of that study, a significant risk factor for stress fracture was serum 25(OH)D below the median level of 75.8nM (Lappe et al, 2008).

Bone Mineral Density

Low bone density has been identified as an etiologic factor for stress fractures in athletes, and has the potential to contribute to the development of stress fractures by reducing bone strength and allowing the microdamage from repetitive loading to accumulate (Guest, 2005). Competitive female athletes who participate in impact sports have been documented as having a higher bone mineral density than other sedentary individuals. However, despite the nature of their activity, female distance runners do not possess comparably high bone mineral densities. Bone mineral density in female runners is similar to that of inactive controls (Winters-Stone, 2004). One study of primary importance was conducted in the early nineties to determine whether low bone density is associated with stress fractures in athletes. In this study, 25 athletes at the University of Cape Town Sports Injury Clinic with a scientigraphically confirmed stress fractures were matched with 25 control athletes with no history of bone injury. Seven fractures occurred in the foot, six in the femoral neck, three in the pubic ramus, three in other areas of the femur, four in the tibia, and two in the fibula. Of the 25 injured subjects, seven had previously had shin splints and five had a history of one or more previous stress fractures. Bone mineral density was lower in the lumbar spine and the proximal femur of injured subjects compared with control subjects. Injured subjects had a significantly lower bone density in the femoral neck and within these subjects, six subjects with stress fractures had drastically lower femoral neck bone density than their counterparts. BMD measured significantly lower in athletes with fractures versus control athletes. On the contrary, one study of 14 female runners found significantly higher lumbar spine and femoral neck bone density in the stress fracture group. The authors speculated that greater external loading forces measured in the stress fracture athletes during running may have been responsible for their higher bone density. Yet, Bennell et al reported either no difference of significantly lower bone density in the stress fracture group (1999).

Male osteoporosis is responsible for one seventh of all vertebral compression fractures and one fourth of all hip fractures in active individuals. The annual expenditure on osteoporotic related fractures is substantial and will increase with the average age of the population (Hetland et al., 1993). For athletes older than 25 years, the addition of exercise provides a relatively ineffective treatment for adult osteoporosis (Turner & Robling, 2005). Static loads do not induce osteogenesis whereas dynamic loading can be effective stimulus for bone formation. Activities such as those involving high impact such as jumping are the best for bone producing (Turner, 1998). However, few studies have determined loss of bone as an outcome of exercise in male runners. One study performed on animals exposed to moderate or long cycles of mechanical loading on a daily basis demonstrated that bone “tunes out” mechanical signals after a couple of dozen exercise cycles so that further exercise adds no further anabolic response (Turner & Robling, 2005). Hetland et al (1993) reached out to male runners who had enrolled in a recreational run in Copenhagen the previous year. Out of the 120 runners, all were in good physical condition and participated in weekly distance running ranging from 0-160km. Twenty-two men were classified as elite runners with a weekly distance of at least 100km and in contrast 12 participants had not been running regularly during the previous 12 months or more. This group constituted the group of non running controls. The bone mineral content of the lumbar spine correlated negatively with the weekly distance run. Bone mineral content in the group of elite runners was significantly lower than that of the non running controls as well. The principle finding of this study presented a significant negative correlation between running volume and bone mass. Long distance runners had a significantly lower bone mineral content in the lumbar spine, proximal femur, distal forearm, and total body than the non runners. The difference between both groups increased with the weekly distance run. For individuals running more than 100km per week, the lumbar bone mineral content averaged 19% lower (Hetland, 1993). MacDougall and colleagues (1992) reviewed the relationship between running mileage and bone density and determined the bone density of the lower legs tended to decrease in the high mileage runners compared to that in the low mileage runners. In a study focusing on vertebral bone density, Bilanin and colleagues (1989) developed research on 11 long distance runners with training intensities similar to those of elite runners and determined that the bone density of the first lumbar vertebra was 10% lower than that in an age-matched group of non running controls.

Menstrual History

Among highly trained endurance athletes, literature suggests that 25-40% of women report fewer than three menses per year (Drinkwater, 1984). It is apparent that few menses result in low estrogen levels which result in decreased bone mass. Given that previous research has concluded that physical activity inhibits and has a reversal effect on bone loss in postmenopausal women, this would suggest that athletes engaging in high frequency, duration and intensity cross country running would present with a protective effect against bone loss in athletes with decreased menses. Drinkwater et al. (1984) discovered a significantly diminished lumbar vertebra mineral density in amenorrheic athletes when compared to eumenorrheic athletes of the same physical characteristics and training regimens. A decrease in estradiol levels in the amenorrheic group when compared to their eumenorrheic counterparts was also noted. In a similar study by Riggs et al., eumenorrheic women presented with BMD similar in range to those in the previously mentioned study. However, Riggs et al reported an average BMD of amenorrheic athletes equivalent to women with an approximate age of 50 years old. Two of the amenorrheic athletes had a vertebral mineral density below the fracture threshold, defined as 0.965g per square centimeter. Also, in larger cohorts of healthy adolescents and pre- and post-menopausal women, the most common finding is that a later age of menarche is related to lower bone density. However, this does not imply a causal relationship since other factors such as genetic background may be major determinants of both variables (Bennell et al, 1999).

Exercise

Exercise type plays a key role in bone mineral density at various sites. It is fairly easy to single out why athletic activities performed in a single plane with a repetitive motion would warrant overuse bone injuries. Total-body and site specific bone mineral density values among division one female athletes in a vast array of sports were evaluated by Mudd and colleagues (2007) to determine which sports, if any, had the greatest affect of bone mineral density due to the type of exercise. Following evaluation of ninety-nine female athletes in twelve sports, it was concluded that runners had the lowest total-body and site-specific bone mineral density values for every site except average leg score when compared with gymnasts and softball players. Overall, runners and swimmers in this study demonstrated lower average bone mineral density in the body as a whole than any other sport. It was also suggested that decreased estrogen levels affect the more metabolically active trabecular bone before the cortical bone which explains why runners are so much more affected than other individual sports (Mudd, 2007).

Training Regimen

A high training volume is a major risk factor in stress fracture development. Individuals who participate in sports that involve high-magnitude loads that are introduced over short periods (eg, sprinters) have increased risk of developing a stress fracture due to high strain magnitudes and rates. On the other hand, individuals who participate in sports that involve high numbers of load repetitions (eg, distance runners) are at heightened risk of stress fracture due to cyclic overload (Warden, Burr & Brukner, 2006). One study in runners have demonstrated that higher weekly running mileage correlates with an increased incidence of stress fractures and overall running injuries (Pepper, Akuthota & McCarty, 2006). However, Brunet et al. surveyed 1505 runners and found that increasing mileage correlated with an increase in stress fractures in women but not men (Bennell et al, 1999). Hetland et al (1993) reported a significant negative correlation between running volume and bone mass. The researchers in this study found that for those who ran more than 100km a week, the lumbar bone mineral content was, on the average, 19% lower. MacDougall et al (1992) found that the bone density of the lower legs tended to decrease in the high mileage runners compared to that in the lower mileage runners. Burrows et al (2003) also found in their study after controlling for differences in body size and age, distance run per week was negatively associated with lumbar spine and femoral neck BMD. In this study, the regression analysis utilized indicated that participants who ran longer distances had a lower femoral neck and lumbar spine BMD than those who ran shorter distances.

Overall, there is little research in athletes with regards to training regimen and volume in comparison to military recruits. Most are anecdotal observations or case-series where training parameters are examined only in those athletes with stress fractures. For example, surveys reporting that up to 86% of athletes can identify some change in their training prior to the onset of the stress fracture do not provide a similar comparison in uninjured athletes (Bennell et al, 1999). Kadel, Teitz and Kronmal (1992) compiled research on ballet dancers and determined that each dancer training for more than 5 hours per day was 16 times more likely to develop a stress fracture compared to dancers training for less than 5 hours per day (Kadel et al, 1992).

Female Athlete Triad

The female athlete triad is defined as a serious syndrome consisting of three interrelated components. Disordered eating, amenorrhea and osteoporosis compose the triad and with people most at risk being those participating in sports in which success is determined by thinness and aesthetics (Micklesfield, 2007). Female athletes at the elite level, those involved in appearance or endurance sports, and those with a low body weight are particularly susceptible to developing the triad (Thompson, 2007). Female athletes who participate in gymnastics, track/cross country, diving, dance and synchronized swimming are affected most frequently (Arasheben et al, 2011). It is imperative to note however eating disorders such as anorexia nervosa and bulimia represent one extreme of the spectrum of disordered eating attitudes and behaviors, more subtle eating disturbances could also have implications for the bone health of women athletes (Guest, 2005). Eating Disorders Not Otherwise Specified (EDNOS), or subclinical eating disorders, account for fifty percent of all eating disorders (Thompson, 2007). At some point throughout their career of female cross country athletes, one if not all of the components of the female athlete triad are prevalent.

Dietary Practices

Disordered eating, or cognitive dietary restraint, is a key role in what is known as the female athlete triad which has been said to predispose an athlete to stress fracture. For female distance runners, cognitive dietary restraint has also been viewed as a huge mental blockade due to the belief that lean appearance equates with success. In a study comparing menstruation and disordered eating, Guest and Barr (2005) used a cross-sectional, descriptive study to support their hypothesis that regularly menstruating female runners with recent lower-extremity stress fracture would warrant higher scores on the cognitive dietary restraint (CDR) sub scale of a Three-Factor Eating Questionnaire when compared to regularly menstruating female runners without history of stress fracture. The results of this study supported their hypothesis which determined that significantly higher CDR scores were seen in runners with recent stress fracture compared to their counterparts without stress fracture. Disordered eating has been noted to be associated with decreased bone mineral density in women despite experiencing normal menstruation (Cobb, 2003). Disordered eating has resulted in increased risk of stress fracture as a single entity. By the use of the Eating Attitudes Test (EAT-40), the role of disordered eating was evaluated in comparison to stress fracture prevalence in track and field athletes (Bennell et al,1995). Twenty-two women in a group of fifty-three female track and field athletes had a history of stress fracture with a total of forty-five reported at the end of the study. Higher scores on the EAT-40 were seen in the stress fracture group when compared to the non-stress fracture group which presents evidence that restrictive eating correlates with stress fracture prevalence. More recently, a large multicentre surgey of 2298 US collegiate athletes revealed that white females with a history of pathogenic weight control behaviors had a relative odds ratio of 1.96 of having a stress fracture compared with those who did not have this history. These studies suggest that disordered patterns of eating are associated with a higher risk for stress fracture (Bennell et al, 1999). Anorexia nervosa has been associated with a significantly decreased BMD. Nearly 75% of adolescent girls with anorexia have a BMD more than two standard deviations below the normal value (Pepper, Akuthota & McCarty, 2006). According to Waugh et al (2011) 90% percent of adolescents and young women with anorexia nervosa (AN) have decreased bone mineral density compared with their healthy peers at one or more skeletal sites. Consequently, women with AN have a significantly higher long-term fracture risk than the general population (Waugh et al, 2011).

Biomechanical Factors

Structural and biomechanical irregularities (ie, leg length differences, per planus/cavus, high Q-angle, foot varus/valgus) may lead to an imbalanced distribution of impact to bone and increase the fracture risk at various bone sites. Individuals with smaller muscle sizes surrounding the tibia have an increased risk of injury given that muscle absorbs an impact at a rate that is approximately 100 times higher than bone (Bennell, 1995). When muscles are dysfunctional (weakened, fatigued, or altered in the activation patterns) their ability to absorb loads becomes compromised, potentially leading to increased loading on the skeleton (Warden, Burr & Brukner, 2006).

It is difficult to establish the contribution of individual biomechanical features to stress fracture risk. This difficulty results from two major factors: 1) assessment of dynamic biomechanical features typically requires complicated measurement tools that are not often readily available and are time-consuming to use, and 2) the prospective study of risk factors for stress fracture requires large numbers of individuals to be studied over long periods in order to generate sufficient statistical power (Warden et al, 2006).

Despite the difficulty, one prospective study have focused on specific biomechanical features influencing the development of stress fractures such as foot structure. Simkin et al. determined that femoral and tibial stress fractures were more frequent in subjects with high-arched feet, whereas metatarsal stress fractures were more frequent in low-arched feet (Warden et al, 2006). However, Dixon et al. discovered that military recruits with a previous history of metatarsal stress fracture did not differ from a control group in static biomechanical measures of the foot, but dynamic biomechanical measures during running differed between the groups (Warden et al, 2006).

CHAPTER 3

METHODOLOGY

Subject Selection and Description

Cross country athletes at the University of Mississippi were recruited to participate in this study. Participants were recruited through the athletic department with the help of team coaches and athletic trainers. An announcement was made during the annual pre-season team meeting serving as the recruitment process. Participation in this study was voluntary and participants were instructed that they could drop out of the study at any time. The Office of Research and Sponsored Programs' Division of Research Integrity and Compliance Institutional Review Board at The University of Mississippi reviewed and approved the study and written informed consent was obtained from each participant. All participants were between 18 and 24 years of age. Age, height, weight, hometown, years of training, smoking status, birth control usage, prior and current vitamin/mineral intake and previous history of stress fracture were all recorded after receiving consent. Subjects were not categorized by race or ethnic decent, nor by any demographics previously listed. Demographics will serve solely for documentation purposes.

DXA

Dual-Energy X-ray Absorptiometry (DXA) scans were performed at The University of Mississippi Bone Mineral Density Laboratory (Hologic, Madison, WI).

Dietary Analysis

Following pre-season physical screening and during the course of the competition season, each participant completed a three-day diet record which was analyzed using Nutrient Data Supernus for Research (NDS-R) (Appendix C). Each diet record was assessed to determine daily energy intake, calcium intake and vitamin D intake.

Training

Each participant completed weekly training logs through Flotrackr (flotrack.org). Flotrack is an online media channel that was created by Flocast LLC, Bergeron by Design. The channel targets running fans and offers articles, videos, and rankings of running events and athletes at every skill level. Training regimens for both female and male cross country runners were divided into three sections: pre-season, season, and post-season. The months of June, July, and August serve as pre-season; September, October, and November serve as season; and December, January, February, March, April and May serve as post season. Weekly mileage, weekly time, season average mileage, and season average time were collected.

Demographics

A questionnaire (Appendix B) was developed by the researcher in order to gain demographic information for each participant. The questionnaire detailed information regarding age, height, weight, ethnicity, hometown, years of training, smoking status, menstrual cycle including age of menarche, number of cycles in the past year, birth control usage, prior and current vitamin/mineral intake and previous history of stress fracture of each participant. Age, height, and weight were also collected prior to the DXA scan.

Data Collection Procedures

Each participant was given a questionnaire and 3-day nutritional assessment form after returning their informed consent. Participants were instructed to complete both the questionnaire and nutrition assessment as accurately as they could and return them to the researcher. Prior to each scan, female participants received a pregnancy test for precautionary measures due to radiation exposure. Lumbar spine, femur, and whole body scans were performed. Results summary included: bone mineral count (g), fat (g), lean (g), lean + bone mineral count (g), total mass (g), area (cm2), bone mineral density t-score (g/cm2), bone mineral density z-score (g/cm2), and percent fat.

Each participant was asked to complete the three-day nutritional assessment in the series of two week days and one weekend day. For each day, participants were asked to include all food or beverage consumed and record the time consumed, portion sizes eaten, where each food/beverage was consumed (i.e. home, fast food, work, other), how the food/beverage was prepared (cooking method, seasonings, additions, etc.), and if ice was included in the beverage consumed. Additionally, each participant answered the following questions: what type of oil was used at home; what type of margarine was used at home; what type of milk was ypically consumed; and what type of bread was typically consumed. Participants were also asked to reflect on each day's intake and state whether or not each day's intake reflected the participant's usual pattern. Finally, each participant was asked whether or not any vitamins or minerals were consumed that day. If so, participants were asked to include the name, brand, strength, and quantity consumed per day.

Each participant was asked to complete training logs via flotrackr.org and participants enter total weekly and monthly overall time, distance, and average pace. Participants were also instructed to log mileage, interval workouts, cross training and races. Each weekly log was to be completed online by 5pm each Friday during the season.

Stress Fractures

Upon diagnosis of stress fracture, participants were not be removed from the study, but were removed from cross country participation until the fracture healed and subject received clearance from the team physician. Each new and/or reoccurring stress fracture was recorded along with previous history of stress fracture.

Statistical Analysis

The chi-square test for independence was used to discover if there was a relationship between stress fracture and non-stress fracture groups with females/males, normal BMD/osteopenia/osteoporosis, and pre-season/season/post-season training. The Statistical Program for Social Sciences (SPSS) computer software program was used to analyze the data.

CHAPTER 4

RESULTS

The purpose of this study was to investigate a Division I collegiate cross country team's predisposing risk factors associated with the development of stress fractures. This chapter discusses the outcomes of this study looking specifically at each of the risk factors assessed including age, gender, ethnicity, body structure and body weight, bone mineral density, menstrual cycle, average calcium intake, supplements, and oral contraceptives. Table 1 summarizes the female and male participant characteristics. Table 2 summarizes physical, dietary, and exercise characteristics for female and male participants.

Table 1: Summary of demographic characteristics of female and male participants

	Females	Males
Age, yr	20.3 +/- 1.09	20.7 +/- 1.31
Height, in	65.9 +/- 2.49	70.5 +/- 1.84
Weight, lbs	122.8 +/- 10.1	146.7 +/- 9.03
% Fat	18.0 +/- 3.23	9.3 +/- 1.64

Table 2: Physical, dietary, and exercise characteristics for female and male participants

	Females	Males
BMD Characteristics		
Whole Body BMD	1.9 +/- 1.03	0.9 +/- 0.87
Femur Neck BMD	0.4 +/- 0.79	0.6 +/- 0.90
Lumbar BMD	-0.7 +/- 0.95	-0.84 +/- 1.06
Nutrition Characteristics		
Energy Intake, kcals/day	1965 +/- 262.1	2691 +/- 332*
Calcium Intake, mg/day	1012.1 +/- 201.1*	1083.7 +/- 241.7*
Vitamin D Intake, IU/day	13 +/- 3.99*	13.7 +/- 3.35*
Protein Intake, percent/day	12.9 +/- 2.27	12.9 +/- 2.64
Fat Intake, percent/day	30.2 +/- 3.64	30.3 +/- 2.83
Carb Intake, percent/day	56.9 +/- 3.51	56.8 +/- 3.81
Training Characteristics		
Season, miles	262.8	302.8
Pre-Season, miles	224.8	274.0
Post-Season, miles	247.0	251.5

*statistically significant with stress fracture development

Age, Gender, Ethnicity

All 42 athletes on the official Division I collegiate cross country roster at the University of Mississippi were asked to participate in this study and all 42 consented to participate. This study consisted of 20 males and 22 females. The male participants ranged in age from 18 to 24 years (M= 20.7 years, SD= 1.31). The female participants ranged in age from 18 to 22 years (M= 20.3 years, SD= 1.09). In this study, 95.2% of the participants reported that they were Caucasian. Only two participants were not Caucasian and they both reported they were African-American.

Female Body Structure and Body Weight

The female participants ranged in height from 61 inches to 70 inches with a mean of 65.68 inches and median of 66.5 inches (SD= 2.49). Their weights ranged from 110 pounds to 145.8 pounds with a mean of 122.8 pounds (SD= 10.1). Their percent body fat ranged from 12.3 to 24.6 with a mean of 18.0 (SD= 3.23).

Male Body Structure and Body Weight

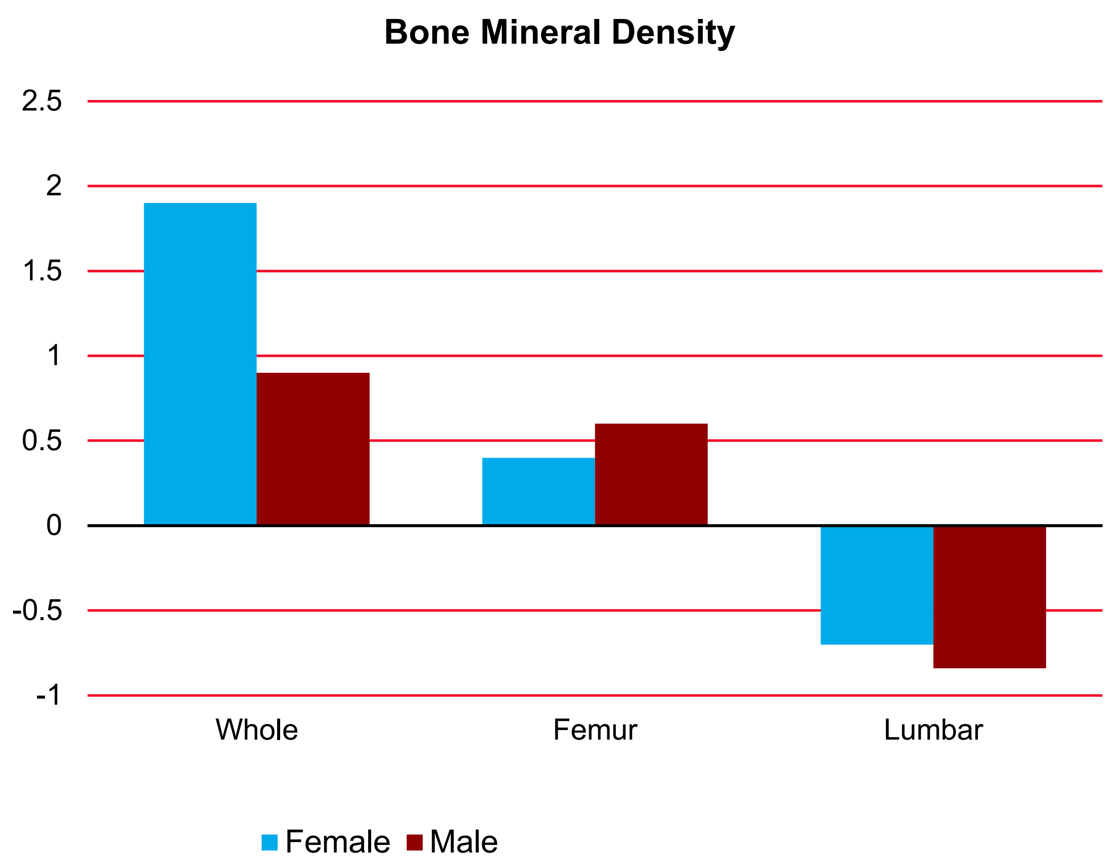
The male participants ranged in height from 67.5 inches to 76 inches with a mean of 70.5 inches (SD= 1.84). Their weights ranged from 126.6 pounds to 163.2 pounds with a mean of 146.7 pounds (SD= 9.03). The percent body fat ranged from 6.6 to 13.1 with a mean of 9.3 (SD= 1.64).

Bone Mineral Density

The women's cross country team's whole body BMD T-score ranged from -0.5 to 4.2 with a mean of 1.9 (SD= 1.03). The men's cross country team's whole body BMD T-score ranged from -1.2 to 2.3 with a mean of 0.9 (SD= 0.87) and median of 1.1. The women's cross country team's lumbar spine BMD T-score ranged from -2.8 to 1.1 with a mean of -0.7 (SD= 0.95) and median of -0.8. The men's cross country team's lumbar spine BMD T-score ranged from -2.5 to 1.5 with a mean of -0.84 (SD= 1.06). The women's cross country team's femur neck BMD T-score ranged from -0.6 to 2.3 with a mean of 0.9 (SD= 0.81) and median of 1.1. The men's cross country team's femur neck BMD T-score ranged from -0.8 to 1.7 with a mean of 0.8 (SD= 0.77) and median of 1.0.

According to the National Osteoporosis Foundation, a bone mineral density T-score greater than -1.1 are considered to be “normal” and at low risk for fractures and osteopenia/osteoporosis. When relating this definition to the results of all DXA scans, 26 or 61% of participants had a normal lumbar spine BMD and 40 or 95.2% of participants had a normal femur neck BMD. One statistic stood out, 31% of participants were identified as having osteopenia and 4.8% as having from osteoporosis when evaluating data on the lumbar spine was evaluated. This is expressed in percentages as 31.8% of males and 30% of females suffering from osteopenia. This is a significant finding about bone health of runners, and are especially key given that the DEXA is considered the “gold standard” for measuring bone mineral density. Table 3 summarizes BMD characteristics for female and male participants.

Table 3: Bone Mineral Density characteristics for female and male participants.



Menstrual Cycle

The participants age at menarche ranged from 11 to 18 years with a mean of 14.2 years (SD= 1.88). Eleven participants, or 50% began menstruating at or before the age of 14 years. Nineteen participants, or 86% began menstruation before age 16 with 2 of those participants beginning menstruation at age 16. Three participants would be classified as having primary amenorrhea according to Lebrun (2000) who classifies primary amenorrhea as any female who has not began menstruation by age 16.

The number of menstrual cycles female participants had in the past year ranged from 1 to 12 with mean of 9.15 (SD= 3.52) and a median of 10 menstrual cycles. Five participants reported having 6 or less cycles in the past year. However, 2 of the 5 subjects that reported less than 6 menstrual cycles in the past year were taking an oral contraceptive designed to have them menstruate every three months. Therefore, by considering the two subjects taking oral contraceptives designed to have them menstruate every three months as being eumenorrheic, three subjects or 13.6% would be classified as having an irregular menstrual cycle defined by having less than 10 menstrual cycles in the past year.

Energy Intake

Energy needs and/or energy expenditure is somewhat difficult to quantify for the cross country team as a whole due to differences in metabolic rates and differences in training miles. However, the female cross country runners in this study need roughly 2,247.0 kilocalories per day given their amount of training. The kilocalorie intake for the female cross country team ranged from 1,423 to 2,295 kilocalories per day with a mean of 1,965 kilocalories per day (SD=

262.1). Based on these results, 91% of female cross country runners did not consume adequate kilocalories to meet daily energy intake requirements. The male cross country runners need roughly 2,742.5kilocalories per day given their amount of training. The kilocalorie intake for the male cross country team ranged from 1,918 to 3,160 kilocalories per day with a mean of 2,691 kilocalories per day (SD= 332.9). Based on these results, 40% of the men did not consume adequate kilocalories to meet daily energy intake requirements. Overall, the kilocalorie intake for cross country runners consisted of 12.9% protein, 56.9% carbohydrates, and 30.2% fats for females and 12.9% protein, 56.8% carbohydrates, and 30.3% fats for the males. The most significant finding with regards to caloric intake was that all females and males with a history of stress fracture did not meet daily energy intake requirements.

Calcium Intake

Based on their 3-day food records, the female cross country team's calcium intake from dietary sources ranged from 680mg to 1,350mg based on their 3-day food records. The mean calcium intake was 1,012.1 mg (SD= 201.1). The male cross country team's calcium intake from dietary sources ranged from 522mg to 1420mg based on their 3-day food records. The mean calcium intake was 1,083.7mg (SD= 241.7). Using the Adequate Intake (AI) for calcium of 1,300mg for 18 year olds and 1,000mg for those subjects 19 and older (Food and Nutrition Board, 1997), 45% of the female cross country team did not meet the recommended amount of calcium and 40% of the male cross country team did not meet the recommended amount of calcium. With regards to stress fractures, all females and males identified with a history of stress fractures did not meet the recommended amount of daily calcium intake.

Vitamin D Intake

The female cross country team's vitamin D intake from dietary sources ranged from 6.19IU to 17.22IU. The mean vitamin D intake was 13IU (SD= 3.99). The male cross country team's vitamin D intake from dietary sources ranged from 6.27IU to 17.41IU with a mean vitamin D intake of 13.7IU (SD= 3.35). All cross country runners need about 15IU per day given their amount of training. Based on using the recommended dietary allowance for Vitamin D of 600IU/day (Food and Nutrition Board, 1997), 59% of the female cross country team and 55% of the male cross country team did not meet the recommended amount of vitamin D. Out of the 59% of females not meeting the required daily vitamin D intake, 69% of these participants reported a history of stress fracture whereas 63% of the 55% of males reported stress fracture history.

Training

The female cross country team averaged 224.8 miles for pre-season, 262.8 miles for the season, and 247.0 miles for post-season. The male cross country team averaged 274.0 miles for pre-season, 302.8 miles for the season, and averaged 251.5 miles for post-season.

Stress Fractures

Based on completed medical history and demographics questionnaire, 9 or 40% of females and 7 or 35% of males reported having a stress fracture during their running careers. Of the participants reporting stress fractures, 2 females and 1 male reported reoccurring stress fractures of the same bone whereas 5 females and 2 males reported suffering from multiple stress fractures of different bones. Overall, fractures to the tibia were most common in females and fractures to the femur and metatarsal bones were most common in males. Table 4 provides a summary of stress fracture characteristics of female and male participants. Table 4: Summary of stress fracture characteristics of female and male participants

	Females	Males
Sacrum	4*	0
Femur	3	4*
Tibia	7*	0
Cubiod	1	0
Metatarsal	3	4*
Navicular	0	1
Calcaneous	0	1

* Includes athletes with reoccurring stress fractures

Correlations

Chi-Square Test of Independence was used to assess the association of BMD, caloric intake, calcium intake, and vitamin D intake with stress fracture development. The association of age of menarche and birth control usage with stress fracture development was also assessed as well using a Chi-Square Test of Independence. Table 4 details the crosstabulations of participants intake requirements with stress fracture development.

Assessing the association of BMD with stress fracture development, no statistical significant association was found in either femur neck BMD categories (χ^2= .126, p > .05) or lumbar spine BMD categories (χ^2 = .106, p > .05) for males nor females.

However, when assessing the dependance of caloric intake on stress fracture, a statistically significant association was found in caloric intake for males (χ^2= 20.000, p < .05) and for males and females combined (χ^2= 17.575, p < .05). Therefore, stress fracture development is statistically associated with caloric intake for males specifically and the combination of males and females. It is important to note however that caloric intake approached significance with stress fracture development in females (χ^2= 3.385, p = 0.066).

Also, when assessing the dependance of calcium intake on stress fracture, a statistically significant association was found in calcium intake for males (χ^2= 12.381, $p < .05$), calcium intake for females (χ^2= 18.277, $p < .05$), and calcium intake for both groups combined (χ^2= 30.190, $p < .05$). This association suggests that stress fracture development is statistically dependent on calcium intake for both males and females.

Lastly, when determining the dependance of vitamin D intake on stress fracture development, a statistically significant association was found in vitamin D intake for males (χ^2= 16.154, $p < .05$), vitamin D intake for females (χ^2= 18.277, $p < .05$), and vitamin D intake for both groups combined (χ^2= 34.462, $p < .05$). This association suggests that stress fracture development is statistically dependent on vitamin D intake for both males and females.

No statistical significance was found with the association of age of menarche and stress fracture development. However, when looking at the association between birth control usage and stress fracture development, the dependance of these two categories approached significance (χ^2= 3.778, p = 0.052).

Other correlations that are statistically significant or approaching significance were found in this study. Pearson correlation was conducted on lumbar spine BMD and age of menarche. Lumbar spine BMD approached significance with age of menarche (r= -0.430, $p<0.05$). This indicates that as the age at onset of menarche increases, lumbar spine BMD decreases. Pearson correlation was also conducted on calcium and vitamin D intake with number of cycles per year. Daily calcium intake (r = 0.497, $p<0.05$) and daily vitamin D intake (r = 0.527, $p<0.05$) were statistically significant with number of cycles per year. Despite that no significant relationship was found between lumbar spine BMD and daily vitamin D intake ($r = 0.132$, $p>0.05$) or daily calcium intake ($r = 0.017$, $p>0.05$), a significant relationship was seen on femur neck BMD and daily caloric intake ($r = 0.310$, $p<0.05$).

Table 4: Crosstabulations of participants intake requirements with stress fracture development.

	Stress Fracture	
	No	Yes
Met Requirements		
Energy Intake	17 (100%)	0 (0%)
Calcium Intake	25 (92.6%)	2 (7.4%)
Vitamin D Intake	24 (100%)	0 (0%)
Not Met Requirements		
Energy Intake	9 (36.0%)	16 (64%)
Calcium Intake	1 (6.7%)	14 (93.3)
Vitamin D Intake	2 (11.1%)	16 (88.9%)

CHAPTER 5

DISCUSSION

This study explored predisposing risk factors associated with the development of stress fractures in a Division I collegiate cross country team. A nutritional assessment consisting of a 3-day food record and measurements of whole body, lumbar spine and hip bone mineral density was conducted on each athlete. Each athlete was also asked to answer a demographic questionnaire composed of questions regarding ethnicity, hometown, smoking status, vitamin/mineral intake, previous stress fracture history, birth control usage and menstrual status and submit their training log to assess weekly and monthly running mileage. This chapter states the limitations to this study, formulates conclusions from the results and compares this study's results to other studies, and makes suggestions and recommendations for future studies.

Discussion

The female cross country runners' mean calcium intake was 1,012mg per day while the men's team mean calcium intake was 1,083mg based on their 3-day food records. Both of these averages are higher than mean calcium intake for collegiate cross country runners in other studies. Slawson et al. (2001) reported a mean calcium intake of 605mg per day for collegiate cross country runners while Burrows et al. (2003) reported a mean intake of 831mg per day for female distance runners. It would appear that participants in our study are at the upper end of the spectrum with regards to calcium intake, however, NCAA Division I female collegiate athletes participating in volleyball, cross country, soccer, cheerleading, track or tennis average 2,059mg of daily calcium intake (Verdegan, 2007). The results of this study are also contradictory to the results reported from a 12-month prospective study evaluating risk factors for stress fracture injuries in female and male track and field athletes by Bennell et al (1995). This study concluded that cross country runners who do not consume the recommended daily allowance for calcium are more susceptible to sustaining a stress fracture. Bennell and collegues (1995), however, found that athletes who sustained stress fracture injuries consumed a greater (though not statistically significant) intake of calcium than non-injured athletes, with athletes approaching or exceeding the current recommended daily allowance value of calcium: 1075 versus 985mg in female and 1325mg versus 1252mg in male individuals. By contrast, Myburgh et al (1990) performed a case-control study evaluating the role of dietary calcium on stress fractures in distance runners that warranted positive results correlating to the results found in this study. Myburgh and collegues (1990) found that current dairy intake and total calcium were significantly lower in the fracture group. Research by Nieves and colleagues (2010) found that women who consumed less than 800mg of calcium per day had nearly 6 times the stress fracture rate of women who consumed more than 1500mg of calcium and more than double the rate for women who consumed between 800 and 1500mg. High levels of physical activity in the presence of low calcium intake can cause additional stress on the skeleton because of the need to offset the substantial cutaneous calcium loss in the sweat. Under conditions of heavy sweating and insufficient calcium intake, calcium is drawn from the bone reservoir under the influence of elevated levels of parathyroid hormone (Lappe, 2008). With this being said, it is possible to infer that insufficient calcium intake would correlate with bone mineral density, yet, this study did not find a statistically significant association. Also, given that vitamin D aids in the absorption of calcium and is present in most calcium-fortified foods (Tenforde, 2010), it makes sense to find statistical significance between calcium intake and vitamin D intake.

Results of this study regarding a relationship seen between femur neck BMD and daily caloric intake is in agreement with the results of other studies mentioned by Burrows et al (2002) suggesting that low energy intake can alter luteinising hormone pulsatile activity and decrease BMD levels.

To date, minimal research is available regarding the role of increased vitamin D intake in prevention of stress fracture injuries in athletes. Ruohola et al (2006) found that serum 25(OH)D level below the mediate (30ng/mL) at onset of training significantly increased the risk of developing stress fractures in young Finnish military recruits. However, exercise in military basic training drastically differs from collegiate cross country running. With this being said, vitamin D and stress fracture development in the present study is a tremendous find.

In recent years, menstrual irregularities have been linked to the development of stress fractures, likely due to the effect of estrogen deficiency on bone turnover (Wentz, 2012). This statement was supported by finding of this study given that there was a statistically significant association between menstrual irregularities and calcium intake found.

The results of a study by Wentz et al (2012) indicated that hours of training per week were negatively correlated with total-body and lumbar-spine BMD and total-body bone mineral count. In another study briefly mentioned by Wentz et al (2012), data collected from endurance runners showed that weekly running distances were negatively correlated with lumbar spine and femoral neck BMD. Burrows et al (2002) also found that distance run per week was negatively associated with lumbar spine and femoral neck BMD. The regression analysis in the study by Burrows and colleagues indicated that participants who ran longer distances had a lower femoral neck and lumbar spine BMD than those who ran shorter distances. Unfortunately, in the present study, all but 4 male and female participants were not compliant with submitting training logs to Flotrackr. Despite not having individual participant data on training, it is understood that all collegiate cross country runners in the study participated in practice and competition together therefore all ran the same mileage. However, due to this unforeseen issue, the effects of training for collegiate cross country runners on BMD, calcium intake, vitamin D intake, and overall caloric intake could not be assessed statistically.

This study found statistical significance with relation to stress fracture development while also revealing various other meaningful statistics. This study proves that research questions 3-5 reject the null and accept the alternative hypotheses, while research question 1 accepts the null hypothesis and does not accept the alternative hypothesis. Unfortunately, all participants in this study met the same miles per week therefore serving as a constant in the study. With this being evident, research question 2 could not be answered statistically.

Conclusion

This study failed to show statistical significance with age of menarche and neither femur neck nor lumbar spine BMD and stress fracture development. The effects of cross country training on stress fracture development could not be statistically answered due to no variation in training mileage. Using Chi-Square Test for Independence, statistical dependence was found with caloric intake, vitamin D intake, and calcium intake on stress fracture development. Pearson correlation was seen between lumbar spine BMD and age of menarche on female participants, calcium and vitamin D intake on number of cycles per year on female participants, daily calcium intake on daily vitamin D intake and femur neck BMD on daily caloric intake in all participants.

This study suggests that the profile of the collegiate cross country runner may be at an increased risk for stress fracture development due to suboptimal caloric intake, vitamin D intake, and/or calcium intake. The associations found between multiple variables in this study is relatively exciting which should be further investigated through longitudinal research.

Recommendations for Future Studies

- Since calcium, vitamin D, and iron are not the only nutrients that affect bone mineral density, assess other nutrients such as phosphorus and magnesium.
- Asses dietary habits such as caffeine intake and alcohol intake.
- Determine nutrition attitudes of female and male cross country runners.
- Determine whether or not nutrient intake through supplements have positive effect on bone density.
- Compare and contrast results from larger sample size and/or runners from other universities.
- Compare training of collegiate cross country runners with a control group of non-collegiate cross country runners for more variety in number of miles run.

Limitations

One limitation is that results may not be generalized to other populations, teams, or track & field as a whole. A second limitation to this study was the lack of ethnic diversity; thus, the statistics should be examined with caution when comparing to various ethnicities. A third limitation is that each subject filled out their own 3-day diet record, and participants can sometimes overestimate or underestimate foods and beverages consumed. Participants were also asked to complete diet records at their leisure within 6 months. Finally, with regards to pre- and post-season categorical data, it is imperative to note that collegiate cross country runners also compete in indoor and outdoor track; therefore for these runners, there is no “true” post-season training. Training regimen for both male and female cross country runners in this study also may not be generalized to other populations and/or teams. The participants in this study competed at the Division I level therefore training may differ at smaller conferences and/or institutions. Also given that many athletes did not complete.

LIST OF REFERENCES

Arasheben, A., Barzee, K. & Morley, C. (2011). A meta-anaylsis of bone mineral density in collegiate female athletes. Journal of American Board Family Medicine, 24, 728-734.

Barrack, M., Gibbs, J., De Souza, M., Williams, N., Nichols, J., Rauh, M., Nattiv, A. (2014). Higher incidence of bone stress injuries with increasing female athlete triad-related risk factors. The American Journal of Sports Medicine, 42(4), 949-958.

Bennell, K.L., Malcolm, S.A., Thomas, S.A., Ebeling, P.R., McCrory, P.R., Wark, J.D. & Brukner, P.D. (1995). Risk factors for stress fractures in female track and field athletes: a retrospective analysis. Clinical Journal of Sports Medicine, 5, 229-235.

Bennell, K., Malcolm, S. & Thomas, S. (1996). Risk factors for stress fractures in track and field athletes: a twelve-month prospective study. American Journal of Sports Medicine, 24, 810-818.

Bilanin, J., Blanchard, M., Russek-Cohen, E. (1989). Lower vertebral bone density in male long distance runners. Medicine and Science in Sports and Exercise, 21, 66-70.

Burrows, M., Nevill, A. & Simpson, D. (2003). Physiological factors associated with low bone mineral density in female endurance runners. British Journal of Sports Medicine, 37, 67-71.

Cobb, K., Bachrach, L., Greendale, G., Marcus, R., Neer, R., Nieves, J., Sowers, M., Brown, B., Gopalakrishnan, G., Luetters, C., Tanner, H., Ward, B. & Kelsey, J. (2003). Disordered eating, menstrual irregularity, and bone mineral density in female runners. Medicine & Science in Sports & Exercise, 35, 711-719.

Drinkwater, B., Nilson, K., Chesnut III, C., Bremner, W., Shainholtz, S. & Southworth, M. (1984). Bone mineral content of amenorrheic and eumenorrheic athletes. The New England Journal of Medicine, 311(5), 277-281.

Fredericson, M., Salamancha, L. & Beaulieu, C. (2003) Sacral stress fractures - tracking down nonspecific pain in distance runners. Physician and Sports Medicine, 31(2), 31-42.

Guest, N. & Barr, S. (2005). Cognitive dietary restraint is associated with stress fractures in women runners. International Journal of Sport Nutrition and Exercise Metabolism, 15, 147-159.

Hetland, M., Haarbo, J. & Christiansen, C. (1993). Low bone mass and high bone turnover in male long distance runners. Journal of Clinical Endocrinology and Metabolism, 77(3), 770-775.

Ihle, R. and Loucks, A. (2004). Dose-response relationships between energy availability and bone turnover in your exercising women. Journal of Bone and Mineral Research, 19(8), 1231-1240.

Kadel, N., Teitz, C. & Kronmal R. (1992). Stress fractures in ballet dancers. American Journal of Sports Medicine, 20, 445-449.

Kalkwarf, H., Khoury, J. & Lanphear, B. (2003). Milk intake during childhood and adolescence, adult bone density, and osteoporotic fractures in US women. American Journal of Clinical Nutritrion, 77(1), 257-265.

Kelsey, J., Bachrach, L., Procter-Gray, E., Nieves, J., Greendale, G., Sowers, M., Brown, B., Matheson, K., Crawford, S. & Cobb, K. Risk factors for stress fracture among young female cross-country runners. Medicine & Science in Sports & Exercise, 39 (9), 1457-1463.

Lappe, J., Cullen, D., Haynatzki, G., Recker, R., Ahlf, R. & Thompson, K. (2008). Calcium and vitamin D supplementation decreases incidence of stress fractures in female navy recruits. Journal of Bone and Mineral Research, 23(5), 741-749.

Lewis, R., Redzic, M. & Thomas, D. (2013). The effects of season-long vitamin D supplementation on collegiate swimmers and divers. International Journal of Sport Nutrition and Exercises Metabolism, 23, 431-440.

Loucks, A. (2007). Low energy availability in the marathon and other endurance sports. Sports Medicine, 37 (4-5), 348-352.

MacDougall, J., Webber, C., Martin, J., et al. (1992). Relationship among running mileage, bone density, and serum testosterone in male runners. Journal of Applied Physiology, 73, 1165-1170.

Meyer, F., O'Connor, H., & Shirreffs, S. (2007). Nutrition for the young athlete. Journal of Sports Sciences, 25(1), S73-S82.

Micklesfield, L., Hugo, J., Johnson, C., Noakes, T. & Lambert, E. (2007). Factors associated with menstrual dysfunction and self reported bone stress injuries in female runners in the ultra- and half-marathons of the Two Oceans. British Journal of Sports Medicine, 41, 679-683.

Moran, D., McClung, J., Kohen, T. & Lieberman, H. (2013). Vitamin D and physical performance. Sports Medicine, 43, 601-611.

Moyer, V. (2013). Vitamin D and calcium supplementation to prevent fractures in adults: U.S. preventive services task force recommendation statement. Annals of Internal Medicine, 158(9), 691-696.

Mudd, L., Fornetti, W., & Pivarnik, J. (2007). Bone mineral density in collegiate female athletes: Comparisons among sports. Journal of Athletic Training, 42(3), 403-408.

Myburgh, K., Hutchins, J., Fataar, A., Hough, S., & Noakes, T. (1990). Low bone density is an etiologic factor for stress fractures in athletes. Annals of Internal Medicine, 113(10), 754-759.

National Institutes of Health, Office of Dietary Supplements. Vitamin D: Dietary upplement fact sheet for health professionals. Washington, DC.

Nieves, J., Melsop, K., Curtis, M., Kelsey, J., Bachrach, L., Greendale, G., ... Sainani, K. (2010). Nutritional factors that influence change in bone density and stress fracture risk among young female cross-country runners. American Academy of Physical Medicine and Rehbailitation, 2(8), 740-750.

Pepper, M., Akuthota, V. & McCarty, E. (2006). The pathophysiology of stress fracture. Clinics in Sports Medicine, 1-16.

Price, C., Langford, J. & Liporace, F. (2012) Essential nutrients for bone health and a review of their availability in the average north american diet. The Open Orthopaedics Journal, 6, 143-149.

Ruohola, J., Laaksi, I., Ylikomi, T., Haataja, R., Mattila, V., Sahi, T., Tuohimaa, P. & Pihlajamaki, H. (2006). Association between serum 25 (OH) D concentrations and bone stress fractures in Finnish young men. Journal of Bone Mineral Research, 21, 1483-1488.

Slawson, D.L., McClanahan, B.S., Clemens, L.H., Ward, K.D., Klesges, R.C., & Vukadinovich, C.M. (2001). Food sources of calcium in a sample of African-American and Euro-American athletes. International Journal of Sports Nutrition and Exercise Metabolism, 11(2), 199-208.

Snow, C. & Beck, B. (2002). Exercise in the prevention of osteoporosis-related fractures. In E. Orwell and M. Bliziotes (Eds.), Osteoporosis: Pathophysiology and Clinical Management (pp. 221-246). Totowa, NJ: Humana Press.

Teegarden, D., Lyle, R., Proulx, W., Johnston, C. & Weaver, C. (1999). Previous milk consumption is associated with greater bone density in young women. American Journal of Clinical Nutrition, 69(5), 1014-1017.

Tenforde, A., Sayres, L., Sainani, K. & Fredericson, M. (2010). Evaluating the relationship of calcium and vitamin D in the prevention of stress fracture injuries in the young athlete: a review of the literature. PM&R, 2, 945-949.

Thompson, S. (2007). Characteristics of the female athlete triad in collegiate cross-country runners. Journal of American College Health, 56 (2), 129-136.

Turner, CH. (1998). Three rules for bone adaptation to mechanical stimuli. Bone, 23, 399-407.

Turner, C. & Robling, A. (2005). Mechanisms by which exercise improves bone strength. Journal of Bone Mineral Metabolism, 23, 16-22.

Warden, S., Burr, D. & Brukner, P. (2006). Stress fractures: pathophysiology, epidemiology, and risk factors. Current Osteoporosis Reports, 4, 103-109.

Waugh, E., Woodside, D., Beaton, D., Cote, P. & Hawker, G. (2011). Effects of exercise on bone mass in young women with anorexia nervosa. American College of Sports Medicine, 43(5), 755-763.

Weaver, C. (2002). Adolescence: the period of dramatic bone growth. Endocrine, 17(1), 43-48.

Wentz, L., Liu, P., Ilich, J., & Haymes, E. (2012). Dietary and Training Predictors of Stress Fractures in Female Runners. International Journal of Sport Nutrition and Exercise Metabolism, 22, 374-382.

Winters-Stone, K. & Snow, C. (2004). One year of oral calcium supplementation maintains cortical bone density in young adult female distance runners. International Journal of Sport Nutrition and Exercise Metabolism, 14, 7-17.

LIST OF APPENDICS

APPENDIX A: INFORMED CONSENT

Informed Consent for Medical Research

Predisposing Risk Factors Associated with Stress Fracture Development in Division I Collegiate Cross Country Runners

You are invited to participate in a research study conducted by Kaci Griffin, ATC from The University of Mississippi. You must be 18 years or older to participate in the study. Your participation is voluntary.

PURPOSE OF THIS STUDY
We are asking you to take part in a research study to determine if nutrition, training, and/or bone mineral density serve as predisposing risk factors associated with stress fracture development in division one collegiate cross country runners.

PROCEDURES
You will participate in bone mineral density testing, complete a three day diet recall, and allow researchers access to your weekly and monthly training logs. You will only be asked to participate and complete the following once.

POTENTIAL RISKS AND DISCOMFORTS
There is potential risk of injury due to training which is inversely related to this study.

PAYMENT/COMPENSATION FOR PARTICIPATION
The investigators of this research do not have any financial interest in the sponsor, products, or equipment being used in this study.

CONFIDENTIALITY
Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. The information collected about you will be coded using a fake name (pseudonym) or initials and numbers, for example abc-123, etc. The information which has your identifiable information will be kept separately from the rest of your data. The data will be stored in the investigator's office in a locked file cabinet/password protected computer. The data will be stored in for approximately seven years after the study has been completed then destroyed.

PARTICIPATION AND WITHDRAWAL
You can choose whether to be a part of this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may also

refuse to answer any questions you are reluctant to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so.

RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have any questions about your rights as a study subject or you would like to speak with someone independent of the research team to obtain answers to questions about the research or in the event research staff cannot be reached, please contact the University of Mississippi Department of Nutrition and Hospitality Management.

I, ________________________, freely give my consent to participate in this research study.

Signature: _______________________________________

Witness: ____

APPENDIX B: QUESTIONNAIRE

NAME:

DEMOGRAPHICS/MEDICAL HISTORY
Please answer the following:

Race/Ethnicity:

Hometown:

Do you smoke? (If so, how often):

Do you take any vitamins or minerals? (If the answer is YES, please answer the following)

What Kind(s) (please include dosage):

How Often:

Do you have a previous history of stress fracture or stress reaction? (If the answer is YES, please answer the following)

When (please include month/year):

How Many:

What Bone(s):

MEDICAL HISTORY (FEMALES ONLY)
Circle YES or NO to the following & if the answer is YES, please write the age at which it occurred or began.

Birth Control	Yes	Age:	No
Age Periods Began	Yes	Age:	No
Irregular Periods	Yes	Age:	No
Amenorrhea (absence of cycles)	Yes	Age:	No

Number of Cycles (within past year):

Date of Last Period:

APPENDIX C: 3-DAY FOOD RECORD

DAY 1

Diet Record
[redacted]
Participant ID__________
Date of Intake:__________
DOB: __________ Gender: M F

Type of oil you use at home?
Type of margarine you use at home?
What type of milk do you typically drink? (Skim,1%, 2%, Whole)
Type of Bread?

When was the last time you had anything to eat or drink?__________

Time AM PM	Food or Beverage *Please list each food eaten on a separate line.*	Portion Eaten?	Where was food consumed? Home Fast Food Work Other	How prepared? Cooking method Seasonings Additions Anything unique?	ICE
Time AM PM					Y N
Time AM PM					Y N
Time AM PM					Y N
Time AM PM					Y N
Time AM PM					Y N
Time AM PM					Y N

DAY 2

Time AM PM	Food or Beverage	Portion Eaten?	When eaten? B L D S1 S2 S3 S4	Where was food consumed? Home Fast Food Work Other	How prepared? Cooking method Seasonings Additions	ICE
Time AM PM						Y N
Time AM PM						Y N
Time AM PM						Y N
Time AM PM						Y N
Time AM PM						Y N
Time AM PM						Y N
Time AM PM						Y N

DAY 3

Participant ID: Page of

Time AM PM	Food or Beverage	Portion Eaten?	When eaten? B L D S1 S2 S3 S4	Where was food consumed? Home Fast Food Work Other	How prepared? Cooking method Seasonings Additions	ICE
Time AM PM						Y N
Time AM PM						Y N
Time AM PM						Y N
Time AM PM						Y N
Time AM PM						Y N

Does this day's intake reflect your usual pattern? Yes or No If no, why not?

Did you take any vitamins or minerals today? Yes or No If yes please provide the following:

1. Name:________________ Brand______________ Strength (i.e. 500 mg or mcg or IU) ____________

How may of these do you take per day?________________

2. Name:________________ Brand______________ Strength (i.e. 500 mg or mcg or IU) ____________

How may of these do you take per day?________________

VITA

KACI GRIFFIN
415 Miller Academy Rd.
Carrollton, GA 30117
klgriff1@go.olemiss.edu

Education

University of Mississippi Oxford, MS August 2014-Present
Master of Science in Nutrition
Anticipated Graduation Date May 2016

Troy University Troy, AL August 2009-May 2014
Bachelor of Science in Athletic Training
CAATE Accredited Athletic Training Education Program
Degree Awarded May 2014

Professional Experience

University of Mississippi Oxford, MS
Department of Athletics – Health and Sports Performance

Graduate Assistant Athletic Trainer June 2014-Present
- Responsible for daily prevention, treatment and care of all injuries and illnesses sustained by members of Div. I level track and field/cross country teams
- Supervisor of student athletic trainers
- Consistent communication with staff athletic trainers, appropriate physician(s), members of the coaching staff, and strength and conditioning coach regarding health status of student-athletes
- Assisted ATCs, team physician(s) in administering annual team preparticipation physical examinations
- Compiled numerous injury reports and documentation of various athletic injuries in computerized athletic software (Presagia/Injury Zone), and previously utilized system (Nextt/Blue Ocean)
- Additional experience with football, cheer, and dance teams
- Provided local high school competition coverage for local Physical Therapy clinic

Intern Athletic Trainer January 2014-May 2014
- Helped ATCs with daily clinical and field experience for track and field/cross country and football
- Aided with daily operations of Manning Center Athletic Training Room
- Served as first responder and assisted ATC at numerous track and field meets

Troy University Troy, AL August 2009 – May 2014
Athletic Training Education Program

Athletic Training Student
- Compiled over 600 athletic training observation hours at the NCAA Division I level
- Worked alongside graduate assistant ATC with daily clinical and field experience for the following sports: track and field/cross country, rodeo, women's basketball, women's soccer, and football

Volunteer Activities

- 64th Annual National Athletic Trainers Association Meeting, Las Vegas, NV — June 2013
- Raycom All-Star Classic Game, Montgomery, AL — January 2013
- Vice President, Troy University Athletic Training Club, Troy, AL — August 2012-August 2013
- Mississippi/Alabama High School Football All-Star Game, Montgomery, AL — December 2011

Professional Development

- 29th Southeast Athletic Trainers Student Symposium, Atlanta, GA — June 2014
- 64th Annual National Athletic Trainers Association Conference, Las Vegas, NV — June 2013
- Troy University ATEP Inaugural "Treating the Entire Athlete" Symposium, Troy, AL — November 2012
- American Sports Medicine Institute 30th Annual Injuries in Baseball Conference, Birmingham, AL — February 2012
- University of Georgia 10th Annual Athletic Training Student Workshop, Athens, GA — June 2008

Creative Activity

- Benson, AK., Griffin, KL. Thoracic Outlet Syndrome Secondary to Effort Thrombosis in a Division I Strength & Conditioning Coach. (*Athletic Therapy and Training* in review) — June 2015
- Griffin, K & Benson A. Thoracic Outlet Syndrome Secondary to Effort Thrombosis in a Division 1 Strength & Conditioning Coach. — February 2014
- 29th Southeast Athletic Trainers Student Symposium, Atlanta, GA

Certifications/Memberships

- Mississippi State Department of Health Professional Licensure License #AT0699 — June 2014-Present
- Board of Certification for the Athletic Trainer Certification #2000016690 — June 2014 - Present
- National Athletic Trainers Association, Member Member #54454 — August 2012-Present
- American Heart Association Basic Life Support (BLS) for Healthcare Providers (CPR and AED) — August 2009 – Present
- Iota Tau Alpha Honor Society, Member — 2009 – Present