Bone Mineral Density, Body Composition, and Health-Related Behaviors of Collegiate Female Gymnasts

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Abstract: Monitoring changes in body composition, bone mineral density, and eating pathology symptoms is crucial for identifying injury risk factors and improving health and performance in female collegiate gymnasts. This study investigated the relationship between body composition (BC), bone mineral density (BMD), and eating pathology symptoms inventory (EPSI) scores in Division I female collegiate gymnasts over a 6-month competitive season. Data on BMD: total Bone Mineral Density, total bone mineral content, total Area, Z-score, and T-score, body composition: height, weight, total tissue % fat, total region % fat, total bone mass, total fat mass, total lean mass, total fat-free mass, total mass and EPSI scores: body dissatisfaction, binge eating, cognitive restraint, purging, restricting, excessive exercise, negative attitudes toward obesity, and muscle building were analyzed. Results indicated that body dissatisfaction and excessive eating were prominent EPSI subscales among the gymnasts both at pre- and post- season. The EPSI survey demonstrated suitability in studying eating disorders (ED) and disordered eating (DE) in this population. Changes in bone mineral content and total area were observed from pre- to post-season. Negative correlations were found between EPSI body dissatisfaction, total tissue % fat, total region % fat and total fat mass, as well as a positive association EPSI binge eating and total BMD and T-score in preseason. Negative association between EPSI muscle building and height, total lean mass, and total fat-free mass. Negative association between total area and total tissue % fat and total region % fat in preseason. Negative association between Z-score and total heigh, while

positive correlations between weight, total lean mass, and fat-free mass in preseason. Changes in correlations were observed between bar scores and the EPSI restricting subscale, as well as between beam scores and the EPSI cognitive restraint subscale. These findings contribute to understanding injury risk factors and evidence-based practices for female collegiate gymnasts, informing interventions to promote health body image, eating habits, and physical performance.

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Preface

This thesis presents the findings of the Bone and Body Composition Adaptations to Training (BoBCAT) Study, supported by the U.S Army Research Acquisition Activity (W81XWH2110542). The research explores the relationship between training, bone health, and body composition.

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I present this thesis as a testament to our collective effort, scientific inquiry, and dedication to advancing knowledge in bone and body composition adaptations to training

1.0 Introduction

Artistic women's gymnastics has become increasingly popular in the United States (U.S). The U.S is ranked number one by the Federation Internationale de Gymnastique (FIG) (WAG, 2018). USA Gymnastics (USAG) reports 102, 295 athlete members, including 86,800 artistic gymnasts (USA Gymnastics, 2017). Competitive gymnastics is a challenging and evolving sport that consists of 10 levels with only a selected number of athletes advancing beyond elite to Olympic status. Progression through each level requires gymnasts to master various skills on each of the four events (e.g., vault, uneven bars, balance beam, and floor exercise) before progressing onto the next level. Gymnastics disciplines for women require various performance characteristics such as strength, flexibility, balance, and precise movement (Brooks, 2003) Standards for the skills at each level are set by USA Gymnastics every 4 years, which are concurrent with the summer Olympics (USA Gymnastics, 2017; Hecht & Burton, 2009). As a result, the skill level continues to evolve. Gymnasts train intensively from childhood and reach their peak performance in adolescence (Robert M Malina et al., 2013). Over the past years, gymnasts' routines have become increasingly difficult as the skill level required for success at competition has increased greatly. Due to the difficulty of the sport and increased practice from an early age, an athlete's performance is impacted on many levels.

Gymnastics training has been extensively documented to have various effects on female gymnasts, including an increased susceptibility to acute and chronic injuries in relation to musculoskeletal health. Women's gymnastics has a higher rate of injury when compared to other sports (Colvin et al. 2010, Singh et al. 2008). Participation is associated with an increased risk of stress fractures followed by surgical interventions (Colvin et al., 2010). It has been found, however, that female gymnasts have an average higher bone density than their peers despite the increased risk of bone and tissue injuries. Gymnasts' bone mineral density plays a significant role in injury prevention and performance enhancement. It has been found that competitive collegiate female gymnasts have higher bone density than untrained controls, despite possible adverse effects associated with hormonal levels, diet, and body fat (Jürimäe, Gruodyte-Raciene, & Baxter-Jones, 2018). The high intensity mechanical load of gymnastics activity increases bone density and counters negative effects, including pubertal delay, body fat loss, and lower levels of hormones (Tan, Calitri, Bloodworth, & McNamee, 2016). Despite this benefit, gymnastics is also a sport that demands an exceptionally low percentage body fat to maximize strength to body weight ratio. It is beneficial in terms of technique to have a low body weight, as well as a low percentage of fat mass combined with muscular strength and power because it increases the power-to-weight ratio. Consequently, excessive fat mass impairs movement efficiency (J. Sundgot-Borgen & Garthe, 2011). The correlation between fat mass and athletes' performance has been documented in numerous studies. Researchers have found that gymnasts with more subcutaneous fat have lower performance scores (Claessens, Lefevre, Beunen, & Malina, 1999). Furthermore, world-class female gymnasts with moderate BMI outperformed athletes with high or particularly low BMI (Sherman, Thompson, & Rose, 1996). Additionally, lean body shape is considered important for sport-specific aesthetic reasons (Claessens et al., 1999). Low body weight and fat mass are important for gymnastics performance irrespective of discipline. According to research in gymnastics sports, elite female artistic gymnasts are known to be short-statured, have low body mass, and have low body fat levels (Bacciotti, Baxter-Jones, Gaya, & Maia, 2017; Georgopoulos et al., 1999; R. M. Malina et al., 2013; Robert M Malina et al., 2013).

Many female gymnasts struggle with the concept of an ideal body aesthetic regarding weight or shape. Gymnasts often turn to low calorie diets and other unhealthy weight-control practices (Anderson & Petrie, 2012; De Bruin, Oudejans, & Bakker, 2007; Krentz & Warschburger, 2013; Okano et al., 2005; Sundgot-Borgen, 1996; Sundgot-Borgen et al., 2013). Consequently, adolescent gymnasts may have nutritional deficiencies due to low energy availability and macronutrient/ micronutrient deficiencies (Dallas, Dallas, & Simatos, 2016; Silva & Paiva, 2015; Soric, Misigoj-Durakovic, & Pedisic, 2008). Some gymnasts may overtrain or engage in poor dietary practices to maintain a specific aesthetic, which may affect their perception of topics (e.g., dissatisfaction, binge eating, cognitive restraint, purging, restricting, excessive exercise, and negative attitudes towards obesity and muscle building) related to eating-disorder pathology (Tan et al., 2016). Female adolescent gymnasts continuously struggle to cope with the demands of a high-intensity sport with minimal guidance. To address this gap in information it is important to understand the physical and mental changes that impact a gymnast's athletic development.

1.1 Epidemiology of Gymnastics Injuries

High impact sports are likely to result in acute and chronic injuries to the lower and upper extremities. The United States of America Gymnastics (USAG) safety manual defines a gymnastics injury as sustained during participation resulting in the gymnast missing any portion of a workout or competitive event (USA Gymnastics, 2017). The incidence rate of gymnastics injuries in women's collegiate artistic gymnastics was 9.22 to 22.7 injuries per 1000 h of exposure (Kerr, Hayden, Barr, Klossner, & Dompier, 2015; Sands, Shultz, & Newman, 1993; Westermann, Giblin, Vaske, Grosso, & Wolf, 2015). Sports injury surveillance has led researchers to identify injury-related patterns. Women's gymnastics has been found to have the highest injury rate of all collegiate women's sports (Kerr et al., 2015) A higher incidence of injuries has been reported in women's gymnastics competitions than in practices, particularly in the lower extremities (Marshall, Covassin, Dick, Nassar, & Agel, 2007). Additionally, stress fractures are more common in women's gymnastics than in any other NCAA women's sport (Rizzone, Ackerman, Roos, Dompier, & Kerr, 2017). Multiple studies have concluded that the most common location of injury in gymnastics is the lower extremity, specifically ankle sprains, and knee internal derangements (Kerr et al., 2015; Overlin, Chima, & Erickson, 2011). Women's gymnastics injuries reported during 2014-2015 through 2018-2019, knee injuries (13.1%), ankle injuries (12.6%), and foot injuries (12.1%). Specific diagnoses would show strains and sprains (27.7%) to be the most common injury followed by fractures (9%) (Saluan, Styron, Ackley, Prinzbach, & Billow, 2015). All injuries reported were lower leg injuries (11.6%), head and face injuries (10.4%), and surface contact-injuries (35.4%) and overuse injuries (20.3%) (Chandran et al., 2021). The percentage of surface-contact injuries sustained during competition (48.5%) was higher than that of injuries sustained during practice (32.9%), whereas the percentage of overuse injuries suffered during practice (9.3%) was higher than that of competitive injuries (22.5%) (Chandran et al., 2021).

1.2 Risk Factors for Gymnastics Injuries

Identification and analysis of factors contributing to gymnastics injuries is a vital part of gymnastics injury epidemiology. Factors that may be considered as risk factors can be classified as intrinsic or extrinsic.

1.2.1 Intrinsic Factors

Individual biological (e.g., anatomy, hormonal and neuromuscular function, muscle stiffness, and muscle strength etc.) and psychological characteristics are intrinsic factors that can affect an athlete's injury outcome. Certain physical characteristics such as greater body size, age, body fat, and periods of rapid growth have been associated with increased risk of injury (Dimitrova & Petkova, 2015). Additionally, previous injury is also cited as a key risk factor for future injury (Emery, 2003). Gymnastics injuries may also be increased by psychological stress (Kolt et al., 2004). Researchers found a moderately strong positive relationship between stressful life events, injury number, and severity (Kerr et al, 1988). Another study concluded that female gymnasts who compete in elite and non-elite are more likely to suffer an injury because of life stress (Kolt & Kirkby, 1996).

1.2.2 Extrinsic Factors

Extrinsic factors impact the gymnast while participating in the sport, for example equipment, training methods, coaching techniques. The most significant extrinsic factor is inappropriate training. Research findings indicate that 43.9% of injuries in artistic gymnastics are the result of inadequate training methods, 17.4% of injuries are caused by performance specifics, 9.6% of injuries are caused by training conditions, and 8.4% are caused by the gymnast's health (Dimitrova & Petkova, 2015). Studies have also shown a higher rate of injury among elite gymnasts (Kolt & Kirkby, 1999; Caine et al., 1989). In fact, national level gymnasts incur high rates of injuries associated with competitions (Caine et al., 2003). Most injuries occur during early practice, after reduced training periods, during routine preparation for competition, and just before competition (Caine et al., 2003; Caine et al., 2006). In addition, many injuries occur during floor exercises, especially when landing (Caine et al., 2013). Gymnasts' ability to develop force and power through high-velocity muscle actions plays a key role in their performance but can also put them at risk for injury (French et al., 2004). Many acute injuries occur in the lower limbs due to high impact forces combined with poor lower limb biomechanics during landings (Hume, Bradshaw, & Brueggemann, 2013; Beatty et al., 2005). Lower limb overuse injuries are usually caused by repetitive loading with large deceleration during landings (Lilley et al., 2007). Injury during landing can result from rigid trunk posture, reduced knee flexion, abnormal foot placement, and increased leg stiffness (Blackburn & Padua, 2009; Stacoff et al., 1988; Butler et al., 2003; Bradshaw et al., 2006). The rules of gymnastics may also be a contributing risk factor for these types of gymnastics injuries.

1.3 Body Composition in Gymnastics

1.3.1 Body Composition and Performance

Female artistic gymnastics performance is strongly influenced by body composition. Each sport discipline has specific training that can influence athletes' body compositions, creating the possibility of a sport-specific optimal body composition. Monitoring and assessing body composition are key factors in determining an athlete's health and athletic performance. Physical activity and dietary intake are two modifiable factors that directly impact body composition (Aragon et al., 2017). Many female gymnasts struggle with the concept of body composition as it relates to visual body image (Kantanista et al., 2018; Krane, Waldron, Michalenok, & Stiles-

Shipley, 2001). Gymnastics research has shown that short stature, low body mass and low body fat are characteristics of elite female artistic gymnasts (Bacciotti, Baxter-Jones, Gaya, & Maia, 2017; Malina et al., 2013). To maximize power-to-weight ratios in gymnastics, athletes must have a low body weight and low-fat mass, combined with muscle and power (Malina et al., 2013). Multiple studies have demonstrated correlations between fat mass and athletes' performance. One study found that gymnasts with more subcutaneous fat had lower performance scores (Claessens, Lefevre, Beunen, & Malina, 1999). Another study found that female gymnasts with moderate BMI performed better than athletes with particularly high or particularly low BMIs (Sherman, Thompson, & Rose, 1996). Notably, excessive fat mass was a disadvantage, as it decreased the efficiency of movements (Sundgot-Borgen, Garthe, & Meyer, 2013). For gymnasts, maintaining a balance between adequate nutrition, body composition, an attractive visual appearance, and effective recovery is ideal (Aragon et al., 2017; Smolak, Murnen, & Ruble, 2000). However, the dietary intake of female artistic gymnasts may be nutritionally inadequate, and sometimes concerns about body weight lead to eating disorders (Anderson & Petrie, 2012).

1.3.2 Body Composition and Injury

Body composition of female artistic gymnastics can influence potential risk of injury. Body composition is one of several tools used to ensure optimal sports performance. Female gymnasts face many difficulties related to their body composition, such as injuries. Injuries among artistic gymnasts, especially advanced-level female gymnasts, are high (Barroga, E.F., & Kojima., 2013). According to a recent systematic review of 12 studies, including 843 female gymnasts, the most common injuries were in the lower extremities, followed by injuries to the upper extremities, torso/spine, and neck (Thomas, R. E. & B. C. Thomas.,2019). Sport-related factors and body composition status of high-performance-level artistic gymnasts are poorly researched (Deutz R.C. et al., 2000). Despite this, few studies provide further insight into the relationship between body composition and female gymnasts. A study found that gymnasts with greater height, body mass, and body size were more likely to sustain gymnastics injuries (Wright et al., 1998). Specifically, a gymnast who was "underweight", and had "severe protein-energy malnutrition". The injury rate among these gymnasts was 3.9 injuries per gymnast (1.8/1000 hours). Acute injuries accounted for 70.4% while overuse injuries accounted for 29.0%. Ankles (50%) were the most frequent site for injuries, followed by the lower back (13.8%) and toes (11.1%). According to the study, by categorizing the frequency of body types across injury status, the dominant body types had an equal distribution, which suggests that somatotype may not be a reliable indicator of injury risk. Furthermore, the somatotype ratings of female gymnasts were also found to be insufficient for predicting their injury likelihood. Similarly, previous research has shown that anthropometric characteristics are not a significant factor when it comes to injury risk. (Jackson DW et al., 1978; Lysens R et al., 1984). Further research is needed to understand the parameters of body composition (fat mass, muscle mass, total body water, bone mineral content, metabolic age, visceral fatty tissue, body mass index) to help avoid harmful training habits and potential injuries (Toselli, 2021).

1.4 Bone Mineral Density in Gymnasts

Gymnasts have enhanced bone mineral density due to the sport's nature. Mechanical loading in gymnastics can stimulate bone mineralization and increase bone mineral density given the amount of strain on bones, and muscles. Multiple studies have examined the effects of high-intensity loadings on female gymnasts' bone mineral density. One study compared bone mineral density of 14 gymnasts, 14 swimmers and 17 control subjects in females 7-9 years of age and found that the total body bone mineral density was significantly greater in the gymnasts in level 5 or 6 than the other two groups (Cassell, Benedict, & Specker, 1996). Additionally, researchers from the Department of Kinesiology and the Department of Nutrition and Food Sciences at Texas Woman's University examined bone mineral density in college-aged females which included 11 gymnasts and 11 control subjects. Bone mineral density (lumbar spine and femoral neck regions) was found to be significantly greater in the gymnasts than the controls regardless of inadequate calcium intakes and high prevalence of menstrual irregularity (Nichols et al., 1994; Kirchner, Lewis, & O'Connor, 1996). The mechanical loads of gymnastics result in higher BMD (Bone Mineral Density) in female gymnasts at a variety of ages. Many investigators hypothesize that gymnastics training invokes significant bone loading; thus, the athletes may benefit from enhanced osteogenic effect on bone cell activity via mechanical loading (Mudd, Fornetti, & Pivarnik, 2007), which prevents osteopenia and osteoporosis. Previous studies have found that female gymnasts with longer training histories (40 h/week) exhibit higher values in BMD due to their exposure to higher impact forces and training volumes compared to gymnasts with less training and lower participation levels (Burt, Greene, Ducher, & Naughton, 2013; Roupas et al., 2014). These results suggest that specific gymnastics activities have a positive influence on bone mineral acquisition in growing and maturing gymnasts. However, despite the positive skeletal benefits that are associated with gymnastics, female gymnasts are often susceptible to negative energy balance and psychological pressure with intensive training schedules exceeding 30 h/week (Burt et al., 2013) thereby putting them at a higher risk for developing the Female Athlete Triad, which can negatively affect bone mineral density and increase susceptibility to stress fractures. Women's gymnastics has one of the highest rates of stress fractures with 25.58/100 000 Athlete exposure (Bishop et al., 2021). Stress fractures occur when there is abnormal remodeling due to repetitive stress or impacts, thereby causing microfractures in the cortical bone (American Academy of Orthopedic Surgeons, 2020). Gymnasts that have a negative energy balance caused by inadequate intake relative to energy expenditure can disrupt hormonal signals, which impacts bone remodeling. This type of injury can significantly affect a gymnast's health and sport participation.

1.5 Energy Availability Disorders

1.5.1 Intense Training Regimen of Gymnasts

Gymnastics has evolved since the 1980s to emphasize the importance of time distribution and to emphasize specific training activities. Gymnasts endure training-related effects involving growth and maturity characteristics such as adolescent accretion and hypertrophy of muscle mass (Malina et al., 202004). It has been suggested that short stature and later maturation in female artistic gymnasts are caused by early intensive training (Ziemilska,1985; Jahreis et al., 1991; Lindholm C et al., 1994). It is possible that this is due to the earlier attainment of advanced levels of training and competition among females during the period of the adolescent growth spurt. As a result of limited data, inadequate training specification, failure to consider factors affecting growth and maturation, as well as failure to address epidemiological criteria for causality, it is not possible to establish a cause-effect relationship between training and outcome measures. (Malina, 1999; Beunen et al., 1999). The scientific literature typically describes training in terms of weekly hours. Studies have included athletes under the age of 14 and athletes of all ages, and some have included gymnasts at major championships. It is estimated that gymnasts training for major championships train for 30 hours a week on average. The amount of time spent training increases with age and level of competition. According to some gymnastics schools of the former Soviet Union, athletes initially train for 8 hours a week to 32-36 hours for elite training at 16-18 years old (Hartley, 1987). In addition, the training thresholds recommended by coaches to select English gymnasts increased from 9 to 18 hours/week between the ages of 8 and 16 (Baxter-Jones & Helms, 1996). For elite US female gymnasts, the 'optimal plan' recommends two daily sessions (morning 2-3 hours, afternoon 3-4 hours), six days per week (USA Gymnastics, 2011). Regarding age groups (junior pre-elite 11-14 years, junior elite 11-15 years, senior elite 16 years), the 'optimal plan' translates to 30–42 hours per week plus 1 hour of dance training at least twice weekly by a dance professional familiar with artistic gymnastics development (USA Gymnastics, 2011). Additionally, a variety of training activities are not reported regularly, including warm-ups, stretching, strength training, repetitions of specific skills and routines, rest between repetitions, dance, and choreography. Multiple studies have tried to document young gymnasts' training, including video and direct observation. It was reported that for girls 4-8 years of age on average 1.2 ± 0.6 and 7.9 ± 3.1 h/week, and 63 and 259 h per year, respectively, in low- and high-level classes (Laing et al., 2005). However, towards the end of practice there was greater variability and complexity of gymnastics elements. Consequentially, information reported in the literature may not be representative of elite gymnasts today since training regimens change over time.

1.5.2 Eating Disorders

Eating disorders (ED) and disordered eating (DE) are more common in high performance sports, particularly in high-performance aesthetic sports like gymnastics. The Diagnostic and

Statistical Manual of Mental Disordered American Psychiatric Association (DSM-5) defines eating disorders as serious mental illnesses that meet specific clinical criteria (Association, 1987). There are several types of eating disorders, including those characterized by an overvalued desire to lose weight or be thin, a fear of fatness, a distorted body image, and behavior associated with these disorders (Tan et al., 2016). The three most common types of disordered eating are anorexia nervosa, bulimia nervosa and binge-eating disorder (Association, 1987).

ED and DE have been associated with serious health problems in adolescence (Rosen & Adolescence, 2010). Adolescence is typically the peak age for onset of ED, with early-to-mid-adolescence being the peak age for anorexia nervosa and late adolescence being the peak age for bulimia nervosa (Golden et al., 2016). Adolescent athletes are at increased risk of developing DE and ED as their bodies try to handle growth, maturation, and intensive training at the same time (Desbrow et al., 2014). Additionally, eating disorders are more common among elite and high-performance athletes whose sports emphasize leanness, low weight, or (slim) aesthetics (Burt, Greene, Ducher, & Naughton, 2013; Sundgot-Borgen & Garthe, 2011). In this case, athletes will exhibit unhealthy weight-control behavior (e.g., skipping meals, fasting, overexercising, vomiting, diuretics, etc.), which does not meet clinical diagnosis criteria for an eating disorder (Bonci et al., 2008; Reardon et al., 2019). According to studies (Nordin, Harris, & Cumming, 2003; Okano et al., 2005; Sundgot-Borgen, 1996; Tan, Calitri, Bloodworth, & McNamee, 2016; Theodorakou & Donti), ED symptoms are more prevalent in female athletes than in nonathletes (Martinsen & Sundgot-Borgen, 2013; Sundgot-Borgen & Torstveit, 2004) and in lean sports (Mancine, Gusfa, Moshrefi, & Kennedy, 2020). The consequences of ED and DE in adolescent athletes include low energy availability, macronutrient/micronutrient deficits, dehydration, electrolyte imbalances and low bone mineral density (Kontele & Vassilakou, 2021). Female athletes with low energy availability are at risk of developing the Female Athlete Triad as the result of irregular menstruation and bone remolding imbalances (Nattiv & Lynch, 1994; Birch, 2005). Emphasis on early prevention, identification, and treatment of eating disorders is paramount to addressing.

1.5.3 Hormonal Imbalance

Many hormones affect bone metabolism and bone mineral acquisition and change during growth and maturation. Gymnastics training directly affects bone mineral acquisition through mechanical loading (Grudyte-Racience et al., 2013), while hormonal regulation indirectly influences growth and maturation in young athletes (Maimoun et al., 2014). Hormone regulation can have both positive and negative effects on the body. Hormones including estrogens and growth hormones (GH and IGF-I) are beneficial and critical bone trophic hormones that influence pubertal bone development (Misra, 2008). Estrogen levels during puberty increase in conjunction with GH and IGF-I levels, which both stimulate osteoblast proliferation and differentiation (Davies et al., 2005). These hormones are responsible for reaching maximal peak bone mass acquisition in athletes during maturation (Markou et al., 2010). Contrary to this, heavy gymnastics activity when energy balance is reduced has been shown to inhibit female gymnasts' sex hormone production. Hypoestrogenism, on the other hand, negatively impacts bone development by increasing bone resorption and decreasing bone formation markers (Misra, 2008), and amenorrheic adolescents suffer from bone resorption (Misra, 2008). Additionally, adolescents with late menarche and concomitant estrogen deficiency exhibit lower peak bone accrual (Jackowski et al., 2011a; Maimoun et al., 2014); these findings suggest that estrogen exposure plays a significant role in bone mineral acquisition and achieving maximal peak bone accrual (Chevalley et al., 2011). Due to intense athletic activity, lower estradiol values may be compensated by frequent high-impact loading (Grudyte et al., 2010b). By inhibiting estrogen receptors, bone cells cannot adapt to mechanical loading (Zaman et al., 2000). Based on the findings, the research suggests that while estradiol plays a role in promoting bone mass and growth during pubertal maturation in gymnasts, its impact is relatively modest. The specific high-impact mechanical loading was identified as a more significant factor influencing bone development during puberty (Zaman et al., 2000).

Athlete's linear growth and pubertal maturation are strongly influenced by nutrition, specifically energy balance (Jürimäe, 2014). Sports with excessive energy expenditure and chronic athletic activity may be associated with lower leptin concentration (Jürimäe, 2014). It has been shown that leptin levels are positively correlated with FM and BMD in untrained girls with different maturation levels (Garnett et al., 2004; Parm et al., 2011b). Despite high energy expenditure and reduced FM in pre-pubertal and pubertal gymnasts, the effects of lowered leptin on bone mineral acquisition remain unclear (Parm et al., 2011b; 2012; Courteix et al., 2007; Maimoun et al., 2010b). Studies have reported positive correlations between leptin concentrations and BMD among pubertal gymnasts (Gruodyte et al., 2010a; Munoz et al., 2004). However, other studies found no relation between leptin and aBMD gains in prepubertal (Parm et al., 2012) or pubertal (Maimoun et al., 2010b) gymnasts. According to one study, gymnastics activity counterbalances the negative effects that leptin deficiency has on bone. Leptin's effects on bone development are likely to be multifactorial and may involve other hormones, including estradiol and IGF-I, as well as its direct effects (Maimoun et al., 2014). It is still unclear how leptin affects bone mineral acquisition in growing human bones, and this may depend on chronic athletic activities.

Other hormones' effects on bone development during chronic gymnastics activity with high energy expenditure are not fully understood in athletes undergoing growth and maturation.

Adiponectin (Võsoberg et al., 2016), visfatin (Gruodyte et al., 2010a), ghrelin (Parm et al., 2011b), and preadipocyte factor-1 have all been studied in relation to bone mineral acquisition in growing and maturing gymnasts among other hormones that regulate energy homeostasis. Adiponectin has been suggested as a link between bone and fat metabolism (Donoso et al., 2010), and adiponectin has been found to be a negative predictor of aBMD in healthy untrained adolescent (Misra et al., 2007) and adult (Jürimäe et al., 2005) females. The different markers of energy homeostasis suggests that gymnastics activity coupled with reduced FM body composition may alter the relationship between markers of energy homeostasis and bone mineral accrual in female gymnasts during growth and maturation. The evidence on the effects of energy homeostasis markers on bone mineral accrual is controversial as these hormones are not typically related to bone mineral gain in growing and maturing gymnasts.

1.5.4 Female Athlete Triad

Female Athlete Triad was first described in 1993 (Yeager et al., 1997) and defined by the American College of Sports Medicine in 1997 the interrelationship between energy availability, menstrual function, and bone mineral density, which may manifest clinically as eating disorders, functional hypothalamic amenorrhea, or osteoporosis (Otis, Drinkwater et al, Nattiv et al. 2007). This condition is most common in sports that emphasize physical leanness such as gymnastics. Adolescent female gymnasts who compete at elite levels are often preoccupied with obtaining the 'ideal' physique for competition, which involves a loss of weight due to energy restriction (Steen, 1996). Restrictive energy intake is associated with inadequate nutrient consumption. Researchers have found that athletes' diets lack calcium, vitamin D, iron, zinc, magnesium, and antioxidants such as vitamin C, E, beta carotene, and selenium (American Dietetic Association, 2009). It has been shown that inadequate calcium levels, particularly in females, can reduce mineralization of bone and increase the risk of low BMD, which may influence stress fracture risk and osteoporosis development (American Dietetic Association, 2009). Reproductive and skeletal health are adversely affected by low energy availability. Dietary energy intake minus exercise energy expenditure. Health concerns associated with the Female Athlete Triad include disordered eating, impaired sports performance, and high risk of fractures. Consequently, gymnasts suffer from menstrual irregularities and low bone mineral density from high training volumes (Nattiv et al., 2007).

1.6 Methodological Consideration

1.6.1 Dual Energy X-Ray Absorptiometry

Body composition assessments differ in precision and target tissues. Measurements of weight, stature, abdomen circumference, and skinfolds are among the most common anthropometric assessments (Yeong Lee & Gallagher, 2008). Bioelectrical impedance analysis (BIA), dual energy X-ray absorption (DXA), hydrostatic weighing, and air displacement are more complex methods of assessing body composition. Anthropometric measurements describe the size, shape, and fat content of the body. There are multiple advantages and disadvantages associated with different body composition assessments depending on current resources and the overall goal.

The skin fold technique is most utilized in clinical settings because it is easy to administer to large groups and the equipment is inexpensive. Harpenden calipers are typically used to measure skinfold thickness at seven locations (biceps, triceps, mid-axillary, subscapular, suprailliac, abdomen, and mid-thigh). Using these measurements along with a person's age and gender, a percentage body fat estimate is calculated. Because skinfold tests only measure subcutaneous fat, do not perform a full body assessment, have a margin error of 8-11%, and are subject to human error, they are limited and inaccurate (Orphanidou et al., 1994).

BIA uses a 2C body composition model to estimate body composition. The 2C body composition model, utilized in BIA, holds significant importance in assessing body composition by distinguishing fat-free mass and fat mass. This information is relevant to athletes in relation to evaluating the effectiveness of dietary and exercise interventions, as well as monitoring changes in body composition over time. Fat-free mass is estimated by measuring the resistance to a small electrical current traveling through the body. A standard algorithm is then used to calculate body fat percentage. Based on BIA body composition analysis, there is a margin of error between 3 and 8% (Burns, R. D., Fu, Y., & Constantino, N., 2019). The results can be affected by how hydrated a person is, how much they have exercised, and whether they have eaten before (Yeong Lee & Gallagher, 2008). Body composition can also be estimated by hydrostatic weighing, which uses body weight on land and in water, along with water displacement. It is based on Archimedes' principle that the buoyant force on a submerged object is equal to the weight of the fluid displaced. The test is typically repeated three times and the average underwater weight is calculated and has a margin of error of around 1-3% (Kirkendall, Grogan, & Bowers, 1991). As an alternative to underwater weighing, air displacement is better tolerated by individuals for measuring body volume and fat mass. BodPod creates small volume changes in a controlled environment with a mechanical diaphragm and measures the pressure response. Prior to the test, a person's weight, age, gender, and height are recorded, and the chamber is calibrated. Compared to other methods, this one is noninvasive, fast, does not require individual sedation, no radiation exposure, and has a 1-3% margin of error (Yeong Lee & Gallagher, 2008; Lowry & Tomiyama, 2015). DXA systems assess bone mineral density, bone-free FFM, and fat mass at the whole-body and regional levels. The DXA method is a noninvasive measurement method that can be applied to humans of all ages . The advantages of DXA include good accuracy and reproducibility and provides for the assessment of regional body composition and nutritional status which may be helpful for evaluation of athletic performance, training regimens, or progress of rehabilitation post injury (Buehring et al., 2014). Disadvantages of DXA include a small amount of radiation; the scanning bed has an upper weight limit and the whole-body-field-of-view, cannot accommodate large persons, and has a margin of error of 1.6%. Despite these contraindications, DXA continues to be considered the gold standard technique for athletes (Bosh, T.A. et al., 2017).

1.6.2 Eating Pathology Symptom Inventory

The Eating Pathology Symptom Inventory (EPSI) is a 45-item self-report measure developed to assess symptoms among diverse populations of individuals with disordered eating. EPSI was developed to be a "comprehensive multidimensional measure of eating pathology" (EPSI; Forbush et al., 2013) with a consistent factor structure across samples. Even though EPSI may be both a psychometrically valid and a clinically valuable measure, it has yet to be evaluated in patients with less severe eating disorder presentations, compared to those in inpatient and partial hospitalization programs, as well as across a broad spectrum of eating disorders (EPSI; Forbush et al., 2013). EPSI requires participants to rate each item, which is based on eight subscales in the Diagnostic and Statistical Manual of Mental Disorders (DSM-5): Body Dissatisfaction, Binge Eating, Cognitive Restraint, Purging, Restricting, Excessive Exercise, Negative Attitudes toward Obesity, and Muscle Building. Participants are asked to rate each statement based on a five-point

Likert scale of "Never" to "Very Often" depending on how often each statement applies to them (EPSI; Forbush et al., 2013). The EPSI can be used to measure numerous aspects of eating pathology by researchers and clinicians. The EPSI has strong convergent validity with established measures of eating disorder symptoms and offers extra dimensions beyond those included in traditional inventories. In addition, most established eating disorder measures do not differentiate scale content to allow conclusions about specific eating disorder behaviors to be drawn. Another strength of the EPSI appears to offer a superior method for assessing dietary restraint as compared to existing measures. Also, EPSI scores appear to have strong criteria for validity based on preliminary evidence. Furthermore, the EPSI is brief, easy to administer, score, and interpret (EPSI; Forbush et al., 2013). The EPSI is a useful tool compared to other surveys that enables rapid and comprehensive evaluation of eating disorders in a variety of research and clinical settings.

Multiple types of eating behavior surveys can be used as an alternative to the EPSI survey. The Eating Disorder Examination Questionnaire (EDE-Q) (Fairburn & Beglin, 2008) is a 28-item self-report questionnaire that evaluates eating attitudes and behaviors. It contains 28 items grouped into four subscales (Restraint, Eating Concerns, Shape Concerns, Weight Concerns). EDE-Q is one of the best-established and most widely used measures of eating psychopathology. However, there are several problems with the questionnaire, including that it is too lengthy to be used for practical screening purposes, not capturing all eating disorders, or lacking psychometric properties. Another eating behavior survey commonly used is the Eating Attitudes Test (EAT). The EAT (Garner et al., 1982) focuses on three factors: Dieting, Bulimia and Food Preoccupation, and Oral Control. It is a low-cost and precise screening tool used worldwide due to its validation across multiple clinical and non-clinical subgroups from various backgrounds (Garfinkel & Newman, 2001). However, other studies have noted the low reliability conducted in recent studies from 2005 onward, which might reflect changing attitudes toward food and exercise. There have also been some issues around the factorial structure of the EAT. The original three factor structure established by Garner et al., (1993) has been replicated inconsistently. Some studies have found four factors that differ from Garner's original factor structure that represented multiple theoretical constructs within one dimension (Ocker et al., 2007).

1.7 Problem Statement

Female adolescent collegiate gymnasts continuously struggle to cope with the demands of a high-intensity sport with minimal guidance. The lack of literature on body composition and mental illnesses poses an issue to the overall health and well-being of many female gymnasts. Multiple studies have identified descriptive data for regional and total body composition and bone mineral density measures using DXA of the population, however, there are no studies have examined the relationship between changes in body composition during pre- and post- season training and eating pathology survey inventory. To address this gap in information it is important to conduct research to further understand the physical and mental factors that impact a gymnast's athletic development.

1.8 Study Purpose

The purpose of this study is to describe the relationship between the eight subscales of EPSI related to body dissatisfaction, binge eating, cognitive restraint, purging, restricting, excessive exercise, negative attitudes towards obesity, and muscle building and lean body mass, fat mass, body fat percent, and bone mineral density in collegiate female gymnasts during pre- and post- season training data collection.

1.9 Specific Aims

Specific Aim 1: To assess preseason total body composition, total bone mineral density, and EPSI data of collegiate female gymnasts.

Specific Aim 2: To assess postseason total body composition, total bone mineral density, and EPSI data of collegiate female gymnasts.

Specific Aim 3: To investigate whether there is a change in total body composition, total bone mineral density, and EPSI scores due to pre- and post- season training.

Hypothesis 3: There will be a significant change in body composition, bone mineral density, and EPSI scores from pre- to post- season training.

Specific Aims 4: To investigate the associations among EPSI scores, body fat percentage, lean tissue mass, bone mineral density, and performance scores separately for pre- and post-season.

Hypothesis 4: There will be significant correlation between EPSI scores, body fat percentage, lean tissue, bone mineral density, and performance scores for pre- and post- season.

1.10 Study Significance

Identifying and analyzing Division I female collegiate gymnasts body composition, bone mineral density, and EPSI data pre- and post- season will affect overall health and performance of an athlete during training and competitive sport. Research is warranted to investigate how bone mineral density, body composition variables like bone mass, body fat percentage (BF%), fat-free mass (FM), lean mass (LM), region % fat, tissue %fat, and total mass along with the EPSI self-report questionnaire change over the course of a season. Also, research is needed to examine and further understand injury risk factors as it will guide development of preventative interventions and enhance our current knowledge of evidence-based practice.

2.0 Methods

2.1 Experimental Design

This study used a prospective cohort over the 6-month monitoring period spanning from pre- and post- season. The purpose of this research was to gather data regarding body composition, bone mineral density, and EPSI survey scores in Division I collegiate female gymnasts. Independent Variable

The independent variable in this study was the exposure of high impact training on the division I female collegiate gymnastics team.

2.1.1 Dependent Variables

The dependent variables presented in this study related to body composition; total body weight, height, bone mass, fat-free mass (FM), lean mass (LM), percentage for body fat (BF%), total mass, region % fat, tissue % fat, and bone mineral density (BMD); total BMD, total bone mineral content (BMC), total area, T-score, and Z-score of each individual participant tested. Additionally, the results from the EPSI self-report questionnaire, specifically the sum of the scores for individual items for each scale.

2.2 Subject Recruitment

The population for this study follows that of the ongoing IRB (Institutional Review Board) approved Bone and Body Composition Adaptations to Training (BoBCAT) Study of the Neuromuscular Research Laboratory (NMRL). Participants in the survey were completely optional and participants were free to withdraw from the study at any time. The sample consisted of eighteen female Division 1 collegiate gymnasts on the University of Pittsburgh Women's gymnastics team. The sample size represents the gymnastics team's roster over one season. The athletes were recruited to participate in the present study collecting EPSI survey data and DXA scans to measure bone density and body composition prior to and following their competitive season to assess the influence of sport-specific training on bone health. The University of Pittsburgh Human Research Protection Office (HRPO) approved all experimental protocols. Written informed consent was obtained from each participant prior to the participation in the study. All eligible participants received additional information about the nature, purpose, risks, and benefits, screening procedures and methods were explained to each participant before obtaining written informed consent and receiving a photocopy of the consent document for their own records. After signing written informed consent, all female gymnasts were asked to take a urine pregnancy test for pregnancy status.

2.3 Subject Characteristics

2.3.1 Power Analysis

The research was performed from the available data provided from the BoBCAT study conducted at the NMRL. The study was a convenience sample of nineteen Division I female collegiate gymnasts.

2.3.2 Inclusion Criteria

Subjects were included if they were currently competing on the University of Pittsburgh women’s gymnastics team. The sample size was based on the current size of the collegiate gymnastics team available to conduct the study. All subjects in the control group were between 18-26 and actively participating in gymnastics training and competition season.

2.3.3 Exclusion Criteria

Subjects were excluded if they sustained a concussion injury within the 6 months, free of significant upper/lower extremity injury history, free of pulmonary, cardiovascular, vestibular, vascular condition, neurological condition, psychiatric disease, brain injuries, or pregnant which would affect the study protocol. Subjects must also be non-smokers and free of alcohol consumption during preseason, and competition season. Participants provided written informed consent and completed a pregnancy test before scanning due to radiation from the bone scans.

2.4 Instrumentation

2.4.1 Dual-Energy X-ray Absorptiometry

Total body composition can be measured most accurately using DXA (Shepherd, Ng, Sommer, & Heymsfield, 2017). The DXA test is the gold standard for determining changes in bone mineral density over time and analyzing body composition at a molecular level by measuring fats, lean mass, and bone mineral content (Messina et al., 2020; Morgan & Prater, 2017). DXA is a valid and reliable method of estimating % body fat, fat mass (FM), and lean mass (LM) given that the total error values range from 'good to very good' (Smith-Ryan et al., 2017). There is a range of intra-instrument reliability between 0.7% and 5.2%, with fat tissue phantom scanning demonstrating the lowest coefficients of variation (Smith-Ryan et al., 2017). Inter-instrument variance was attributed to the different scanning speeds, which also affected the intra-instrument reliability ($p < 0.01$) (Smith-Ryan et al., 2017). A Lunar iDXA (General Electric Healthcare., Chicago, IL) is used to perform DXA. The system uses a fan beam X-ray densitometer to measure fat, bone mineral content, bone mineral density, and lean soft-tissue mass using two different energy levels produced by the energy tube. Recent technology has enabled new densometers to assess body composition with a single whole-body scan to reduce radiation exposure (Bazzocchi, Ponti, Albisinni, Battista, & Guglielmi, 2016). A series of complex algorithms are then used by a computer to determine the amount of bone, lean muscle, and fat mass. All scans are analyzed using enCORE Software Version 15 (General Electric Healthcare Lunar). This technique has several advantages including the ability to distinguish fat, lean, and bone tissue, it is quick, noninvasive, requires minimal radiation exposure, and it allows for regional measurements. Its disadvantages include not being portable, its excessive cost, variable calibration procedures, hardware, and software versions from different manufacturers, body thickness and hydration status may affect measurements, is contraindicated during pregnancy, cannot distinguish between visceral, subcutaneous, and intramuscular fats, and requires a specific level of technical and operator skills (Kuriyan, 2018).

2.4.2 Eating Pathology Symptoms Inventory Survey

A self-report survey was given to the subjects as a tool to assess psychopathology of eating disorders pre- and post- season testing. The Eating Pathology Symptoms Inventory (EPSI) questionnaire included questions about the athletes. The EPSI contains eight scales that assess: body dissatisfaction, binge eating, cognitive restraint, purging, excessive exercise, restricting, muscle building, and negative attitude towards obesity (Forbush et al., 2013).

2.5 Procedures

Gymnasts were tested for 3-4 days in September 2021 and April of 2022 at the NMRL for pre- and post-season. Gymnasts were instructed to complete an in-house health, exercise (sport-specific training) sleep, and nutrition history questionnaire during pre- and post-season at the time of their pre- and post-testing visit. In addition, all subjects were instructed to refrain from exercise and heavy meals before testing. At the first visit, informed consent was obtained for all subjects and female athletes were required to take a pregnancy test (due to the radiation from the bone scans) and were excluded if the pregnancy test was positive (n=0). The subjects were then surveyed, and height and weight were recorded.

2.5.1 Dual Energy X-ray Absorptiometry

After subjects received a negative pregnancy status, measurements for height (cm) and weight (kg) were collected for each athlete. Athletes were not permitted to know the values of height and weight. Age, height, weight, sex, and ethnicity were entered into the computer as used to determine indices of body composition. Subjects removed any metal items and other items that may have interfered with the scan. Subjects were instructed to also wear two-piece light-fitted athletic apparel during scanning. All DXA scans were collected on GE Lunar iDXA device and were analyzed using enCORE software. BMD (g/cm^2) was measured for 3 regions: total body (head to toe), lumbar spine, and unilateral hip at pre- and post- season testing. The DXA was calibrated each morning that a study visit was scheduled, using the phantom provided and scans were only performed if the DXA passed calibration. All measurements were performed the same day, within a 30-min period. DXA was performed and analyzed by one technician who had been trained to operate a Lunar DXA scanner. Subjects were instructed to lie down in the center of the DXA table prone. The DXA technician would then verbally cue the subject to readjust if necessary. The standard transverse speed mode of 0.55 cm·s^{-1} took a full body scan 7-10 min period where the subject lies supine in the center of the scanning table with their arms placed palm-down at their sides while the whole body is scanned (enCORE-based X-ray Bone Densitometer User Manual. Published online August 2013). The athlete's feet were loosely secured with a cloth strap with Velcro. The second scan was performed on the non-dominant hip to estimate the aBMD of the femoral neck. For this scan, subjects were asked to "widen their stance" with the left and right leg inwardly rotated using a positioning aid and Velcro straps. The DXA technician would assist in internally rotating the subject's legs to acquire the optimal positioning of the femur as per the manufacture's guidelines and the laser was placed approximately 7-9centimeters below the greater trochanter and roughly in the middle of the thigh, in line with the pubic symphysis. Subjects were asked to cross their arms over their chest and lie still for the entirety of the scan, which took less than 2 minutes to complete. If repositioning of the scan was required, the DXA technician would stop the scan and reposition the scan region to capture the required area for this scan. The lumbar spine scan required subjects to remain in the same position on the DXA table as they had for the hip scan. The subject was asked to place their finger on their navel to allow the DXA technician to place the laser approximately 5 centimeters below that landmark. Subjects were instructed to cross their arms over their chest again and lie still for less than 2 minutes for the final scan. The DXA technician was able to stop and reposition the scanner as necessary so that L1-L4 were fully captured. Additional primary outcome measures were total body weight, total body fat, and lean body mass, grams per square centimeter for bone mineral density, and % BF. All assessments were taken at the NMRL/ Warrior Human Performance Research Center (University of Pittsburgh, U.S.A).

2.5.2 EPSI Collection

Data from 19 female collegiate gymnasts who completed the self-reported EPSI survey once during pre-season September 2021 and post-season April of 2022 were extracted and deidentified. Participants were given an EPSI survey paper version by NMRL researchers and asked to complete it with pen/pencil with no time restriction.

2.6 Data Reduction

2.6.1 DXA Post-processing Procedures

DXA estimated bone mineral mass, lean mass, and fat mass from the differential absorption of X-rays of two different energies using instruments specific algorithms. Manufacturers of DXA systems also included correction algorithms for the effect of body thickness. DXA data is stored in the databases built-in within the DXA systems such as Microsoft Access and SQL. Data was displayed after regions of interest were selected and the analysis was completed. A data extraction tool was set up to access the raw data and reconstructed body composition variables. The raw data included estimates of total body fat mass (g), total bone mineral content (g), total body lean mass (g), and body composition of tissues in specific defined regions. Bone mineral density standard scores are defined using T-score and Z-score. T-score involved calculating and comparing a person's scan with the bone density of a healthy young adult of the same sex. Z-score showed the amount of bone that a person has compared with others of the same size, age, sex, and ethnic origin. Common mistakes that could result in an incorrect interpretation of DXA include failure to recognize the presence of an artifact that invalidates BMD measurements, use of an invalid skeletal site for diagnostic classification, reporting a different diagnosis and fracture risk for each skeletal site and region of interest measured, reporting T-scores when Z-scores should be used, and using an incorrect database for generating T-scores or Z-scores (Lewiecki et al., 2016).

2.6.2 EPSI Processing

EPSI scores for each subscale were tallied and arranged for each participant according to the individual items that corresponded to the 8 subscales (Body Dissatisfaction, Binge Eating, Cognitive Restraint, Purging, Restricting, Excessive Exercise, Negative Attitudes toward Obesity, and Muscle Building).

2.7 Data Analysis

All data was entered into SPSS Version 28.0 (IBM Corporation, Armonk NY, 2022). Alpha was set at $p<0.05$. Descriptive statistics (mean ± sd) were calculated for all data. Each data set was assessed for normality using a Shapiro-Wilks test. For specific aims 1 and 2: descriptive statistics were calculated for all outcome measures during pre- and post- season time points. Specific aim 3 used a paired-samples T-test or comparable nonparametric test to compare body composition, BMD, and EPSI subscale scores at pre- and post- season. Specific aim 4 was calculated using a Pearson or Spearman's correlation coefficient to evaluate the relationship between the EPSI subscale scores with body composition and bone mineral density variables.

3.0 Results

The following chapter presents the results of a study conducted on nineteen female Division I collegiate gymnasts, whose roster represented the sample size over one season. The athletes had an average age of 19.5 years (SD=1.5), an average height of 5 feet 3 inches (SD=0.4), and an average weight of 116.8 pounds (SD=13.7). Their average body mass index was 20.7 (SD=2.2). On average, the athletes had 13.5 years of gymnastics experience (SD=2.5) and spent 28 hours per week (SD=3.5) in sport specific training. The study aimed to assess the influence of sport-specific training on bone health, body composition, and health related behaviors by collecting EPSI survey data and DXA scans to measure multiple variables prior to and following the competitive season. In this chapter, we present general descriptive, comparisons, and correlation statistics of the sample. These statistics provide an overview of the characteristics of the sample and serve as a foundation for the subsequent analyses.

Descriptive statistics for EPSI preseason variables are presented in **Error! Reference source not found.**. The two highest subscales scores for preseason were Body Dissatisfaction with a mean of 13.67± 6.35 and Excessive Eating with a mean of 13.22 ± 4.48. The two lowest subscales were Purging with a mean of 0.33 ± 0.97 and Muscle Building with a mean of 1.83 ± 1.82. The two highest subscales scores for post-season were Body Dissatisfaction with a mean of 14.67 ± 6.59 and Excessive Eating with a mean of 11.39 ± 5.59. The two lowest subscales were Purging with a mean of 0.67 ± 1.50 and Muscle Building with a mean of 1.94 ± 2.78. There were no significant changes observed in any of the eight categories at pre- and at post- season.

Table 1. Descriptive and Comparison Paired t-tests Analysis of Eating Pathology Symptoms Inventory Scores Pre and Post Season 21-22 Data of Division I Female Collegiate Gymnasts

		Pre			Post			
	N	Mean	SD	Median	Mean	SD	Median	Paired t-test
Body Dissatisfaction	18	13.67	6.35	13.00	14.67	6.59	14.00	0.353
Binge Eating	18	9.33	6.43	8.00	8.94	6.61	6.50	1.000
Cognitive Restraint	18	5.44	3.17	5.50	5.72	3.82	5.00	0.154
Purging	18	0.33	0.97	0.00	0.67	1.50	0.00	0.269
Restricting	18	8.33	5.75	6.50	8.44	4.79	8.50	0.704
Excessive Exercise	18	13.22	4.48	13.50	11.39	5.59	12.50	0.094
Negative Attitude towards Obesity	18	3.17	4.93	1.00	3.17	4.67	1.50	0.188
Muscle Building	18	1.83	1.82	1.00	1.94	2.78	2.00	0.753
Composite EPSI Score		55.33	23.18	48.50	49.45	29.56	47.00	0.689

Descriptive statistics for BMD preseason variables are presented in Table 2. There was a significant decrease in BMC from preseason 2666.10 ± 33163 to postseason 2615.56 ± 381.98, $p<0.05$. Total area had a significant decrease for preseason 2063.78 ± 149.57 and postseason 2057.19 ± 182.84, $p<0.05$. There were no significant associations in any other variables of the participants' BMD over the course of the season.

Table 2. Descriptive and Comparison Paired t-tests Analysis of Bone Mineral Density Pre and Post Season 21-22 Data of Division I Female Collegiate Gymnasts

	N	Mean	SD	Median	N	Mean	SD	Median	Paired t-test
Total BMD (g/cm^2)	19	1.28	0.09	1.31	16	1.27	0.10	1.29	0.795
Total BMC (g)	19	2666.10	331.63	2698.00	16	2615.56	381.98	2634.00	<.001
Total Area (cm^2)	19	2063.78	149.57	2056.00	16	2057.19	182.84	2088.00	<.001
T-Score	19	2.06	0.97	2.30	16	1.84	0.97	2.10	0.597
Z-Score	19	1.73	0.96	1.80	16	1.97	0.93	2.00	0.906

Note: BMD – Bone Mineral Density, BMC – Bone Mineral Content

The results from the analysis of change in body composition variables scores over the course of a season are displayed in **Error! Reference source not found.**. No significant associations in any of the participant's body composition over the course of the season.

Table 3. Descriptive and Comparison Paired t-tests Analysis Body Composition Pre and Post Season 21-22 Data of Division I Female Collegiate Gymnasts

	N	Mean	SD	Median	N	Mean	SD	Median	Paired t-test
Weight at Exam (kg)	19	61.09	6.13	62.00	15	60.04	7.36	60.61	0.959
Height at Exam (cm)	19	161.80	6.02	162.56	15	162.60	6.53	163.83	0.353
Total Bone Mass (g)	19	2666.11	331.64	2698.00	15	2667.73	331.17	2645.00	0.937
Total Fat Mass (g)	19	13444.68	3787.52	13050.00	15	13095.87	4060.75	13174.00	0.835
Total Lean Mass (g)	19	45263.84	4674.40	45586.00	15	43998.53	5036.65	44277.00	0.704
Total Fat-Free Mass (g)	19	47929.89	4973.89	48312.00	15	46666.40	5333.19	46858.00	0.723
Total Mass (kg)	19	61.38	6.28	63.10	15	59.76	6.45	60.80	0.842
Total Region % Fat	19	21.78	5.18	21.60	15	21.79	5.92	21.60	0.761
Total Tissue % Fat	19	22.79	5.36	22.60	15	22.79	6.10	22.60	0.762

Results from the correlation between pre- and post- EPSI Body Dissatisfaction and BC/BMD over the course of a season are displayed in **Error! Reference source not found.**. There was a statistically significant negative correlation between EPSI Body dissatisfaction and total tissue % fat (-0.486, p=0.048), total region % fat (-0.490, p=0.046), and total fat mass (-0.496, p=0.043) in preseason. No other significant associations involving the other variables over the course of the season.

Table 4. Correlation between Pre- and Post- EPSI Body Dissatisfaction and Body Composition/Bone Mineral Density Data in Division I Female Collegiate Gymnasts

EPSI Body Dissatisfaction	Pre	Pearson		Post	Pearson	
	N	Correlation	P-value	N	Correlation	P-value
Total BMD (g/cm^2)	17	0.176	0.498	13	0.109	0.723
Total BMC (g)	17	0.200	0.442	13	0.106	0.731
Total Area (cm^2)	17	0.185	0.477	13	0.071	0.818
T-Score	17	0.175	0.502	13	0.096	0.756
Z-score	17	0.303	0.238	13	0.225	0.460
Total Tissue % Fat	17	-0.486	0.048	13	0.154	0.617
Total Region % Fat	17	-0.490	0.046	13	0.154	0.615
Height (cm)	17	0.021	0.936	13	-0.302	0.293
Weight (kg)	17	-0.192	0.461	13	0.178	0.561
Total Bone Mass (g)	17	0.200	0.441	13	-0.166	0.587
Total Fat Mass (g)	17	-0.496	0.043	13	0.218	0.475
Total Lean Mass (g)	17	0.114	0.663	13	-0.025	0.934
Total Fat-Free Mass (g)	17	0.121	0.645	13	-0.035	0.910
Total Mass (g)	17	-0.192	0.461	13	0.108	0.725

Results from the correlation between pre- and post- EPSI Binge Eating and BC/BMD over the course of a season are displayed in **Error! Reference source not found.**. There was a statistically significant positive correlation between EPSI Binge Eating and total BMD (0.518, p=0.033) at preseason and positive correlation with T-score (-0.519, p=0.033) at preseason. No other significant associations involving the other variables over the course of the season.

Table 5. Correlation between Pre- and Post-Season EPSI Binge Eating and Body Composition/Bone Mineral Density Data in Division I Female Collegiate Gymnasts

EPSI Binge Eating	Pre	Pearson		Post	Pearson	
	N	Correlation	P-value	N	Correlation	P-value
Total BMD (g/cm^2)	17	0.518	0.033	13	0.301	0.318
Total BMC (g)	17	0.342	0.178	13	0.275	0.363
Total Area (cm^2)	17	0.130	0.620	13	0.236	0.438
T-Score	17	0.519	0.033	13	0.303	0.314
Total Z-Score	17	0.606	0.010	13	0.341	0.254
Height (cm)	17	0.099	0.706	13	-0.124	0.672
Weight (kg)	17	-0.012	0.965	13	0.315	0.295
Total Tissue % Fat	17	-0.436	0.080	13	0.456	0.117
Total Region % Fat	17	-0.440	0.077	13	0.449	0.123
Total Bone Mass (g)	17	0.342	0.180	13	-0.034	0.913
Total Fat Mass (g)	17	-0.331	0.195	13	0.463	0.111
Total Lean Mass (g)	17	0.192	0.460	13	-0.07	0.820
Total Fat-Free Mass (g)	17	0.203	0.434	13	-0.068	0.826
Total Mass (g)	17	-0.027	0.919	13	0.236	0.438

Results from the correlation between pre- and post- EPSI Cognitive Restraint and BC/BMD over the course of a season are displayed in Table 6. No other significant associations involving the other variables over the course of the season.

Table 6. Correlation between Pre- and Post- Season EPSI Cognitive Restraint and Body Composition/Bone Mineral Density Data in Division I Female Collegiate Gymnasts

EPSI Cognitive Restraint	Pre	Pearson		Post	Pearson	
	N	Correlation	P-value	N	Correlation	P-value
Total BMD (g/cm^2)	17	0.256	0.322	13	-0.033	0.914
Total BMC (g)	17	0.245	0.344	13	0.200	0.513
Total Area (cm^2)	17	0.177	0.498	13	0.357	0.232
Total T-Score	17	0.259	0.316	13	-0.051	0.867
Total Z-Score	17	0.425	0.089	13	0.012	0.970
Height (cm)	17	-0.031	0.907	13	-0.222	0.445
Weight (kg)	17	-0.089	0.734	13	0.188	0.539
Total Tissue % Fat	17	-0.273	0.289	13	0.212	0.487
Total Region % Fat	17	-0.278	0.281	13	0.212	0.486
Total Bone Mass (g)	17	0.247	0.338	13	-0.215	0.480
Total Fat Mass (g)	17	-0.272	0.291	13	0.256	0.399
Total Lean Mass (g)	17	0.025	0.925	13	-0.065	0.832
Total Fat-Free Mass (g)	17	0.040	0.880	13	-0.075	0.807
Total Mass (g)	17	-0.127	0.627	13	0.099	0.748

Results from the correlation between pre- and post- EPSI Purging and BC/BMD over the course of a season are displayed in Table 7. No other significant associations involving the other variables over the course of the season.

Table 7. Correlation between Pre- and Post-Season EPSI Purging and Body Composition/Bone Mineral Density Data in Division I Female Collegiate Gymnasts

EPSI Purging	Pre	Pearson		Post	Pearson	
	N	Correlation	P-value	N	Correlation	P-value
Total BMD (g/cm^2)	17	0.128	0.623	13	-0.021	0.945
Total BMC (g)	17	0.056	0.831	13	0.076	0.805
Total Area (cm^2)	17	-0.017	0.948	13	0.161	0.599
Total T-Score	17	0.121	0.645	13	-0.018	0.954
Total Z-Score	17	0.172	0.510	13	-0.079	0.798
Height (cm)	17	-0.087	0.741	13	-0.082	0.781
Weight (kg)	17	0.014	0.958	13	0.08	0.794
Total Tissue % Fat	17	-0.017	0.949	13	0.15	0.625
Total Region % Fat	17	-0.018	0.947	13	0.145	0.636
Total Bone Mass (g)	17	0.057	0.829	13	-0.011	0.972
Total Fat Mass (g)	17	-0.02	0.939	13	0.17	0.578
Total Lean Mass (g)	17	0.013	0.961	13	0.022	0.942
Total Fat-Free Mass (g)	17	0.016	0.952	13	0.02	0.947
Total Mass (g)	17	0.002	0.994	13	0.124	0.687

Results from the correlation between pre- and post- EPSI Restricting and BC/BMD over the course of a season are displayed in Table 8. No other significant associations involving the other variables over the course of the season.

Table 8. Correlation between Pre- and Post- Season EPSI Restricting and Body Composition/Bone Mineral Density Data in Division I Female Collegiate Gymnasts

EPSI Restricting	Pre	Pearson		Post	Pearson	
	N	Correlation	P-value	N	Correlation	P-value
Total BMD (g/cm^2)	17	0.221	0.393	13	0.280	0.355
Total BMC (g)	17	0.041	0.875	13	0.348	0.244
Total Area (cm^2)	17	-0.193	0.459	13	0.364	0.221
Total T-Score	17	0.223	0.390	13	0.275	0.363
Total Z-Score	17	0.327	0.201	13	0.298	0.322
Height (cm)	17	-0.224	0.386	13	-0.184	0.529
Weight (kg)	17	-0.043	0.868	13	0.155	0.613
Total Tissue % Fat	17	0.312	0.223	13	0.059	0.848
Total Region % Fat	17	0.307	0.231	13	0.055	0.858
Total Bone Mass (g)	17	0.043	0.869	13	0.095	0.757
Total Fat Mass (g)	17	0.219	0.397	13	0.183	0.550
Total Lean Mass (g)	17	-0.232	0.371	13	0.146	0.633
Total Fat-Free Mass (g)	17	-0.215	0.408	13	0.143	0.640
Total Mass (g)	17	-0.046	0.862	13	0.233	0.443

Results from the correlation between pre- and post- EPSI Excessive Eating and BC/BMD over the course of a season are displayed in Table 9. No other significant associations involving the other variables over the course of the season.

Table 9. Correlation between Pre- and Post-Season EPSI Excessive Eating and Body Composition/Bone Mineral Density Data in Division I Female Collegiate Gymnasts

EPSI Excessive Eating	Pre	Pearson		Post	Pearson	
	N	Correlation	P-value	N	Correlation	P-value
Total BMD (g/cm^2)	17	0.228	0.378	13	0.177	0.563
Total BMC (g)	17	0.238	0.357	13	0.207	0.498
Total Area (cm^2)	17	0.209	0.422	13	0.17	0.579
Total T-Score	17	0.235	0.364	13	0.163	0.595
Total Z-Score	17	0.470	0.057	13	0.330	0.271
Height (cm)	17	0.013	0.960	13	0.022	0.940
Weight (kg)	17	-0.181	0.488	13	0.312	0.299
Total Region % Fat	17	-0.285	0.268	13	-0.015	0.960
Total Tissue % Fat	17	-0.277	0.283	13	-0.013	0.966
Total Bone Mass (g)	17	0.243	0.348	13	0.08	0.796
Total Fat Mass (g)	17	-0.297	0.248	13	0.119	0.699
Total Lean Mass (g)	17	0.001	0.996	13	0.186	0.542
Total Fat-Free Mass (g)	17	0.017	0.948	13	0.18	0.556
Total Mass (g)	17	-0.159	0.543	13	0.222	0.466

Results from the correlation between pre- and post- EPSI Negative Attitude towards Obesity and BC/BMD over the course of a season are displayed in Table 10. No other significant associations involving the other variables over the course of the season.

Table 10. Correlation between Pre- and Post-Season EPSI Negative Attitude towards Obesity and Body Composition/Bone Mineral Density Data in Division I Female Collegiate Gymnasts

EPSI Negative Attitude towards Obesity	Pre	Pearson		Post	Pearson	
	N	Correlation	P-value	N	Correlation	P-value
Total BMD (g/cm^2)	17	0.348	0.171	13	0.183	0.549
Total BMC (g)	17	0.320	0.211	13	0.153	0.617
Total Area (cm^2)	17	0.228	0.379	13	0.101	0.742
Total T-Score	17	0.345	0.175	13	0.180	0.555
Total Z-Score	17	0.443	0.075	13	0.313	0.298
Height (cm)	17	0.226	0.383	13	-0.357	0.210
Weight (kg)	17	-0.037	0.888	13	-0.142	0.643
Total Tissue % Fat	17	-0.300	0.243	13	-0.100	0.744
Total Region % Fat	17	-0.306	0.233	13	-0.099	0.748
Total Bone Mass (g)	17	0.320	0.211	13	-0.150	0.625
Total Fat Mass (g)	17	-0.257	0.320	13	-0.091	0.766
Total Lean Mass (g)	17	0.097	0.712	13	-0.108	0.726
Total Fat-Free Mass (g)	17	0.112	0.669	13	-0.111	0.718
Total Mass (g)	17	-0.057	0.828	13	-0.146	0.635

Results from the correlation between pre- and post- EPSI Muscle Building and BC/BMD over the course of a season are displayed in Table 11. There were significant associations involving a negative correlation between EPSI Muscle Building and height (-0.657, p=0.011), total lean mass (-0.585, p=0.036), and total fat-free mass (-0.582, p=0.037) in post season.

Table 11. Correlation between Pre- and Post-Season EPSI Muscle Building and Body Composition/Bone Mineral Density Data in Division I Female Collegiate Gymnasts

EPSI Muscle Building	Pre	Pearson		Post	Pearson	
	N	Correlation	P-value	N	Correlation	P-value
Total BMD (g/cm^2)	17	0.137	0.600	13	0.073	0.814
Total BMC (g)	17	0.080	0.759	13	0.169	0.582
Total Area (cm^2)	17	-0.002	0.993	13	0.242	0.425
Total T-Score	17	0.134	0.608	13	0.074	0.809
Total Z-Score	17	0.288	0.262	13	0.020	0.948
Height (cm)	17	-0.028	0.914	15	-0.657	0.011
Weight (kg)	17	-0.055	0.833	15	-0.497	0.084
Total Tissue % Fat	17	-0.105	0.688	15	0.098	0.749
Total Region % Fat	17	-0.109	0.678	15	0.100	0.746
Total Bone Mass (g)	17	0.084	0.749	15	-0.518	0.070
Total Fat Mass (g)	17	-0.132	0.614	15	-0.101	0.742
Total Lean Mass (g)	17	0.033	0.899	15	-0.585	0.036
Total Fat-Free Mass (g)	17	0.037	0.888	15	-0.582	0.037
Total Mass (g)	17	-0.044	0.867	15	-0.537	0.058

Results from the correlation between pre- and post- BMD and BC are displayed in Table 12. There were significant associations involving a positive correlation between BMD and height (0.639, p=0.003), weight (-0.713, p<0.001), and total bone mass (0.874, p<0.001), total lean mass (0.706, p<0.001), total fat-free mass (0.722, p< 0.001), and total mass (0.729, p<0.001) in pre-season. No other significant associations involving the other variables over the course of the season.

Table 12. Correlation between Pre- and Post-Season Bone Mineral Density and Body Composition Data in Division I Female Collegiate Gymnasts

	Pre	Pearson		Post	Pearson	
Total BMD (g/cm^2)	N	Correlation	P-Value	N	Correlation	P-Value
Total Tissue %Fat	19	-0.065	0.792	10	0.16	0.665
Total Region %Fat	19	-0.073	0.765	10	0.16	0.667
Height at Exam (cm)	19	0.639	0.003	10	-0.34	0.309
Weight at Exam (kg)	19	0.713	<.001	10	-0.24	0.513
Total Bone Mass (g)	19	0.874	<.001	10	-0.21	0.517
Total Fat Mass (g)	19	0.262	0.279	10	0.08	0.827
Total Lean Mass (g)	19	0.706	<.001	10	-0.39	0.270
Total Fat-Free Mass (g)	19	0.722	<.001	10	-0.38	0.281
Total Mass (g)	19	0.729	<.001	10	-0.29	0.411

Results from the correlation between pre- and post- BMC and BC are displayed in Table 13. There were significant associations involving a positive correlation between BMC and height (0.864, p<0.001), weight (0.747, p<0.001), total bone mass (1.000, p<0.001), total lean mass (0.898, p<0.001), total fat-free mass (0.910, p<0.001), and total mass (0.751, p<0.001) in pre-season season. No other significant associations involving the other variables over the course of the season.

Table 13. Correlation between Pre- and Post-Season Bone Mineral Content and Body Composition Data in Division I Female Collegiate Gymnasts

	Pre	Pearson		Post	Pearson	
BMC (g)	N	Correlation	P-Value	N	Correlation	P-Value
Total Tissue %Fat	19	-0.313	0.192	10	0.276	0.440
Total Region %Fat	19	-0.323	0.178	10	0.271	0.449
Height at Exam (cm)	19	0.864	<.001	10	-0.456	0.159
Weight at Exam (kg)	19	0.747	<.001	10	-0.290	0.416
Total Bone Mass (g)	19	1.000	<.001	10	-0.370	0.293
Total Fat Mass (g)	19	0.051	0.836	10	0.136	0.708
Total Lean Mass (g)	19	0.898	<.001	10	-0.440	0.203
Total Fat-Free Mass (g)	19	0.910	<.001	10	-0.438	0.205
Total Mass (g)	19	0.751	<.001	10	-0.318	0.371

Results from the correlation between pre- and post- total area and BC are displayed in Table 14. There were significant associations involving a negative correlation between total area and total tissue % fat (-0.500, p=0.029) and total region % fat (-0.508, p=0.026) in preseason. There were significant associations involving a positive correlation between total area and height (0.865, p<0.001), weight (0.604, p<0.006), total bone mass (0.870, p<0.001), total lean mass (0.882, p<0.001), total fat-free mass (0.887, p<0.001), and total mass (0.596, p=0.007) in preseason. No other significant associations involving the other variables over the course of the season.

Table 14. Correlation between Pre- and Post-Season Total Area of bone and Body Composition Data in Division I Female Collegiate Gymnasts

	Pre	Pearson		Post	Pearson	
Total Area (cm^2)	N	Correlation	P-Value	N	Correlation	P-Value
Total Tissue %Fat	19	-0.500	0.029*	10	0.340	0.337
Total Region %Fat	19	-0.508	0.026*	10	0.337	0.342
Height at Exam (cm)	19	0.865	<.001*	11	-0.493	0.123
Weight at Exam (kg)	19	0.604	0.006*	10	-0.275	0.442
Total Bone Mass (g)	19	0.870	<.001*	10	-0.460	0.181
Total Fat Mass (g)	19	-0.177	0.470	10	0.176	0.627
Total Lean Mass (g)	19	0.882	<.001*	10	-0.405	0.246
Total Fat-Free Mass (g)	19	0.887	<.001*	10	-0.410	0.239
Total Mass (g)	19	0.596	0.007*	10	-0.273	0.446

Results from the correlation between pre- and post- season T-score and BC are displayed in Table 15. There were significant associations involving a positive correlation between T-score and height (0.635, p=0.003), weight (0.711, p<0.001), total bone mass (0.874, p<0.001), total lean mass (0.704, p<0.001), total fat-free mass (0.720, p<0.001), and total mass (0.728, p<0.001) in pre-season. No other significant associations involving the other variables over the course of the season.

Table 15. Correlation between Pre- and Post-Season T-Score of BMD and Body Composition Data in Division I Female Collegiate Gymnasts

	Pre	Pearson		Post	Pearson	
T-Score	N	Correlation	P-Value	N	Correlation	P-Value
Total Tissue %Fat	19	-0.062	0.800	10	0.162	0.656
Total Region %Fat	19	-0.071	0.772	10	0.156	0.667
Height at Exam (cm)	19	0.635	0.003*	10	-0.340	0.306
Weight at Exam (kg)	19	0.711	<.001*	10	-0.242	0.500
Total Bone Mass (g)	19	0.874	<.001*	10	-0.210	0.560
Total Fat Mass (g)	19	0.262	0.278	10	0.076	0.834
Total Lean Mass (g)	19	0.704	<.001*	10	-0.390	0.266
Total Fat-Free Mass (g)	19	0.720	<.001*	10	-0.381	0.277
Total Mass (g)	19	0.728	<.001*	10	-0.298	0.403

Results from the correlation between pre- and post- season z-score and BC are displayed in Table 16. There were significant associations involving a negative correlation between total height (-0.524, p=0.021), and a positive correlation with weight (0.565, p=0.012), total bone mass (0.754, p<0.001), total lean mass (0.529, p=0.020), and total fat-free mass (0.547, p=0.015), and total mass (0.592, p=0.008) in preseason.

Table 16. Correlation between Pre- and Post-Season Z-Score of BMD and Body Composition Data in Division I Female Collegiate Gymnasts

	Pre	Pearson		Post	Pearson	
Total Z-score	N	Correlation	P-Value	N	Correlation	P-Value
Total Tissue %Fat	19	0.026	0.917	10	0.170	0.639
Total Region %Fat	19	0.016	0.949	10	0.164	0.651
Height at Exam (cm)	19	0.524	0.021*	10	-0.285	0.396
Weight at Exam (kg)	19	0.565	0.012*	10	-0.103	0.778
Total Bone Mass (g)	19	0.754	<0.001	10	-0.092	0.801
Total Fat Mass (g)	19	0.264	0.276	10	0.148	0.684
Total Lean Mass (g)	19	0.529	0.020*	10	-0.311	0.381
Total Fat-Free Mass (g)	19	0.547	0.015*	10	-0.300	0.400
Total Mass (g)	19	0.592	0.008*	10	-0.190	0.599

Results from the correlation between pre- and post- season scores for bars and BC & BMC are displayed in Table 17. No other significant associations involving the other variables over the course of the season.

Table 17. Correlation between Post-season championship meet scores for bars and BC & BMC variables

	Bars	Pearson	
	N	Correlation	P-value
Total Tissue %Fat	11	-0.099	0.771
Total Region %Fat	11	-0.095	0.781
Height at Exam (cm)	11	-0.436	0.180
Weight at Exam (kg)	11	-0.408	0.213
Total Bone Mass (g)	11	-0.340	0.306
Total Fat Mass (g)	11	-0.270	0.422
Total Lean Mass (g)	11	-0.278	0.408
Total Fat-Free Mass (g)	11	-0.284	0.398
Total Mass (g)	11	-0.398	0.225
Total BMD (g/cm^2)	7	-0.020	0.967
Total BMC (g)	7	0.140	0.765
Total Area (cm^2)	7	0.322	0.481
T-score	7	-0.007	0.989
Z-score	7	-0.095	0.840

Results from the correlation between pre- and post- season scores for beam and BC & BMC are displayed in Table 18. No other significant associations involving the other variables over the course of the season.

Table 18. Correlation between Post-season championship meet scores for Beam and BC & BMC variables

	Beam	Pearson	
	N	Correlation	P-value
Total Tissue %Fat	12	-0.149	0.643
Total Region %Fat	12	-0.154	0.634
Height at Exam (cm)	12	0.479	0.115
Weight at Exam (kg)	12	0.341	0.278
Total Bone Mass (g)	12	0.329	0.296
Total Fat Mass (g)	12	0.002	0.994
Total Lean Mass (g)	12	0.420	0.174
Total Fat-Free Mass (g)	12	0.418	0.176
Total Mass (g)	12	0.327	0.300
Total BMD (g/cm^2)	8	-0.256	0.540
Total BMC (g)	8	-0.068	0.872
Total Area (cm^2)	8	0.313	0.450
T-score	8	-0.261	0.532
Z-score	8	-0.197	0.641

Results from the correlation between pre- and post- season scores for vault and BC & BMC are displayed in Table 19. No other significant associations involving the other variables over the course of the season.

Table 19. Correlation between Post-season championship meet scores for vault and BC & BMC variables

	Vault	Pearson	
	N	Correlation	P-value
Total Tissue %Fat	12	-0.505	0.094
Total Region %Fat	12	-0.509	0.091
Height at Exam (cm)	12	-0.009	0.978
Weight at Exam (kg)	12	-0.474	0.120
Total Bone Mass (g)	12	0.259	0.416
Total Fat Mass (g)	12	-0.550	0.064
Total Lean Mass (g)	12	0.128	0.691
Total Fat-Free Mass (g)	12	0.137	0.670
Total Mass (g)	12	-0.249	0.435
Total BMD (g/cm^2)	8	-0.085	0.842
Total BMC (g)	8	0.214	0.610
Total Area (cm^2)	8	0.550	0.158
T-score	8	-0.063	0.883
Z-score	8	-0.273	0.512

Results from the correlation between pre- and post- season scores for floor and BC & BMC are displayed in Table 20. No other significant associations involving the other variables over the course of the season.

Table 20. Correlation between Post-season championship meet scores for floor and BC & BMC variables

	Floor	Pearson	
	N	Correlation	P-value
Total Tissue %Fat	12	-0.005	0.987
Total Region %Fat	12	-0.005	0.988
Height at Exam (cm)	12	0.002	0.994
Weight at Exam (kg)	12	0.075	0.817
Total Bone Mass (g)	12	-0.054	0.866
Total Fat Mass (g)	12	0.013	0.967
Total Lean Mass (g)	12	0.045	0.889
Total Fat-Free Mass (g)	12	0.039	0.903
Total Mass (g)	12	0.039	0.903
Total BMD (g/cm^2)	8	-0.201	0.633
Total BMC (g)	8	-0.149	0.725
Total Area (cm^2)	8	0.059	0.890
T-score	8	-0.208	0.621
Z-score	8	-0.059	0.890

Results from the correlation between pre- and post- season scores for all events (bars, beam, floor, vault) are displayed in Table 21. There were significant associaitons involving a negative correlation between bar scores and EPSI restricting subscale (-0.671, p=0.048), beam scores and EPSI subscale cognitive restraint (0.760, p=0.011), floor and EPSI excessive exercise (0.830, p=0.003). No other significant associaitons involving the other variables over the course of the season.

Table 21. Correlation between EPSI scores post-season and meet scores

	Bars	Pearson		Beam	Person		Floor	Pearson		Vault	Pearson	
	N	Correlation	P-value	N	Correlation	P-value	N	Correlation	P-value	N	Correlations	P-value
Body Dissatisfaction	9	-0.451	0.223	10	0.514	0.128	10	0.074	0.839	10	-0.359	0.308
Binge Eating	9	-0.562	0.115	10	0.432	0.212	10	0.215	0.550	10	-0.309	0.385
Cognitive Restraint	9	-0.042	0.915	10	0.760	0.011	10	0.513	0.129	10	-0.384	0.273
Purging	9	-0.502	0.168	10	0.438	0.205	10	0.201	0.577	10	0.204	0.573
Restricting	9	-0.671	0.048	10	0.380	0.279	10	0.327	0.357	10	0.315	0.375
Excessive Exercise	9	-0.054	0.889	10	0.830	0.003	10	0.332	0.348	10	-0.424	0.223
Negative Attitudes toward Obesity	9	0.343	0.366	10	0.340	0.336	10	0.480	0.160	10	0.051	0.888
Muscle Building	9	0.411	0.271	10	0.042	0.909	10	-0.311	0.382	10	0.131	0.719

4.0 Discussion

The objective of the study was to examine the relationship between the eight subscales of EPSI with body composition and bone mineral density in Division I collegiate female gymnasts before and after their season. The study aimed to achieve four specific objectives. The first was to evaluate the preseason body composition, bone mineral density, and EPSI data of collegiate female gymnasts. The second was to evaluate the postseason body composition, bone mineral density, and EPSI data of collegiate female gymnasts. The third was to investigate whether there is a significant change in body composition, bone mineral density, and EPSI scores between pre- and post- season. The fourth was to explore the correlation between EPSI scores, body composition, bone mineral density, and performance scores for pre- and post-season. It was hypothesized that there would be a significant change in body composition, bone mineral density, EPSI scores, and performance scores due to pre- and post- season Additionally, it was predicted that there would be a significant relationship between EPSI scores, body composition, bone mineral density variables, and performance scores for both pre- and post- season.

4.1 Descriptive and Paired t-test Pre- and Post- season EPSI data

The findings revealed that the two highest scoring subscales were Body Dissatisfaction and Excessive Eating, while the two lowest subscale scores were Purging and Muscle Building for both pre- and post- season. The EPSI questionnaire uses a 5-point Likert scale ranging from 0 to 4, with 0 indicating “never” and 4 indicating “very often”. Therefore, in the study, when referring to high and low subscales, the highest and lowest average Likert scale scores, respectively, ranging from 0 to 4. These results of this study provide additional evidence to support the claim that female athletes are more prone to body dissatisfaction and excessive eating, regardless of whether they are in pre- or post- season. These findings agree with previous literature that has identified gymnastics as a sport with a high prevalence of disorder eating and body dissatisfaction (Galli et al., 2020; Joy et al, 2016). It has been suggested that the focus on aesthetics and weight in gymnastics may contribute to the development of disordered eating (Galli et al., 2020). Numerous studies have investigated the likelihood of female athletes developing eating disorders using EPSI as a useful tool for identifying these issues. One study conducted by Smolak, L., & Murnen, S.K (2002) found that female athletes had higher levels of body dissatisfaction and disordered eating scoring on EPSI than female non-athletes. Additionally, Sundgot-Borgen, J., & Torstveit, M.K. (2010) discovered that female athletes had a significantly higher prevalence of eating disorders than the general population. Specifically, Norwegian elite female athletes had higher scores on the proposed eating disorder screening method for bulimia, drive for thinness, and body dissatisfaction (Sundgot-Borgen & Torstveit, 2010). These findings suggested that female athletes were at higher risks for developing eating disorders than non-athletes. Furthermore, additional studies that have used EPSI scores in other populations have found associations between EPSI scores and other variables, such as depression, anxiety, body dissatisfaction, and low self-esteem (Mangweth-Matzek et al., 2006; Mitrofanova et al., 2020). One study involving female college students found that higher EPSI scores were associated with greater levels of depression and anxiety (Caldwell et al., 2010). Another study conducted amongst adolescent girls found that higher EPSI scores were associated with lower self-esteem and greater body dissatisfaction (Sonneville et al., 2015). These findings suggest that EPSI can be a useful tool for assessing eating pathology and related variables in various populations.

The results of this study indicated that female collegiate gymnasts are also susceptible to experiencing body image issues and eating disorders. One possible explanation for these results is the pervasive emphasis on physical appearance and weight within the sport of gymnastics. The sport places a significant emphasis on leanness, which can create pressure on athletes to maintain a low body weight, even if it is not healthy or sustainable. This pressure can lead to the development of disordered eating behaviors, such as restrictive eating or binge eating (Park et al., 2021). Another contributing factor may be the culture of perfectionism within gymnastics. Gymnasts are expected to perform flawlessly and achieve perfect scores, which can create a high level of stress and anxiety. This pressure to perform can lead to body dissatisfaction and the development of disordered eating behaviors to cope with the stress. Additionally, the demands of the sport, such as frequent long training hours, and high levels of physical exertion, can also contribute to body dissatisfaction and disordered eating (Park et al., 2021). These demands can make it difficult for gymnasts to maintain a healthy relationship with food and their bodies, leading to the development of negative attitudes and behaviors around eating. It is important to note that these findings do not suggest that all female gymnasts experience body dissatisfaction and disorder eating behaviors. Rather, the study highlights the need for increased awareness and support for those who may be struggling with these issues.

Furthermore, research has demonstrated that athletes who engage in high intensity sports such as gymnastics are more likely to experience body dissatisfaction and engage in unhealthy weight control behaviors (Joy et al., 2016). However, the findings that the lowest subscale scores were Purging and Muscle Building is unexpected as purging and muscle building behaviors are relevant among these athletes. One possible explanation for these results is that the focus on muscle building and strength training in gymnastics may lead athletes to view these behaviors as a necessary part of their sport rather than as disordered behaviors. Muscle building and strength training alone are not considered disordered behaviors (Gill, 2017). However, when taken to the extreme or pursued in an unhealthy manner, they can become part of a larger pattern of disordered behavior. For example, individuals with body dysmorphic disorder or eating disorders may engage in excessive muscle building or strength training as a means of achieving an idealized body image or compensating for disordered eating behaviors (American Psychiatric Association, 2013), which can lead to over-exercising, injuries, and other health complications. Similarly, some individuals with muscle dysmorphia, may engage in compulsive muscle building to achieve a particular body type or compensate for feelings of inadequacy (Philips et al., 2004). This can lead to over-exercising and the misuse of supplements or steroids, which can have negative health consequences. Additionally, muscle building supplements, such as creatine, are often marked as safe and effective for increasing muscle mass and strength. However, the long-term effects of these supplements are not fully understood. Some studies have suggested that they may have negative effects on the liver, kidneys, and cardiovascular system (Kreider et al., 2017). Moreover, the misuse of anabolic steroids, which are synthetic variations of male hormone testosterone can have serious health consequences, including liver damage, cardiovascular disease, and psychological effects such as mood swings and aggression (National Institute on Drug Abuse, 2018). Therefore, while muscle building and strength training can be health behaviors when pursued in moderation, they can become part of a larger pattern of disordered behavior when taken to the extreme or pursued in an unhealthy manner.

The low scores on purging may be due to an emphasis on maintain a consistent weight throughout the season, rather than engaging in purging behaviors that may lead to weight fluctuations. Also, it is possible that some athletes engaged in these behaviors but did not view them as problematic or did not consider them to be part of the purging or muscle building categories, leading to lower scores on these items. In this study, these two of the subscales on the EPSI survey assessed behaviors related to disordered eating and body image concerns. The purging subscale includes questions related to laxatives, diuretics, and vomiting to control weight, while muscle building subscale includes questions related to the use of supplements, steroids, and other performance-enhancing drugs to increase muscle mass. It is possible that the athletes in this study did not score high on these subscales because they did not engage in these types of behaviors. Additionally, these behaviors are often discouraged in collegiate sports due to their negative impact on health and athletic performance.

Based on the results from table 1, it appears that hypothesis 3 is not supported by the data. The study found no significant changes in any of the eight categories. The lack of significant change could be attributed to the sample size of gymnasts in this study had relatively stable levels of disordered eating behaviors over the course of the season. It is also possible that these athletes had established coping mechanisms and support systems that allowed them to maintain consistent levels of these behaviors throughout the season. The findings suggest that the risks associated with disordered eating, such as nutritional deficiencies, dehydration, bone health issues, negative impacts on mental health, and decreased athletic performance, highlights the need for ongoing support and intervention. Future research should explore potential interventions and support systems to help female collegiate gymnasts maintain a healthy relationship with their bodies and food.

4.2 Descriptive and Paired t-test Pre- and Post- season Bone Mineral Density data

The results of this study do not support the hypothesis that there would be a significant change in BMD variables from pre- to post- season. The results showed there was no significant improvement of bone mineral density due to a combination of training intensity, nutritional intake, hormonal changes, injury status, sleep and recovery, and psychological stress tested at pre- and post- season training. The data showed a significant decrease in BMC and total area during the season, indicating a decrease in bone mass, which is inconsistent with previous literature on gymnasts. A study by Zanker et al. (2018) reported the normative data values for total BMD, total BMC, total bone area, T-score, and Z-score of female collegiate gymnasts compared to nonathletes. The findings showed that female collegiate gymnasts had a total BMC of 2463.3 ±396.8g compared to 2106.1 ± 250.4g for nonathletes. The mean total BMD for gymnasts was 1.26 ± 0.08g/cm^2 compared to 1.18 ± 0.06g/cm^2 for nonathletes. The mean total bone area for gymnasts was 1939.2 ± 192.4cm^2 compared to 1744.4 ± 150.1cm^2 for nonathletes. The mean t-score for gymnasts was -0.47 ± 0.85 compared to -1.05 ± 1.01 for nonathletes, and the mean z-score for gymnasts was 0.17 ± 0.97 compared to -0.56 ± 0.95 for nonathletes. This study's BMC was 2640g compared to 2463g in Zanker et al. (2018), suggesting potentially greater BMC in this study's population. The BMD of 1.27g/cm2 in this study and 1.26g/cm2 in Zanker et al. (2018) were similar. The bone area of 2060g in this study was higher than 1939g in Zanker et al. (2018), indicating potentially greater bone size. The T-score of 1.95 in this study, compared to -0.47 in Zanker et al. (2018), suggests a higher standard deviation from mean bone density, potentially indicating greater bone density. The Z-score of 1.85 in this study, compared to 0.17 in Zanker et al. (2018), suggests a higher standard deviation from mean bone density for age-matched individuals. Overall, this study's population of female collegiate gymnasts may have greater bone density, larger bone size, and potentially higher bone mineral content compared to the gymnasts in Zanker et al. (2018) and non-athletes.

These findings provide evidence that the physical demands of gymnastics training may contribute to higher bone density and greater bone area in this population compared to non-athletes. The decrease in BMC and total area of BMD from pre- to post- season could be attributed to the intense training and competition schedule that may have caused an increase in levels of fatigue and physical stress. This physical stress may have resulted in a decrease in BMC and BMD, as the body directs its energy towards more immediate needs, such as muscle repair and recovery, rather than bone growth (Tenforde et al., 2015). Moreover, the nutritional demands of high-intensity training and competition may have led to insufficient dietary intake of calcium and other essential nutrients required for bone health. This can contribute to a decrease in BMD over time (Holick, 2007). It is important to note that the decrease in BMC and total area of BMD from preseason to post- season is not necessarily a negative outcome, as it may reflect the body's natural adaptation to the demands of intense physical activity. However, maintaining bone health and minimizing the risk of stress fractures and other injuries should be a priority for gymnasts and their coaches. To address these issues, gymnasts and coaches can implement strategies such as ensuring adequate nutritional intake, incorporating recovery time into training schedules, and monitoring training intensity to avoid overtraining and excessive stress. Additionally, regular bone density screenings can help identify any issues early on, allowing for timely intervention and prevention of further bone loss or injury (Teneforde et al., 2015).

4.3 Descriptive and Paired t-test Pre- and Post- season Body Composition data

The body composition of female collegiate gymnasts has been a topic of interest in research due to the demands of the sport and its potential influence on athletes' overall health. To establish normative values for this population, previous studies have looked at the body composition of gymnasts using various methods. For example, a study by João and Filho (2015) analyzed the body composition of Brazilian female artistic gymnasts using BIA and found values of 21.07 ± 3.38 kg for lean body mass, 7.55 ± 2.73 kg for fat mass, 38.12 ± 5.77 kg for fat-free mass, and a fat percentage of 15.84 ± 3.79%. These findings corroborated with established profiles of artistic gymnasts in the literature. Another study by Deutz et al. used DXA to measure body fat percentage in elite female gymnasts and found a mean value of 12.36 ± 3.96%. In comparing the study's findings with the studies by João and Filho (2015) and Deutz et al., significant differences were observed. The current study reported higher values for lean mass, fat mass, fat-free mass, and fat percentage compared to João and Filho (2015). Specifically, the study found a lean mass of 26,066 kg, fat mass of 13,444.68 kg, fat-free mass of 47,929.89 kg, and a fat percentage of 22.79%. In contrast, João and Filho (2015) reported a lean body mass of 21.07 ± 3.38 kg, fat mass of 7.55 ± 2.73 kg, fat-free mass of 38.12 ± 5.77 kg, and a fat percentage of 15.84 ± 3.79%. These differences suggest potential variations in muscle mass, fat accumulation, and adiposity between the two study populations. Furthermore, Deutz et al. reported a lower mean body fat percentage of 12.36 ± 3.96%. It is important to note that these variations may arise due to differences in measurement methods and sample characteristics. These studies provide valuable insights into the body composition characteristics of female collegiate gymnasts and can be used as a reference for future research. Several other studies indicate that these athletes exhibit different body composition characteristics compared to sedentary women. Specifically, gymnasts tend to have lower levels of fat mass and higher levels of lean mass and fat-free mass. In a study by Hoffman et al. (2019), the mean fat mass of female collegiate gymnasts was found to be 9.2 ± 2.5 kg, whereas nonathletes typically have a mean fat mass of 15-25 kg. Similarly, the mean lean mass of gymnasts was found to be 44.3 ± 3.3 kg, while nonathletes typically have a mean lean mass of 34-38 kg. The mean fat-free mass of gymnasts was 53.6 ± 4.7 kg, whereas nonathletes typically have a mean fat-free mass of 50-55 kg. However, the mean total mass of female collegiate gymnasts was lower than that of sedentary college-aged women, with a mean body weight of 56.7 ± 5.5 kg compared to nonathletes, who typically weigh around 60-70 kg. Additionally, female collegiate gymnasts generally exhibit lower levels of body fat, with a mean body fat percentage of 15.3 ± 2.9%, compared to sedentary college-aged women who have a mean body fat percentage of around 30%. These findings suggest that the unique body composition characteristics of female collegiate gymnasts are likely due to the physical demands of gymnastics training. In this study, the mean fat mass of female collegiate gymnasts was 13.09 ± 4.0 kg, the mean lean mass was 43.99 ± 5.03 kg, and the mean fat-free mass was 46.66 ± 5.33 kg. The results from this study add to the study presented by Hoffman et al. by providing additional data on the body composition of female collegiate gymnasts. The findings slightly deviate from those reported by Hoffman et al., however, they support the overall findings that gymnasts have a lower fat mass and higher lean and fat-free mass compared to sedentary college-aged women. Overall, the results presented in this study provide further evidence that the physical demands of gymnastics training may contribute to the distinct body composition characteristics observed in female collegiate gymnasts.

The lack of significant change in body composition from pre to post-season among female collegiate gymnasts may be attributed to the high levels of physical activity and strict dietary control that are typically maintained throughout the year. Moreover, the BC of the athletes at the start of the season may have been optimal for their sport-specific needs, and any changes that occurred during the season may have been small and within the normal range for athletes at this level (Ackerman et al., 2017). Additionally, BC is a complex and multifactorial measure that can be influenced by a range of factors beyond just training and nutrition, such as genetics, hormonal fluctuation, and sleep quality (Tenforde et al., 2015). Therefore, the lack of significant change in BC from pre to post-season may be due to a variety of factors, and further research is needed to better understand the specific factors that contribute to changes in BC in female collegiate gymnasts.

4.4 EPSI Correlations with BMD and BC measurements

The hypothesis of this study proposed that there would be a significant relationship between EPSI scores, BD, and BC. The results of the study support this hypothesis to some extent, as there was a significant negative correlation between EPSI Body dissatisfaction and total % fat, total region % fat, and total fat mass in preseason, meaning the higher body dissatisfaction score the lower total % fat, total region % fat, and total fat mass. These results are inconsistent with a previous study that found a significant positive correlation between EPSI subscales relevant to ED and total body fat percentage, indicating that gymnasts with a higher level of disordered eating behaviors also had higher levels of body fat (Lally & Dickson, 2015).

The correlation between EPSI body dissatisfaction scores and BC measures, such as total % fat, total region % fat, and total fat mass, may reflect the complex relationship between body image perception and actual body composition. Research suggests that individuals with higher levels of body dissatisfaction may engage in unhealthy eating behaviors, such as restrictive eating or binge eating, which can have a negative impact on body composition and result in higher levels of body fat (Stice et al., 2013). Female gymnasts aim to maintain a lean physique, which can lead to a preoccupation with body weight and shape, and an increased risk of disordered eating behaviors (Beals & Manore, 1994). These behaviors can result in reduced body fat and muscle mass, which are reflected in lower body composition measures. Additionally, the emotional and psychological effects of body dissatisfaction may lead to increased levels of stress, which can also contribute to decreased body fat and muscle mass. Stress has been shown to increase levels of the hormone cortisol, which can promote muscle breakdown and the accumulation of body fat in the abdominal region (Epel et al., 2000). Therefore, it is possible that the higher body dissatisfaction scores observed in this study were associated with disordered eating behaviors, physical inactivity, and stress, which may have led to lower levels of body fat and muscle mass, as reflected in the BC measures of total % fat, total fat mass, and total region % fat.

The results of the study support this hypothesis as there was a significant negative correlation between EPSI binge eating on BMD and T-score. One possible explanation is that athletes who engage in binge eating are more likely to have inadequate nutrient intake, particularly in terms of calcium and vitamin D, which are critical for bone health (Papadimitriou et al., 2016). Inadequate intake of these nutrients can lead to a decrease in BMD and increased risk of fractures. Additionally, hormonal changes can negatively affect bone health. Some studies have shown that binge eating behaviors is associated with elevated levels of cortisol, a stress hormone that can increase bone resorption and decrease bone formation (Petrelli et al., 2019). Furthermore, individuals who engage in binge eating behavior are more likely to have a higher body mass index and body fat percentage, which are also associated with decreased BMD (Compstron et al., 2019).

Excess body fat can increase the production of inflammatory cytokines, which can accelerate bone loss and negatively impact bone health.

Another significant finding from the study that supports this hypothesis was a significant negative impact between EPSI muscle building on total lean mass and total fat free mass in post-season. The negative correlation may be the cause of overtraining and inadequate rest and recovery time, which can result in a loss of lean mass and decrease in fat-free mass Research has shown that excessive exercise can lead to negative changes in BC, including a decrease in lean mass and an increase in fat free mass (Pasiakos et al, 2013). This is likely due to the catabolic effects of excessive exercise on muscle tissue, which can lead to a breakdown of muscle protein and a decrease in muscle mass. Additionally, excessive muscle-building behaviors may be associated with inadequate nutrient intake, particularly in terms of protein and carbohydrates, which are critical for muscle growth and recovery (Helms et al., 2014). Inadequate intake of these nutrients can lead to a decrease in muscle mass and strength. Decreases in total lean mass and total fat-free mass may also be related to changes in training intensity and volume during the gymnastics season.

The lack of significant correlations between other subscales of the EPSI questionnaire and BC and BMD measurements may be due to several factors. Firstly, the subscales of cognitive restraint, purging, restricting, excessive eating, and negative attitude towards obesity are not directly related to changes in BC and BMD. These subscales may be more reflective of attitudes and behaviors towards for and body image, rather than actual changes in physical measures. Also, the sample size or statistical power of the study may have not been sufficient to detect significant correlations between these EPSI subscales and BC and BMD. Additionally, it is important to note that other variables such as training load or hormonal changes, may have a greater impact on changes in BC and BMD than the EPSI subscales. Furthermore, there may be other unmeasured factors (i.e., genetics, dietary factors, and sleep quality) that could contribute to changes in BC and BMD that are more important determinants than specific attitudes and behaviors assessed by the EPSI questionnaire. Some studies have found a significant positive correlation between ED, DE, and muscle dysmorphia scores in female collegiate gymnasts. Thereby, indicating that gymnasts with higher levels of discorded eating behaviors were also likely to have symptoms of muscle dysmorphia (Koehler et al., 2018). Additionally, there was a significant positive correlation between EPSI scores and total body fat percentage, as well as a significant negative correlation between EPSI scores and BMD, suggesting that gymnasts with higher levels of disordered eating behaviors are at a greater risk of decreased bone density and increased body fat (Koehler et al., 2018). However, there were significant differences between pre-season and post-season measurements, with gymnasts having higher body fat percentages and lower lean body mass during the pre-season. Additionally, there was a significant positive correlation between EPSI scores and total body fat percentage, indicating that gymnasts with higher levels of disordered eating behaviors also had higher levels of body fat (Lally & Dickson, 2015). These findings suggest disordered eating behaviors are prevalent in female collegiate gymnasts and are associated with negative health outcomes such as injury risk, decreased bone mineral density, and increased body fat percentage.

Currently, there are not many studies that have examined the connection between EPSI and BC or BMD variables in female collegiate gymnasts and non-athletes. However, there have been studies that have examined the relationship between other measures of eating disorder and body composition or bone health in other populations. One study by Legroux-Gérot et al. (2019) found that women with anorexia nervosa had lower bone mineral density compared to healthy controls. Another study by Eddy et al. (2015) found that women with bulimia nervosa had lower bone mineral density in certain areas of the body compared to healthy controls. These studies suggest that eating disorders may have negative effects on bone health, however, further research is needed to understand the specific relationship between EPSI and BMC or BMD.

4.5 Correlations between BMD and Body Composition variables

The hypothesis of this study proposed that there would be an association between BMD and BC variables at pre-season and post-season. The results of the study support this hypothesis to some extent, as there was a significant positive correlation between BMD and BC variables. Numerous studies have reported a positive correlation between BMD and height in female collegiate gymnasts. Some explanations for this association are attributed to the mechanical loading imposed on the skeleton during gymnastics activity. Gymnasts with greater height can generate higher mechanical loading, which stimulates bone formation and remodeling, leading to increased BMD (Dutcher et al., 2009). Another study observed the skeletal benefits of weight-bearing exercises were more pronounced in taller individuals (Ireland et al., 2014). Additionally, genetic factors may contribute to the positive correlation between BMD and height in this population. Researchers have demonstrated that height and BMD share a genetic component, thereby indicating that genetic variations associated with taller stature could also affect BMD (Flicker et al., 1995). Furthermore, hormonal factors such as estrogen and insulin-like growth factor-1 (IGF-1) have been known to influence bone growth and development (Lindsay et al., 2001; Baxter-Jones et al., 2002).

The positive correlation found between BMD and weight in female collegiate gymnasts can be attributed to multiple factors. Studies have shown a positive association between body weight and BMD in female collegiate gymnasts, like the positive correlation observed weight height (Dutcher et al., 2009; Ireland et al., 2014). The mechanical loading experienced during weight-bearing activities in gymnastics contributes to the improvement of BMD, thereby suggesting higher weight leads to greater mechanical loading and subsequent improvements in bone health. Similar to height, higher body weight in female collegiate gymnasts may contribute to a positive correlation with bone mineral density (BMD). Hormonal factors, such as the secretion of bone-stimulating hormones like leptin by adipose tissue, influenced by body weight, have been associated with improved bone formation and BMD (Jürimäe et al., 2012; Pollock et al., 2011). The increased adipose tissue and higher levels of bone-stimulating hormones in gymnasts with higher body weight likely contribute to the positive association observed between body weight and BMD. Furthermore, sufficient energy availability is a critical factor to consider. Inadequate energy intake can have a detrimental effect on bone health. Research emphasizes the significance of maintaining adequate energy availability to support optimal bone health and higher BMD (Bennell et al., 1999; Otis et al., 1997). In conclusion, the positive correlation between BMD and both height and weight in female collegiate gymnasts can be attributed to mechanical loading, genetic factors, hormonal factors, and energy availability.

The positive correlation between BMD and total bone mass observed in the results section is supported by several studies in the literature. Previous research conducted on athletic populations have reported a positive association between BMD and bone mass in older male athletes (Slemenda at al., 1997). Another study observed this finding in individuals with osteopenia, emphasizing the role of bone mass in maintaining skeletal health (Pietschmann et al., 2009). Additionally, researchers have examined the cross-sectional geometry of weight-bearing tibia in female athletes and reported a positive correlation between BMD and bone mass (Nikander et al., 2010). These findings collectively support the notion that higher total bone mass is indicative of increased BMD in athletes.

The results revealed a significant positive correlation between BMD and total lean mass in the female collegiate gymnasts. This finding is consistent with previous research conducted on athletes from various populations. One study investigated the relationship between lean mass and BMD in a sample of adolescent athletes and found a positive association between the variables (Iglay et al., 2017). Another study, discussed the complex interplay between exercise, lean mass, and bone health in athletes across different sports, emphasizing the importance of lean mass in maintaining optimal bone health (Tenforde et al., 2017). These studies provide additional evidence for the positive correlation between BMD and total lean mass in athletes. This association can be attributed to factors such as increased muscle forces during exercise, the production of bone-stimulating hormones, improved energy availability for bone formation, and the mechanical loading from weight-bearing activities (Teneforde et al., 2017). The significance of lean mass as a contributing factor to bone health underscores the importance of promoting and maintaining adequate lean mass in athletes.

The association between BMD and total fat-free mass showed a positive correlation in female collegiate gymnasts. This finding is consistent with previous research as multiple studies have investigated the relationship between these two variables and reported a positive association (Tenforde et al., 2015; Kish et al., 2018). Additionally, another study has further explored the impact of body composition on bone health in female athletes and observed a positive relationship between FFM and BMD. These results can be attributed to FFM representing muscle mass, and the mechanical forces generated during gymnastics activities that stimulate bone remodeling, which leads to increased BMD (Teneforde et al., 2015). Moreover, FFM is associated with higher levels of physical activity, which can promote the production of bone-stimulating hormones and improve a person's overall bone health (Kish et al., 2018). Gymnasts often exhibit lower body fat levels and a higher proportion of FFM relative to their total body weight. The combination of factors may explain the observed positive association between FFM and BMD in female collegiate gymnasts.

The positive association between BMD and total mass in female collegiate gymnasts are consistent with the findings from previous research conducted on athletes from various backgrounds. Researchers of one study investigated the relationship between these two variables in adolescent athletes and concluded that this positive association may be attributed to factors such as increased mechanical loading during exercise and higher levels of physical activity such as gymnastics (Iglay et al., 2017). Another study conducted on a diverse range of female athletes concluded a positive correlation between BMD and total mass as it may be attributed to the impact of physical activity on bone health (Maïmoun et al., 2014). Additionally, the relationship between BMD and body composition was further explored in collegiate athletes. The results suggested that higher total mass may reflect greater muscularity and mechanical loading, leading to increased BMD. These studies support the evidence that higher total mass is associated with increased BMD in female collegiate gymnasts and athletes in general. The positive correlation between BMD and BC variables such as height, weight, total bone mass, total lean mass, fat-free mass, and total mass, may also observed for BMC due to similar underlying mechanisms. BMC represents the amount of mineralized tissue present in bones. It can also be affected by the similar factors as BMD including mechanical loading, physical activity, and body composition.

The negative correlation between total area of bone and total tissue % fat, as well as total region % fat in preseason may suggest that increased adiposity may negatively impact bone health in female collegiate gymnasts. This result is consistent with previous research which has found that higher levels of body fat can be detrimental to bone health, especially in high weight-bearing athletes like gymnasts (Hooper et al., 2011; Maïmoun et al., 2013). The positive correlation between total area of bone and body composition variables including height, weight, bone mass, lean mass, fat-free mass, and total mass in female collegiate gymnasts are supported by several studies. One study found that taller individuals had larger bone areas, which supported the positive association between total bone area and height (Petit et al., 2005). The longer bones provide a greater surface area for bone mineral deposition and contribute to an overall increase in bone area. Additionally, genetic factors and growth hormone secretion can also play a role in bone development. Individuals with greater height potential and higher growth hormone levels are likely to have larger bone areas. Moreover, height is associated with increased mechanical loading on bones because it stimulates bone remodeling, which leads to increased bone area as a response to the demands placed on the skeletal system (Iglay et al., 2017). Another study observed a positive relationship between body weight and bone area in military recruits, indicating that greater weight was associated with greater muscle mass and strength, which contributes to increased total bone area (Beck et al., 2009). Additionally, a study concluded the reason for a positive correlation between total bone area and BMC in male gymnasts, which indicated an association between higher bone mass and larger bone areas. Furthermore, other sources concluded that greater lean mass was positively associated with total bone area (Ackerman et al., 2017) and that a positive relationship existed between total mass and total bone area in female athletes due to weight-bearing activities. The positive correlation between T-score of BMD and BC variables including height, weight, bone mass, lean mass, fat-free mass, and total mass is supported by previous literature. These associations are influenced by factors such as genetic composition, growth hormone secretion, and increased mechanical loading during training, which have been consistently identified in the existing research.

The negative correlation between total height and z-scores in preseason may indicate that taller gymnasts may have lower bone mass compared to their shorter teammates. This is consistent findings with previous studies which have found that taller athletes may be at a greater risk for low bone mass and osteoporosis due to the increased mechanical loading on the bones (Wetzsteon et al., 2009; Fuchs et al., 2011).

The positive correlation between weight, total lean mass, and fat-free mass in preseason and Z-scores suggests that increased body weight and lean mass may have a positive effect on bone heath in female collegiate gymnasts (Wetzsteon et al., 2009; Fuchs et al., 2011). These results underscore the importance of monitoring body composition and bone health in female collegiate gymnasts, as well as implementing strategies to optimize bone health, such as weight-bearing exercises, adequate nutrient intake, and health body composition.

The positive correlation between T-score of BMD and BC variables including height, weight, bone mass, lean mass, fat-free mass, and total mass are supported by previous literature.

4.6 Correlation between meet events and BMC/BMD variables.

There were no significant correlations between the gymnastics event scores and body composition or bone mineral density variables, suggesting that these variables are not strongly related to performance in gymnastics events among collegiate female gymnasts.

Further investigation showed no studies were found that directly investigated the correlation between meet event scores and BMC or BMD variables in female collegiate gymnasts.

However, other studies have examined the relationship between these variables with other populations. A study by Tenforde et al. (2015) found that low BMD was associated with an increased risk of stress fractures in female athletes. Another study conducted by Kahn et al. (2021) found that body composition, including lean mass and fat mass, was positively correlated with athletic performance in female soccer players. Additionally, another study examined the relationship between BMD and running performance in male and female track and field athletes (Journal of Bone and Mineral Research, 2005). The researchers found that BMD was positively correlated with running performance in both female and male athletes, but the relationship was stronger in female athletes. These studies suggest that bone mineral density and body composition may be important factors in athletic performance and injury risk in female athletes. While the study did not find significant correlations between gymnastics event scores and body composition or bone mineral density variables, it’s important to note that performance data in gymnastics is multifaceted. Gymnasts are scored based on numerous metrics related to technique, execution, artistry, and skill difficulty. These factors may play a more significant role in event scores than BMC/BMD variables. Additionally, this study only examined collegiate female gymnasts, thereby introducing the possibility that the relationship between BMC/BMD variables and performance could differ in other populations or competitive levels.

4.7 EPSI Subscales and Meet Scores

The findings show a significant negative correlation between EPSI subscale restricting and bars scores. This indicates a moderate-to-strong relationship between the two variables, such that higher restricting scores are associated with lower scores on bars. This result may provide further evidence that supports research about female gymnasts engaging in caloric restriction and have a high prevalence of disordered eating behaviors, which can negatively impact their performance on bars (Hulley et al., 2018; Sundgot-Borgen & Torstveit, 2010). The EPSI subscale restricting measures the extent to which individuals restrict their food intake and may indicate a relationship between food restriction and low energy levels that can negatively affect gymnasts' performance on bars. Moreover, psychological factors such as anxiety and depression, which are often associated with restricting behavior, may also negatively impact gymnasts' performance on bars (Holt & Hoar, 2006). Additionally, the results showed a strong positive correlation between cognitive restraint and beam scores, which means higher scores on one variable are associated with higher scores on the other variable. This finding may support the idea that gymnasts who engage in more cognitive restraint is able to control their food intake and make healthy food choices (Westenhoefer, 2013). This is supported by research that has found a positive association between cognitive restraint and improved concentration, which can positively impact their performance on beam given its level of focus and precision (Scholey et al., 2010). Additionally, cognitive restraint is often associated with better overall physical health (Westenhoefer, 2013). Gymnasts who engage in cognitive restraint may be able to maintain a healthy weight and have more energy, which could positively impact their performance on beam. Furthermore, cognitive restraint has been associated with improved mental health (Westenhoefer, 2013), which may translate to improved performance on the beam as it requires a higher degree of focus, self-confidence, and emotional control. The positive association between higher beam scores and EPSI subscale excessive exercise in female collegiate gymnasts can be attributed to various factors. Excessive exercise behavior is often driven by a desire for perfection and performance excellence in gymnastics. It is also associated with higher levels of commitment and self-discipline (Lichtenstein et al., 2017)

Gymnasts that engage in excessive exercise habits may exhibit more focused and dedicated training, which can translate to improved skills and performance on the balance beam. Additionally, excessive exercise behavior can be linked to a higher level of commitment and self-discipline (Lichtenstein et al., 2017). Gymnasts that exhibit these traits are more likely to invest significant time and effort into their training, which includes balance beam. This increased practice and training can lead to better performance outcomes such as higher scores. Furthermore, excessive exercise has been associated with higher levels of physical fitness (Lichtenstein et al., 2017). Gymnasts participating in intense exercise regimens tend to have better strength, flexibility, and overall athleticism, which can positively influence their beam performance. The complex association between event meet scores and EPSI subscales in female collegiate gymnasts can be attributed to the intricate interplay of psychological, physical, and technical factors in this population.

4.8 Limitations

The current study aimed to investigate the changes in body composition, bone mineral density, and health-related behaviors in a sample of collegiate female gymnasts using DXA scans and the EPSI questionnaire. Despite the valuable insights gained from this study, it is important to acknowledge several limitations that could affect the generalizability and interpretation of the findings. One limitation is the issue of missing data due to absenteeism from DXA scans and/or EPSI questionnaire. This could potentially skew the data if those who missed further data collection due to injury or lack of participation differ significantly from those who completed them both pre- and post- season, leading to a biased sample. Additionally, the sample size was relatively small, which may have limited the power to detect significant changes in some of the variables of interest. Furthermore, the study was limited to a specific population of collegiate female gymnasts, which may limit the generalizability of the findings to other populations.

The use of DXA to measure BMD and BC in female gymnasts is subject to certain limitations. According to Gabe et al. (2016), DXA has limitations in measuring BMD in gymnasts, including limited precision, regional measurements, soft tissue interference, radiation exposure and cost. These limitations may affect the accuracy of the measurements and the ability to detect changes in BMD over time. Therefore, it is important to consider using additional imaging methods to obtain a more comprehensive understanding of BMD and BC. Furthermore, the menstrual cycle can also affect BMD measurements, potentially leading to underestimations. Furthermore, the lack of reference data and the unique BC of female gymnasts can make interpretation of DXA results difficult. Therefore, caution should be exercised when using DXA to measure BMD and BC in female collegiate gymnasts, and results should be interpreted with these limitations in mind.

EPSI survey questionnaire possesses certain limitations that may not capture the unique challenges and experiences of gymnasts regarding their body image and eating patterns. Gymnasts are often subject to intense pressure to maintain a specific body shape and weight, which could result in disordered eating patterns that may not be fully captured by the EPSI questionnaire. The EPSI questionnaire relies on self-reporting, which could be subject to social desirability bias. Even though the participants were instructed to answer truthfully, some may have provided socially desirable responses or may not have accurately recalled their behavior, leading to an underestimation or overestimation of the reported data due to fear of stigmatization or repercussions from coaches or teammates. Additionally, the EPSI questionnaire may not be fully applicable to the athletic population. Athletes, particularly gymnasts, may have different nutritional needs and patterns than non-athletic populations, and their behaviors may not necessarily reflect disordered eating. Furthermore, the EPSI questionnaire may not capture the severity and duration of disordered eating patterns, which could vary widely among gymnasts. The questionnaire only provides a snapshot of current symptoms and does not assess long-term or chronic disordered eating patterns. It is important to note that the EPSI questionnaire is a self-assessment tool, and its results may not be fully accurate without clinical diagnosis and assessment by a healthcare professional.

4.9 Future Research

This study provides important insights into the prevalence of disordered eating behaviors and importance of BMD and BC among female collegiate gymnasts. However, there are several avenues for further research that could expand on these findings. Future research should continue to explore the relationship between EPSI scores and DXA measurements in female collegiate gymnasts. Specifically, larger sample sizes and longitudinal studies could provide further insight into the stability and changes of EPSI scores, BC, and BMD measures over time. Additionally, future research should investigate potential interventions and support systems to help female collegiate gymnasts maintain a healthy relationship with their bodies and food. Interventions could include team-based education on nutrition and body image, individual counseling for athletes experiencing disordered eating and negative body image and wellness overweight and aesthetics. Additionally, research could examine the impact of these interventions on both EPSI scores, BMD, and BC measures.

Understanding injury outcomes and the various factors that influence them is a critical aspect of sports medicine research. Injuries can impact on an athlete's performance, quality of life, and long-term health. According to the American College of Sports Medicine, the injury rate for collegiate gymnasts is high with an estimated 3.9 injuries per 1000 athlete-exposure (Shrier & Gabet, 2021). Previous research has found that low bone mineral density is associated with increased risk of stress fractures in female athletes (Bennell et al., 1999). Similarly, low body weight and body fat percentage have been associated with an increased risk of stress fractures in female athletes (Nattiv et al., 2007). Given the high prevalence of stress fractures in gymnastics, it is essential to further comprehend and examine the relationship between injury outcomes and BMD and BC. Therefore, collecting injury incidence and prevalence data in gymnastics is essential to better understand the relationship between bone mineral density, body composition, and health-related behaviors in female collegiate gymnasts to develop strategies to prevent and manage injuries in this population.

To collect and review injury incidence and prevalence data through a variety of means, such as athlete self-reporting, medical records, coaches' reports, and physical examination. By analyzing data alongside BMD, BC, and energy availability (EA), researchers could potentially identify patterns or associations between injury risk and these other factors. Previous research has suggested that low EA can increase the risk of bone stress injuries in female athletes (Teneforde et al., 2015). Therefore, if injury data showed a higher incidence of bone stress injuries in gymnasts with lower EA, this could provide further evidence for support for the importance of monitoring EA in this population. Similarly, researchers could examine the relationship between EA and injury risk, to investigate whether athletes with low energy availability are more prone to certain types of injuries such as muscle strains or ligament sprains. Additionally, monitoring injury outcomes could help identify potential risk factors for injury and inform injury prevention and management strategies such as modifying training programs to reduce injury risk, implementing injury screening protocols, and providing appropriate medical care and rehabilitation for injured athletes. Furthermore, future studies could focus on interventions aimed at improving body composition and bone mineral density in female collegiate gymnasts. Some interventions could target reducing body fat percentage and increasing lean mass as this may potentially improve bone mineral density in this population. Moreover, further research could investigate the role of nutrition and dietary intake on body composition and bone health as well as examine the impact of training regimens on body composition and bone health outcomes in female collegiate gymnasts.

Another direction for future research could involve exploring the relationship between EPSI scores, BC, and BMD measures and athletic performance outcomes. Research could investigate whether there are specific EPSI subscales, BMD, or BC measures that are more strongly associated with athletic performance outcomes such as strength, power, and endurance or injury risk. Finally, future research could investigate the use of alternative measures of BC and BMD in female collegiate gymnasts. While DXA is considered the gold standard for BC assessment other methods such as bioelectrical impedance analysis (BIA) and air displacement plethysmography (ADP) may offer advantages such as low cost and greater accessibility, particularly for smaller programs or institutions with limited resources. Therefore, it may be worthwhile to investigate the use of alternative measures. This also applies to implementing other alternatives such as the eating disorder examination questionnaire (EDE-Q), eating disorder inventory-3 (EI-3) to the use of the EPSI questionnaire.

4.10 Conclusion

In conclusion, this study provides valuable insights into the disordered eating behaviors, bone mineral density and body composition measurements of female collegiate gymnasts. The findings highlight the high prevalence of body dissatisfaction and excessive eating among these athletes, which are persistent issues both in pre- and post-season periods. The study also suggests that there may be specific relationships between EPSI sub scores and body composition measurements, which may require further investigation in larger samples.

The results of this study suggest that female collegiate gymnasts may require targeted interventions and support to address disordered eating behaviors and body image concerns. The high levels of body dissatisfaction and disordered eating behaviors observed among these athletes may be attributed to the intense demands and expectations of the sport, including the emphasis on physical appearance and weight, the culture of perfectionism, and the demands of high-intensity training. The lack of significant changes in disordered eating behaviors over the course of the season highlights the need for ongoing support and intervention for female gymnasts.

Future research could explore potential interventions and support systems to help these athletes maintain a healthy relationship with their bodies and food. Additionally, larger studies could explore the potential relationship between EPSI sub scores and body composition measurements, which could have important implications for understanding the health and well-being of female gymnasts.

This study has shed light on the complex relationship between disordered eating behaviors and body composition in female collegiate gymnasts. It is important to note that the correlations found in this study does not imply causation as other factors may also be influencing the relationship between these variables, which would warrant further research to determine causality.

It is hoped that the findings of this study will contribute to the development of interventions and support systems that will enable these athletes to achieve a healthy and sustainable relationship with their bodies and food, and ultimately improve their overall health and well-being.

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