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FACTORS ASSOCIATED WITH BONE MINERAL DENSITY IN ELITE FEMALE GYMNASTS

By

ERIN MILLSON

A Thesis Submitted to the Graduate Faculty of Georgia State University in Partial Fulfillment
of the
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The author of this thesis is:

Erin Millson
168 Garden Lane, Apt. A
Decatur, GA 30030

The Chair of the committee for this thesis is:

Dan Benardot, PhD, RD, LD, DHC, FACSM
Professor, Division of Nutrition
Georgia State University
Atlanta, Georgia 30303

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2000-2004	Boston University Boston, Massachusetts Bachelor of Arts in History
2008-2011	Georgia State University Atlanta, Georgia Master of Science in Health Sciences: Specialization in Nutrition (GPA: 3.93) Graduate Research Assistantship: Critical Thinking through Writing Consultant
2010-2011	Dietetic Internship Southern Regional Medical Center Riverdale, Georgia
2011-present	Bionutrition Research Manager Atlanta Clinical and Translational Science Institute Emory University Hospital Atlanta, Georgia

ABSTRACT

Introduction: Gymnastics participation involves movements that place repeated strain on bone and muscle, which positively affects bone mineralization. Although increased bone mineralization is protective against the development of osteopenia and osteoporosis later in life, the elite female gymnastics population is at risk for the development of the Female Athlete Triad, which can negatively affect bone mineral density (BMD). This study looks at factors that can influence BMD in this population.
Purpose: To investigate the influence of muscle mass, menstrual status, calcium intake, sunlight exposure, and other related factors on BMD in elite female gymnasts.
Methods: This study represents a secondary analysis of existing data that were obtained between 1994 and 1996. Using dual-energy X-ray absorptiometry, a group of US National Team female gymnasts (n=43) in this study was screened at the Laboratory for Elite Athlete Performance at Georgia State University. BMD values (g/cm^2) were collected on total body, arms, legs, trunk, ribs, pelvis, and spine. These measurements were compared to other variables and assessed for statistical significance.
Results: Age of gymnasts was positively associated with BMD at all measured sites ($p < 0.001$; r=0.62-0.68). Weight was positively associated with BMD at all measured sites ($p < 0.001$; r=0.82-0.90). Lean body mass was positively associated with BMD at all measured sites ($p < 0.001$; r=0.74-0.87). Body fat percentage was positively associated with BMD at all measured sites ($p < 0.001$-$p=0.01$; r=0.39-0.54). However, calcium intake was not significantly associated with any of the BMD sites. Sunlight exposure and indirect estimates of vitamin D were not significantly associated with any of the BMD sites; all r-values indicated a weak positive association with BMD. Of the gymnasts who had experienced menses (n=15), those with regular menstrual periods (n=8) had significantly higher BMD values at the arm, leg, trunk, rib, and spine, and total body than those who did not have regular menstrual periods (n=7). There was no significant difference in BMD for gymnasts who had regular periods at the pelvis. A regression analysis was performed. The predictors total BMD values from the regression equation were the following: regular menses, height, weight, percent kilocalorie requirement consumed from predicted kilocalorie needs, calcium intake with supplements, lean body mass, hourly deficits >300 kilocalories from predicted kilocalorie needs, and hourly surpluses >300 kilocalories from predicted kilocalorie needs.
Conclusions: The relationship of BMD to muscle mass, menstrual status, calcium intake, and sunlight exposure is complicated. The literature suggests that there are positive associations with calcium, sunlight exposure, and BMD, but those factors were not found to be associated with BMD in this population. There are only a small number of elite female gymnasts who compete on the USA National Team at one time, so findings from this study may only be applicable to similar populations.

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LIST OF ABBREVIATIONS

ADA	American Dietetic Association
AI	Adequate intake
ANOVA	Analysis of variance
BMD	Bone Mineral Density
cm	Centimeter
DEXA	Dual X-Ray absorptiometry
DRI	Dietary Reference Intake
F.A.T.	Female Athlete Triad
FFM	Fat-free mass
g	Gram
g/cm^2	Grams per square centimeter
hr	Hour
IRB	Institutional Review Board
IU	International Units
kcal	Kilocalorie
kg	Kilogram
LH	Luteinizing hormone
mg	Milligram
NOF	National Osteoporosis Foundation
PTH	Parathyroid hormone
RDA	Recommended Daily Allowance
REE	Resting energy expenditure
SEE	Standard error of the estimate
USA	United States of America
WHO	World Health Organization

CHAPTER 1: INTRODUCTION

Title

Factors associated with bone mineral density in elite female gymnasts

Purpose

The purpose of this study was to determine factors associated with bone mineral density (BMD) in elite female gymnasts. Gymnastics places repeated load-bearing force on bone and muscle, which has been shown to positively influence BMD (Egan et al., 2006). Maximal accrual of BMD during the adolescent years may be protective of bone and may help prevent or delay the development of bone-related diseases such as osteopenia and osteoporosis later in life (Kudlac et al., 2004). Generally, adolescence is marked with the onset of puberty; in females, the hormones that are associated with regular menstrual cycles help increase BMD. However, gymnasts performing at an elite level, such as those assessed for this study, often have delayed development of secondary sexual characteristics that is associated with a later onset of menstruation; those who begin menstruating often have irregular menstrual cycles (Hobart & Smucker, 2000; Manore, 2002). As a result, gymnasts may not experience optimal BMD values during this crucial period of adolescence, which could potentially affect osteopenia or osteoporosis risk later in life.

This study aims to assess factors associated with dietary intake, sunlight exposure, activity, and menstrual status that are the most significantly related to higher BMD values in this sample of elite female gymnasts. To achieve this goal, a secondary analysis of longitudinal data collected by Dr. Dan Benardot from 1994-1996, as part of an IRB-approved protocol, was assessed. After an extensive literature review to determine the primary factors that consistently influence BMD in female athletes and the general population, these data were analyzed and compared to findings in the literature. So as to structure the data analysis and review of the literature, four different hypotheses and null hypotheses were formulated.

Hypotheses

Hypothesis 1: Higher muscle mass is positively associated with BMD in elite female gymnasts.

Null Hypothesis 1: Higher muscle mass is not positively associated with BMD in elite female gymnasts.

Hypothesis 2: Regular menstruation is positively associated with BMD in elite female gymnasts.

Null Hypothesis 2: Regular menstruation is not positively associated with BMD in elite female gymnasts.

Hypothesis 3: Sunlight exposure (hours/week) is positively associated with BMD in elite female gymnasts.

Null Hypothesis 3: Sunlight exposure (hours/week) is not positively associated with BMD in elite female gymnasts.

Hypothesis 4: Dietary calcium intake (mg/day) is positively associated with BMD in elite female gymnasts.

Null Hypothesis 4: Dietary calcium intake (mg/day) is not positively associated with BMD in elite female gymnasts.

CHAPTER 2: REVIEW OF LITERATURE

INTRODUCTION

Osteoporosis and osteopenia affect nearly fifty-five percent of Americans over the age of fifty. The National Osteoporosis Foundation (NOF) estimates that around eighty percent of this population is female (National Osteoporosis Foundation, 2010). There are many risk factors that predispose a person to developing bone-related problems later in life, but there are also factors that help prevent the development of osteoporosis, including regular exercise and weight resistance training (Daly et al., 2004). The development of peak bone mass during childhood and adolescence, when the skeleton is developing quickly, is thought to be a major determinant in the prevention of later osteopenia and osteoporosis. Most elite female gymnasts begin training at a young age, and participate in intensive, load-bearing exercise that can potentially have protective effects on bone mineralization and overall bone health later in life. However, these athletes may also be at risk for factors that negatively impact bone mineralization and overall bone health, leading to questions about how protective this intensive exercise and weight-bearing activity during adolescence is in relation to osteoporotic risk later in life.

This literature review explores the factors that are associated with BMD in both the general population and in elite female gymnasts.

BONE MINERAL DENSITY

During childhood and adolescence the skeleton undergoes rapid change, which should result in large gains in bone mass (Bass et al., 2000). Factors that influence accrual of BMD may vary with gender and genotype. Studies have shown that regular load bearing exercise is strongly correlated with increased BMD in children and adolescents (Daly et al., 2004; Egan et al., 2006; Bass, 2000). Large gains in BMD in adolescence and puberty seem to carry over to adulthood; these gains during adolescence may influence risk factors for bone-related diseases such as osteopenia and osteoporosis later in life (Kudlac et al., 2004; Bass, 2000).

Bone growth does not occur consistently throughout the life cycle. Bones form rapidly in infancy and then again during the onset of the adolescent growth spurt. After this growth spurt is complete, the majority of bone mass is formed (Bertelloni et al., 2006). Thus, accrual of maximal bone mass is a necessity during this crucial period of adolescent growth. In females, accrual of BMD may occur at a slower rate until the early to mid-twenties, but the exact age at which bone growth ceases is still unclear (Gropper et al., 2009; Parfitt et al., 2000). After peak BMD has been reached, bone is then maintained by a process of remodeling. Bone remodeling refers to a process that involves both bone formation and bone resorption. This process occurs constantly in the body and helps maintain calcium homeostasis in extracellular fluids (Seeman, 2008). Specialized cells called osteoclasts respond to plasma calcium levels and carefully

maintain these levels through a process called resorption. Osteoclasts resorb minerals, including calcium, and organic materials from the bone. During this process, osteoclasts remove microscopic portions of minerals and organic material from the surface of the bone, thereby leaving small deficits in the bone (Prentice, 2004). In contrast, osteoblasts replace, or repair, the deficits left in bone during resorption (Confavreux, 2011). Ideally, the process of osteoblastic and osteoclastic activity would occur in equilibrium. However, if dietary calcium intake and vitamin D status are inadequate, osteoclastic activity may occur at a faster rate than osteoblastic activity, leading to decreased BMD (Parfitt et al., 2000). Furthermore, as one ages, osteoblastic activity slows even more, sometimes taking up to a year or more to fill the deficits left by osteoclastic activity (Mahan & Escott-Stump, 2008). Thus, accrual of maximal BMD during adolescence and maintenance of adequate vitamin and mineral status during the lifespan may delay, or even prevent, the development of osteoporosis later in life.

In gymnasts, BMD is directly and indirectly correlated to a number of different factors. Females who participate in athletics during childhood can benefit from increased BMD, especially if the sport involves load-bearing exercise (Daly et al., 2004). Load-bearing exercise refers to any type of exercise that places strain on muscle and bone, which can lead to increased muscle mass and increased BMD. Artistic gymnastics is an example of this type of sport. It is well documented that females who practice artistic gymnastics at an elite level and from a young age generally have higher-than-normal BMD for their age (Dowthwaite et al., 2006; Mudd et al., 2007; Bass et al., 2000). Competitive artistic gymnasts repeatedly practice movements that place a high amount of

strain on muscle and bone. These movements increase muscle mass and also enhance BMD (Taaffe & Marcus, 2004).

Types of Bone

There are two main types of bone that make up the framework of the skeleton: cortical and trabecular bone, with the majority of bone (around 80%) consisting of cortical bone. Cortical bone forms the hard outer layer of long bones, while trabecular (cancellous) bone is present in the lining of bone marrow, the ends of long bones, and in ribs, scapulae, vertebrae, and pelvic bones (Mahan & Escott-Stump, 2008). Cortical bone is rigid and is mostly calcified, so it has a high BMD when compared to trabecular bone. Trabecular bone, on the other hand, is less dense than cortical bone, has a larger surface area, and has a spongy appearance. Large gains in BMD during periods of growth are seen in trabecular bone due to this increased surface area (Mahan & Escott-Stump, 2008).

Measurement of BMD

According to the World Health Organization (WHO), the most accurate current means of measuring BMD in human subjects is by a dual energy x-ray absorptiometry (DEXA) scan (Egan et al., 2006). This type of scan uses dual low frequency x-ray waves to differentiate between tissues (muscle, bone, adipose) and provides an accurate measurement of BMD in whole-body and regional bone density values (Egan et al., 2006). DEXA results are given in bone mineral content (total grams) and BMD (g/cm^2). To achieve the most accurate measurement of BMD in elite female gymnasts, DEXA

scans should be implemented. Most of the current literature involving BMD and athletes involves this type of scan (Sherman & Thompson, 2004).

FAT-FREE MASS

Fat-free mass (FFM) refers to body mass that is free of adipose tissue (e.g., muscle, water, and bone). The relationship between muscle and bone is dynamic and has significant implications regarding athletic performance. This is largely because changes in muscle in response to higher loading forces and more intense exercise is one of the predominant determining factors of changes in bone size, mass, and density (Daly et al., 2004). In a controlled animal study, it was shown that jumping and bounding exercises significantly increased muscle strength, stimulated bone formation, and improved the overall structure of bone by stimulating osteoblastic activity and slowing osteoclastic activity (Notomi et al., 2000). There are important implications from these findings for the human model. Jumping and bounding exercises are integral to gymnastic performance, and this type of mechanical loading puts an enormous amount of force on both muscle and bone. Gymnastic exercises such as vaulting, tumbling, and beam work can "generate vertical ground reaction forces of approximately 3.5 to 10 times body weight," in upper and lower extremities (Dowthwaite & Scerpella, 2009). To be able to withstand this type of force, BMD must increase concomitantly with muscle mass. If deficits are present in bone in this population, the likelihood of developing stress fractures as a result of repeated jumping and bounding activities also increases (Loud et al., 2005).

Deficits in BMD in relation to muscle mass in elite female gymnasts often result from the requirements for success that are inherent to the sport. To perform at the elite level, a certain body type is necessary for success. This body type is "characterized by short stature, light body mass, narrow hips with relatively broad shoulders…and a low percentage body fat with a high fat-free mass" (Claessens et al., 1999). The literature suggests that certain genetic factors predispose a gymnast to success later in life; elite gymnasts tend to be shorter in stature long before they begin training, which may make it easier to achieve success and compete at an elite level (Bass et al., 2000). Although genetic factors may play a role in athletic predisposition, the maintenance of the abovementioned characteristics in elite female gymnasts can result in bone deficits.

Gymnasts with low body weight are generally able to achieve higher performance scores than those who have higher body weights or higher percentages of overall body fat (Classesns et al., 1999). Thus, maintaining a low percentage of body fat and a high percentage of muscle mass may determine success in this sport. Often, gymnasts achieve this type of physique by restricting energy intake so that adiposity is not increased (Lindholm et al., 1995). However, long-term energy restriction and chronic low body fat percentage can lead to delayed puberty (Manore, 2002). This can prevent the accrual of maximal BMD due to the lack of bone-building hormones that are present in adolescent females who achieve puberty during adolescence. A study published in the *Journal of Pediatrics* found a correlation between delayed skeletal maturation and restriction of energy intake in gymnasts; the authors also stated that onset of puberty may impair gymnastic performance (Bass et al., 2000). Taken together, these facts suggest that elite female gymnasts who have high muscle mass, but who experience delayed puberty, may

not be able to maximize BMD, which could lead to stress fractures, increased risk for injury, and impaired performance.

FEMALE ATHLETE TRIAD (F.A.T.)

Female athletes, including those who participate in aesthetic sports at an elite level, are at increased risk for developing a set of symptoms that characterize a disorder referred to as the Female Athlete Triad (F.A.T.). The interrelated symptoms that characterize the F.A.T. are disordered eating, amenorrhea, and osteoporosis (Sherman & Thompson, 2004). According to an article published in the *Journal of Sports Sciences*, females who participate in sports that emphasize low body weight, such as artistic gymnastics, may be at greater risk for developing this disorder because these females are more likely to restrict energy intake (Manore et al., 2007). This restriction of energy intake happens as these athletes improve or progress in a sport.

Adolescent females who begin to compete at elite levels may become preoccupied with achieving an 'ideal' physique for competition, which involves loss of body weight as a result of energy restriction (Steen, 1996). These behaviors are often encouraged by coaches or parents, but also can be brought about by the athlete herself (Steen, 1996). Due to this energy restriction, which may be associated with disordered eating, the other symptoms of the F.A.T. may concomitantly occur. Inadequate nutrient consumption is associated with restricted energy intake. In fact, the primary minerals that have been shown to be lacking in the diets of athletes are "calcium, vitamin D, iron, zinc, and magnesium, as well as some antioxidants such as vitamins C and E, beta carotene, and selenium" (American Dietetic Association, 2009). Inadequate calcium levels, especially

in female athletes, can decrease the mineralization of bone and increase the risk of low BMD, which may influence stress fracture risk and the development of osteoporosis later in life (American Dietetic Association, 2009). Development of the F.A.T. in adolescence can have detrimental consequences for these athletes. It is important for these athletes, their coaches, and their parents to understand the long- and short-term consequences and implications of developing the symptoms associated with the F.A.T.

Disordered Eating

One symptom of the F.A.T. is disordered eating. The term 'disordered eating' should not be confused with the term 'eating disorder.' The former refers to a broad range of habits, tendencies, and dispositions associated with food consumption and exercise. In contrast, the latter refers to clusters of symptoms linked by specific physiological and psychological etiologies defined by the American Psychiatric Association (e.g., anorexia nervosa and bulimia nervosa). Disordered eating is of concern among elite female gymnasts due to the sport's aesthetic nature, which includes an emphasis on low body weight and subjective performance scoring by judges (West, 1998). Much of the time, disordered eating includes a restriction of caloric intake in an attempt to achieve a desirable lower body weight. In addition, some athletes may engage in behaviors other than simply restricting caloric intake. These behaviors may include purging behaviors such as vomiting, and the use of diet pills, diuretics, or laxatives (West, 1998). Restriction of caloric intake and the aforementioned purging behaviors may result in electrolyte and fluid imbalances in the body (Hobart & Smucker, 2000). This type of imbalance in athletes can be detrimental to performance by causing fatigue,

decreased strength, endurance, and speed, as well as an inability to concentrate (West, 1998). Furthermore, inadequate macronutrient and micronutrient intake, which may result from purging and/or restriction of caloric intake, can affect optimal growth and development of an athlete (Jonnalagadda et al., 2000).

It is important to note that disordered eating can be directly related to the other facets of the F.A.T.: abnormal menstrual function and decreased BMD. Inadequate energy intake and low body weight may cause dysmennorhea (menstrual dysfunction) in athletes. This disrupted menstrual function may lead to decreased BMD (Manore et al., 2007). Female athletes with disordered eating have increased risk of developing the other features of the F.A.T. To avoid the long-term health consequences associated with all components of the F.A.T., coaches, parents, and the athletes should be aware of the dangers associated with disordered eating and make sure that caloric intake is on par with the amount of calories expended during training and daily exercise.

Abnormal Menstrual Function (Amenorrhea)

Menstrual status in adolescence and adulthood can be described using several different terms. Amenorrhea refers to the absence of a menstrual period in a female who has reached reproductive age. This term can be further classified into two categories: primary amenorrhea and secondary amenorrhea. A female with primary amenorrhea is defined as someone who has never had a menstrual period by the age of sixteen, or has not reached sexual development by the age of fourteen (West, 1998). A female with secondary amenorrhea has previously had a menstrual period, but has had an absence of menstruation for at least three monthly cycles (West, 1998). Oligomenorrhea refers to an

irregular menstrual cycle, with menstrual cycles occurring more than thirty-five days apart (Manore et al., 2007). These abnormalities in menstrual function are common among young elite athletes, and may even be "viewed as normal by athletes and sports personnel" (Sherman & Thompson, 2004). The causes of amenorrhea and oligomenorrhea vary, and may be comorbid with the other symptoms associated with the F.A.T.

Dysmenorrhea in female adolescent athletes can be caused by a number of different factors. As previously mentioned, many young females who participate in aesthetic sports restrict energy intake to achieve a desired physique, which may temporarily and positively influence athletic performance. Elite female gymnasts with lower percentages of body fat tend to have higher performance scores when compared to gymnasts who have a higher percentage of body fat or are more endomorphic (Claessens et al., 1999). When athletes consume too little energy in comparison with their daily energy expenditure, menstrual dysfunction can occur (Sherman & Thompson, 2004). Amenorrhea caused by low energy intake is "classified as functional hypothalamic amenorrhea" (Manore et al., 2007). In this type of amenorrhea, a reproductive hormone called luteinizing hormone is expressed at a lower rate than that of eumenorrheic females, causing decreased ovulation and ovarian function (Manore et al., 2007). Another hormonal consequence associated with amenorrhea in adolescent females is a lower concentration of estrogen in circulation. Low levels of estrogen can have significant effects on bone health. This is due to decreased calcium homeostasis in the kidneys and intestines, which may result in greater osteoclastic activity in the bones (West, 1998).

There is an increased need for dietary calcium, and if calcium in the diet is deficient, the risk for osteoporosis later in life increases (West, 1998).

Problems with BMD

Another problem associated with development of the F.A.T. is increased risk of developing premature bone loss, namely, osteopenia and osteoporosis. Osteopenia refers to lower-than-normal BMD, but does not classify as osteoporosis, while osteoporosis is "a disease characterized by low bone mass and structural deterioration of bone tissue, leading to bone fragility and an increased susceptibility to fractures" (National Osteoporosis Foundation, 2010). The importance of bone development in childhood and adolescence is crucial; osteoporosis has been called "a pediatric disease with geriatric consequences" (Golden, 2000). Thus, problems associated with the F.A.T. in childhood and adolescence can lead to long-term skeletal problems associated with osteoporosis.

Chronic hypoestrogenemia in adolescence, when bone formation and metabolism is at a critical stage, may significantly increase the chances of a female developing osteoporosis as an adult (Cupisti et al., 2000). Amenorrhea and later onset of menarche in female athletes can also decrease peak bone mass. Aside from increasing the risk for osteoporosis, decreased peak bone mass in female athletes may increase susceptibility for stress fractures (Yingling, 2009). Stress fractures are problematic for elite female gymnasts and may affect performance and training schedule for long periods of time.

The symptoms associated with the F.A.T are intertwined and often result from a desire to improve athletic performance by achieving a low body weight (Hobart &

Smucker, 2000; Manore et al., 2007; West, 1998). However, the restriction of calories and other behaviors associated with disordered eating can lead to amenorrhea, which can lead to decreased bone mineralization during adolescence. All of these behaviors can be detrimental to the female athlete and may cause irreversible long-term consequences. Therefore, elite female gymnasts, among other athletes, should be aware of the dangers associated with the F.A.T., and should turn to other methods of improving performance than those associated with the F.A.T.

CALCIUM INTAKE

Calcium functions as one of the major macrominerals in the body. The majority of the calcium present in the body is stored in bones, and a small amount (around one percent) is present in plasma. Adequate calcium consumption throughout the lifecycle may help in the prevention of chronic diseases such as osteoporosis, hypertension, and certain types of cancer later in life (Gropper et al., 2009). However, average calcium intake in adolescents is significantly lower than the recommended dietary allowance (RDA) that is suggested for calcium (Steen, 1996). Furthermore, athletes who participate in aesthetic sports like gymnastics often have low intakes of calcium, which may correlate with inadequate energy intake and dietary restriction of calcium-rich foods, such as dairy products (Manore, 2002). As a result, adolescent elite female gymnasts are particularly susceptible to long- and short-term effects of suboptimal calcium intake.

Calcium is present in a variety of different foods. However, some foods are better sources of calcium than others. The best sources of dietary calcium are dairy products (milk, cheese, and yogurt), fish with bones, clams, and oysters. Other sources of calcium

include broccoli, leafy greens, dried fruits, and legumes (Gropper et al., 2009). There is an RDA for calcium, which varies among gender and age group. For adults between the ages of 19 and 50 years, the RDA for calcium is 1000 mg per day. However, for adolescents and teenagers between the ages of 9 and 18 years, the RDA for calcium is 1300 mg per day (Office of Dietary Supplements – National Institutes of Health). This is equivalent to approximately four glasses of milk per day.

Calcium Intake in Adolescence

An adequate intake of dietary calcium supports bone formation, especially during times of growth (Quintas et al., 2003). Because elite female gymnasts train while they are still maturing, it is important for them to maintain adequate calcium intake throughout their careers. Moreover, some studies have shown that athletes may need more calcium than non-athletes (Kudlac et al., 2004). This potential increased calcium requirement may present problems in gymnasts who are still growing, yet restrict energy intake.

According to the American Dietetic Association (ADA), calcium is one of the primary minerals that is often inadequately consumed by athletes. This may be attributed, at least in part, to both energy restriction and the restriction of dairy products in their diets (American Dietetic Association, 2009). In addition, recent research has shown that mean daily intake of calcium tends to decrease during the transition from middle adolescence to young adulthood. This has been correlated with lower consumption of dairy products during these years (Larson et al., 2009). Because dairy consumption tends to decrease during this transitional period, adolescents and teenagers may not consume adequate amounts of calcium on a daily basis and may be at increased

risk for developing osteoporosis or other bone-related issues later in life (Larson et al., 2009). This evidence has serious implications for elite female gymnasts because most competitive gymnasts train throughout this period. This information, combined with an increased propensity towards restricting energy intake and decreased estrogen levels due to amenorrhea, may have detrimental effects on BMD and the risk for osteoporosis later in life.

Calcium and BMD

The vast majority of calcium in the body is found in bones and teeth. Thus, one main function of calcium in the body is bone mineralization. Bones are comprised of both inorganic and organic substances. Much of the inorganic material in bone is made up of minerals, such as calcium, phosphorous, and magnesium, while the organic material is made up of different proteins that function together to form the bone matrix (Gropper et al., 2009). Calcium helps the proteins that are present in bone to interact with each other and form a stable matrix. As previously mentioned, osteoblasts are specialized cells that help form bone. Although the exact processes of bone mineralization at the cellular level are not clearly outlined at this point in time, it is thought that osteoblasts release substances on the surface of the bone that help to bind calcium and increase mineral deposition in bone (Mahan & Escott-Stump, 2008). Osteoclasts, on the other hand, are specialized bone cells that promote the break-down of bone. When plasma calcium concentrations are low, osteoclastic activity in the bone will increase. This, in turn, causes the release of calcium into the blood. Although plasma calcium concentrations will generally remain consistent due to osteoclastic activity, low dietary

consumption of calcium can negatively affect bone mineralization, which may increase the likelihood of developing osteopenia or osteoporosis later in life.

Regulators of calcium in the body

The hormones that regulate calcium homeostasis in the body are interrelated, and work in conjunction with one another. If one hormone or regulator is deficient or under-produced, calcium homeostasis must be maintained at the expense of bone demineralization. Thus, maintaining adequate vitamin and mineral status and having adequate function of organs that maintain calcium homeostasis are imperative to maintaining BMD and bone health.

Parathyroid Hormone

One vital hormone that helps regulate calcium in the body is parathyroid hormone (PTH), which is secreted by the parathyroid gland when plasma calcium concentration is low. There are specialized sensors on the parathyroid gland that monitor plasma calcium levels. The presence of PTH in the blood causes resorption of calcium from bones and stimulates production of calcitriol (the active form of vitamin D), which stimulates the reabsorption of calcium from the kidneys. Reabsorbed calcium from the kidneys enters the bloodstream, maintaining plasma calcium concentrations (Perez et al., 2008). In addition, PTH is also thought to bind with osteoblastic receptors, signaling cessation of osteoblastic activity. Thus, osteoclastic activity is enhanced and calcium is also released into the bloodstream via direct PTH action on the bone (Gropper et al., 2009).

Vitamin D

Adequate vitamin D status in the body helps with the absorption of calcium. Vitamin D, stored in the kidneys as calcidiol, must be converted to the active form of vitamin D (calcitriol) to promote reabsorption of calcium from the kidneys (Mahan & Escott-Stump, 2008). This conversion occurs via an enzyme called renal-hydroxylase to convert calcidiol to calcitriol (1,25 dihydroxycholecalciferol) (Gropper et al., 2009). Once calcitriol is released from the kidneys and into the blood, calcium absorption in the intestine increases, which leads to slightly increased plasma calcium levels. More importantly, though, this release of PTH and calcitriol into the blood stimulates resorption of calcium from the bone via osteoclastic activity (Gropper et al., 2009). If vitamin D is not present in the body in adequate amounts, the dynamic process involving PTH and calcitriol may be compromised. Long-term deficiency of vitamin D in the body leads to lower calcium absorption in the intestine, and can result in low calcium levels in the blood (Perez et al., 2008). Consistently low plasma calcium levels result in consistently high plasma PTH levels; this disruption of calcium homeostasis can cause problems with bone mineralization and leads to softening of the bone, or osteomalacia (Bhan et al, 2010). Vitamin D production and its relation to elite female athletes and BMD will be discussed in further detail below.

Calcitonin

Calcitonin essentially has the opposite effect of PTH on calcium status in the body. When calcitonin is released by the thyroid gland, plasma calcium levels are lowered, osteoclastic activity is inhibited, and osteoblastic activity is stimulated. Therefore,

calcitonin stimulates the construction of the bone and helps to minimize bone resorption (Mahan & Escott-Stump, 2008). In addition, the conversion of calcidiol to calcitriol in the kidneys is decreased when plasma calcitonin levels are increased. This promotes the excretion of calcium from the kidneys into urine instead of promoting renal calcium reabsorption (Gropper et al., 2009). PTH, vitamin D, and calcitonin work in conjunction to carefully maintain calcium homeostasis. However, in females, other hormones, such as estrogen, affect bone mineralization and disrupt equilibrium of the remodeling process.

Estrogen

Estrogen is a female sex hormone that plays an important role in maintenance of BMD. In females, estrogen production in the ovaries is stimulated by luteinizing hormone (LH) during each menstrual cycle. Estrogen production increases when an adolescent female begins her menstrual cycle; this increase in estrogen leads to hormone-induced gains in bone mineralization and generally coincides with the cessation of the adolescent growth spurt. Females who are amenorrheic experience a significant decrease in the production of reproductive hormones – particularly estrogen (Manore, 2002). Low circulating levels of estrogen in females with primary or secondary ameorrhea may cause problems with BMD and bone metabolism; this is concerning especially when combined with low calcium intake (Cupisti et al., 2000). Several theories have been proposed about why menstrual dysfunction and decreased estrogen production commonly occur in female athletes. Recent evidence has suggested that decreased energy take and decreased energy availability to muscle and other body tissues may be the source of menstrual dysfunction in this population (Loucks, 2003). This is potentially due to a disruption in LH, and thus

a decreased production of estrogen (Loucks, 2003). Adequate energy balance and energy intake in gymnasts, therefore, may be protective against menstrual dysfunction and later development of bone-related diseases.

SUNLIGHT EXPOSURE/VITAMIN D

Vitamin D is a fat-soluble vitamin that is present in many commonly consumed foods. Good sources of vitamin D include flesh of fatty fish, fish liver oils, and fortified products such as milk, cheese, and margarines (Mahan & Escott-Stump, 2008). In 2010, the Institute of Medicine stated that the dietary reference intake (DRI) for vitamin D in healthy adults is 600 international units (IU) per day (Institute of Medicine, 2010). This vitamin has a steroid structure, and is considered to be a "seco-steroid" due to incomplete formation of one of its four steroid rings (Gropper et al., 2009). Since vitamin D status in the body has implications for the maintenance of bone health and BMD throughout the life cycle, it is important that people at risk for decreased BMD consume enough dietary vitamin D, or that they synthesize an adequate amount of vitamin D endogenously.

Vitamin D is present in the body in several different forms, but the ones most important to bone health are calcidiol and calcitriol. There are two main sources of dietary vitamin D that serve as the precursors for calcidiol and calcitriol in the body. These precursors are ergocalciferol, or vitamin D_2, and cholecalciferol, or vitamin D_3. Cholecalciferol is also produced via thermal isomerization in the body after exposure to sunlight. Thus, vitamin D can be consumed in the diet or produced endogenously via sunlight exposure (Gropper et al., 2009). Once cholecalciferol is absorbed from the digestive tract, it travels to the liver via chylomicron transport. It is converted to calcidiol

via an enzyme called 25-hydroxylase and stored in the kidney as calcidiol. This is the form of vitamin D that needs to be present in the body for production of calcitriol to occur (Gropper et al., 2009).

As indicated previously, vitamin D is converted from calcidiol to calcitriol via renal hydroxylase and is regulated by PTH secretion by the parathyroid gland in response to low plasma calcium levels. Elite female gymnasts may be at risk for under-production of calcitriol and therefore may be at a higher risk for developing bone-related consequences later in life (Quintas et al., 2003). This is due to a couple of different factors. These athletes may restrict energy intake as a means to keep body weight low, and may not consume enough dietary sources of vitamin D, particularly if dairy products are not consumed on a regular basis (Gabel, 2006). Furthermore, elite female gymnasts train indoors and may not receive enough sunlight exposure during training, resulting in inadequate production of vitamin D via thermal isomerization (American Dietetic Association, 2009). If these athletes do not consume enough dietary vitamin D and do not produce enough via sunlight, it is likely that calcitriol production will decrease. This can lead to decreased calcium absorption from the intestine and low plasma calcium levels. Osteomalacia can be a long-term consequence of inadequate vitamin D status in the body (Bhan et al., 2010). Osteomalacia is another bone-related disease that may affect elite female gymnasts later in life if sunlight exposure is limited and dietary consumption of vitamin D is inadequate. However, it has been shown that vitamin D supplementation in children and adolescents with low serum vitamin D may help prevent bone-related problems by correcting the insufficiency and clinically improve overall bone health (Winzenberg et al., 2011).

CONCLUSION

BMD in both males and females is influenced by many different factors, some of which are controllable (e.g., adequate vitamin and mineral intake, consistent exercise throughout the life cycle, etc.) and some of which are determined before birth (e.g., genotype). During adolescence, female gymnasts typically experience large gains in muscle mass, which can positively influence mineralization of bone and possibly protect from the risk of developing osteopenia or osteoporosis later in life, even after intensive gymnastic training has ceased (Kudlac et al., 2004). However, elite female gymnasts are also at risk for developing the F.A.T., which includes menstrual abnormalities, disordered eating, and problems with BMD. Taken together, it is unclear whether or not intense gains in muscle mass and higher-than-normal BMD during adolescence can "make up" for hormonal disruptions and vitamin and mineral deficiencies that are common among this population. Currently, there are no long-term longitudinal studies available that examine BMD in adolescent female gymnasts during intensive training in comparison to BMD in the same female gymnasts after their gymnastic career is over (i.e., when they have aged, are post-menopausal, and are more susceptible to developing osteoporosis or other bone-related problems). Therefore, at this point, one can only speculate what the correlations may look like for this population in relation to bone health over the life span. Further studies are needed before definitive statements can be made about which factors have the strongest influence on BMD in elite female gymnasts over the course of the life span.

CHAPTER 3: METHODS

The data used in this study were collected by Dr. Dan Benardot over a two-year period from 1994-1996 at Georgia State University through an IRB-approved protocol. This thesis represents a secondary analysis of those data. USA National Team female gymnasts were included in the data acquisition and analysis. A second IRB approval for the current analysis of data was received on July 23, 2009. Anthropometric data, including height and weight, were collected for each of the gymnasts. The gymnasts were also asked to complete a 24-hour dietary recall to obtain information about nutritional status. Energy needs were predicted using the obtained activity, anthropometric, and dietary intake data. Additional questions were asked about menstrual status, time (hours) spent outside weekly, vitamin/mineral supplementation (including calcium supplementation), and history of weight loss and dieting. Wingate tests were performed to assess anaerobic power and anaerobic endurance. DEXA scans were performed on each volunteer participant to measure the following BMD sites: arm, leg, trunk, rib, pelvis, spine, and total BMD. The DEXA scans also provided an assessment of body composition that included fat mass, fat-free mass, and body fat percent.

For the secondary analysis of the questionnaires and nutrition status, two-tailed Pearson Correlation tests were performed to determine significance of relationships

between BMD and other collected variables. A one-way ANOVA with a Bonferroni post-hoc test was performed to assess the variance explained in BMD by age category (12-13 years; 14-15 years; $\geq$ 16 years). Regression analyses were also performed to determine if BMD could be predicted from selected variables including the following: height, weight, energy balance, total calcium intake, lean body mass, time spent in energy deficits ($\geq$ 300 kcals), and time spent in energy surpluses ($\geq$ 300 kcals). All data were assessed for significance using a probability level of $p < 0.05$ and the results were organized into tables for discussion.

CHAPTER 4: RESULTS

DESCRIPTIVE STATISTICS

Demographics

A total of forty-three USA National Team female gymnasts were recruited for this study. The average age for the participants was approximately 15 years (± 1.9 years). The average height was 151.4 cm (± 7.1 cm), and the average weight was 46.8 kg (± 8.2 kg). Body fat percentage was predicted using two methods: skinfold measurement using calipers and DEXA measurement. The average body fat percentage using skinfold measurements and DEXA were 11.7% (± 1.99%) and 15.4% (± 3.64%), respectively. (See Table 1)

Table 1: Demographics of Assessed USA National Team Female Gymnasts (N=43)

	Mean	Std. Deviation
Age(yr)	15.07	1.882
Height (cm)	151.3558	7.10393
Weight (kg)	46.8463	8.22603
Skinfold Body Fat %	11.7028	1.98682
DEXA Body Fat %	15.4186	3.64471

Of the forty-three gymnasts included in this study, the majority (n=38) were Caucasian. Four gymnasts were African American, and one gymnast was Asian. (See Table 2)

Table 2: Ethnicity of Assessed USA National Team Female Gymnasts

		Frequency	Valid Percent	Cumulative Percent
Valid	Caucasian	38	88.4	88.4
	African American	4	9.3	97.7
	Asian	1	2.3	100.0
	Total	43	100.0	

Bone Mineral Density

BMD measurements were obtained using full-body DEXA scans which provided BMD values for seven anatomical sites on all forty-three participants. All BMD values are provided as cross sectional area (g/cm^2). The average total BMD was 1.15 g/cm^2 ($\pm$ 0.11 g/cm^2). The following are average BMD values for the other sites measured: arm (0.91 g/cm^2, $\pm$ 0.11 g/cm^2), leg (1.25 g/cm^2, $\pm$ 0.13 g/cm^2), trunk (0.97 g/cm^2, $\pm$ 0.11 g/cm^2), rib (0.74 g/cm^2, $\pm$ 0.08 g/cm^2), pelvis (1.20 g/cm^2 , $\pm$ 0.15 g/cm2), and spine (1.18 g/cm^2, $\pm$ 0.18 g/cm^2). (See Table 3)

Table 3: Bone Mineral Density of Assessed USA National Team Female Gymnasts (N=43)

	Mean	Std. Deviation
BMD arm (g/cm^2)	0.91077	0.110718
BMD leg (g/cm^2)	1.25400	0.133435
BMD trunk (g/cm^2)	0.96907	0.107326
BMD rib (g/cm^2)	0.73907	0.075010
BMD pelvis (g/cm^2)	1.20353	0.145648
BMD spine (g/cm^2)	1.17586	0.181664
BMD total (g/cm^2)	1.15260	0.112812
Valid N (listwise)		

Energy Balance Dynamics

Energy requirements were predicted in forty-two of the forty-three participants; resting energy expenditure (REE) was measured using indirect calorimetry. The difference between these values was then calculated. All of these values were measured in hourly energy requirements. The average predicted REE was 38.9 kcals/hour ($\pm$ 7.0 kcals/hour), or 933 kcals/day. The measured REE using indirect calorimetry was 52.5 kcals/hour ($\pm$ 11.3 kcals/hour), or 1260 kcals/day. The difference between the predicted and measured REE values was 13.5 kcals/hour ($\pm$ 9.0 kcals/hour), or 324 kcals/day. Energy consumption was measured for all forty-three participants using the 24-hour dietary recall filled out by each participant. Energy expenditure was predicted using the Harris-Benedict equation. The average energy consumption was 1537 kcals/day ($\pm$ 528

kcals/day), while the average energy expenditure was 2150 kcals/day (± 151 kcals/day). The average percentage of kcals consumed when compared to energy expended was 72.3% (± 27.7%). Hourly energy deficits and surpluses were calculated using the 24-hour dietary recall. The largest average energy deficit over any one-hour period during 24 hours was 398 kcals (± 341 kcals), while the largest energy surplus over a one-hour period was 357 kcals (± 397 kcals). (See Table 4)

Table 4: Energy Consumption, Requirements, & Balance of Assessed USA National Team Female Gymnasts

	N	Mean	Std. Deviation
Predicted REE (kcals/hr)	42	38.931	6.9993
Actual REE (kcals/hr)	42	52.455	11.2698
REE Difference (kcals/hr)	42	13.5264	9.00120
Energy Consumed (kcal)	43	1536.93	528.356
Energy Expended (kcal)	43	2149.58	150.831
Percent Kcal Requirement	43	72.26	27.725
Largest Energy Deficit (kcal)	43	397.63	341.307
Largest Energy Surplus (kcal)	42	357.19	397.954

Average time (hours) spent in energy deficits and surpluses was calculated using the completed 24-hour dietary recall for forty-one participants. The average amount of time spent in a deficit of > 300 kcals/day was 2.7 hours (± 2.7 hours) and the average amount of time spent in a surplus of > 300 kcals/day was 2.8 hours (± 3.8 hours). (See Table 5)

Table 5: Time Spent in Kcal Deficit and Surplus of Assessed USA National Team Female Gymnasts (N=41)

	Mean	Std. Deviation
Time Line Deficits > 300 (hr)	2.7073	2.70411
Time Line Surpluses > 300 (hr)	2.7805	3.83740

Factors Affecting BMD: Calcium and Sunlight Exposure (Vitamin D)

Calcium intake for all forty-three participants was calculated using the completed 24-hour dietary recall. The average calcium intake from food was 859 mg/day (± 404 mg/day). Of the participants taking supplements (n=26), the average calcium intake with food and supplements was 1274 mg/day (± 636 mg/day). All participants were asked if they spent time outside, and were asked to indicate how many hours they spent outside per week. Of the participants who spent time outside every week (n=36), the average amount of time spent outside was 1.4 hours/week (± 1.9 hours/week). (See Table 6)

Table 6: Calcium Intake and Time Spent Outside of Assessed USA National Team Female Gymnasts

	N	Mean	Std. Deviation
Calcium Intake w/Supplements (mg)	26	1274.4731	636.39797
Calcium Intake Food Only (mg)	43	858.7635	404.35455
Time Spent Outside (hr)	36	1.42	1.933

Menstrual Status

All participants (n=43) were asked about their menstrual status. Of the participants who had begun menstruating (n=15), the average age of menstrual onset was approximately 15.1 years (± 1.4 years). (See Table 7 and Table 8)

Table 7: Menstrual Status of Assessed USA National Team Female Gymnasts

Have period?		Frequency	Percent	Valid Percent
Valid	Yes	15	34.9	34.9
	No	28	65.1	65.1
	Total	43	100.0	100.0

Table 8: Age at First Period of Assessed USA National Team Female Gymnasts

	N	Mean	Std. Deviation
What Age 1st Period?	15	15.13	1.356
Valid N (listwise)	15		

The participants who had begun menstruating (n=15) were also asked if they had regular menstrual cycles. Of these participants, eight indicated that they had regular menstrual cycles and seven indicated that they did not have regular menstrual cycles. (See Table 9)

Table 9: Menstrual Regularity of Assessed USA National Team Female Gymnasts

Regular Period?		Frequency	Percent	Valid Percent
Valid	N/A	27	62.8	64.3
	Yes	8	18.6	19.0
	No	7	16.3	16.7
	Total	42	97.7	100.0
Missing	System	1	2.3	
Total		43	100.0	

STATISTICAL ANALYSIS

To determine statistical relationships between BMD and related factors among subjects, Pearson Correlation statistics were assessed using two-tailed significance. This assessment includes correlations (r-values) and probabilities (p-values) to assess significance levels.

Demographic Data Analysis

Age of the gymnasts was positively and significantly associated with BMD in all categories ($p < 0.001$ for arm, leg, trunk, rib, pelvis, spine, and total BMD). All of the r-values for BMD indicated a strong positive association with BMD (range $r=0.62$ to $r=0.68$), except for BMD in the pelvis, which had a moderate positive association ($r=0.55$). Statistical analysis was performed using a t-test to assess differences in BMD between Caucasian (n=38) and non-Caucasian (n=5) subjects. There was no significant difference between Caucasians and non-Caucasians in BMD values.

Anthropometric Data Analysis

Weight was significantly associated with BMD in all categories ($p < 0.001$ for arm, leg, trunk, rib, pelvis, spine, and total BMD). All of the r-values indicated a very strong positive association with BMD, ranging from $r=0.82$ to $r= 0.90$ for all sites. Lean body mass, assessed by DEXA scans, was significantly associated with BMD in all categories ($p<0.001$ for arm, leg, trunk, rib, pelvis, spine and total BMD). All r-values for lean body mass and BMD indicated a strong positive association, ranging from $r=0.74$ to $r=0.87$ for all sites. Body fat percentage, assessed by DEXA scans, was also significantly associated with BMD at all sites, with p-values ranging from $p<0.001$ to $p=0.01$. The r-values for BMD and percent body fat showed moderate positive associations, ranging from $r=0.39$ to $r=0.54$.

Vitamin Status Data Analysis

Calcium intake was not significantly associated with any of the BMD sites, and all of the r-values indicated a weak negative association with BMD. Similarly, sunlight exposure and indirect measures of vitamin D were not significantly associated with any of the BMD sites, and all of the r-values indicated a weak positive association with BMD. (See Table 10)

Table 10: BMD and Related Factors of Assessed USA National Team Female Gymnasts

BMD (g/cm^2)	***Age r (p)***	***Weight r(p)***	***Calcium r(p)***	***Sunlight exposure r(p)***	***Lean Body Mass r(p)***	***Percent Body Fat DEXA r(p)***
Arm	0.68 (<0.001)	0.83 (<0.001)	-0.17 (0.28)	0.082 (0.63)	0.82 (<0.001)	0.44 (0.003)
Leg	0.64 (<0.001)	0.90 (<0.001)	-0.14 (0.37)	0.13 (0.44)	0.84 (<0.001)	0.53 (<0.001)
Trunk	0.63 (<0.001)	0.89 (<0.001)	-0.17 (0.28)	0.20 (0.24)	0.87 (<0.001)	0.47 (0.002)
Rib	0.64 (<0.001)	0.82 (<0.001)	-0.20 (0.20)	0.13 (0.45)	0.74 (<0.001)	0.52 (<0.001)
Pelvis	0.55 (<0.001)	0.87 (<0.001)	-0.21 (0.18)	0.23 (0.19)	0.86 (<0.001)	0.39 (0.01)
Spine	0.62 (<0.001)	0.87 (<0.001)	-0.16 (0.30)	0.15 (0.40)	0.82 (<0.001)	0.47 (0.002)
Total	0.68 (<0.001)	0.87 (<0.001)	-0.20 (0.20)	0.12 (0.48)	0.81 (<0.001)	0.54 (<0.001)

Menstrual Status Data Analysis

Regular menstrual status was assessed among the fifteen gymnasts who had begun menstruating. The average BMD values were assessed for each site for participants who had regular periods and those who did not have regular periods. The significance between these values was then assessed. The average arm BMD for gymnasts with regular periods was 1.06 g/cm^2, while the average arm BMD for gymnasts without regular periods was 0.94 g/cm^2 (p=0.05). The average leg BMD for gymnasts with regular periods was 1.41 g/cm^2, while the average leg BMD for gymnasts without a regular period was 1.33 g/cm^2 (p=0.04). The average trunk BMD for gymnasts with regular periods was 1.11 g/cm^2, while the average trunk BMD for gymnasts without regular periods was 1.01 g/cm^2 (p=0.01). The average rib BMD for gymnasts with regular periods was 0.84 g/cm^2, while the average rib BMD for gymnasts without regular

periods was 0.75 g/cm^2 (p=0.01). The average pelvic BMD for gymnasts without regular periods was 1.34 g/cm^2, while the average pelvic BMD for gymnast with regular periods was 1.27 g/cm^2 (p=0.10). The average spine BMD for gymnasts with regular periods was 1.42 g/cm^2, while the average spine BMD for gymnasts without regular periods was 1.24 g/cm^2 (p=0.02). The average total BMD for gymnasts with regular periods was 1.30 g/cm^2, while the average total BMD for gymnasts without regular periods was 1.20 g/cm^2 (p=0.003). (See Table 11)

Table 11: Regular Menstrual Status and BMD (g/cm^2) of Assessed USA National Team Female Gymnasts

		Arm (mean) p=0.05	**Leg (mean) p=0.04**	**Trunk (mean) p=0.01**	**Rib (mean) p=0.01**	**Pelvis (mean) p=0.10**	**Spine (mean) p=0.02**	**Total (mean) p=0.003**
Regular Menses?	**Yes**	1.06	1.41	1.11	0.84	1.34	1.42	1.30
	No	0.94	1.33	1.01	0.75	1.27	1.24	1.20

Predictors of Total BMD

A regression analysis was performed to determine which factors were strong predictors of total BMD values in the assessed gymnasts. This dependent variable in this analysis was total BMD (g/cm^2) and the independent variables were regular menses, height, weight, percent of kcals consumed from predicted kcal requirement (from indirect calorimetry), calcium intake with supplements, lean body mass (from DEXA), time line deficits >300 kcals, and time line surpluses >300 kcals. The R^2 value for this equation was 0.999, the adjusted R^2 value was 0.997, and the standard error of the estimate (SEE) was 0.005244 (See Table 12).

Table 12: Regression Equation to Predict Total BMD (g/cm2) in Assessed USA National Team Female Gymnasts

BMD total (g/cm^2*)* = regular menses(-0.21) + height(0.014) + weight (0.001) + percent kcal requirement (0) + calcium intake w/supplements(-0.00006) + lean body mass (-0.003) + time line deficits >300(-0.01) + time line surpluses >300(-0.01) + 0.005244
R^2: 0.999 **adjusted R^2**: 0.997 **SEE**: 0.005244

CHAPTER 5: DISCUSSION AND CONCLUSIONS

DISCUSSION

The purpose of this study was to assess factors that are associated with BMD in elite female gymnasts. Gymnastics is a high-impact sport that can positively affect BMD, due to increased muscle mass and repeated load-bearing movements (Dowthwaite & Scerpella, 2009). As osteoporosis and osteopenia affect nearly fifty-five million Americans, it is important to maximize accrual of BMD during the formative years of adolescence (National Osteoporosis Foundation, 2010). In this study, there were several strong predictors of increased BMD in the assessed USA National Team female gymnasts. Increased age was positively associated with increased BMD, which indicates that the gymnasts involved in the study experienced age-related gains in BMD that are similar to those seen in non-gymnast adolescents. Increased weight and increased fat-free mass had strong positive associations with increased BMD in this population. It is well-documented in the literature that increased muscle mass has positive effects on BMD (Bertelloni et al., 2006; Daly et al., 2004; Egan et al., 2006; Taaffe & Marcus, 2004). Since muscle adds weight to the body, these factors are intertwined (i.e., increased muscle mass = increased body weight). Increased muscle mass can also lead to increased power and better performance overall (Claessens et al., 1999). Although percent body fat was statistically significant in regards to BMD, increased body fat was

only moderately associated with increased BMD. Since the average body fat percentage for the assessed gymnasts was quite low in comparison to average body fat percentage in non-gymnast adolescents, it may be difficult to predict BMD with regards to body fat percentage in this population.

One unexpected result of the data assessment done in this study was that there was no statistically significant association with either sunlight exposure or calcium intake with BMD. Calcium and vitamin D play important roles in the maintenance and building of bones. It has been shown in the literature that vitamin D status and calcium intake are positively associated with increased BMD in the general population, but that was not the case with this population (Bhan et al., 2010; Larson et al., 2009; Prentice, 2004). Since the dietary information given by the participants was in the form of a 24-hour dietary recall, there could have been discrepancies in normal calcium intake among the participants. The calcium status may have been under- or over-estimated among the gymnasts. In addition, there was a large standard deviation in calcium intake (mean intake without supplements = 859 mg/day $\pm$ 404 mg/day). This large standard deviation may indicate a wide distribution of data, and may have affected the significance of the data. Sunlight exposure was the sole measure of vitamin D status in these gymnasts, but vitamin D status is also influenced by dietary intake and supplementation. Therefore, sunlight exposure alone may not be a strong enough predictor of increased BMD values.

Regular menstrual status was significantly associated with BMD at all sites. Of the fifteen gymnasts who had begun menstruating, the gymnasts with regular periods had significantly higher BMD at all measured sites than those who did not have regular periods. This finding is in agreement with the literature, which indicates that regular

menstruation among female adolescents is associated with higher BMD during puberty and into adulthood (Loud et al., 2005; Yingling, 2009). It is also indicative of a larger problem among the assessed gymnasts in this study. Of forty-three gymnasts, only eight had regular periods (approximately 19% of the study population). The gymnasts who had regular periods had significantly higher BMD than the gymnasts who did not have regular periods, which indicates that regular menstrual status provides protective effects to BMD and can positively influence maximal accrual of BMD. Since the majority of the assessed gymnasts had not begun menstruating, and the average age of menstruation was 15 years, it may be assumed that these gymnasts are not benefiting from maximal BMD accrual during their adolescent years. This could have detrimental effects later in life, and they could be a higher at risk for developing osteopenia and osteoporosis than those who had regular periods.

The regression analysis to predict total BMD had a very strong positive predictive R^2 value of 0.999 (adjusted R^2 value=0.997, SEE=0.005244). The regression equation developed from the regression analysis indicates that 99.9% of the variance in the dependent variable (total BMD) can be predicted by the using the following independent variables: regular menstruation, height, weight, percent kcal intake from predicted kcal requirement (from indirect calorimetry), calcium intake (with supplements), lean body mass (from DEXA), time line deficits >300 kcals in any one-hour period over 24 hours, and time line surpluses >300 kcals in any one-hour period over 24 hours. This regression equation should be able to accurately predict total BMD only when used with age-matched elite female gymnasts. It is important to note that this is a limited population, as there are only a small number of gymnasts that are able to compete on the USA National

Team. However, the highly predictive R^2 value and the small SEE value are significant. Even though some of the independent variables from this equation were not significant predictors of total BMD on their own (e.g., calcium intake, time line deficits and surpluses), these values become significant and predictive when combined with other independent variables to form this regression equation.

CONCLUSIONS

In conclusion, the findings from this study are, for the most part, in general agreement with the literature. The literature suggests that BMD is positively influenced by increased muscle mass and decreased body fat percentage (Bertelloni et al., 2006; Daly et al., 2004; Egan et al., 2006). In this study, both increased muscle mass and decreased body fat percentage had significant and positive associations with increased BMD. Therefore, the null hypothesis that increased muscle mass does not positively influence BMD can be rejected. Weight is also closely related to both increased muscle mass and decreased fat mass, and it was found that increased weight was also a significant predictor of increased BMD in this population. The average weight for these gymnasts was approximately 47 kg and the average age was approximately 15 years; clearly, this is not representative of the average weight for age for non-gymnast peers. Therefore, generalizations cannot be made for non-gymnasts when looking at weight and age as positive predictors of BMD. It was found that gymnasts who had regular menstrual cycles had significantly higher BMD values at all sites (except for pelvic BMD) than those who did not have regular menstrual cycles. The null hypothesis that regular menstruation does not positively influence BMD in this population can be

rejected. In this study, dietary calcium intake did not significantly influence BMD values at any site. Therefore, the null hypothesis that dietary calcium intake (mg/day) does not positively influence BMD must be accepted. Similarly, it was found that sunlight exposure had a weak positive association with BMD, but the relationship was not significant. The null hypothesis that sunlight exposure (hours/week) does not positively influence BMD must be accepted.

The results from this data analysis indicate that elite female gymnasts participate in activities that positively influence the accrual of BMD. All gymnasts had a high muscle mass to percent body fat ratio; this ratio may be helpful in protecting this population from the development of bone-loss later in life. However, the gymnasts that had regular menstrual cycles had significantly higher BMD values overall than gymnasts who had not begun menstruating, or who had irregular menstrual cycles. This indicates that the onset of puberty positively influences the accrual of BMD. The majority of the assessed gymnasts (approximately 81%) had not experienced the onset of menses. Thus, these gymnasts may not be accruing maximal BMD during adolescence, and this could have serious implications for the development of osteopenia or osteoporosis later in life. It would be interesting to perform further studies on former elite female gymnasts after training has ceased and into menopausal years to assess whether or not increased BMD in adolescence and age of menstruation onset are protective to BMD values as these gymnasts age.

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