COMPARISON OF BONE MINERAL DENSITY IN FEMALE MOUNTAIN CYCLISTS, ROAD CYCLISTS, AND RUNNERS

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ABSTRACT

Osteoporosis and osteopenia are far more common in women than men. The levels of bone mineral density (BMD) in women mountain cyclists are unknown. **PURPOSE:** To compare the BMD of recreational road (n = 12) and mountain (n = 15) women cyclists with age- and training volume-matched women runners (n = 17), 20-40 years of age. **METHODS:** Forty-six women volunteered to take part in the study. All participants completed food frequency questionnaires that assessed calcium, vitamin D, and caffeine intake and a life-long physical activity questionnaire. Anthropometric measurements (height, weight, and age) and 1-repetition maximal tests to find leg and hand strength were conducted. Dual-energy X-ray absorptiometry was used to assess BMD of the radius, femoral neck, spine, hip, and total body. **RESULTS:** Fifteen mountain cyclists who rode 9.4 ± 4.5 hours per week for 7.8 ± 4.9 years, 12 road cyclists who rode 8.2 ± 2.8 hours per week for 8.5 ± 3.5 years, and 17 runners who ran 4.6 ± 1.7 hours per week for 11.5 ± 4.9 years met the inclusion criteria. Road cyclists and runners had significantly ($p \leq 0.05$) lower calcium intake than mountain cyclists. Body mass, lean body mass, fat mass, and handgrip score were positively correlated with BMD. Runners had significantly ($p \leq 0.05$) higher BMD at the femoral neck than mountain cyclists. There were no significant differences in BMD between mountain and road cyclists. **CONCLUSION:** Recreationally active and competitive mountain cyclists do not experience greater osteogenic benefits than age- and training-matched road cyclists. Running provided a greater osteogenic stimulant at the femoral neck than mountain cycling. Most participants did weight-bearing physical activity through childhood and adolescence and had healthy levels of BMD at all sites tested. Body mass was found to be the most important determinant of BMD at all sites, indicating that underweight individuals are most susceptible to osteopenia and osteoporosis.

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CHAPTER I: INTRODUCTION

Introduction

Measurement of bone mineral density (BMD) has increased over the years and is now fairly common in older adult primary care check-ups within the general population (1). BMD is characterized as a biophysical parameter assessing bone quality and can be measured through radiographic images via dual-energy X-ray absorptiometry (DEXA), computed tomography (CT), or magnetic resonance imaging (MRI) (2). BMD is the ratio of bone mineral content (BMC) to bone size and is commonly measured as grams per centimeter squared (3). Peak total body BMD varies throughout the lifespan but usually peaks between the ages of 20-30 years in women and men (4-7). There is a decrease in BMD after 50 years of age for both women and men (8).

An individual's BMD measurements can be compared to the mean values, or norms, of their sex- and age-matched population to further describe their bone health. Bone health is often expressed by taking the difference in terms of standard deviations (S.D.) from these established norms (9). The lumbar spine and femoral neck are the clinically significant sites used to compare BMD values to the norm values (10). When an individual's BMD falls between one and 2.5 S.D. below their sex- and age-matched healthy population's mean value, then the individual is diagnosed with osteopenia. When an individual's BMD falls more than 2.5 S.D. below their sex- and age-matched population's mean value, then the individual is diagnosed with osteoporosis (9). Osteopenia is defined as having low bone mass and is a precursor of osteoporosis. Osteoporosis is the most common chronic metabolic bone disease defined by very low bone mass, structural deterioration of bone tissue, and reduced bone strength (10-12). According to the National Health and Nutrition Examination Survey (NHANES) from 2017-2018, the prevalence of osteopenia at the femoral neck or lumbar spine for adults over 50 years of age was 33.5% for

men and 51.5% for women. NHANES also measured an increase in the prevalence of osteoporosis in women from 2007-2008 to 2017-2018 in the prevalence of osteoporosis in women, but not men. The prevalence of osteoporosis at the femoral neck or lumbar spine for adults over 50 years of age was 4.4% for men and 19.6% for women in 2017-2018 (10). Bone density is one of the most reliable indicators of fracture risk (1). Women have a high risk of bone fractures past 50 years of age which reduces their ability to perform daily activities safely. A few reasons for this increased risk are that women have lower bone mass and bone size, longer life span, and negative hormonal negative effects from menopause (13).

There are both non-modifiable and modifiable risk factors that contribute to low BMD. Non-modifiable risk factors include age, sex, genetics, and ethnicity or race. Past 50 years of age reduced BMD is more prevalent and severe in women. Additionally, studies have found that genetics determine 50-70% of the peak bone mineral density within a population (6, 11). In some populations, such as Black- and Mexican-Americans, lower rates of osteoporosis are observed compared with Asian-American and Caucasian populations that have the highest rates of osteoporosis (11, 14). Modifiable risk factors contributing to osteoporosis include tobacco use, low vitamin D intake or absorption, low calcium, alcohol abuse, being underweight, low sex hormone levels, excessive caffeine intake, and physical inactivity. Smoking and vitamin D deficiency cause a reduced ability to absorb calcium which negatively affects bone metabolism. Alcohol abusers experience suppressed new bone formation, heightened pro-inflammatory markers, and increased possibility of falling when intoxicated (15). Being underweight results in reduced forces on the bones due to decreased body weight and muscle mass. Additionally, being underweight may be an indicative of a poor diet lacking the vitamins and nutrients necessary for

building and maintaining healthy bones (11). Low sex hormone levels and high caffeine consumption have each been shown to be related to fracture risk and reduced BMD (12).

Finally, physical activity is a primary stimulus for bone mass accretion by creating skeletal loading which causes bones to momentarily bend through muscles contractions. The bending acts as an osteogenic stimulus; therefore, BMD is maintained or increased when muscles respond to external forces during physical activity. When an individual is physically inactive, there is no recruitment of skeletal muscle, no bending of bones, and no bone mass accretion. During long periods of physical inactivity or zero gravity (e.g., during spaceflight), BMD declines and the risk for being diagnosed with osteopenia or osteoporosis increases (11, 16, 17).

Certain types of physical activity have a greater osteogenic effect than others. Weight-bearing physical activities (i.e., running, gymnastics, football) can increase and maintain BMD while non-weight-bearing physical activities (i.e., cycling, swimming) do not have a positive effect on BMD (18, 19). Additionally, physical activities or sports that include large ground reaction forces or in which there are large muscle groups recruited or high joint reaction forces in irregular amounts and uneven distributions produce the largest osteogenic stimulus (16). The adjective “large” is important because strain below a minimum threshold will only cause bone resorption, while strain above the threshold will elicit bone mass accretion (20). Several studies have examined the relationship between physical activity and BMD in groups performing certain types of physical activities (i.e., running, walking) for women and men (7, 21). One study assessed road cyclists and little to no relationship was found between training volume and bone density in women and men. This could be due to the smooth, rhythmic pedaling action in road cycling and the non-weight-bearing nature of the activity (16, 22).

Another form of cycling is mountain or off-road cycling. Mountain cyclists commonly stand up on their pedals, experience vibration in their upper and lower body from rough terrain and undergo large ground reaction and muscle forces throughout their entire body. On the other hand, road cyclists commonly remain seated on the bike, ride smooth road surfaces, and experience repetitive forces due to easy predictability on the road. Two studies have shown a positive relation between mountain cycling and BMD; however, both studies only examined male mountain cyclists (17, 20). As the cycling industry continues to grow in the United States, more women and men are participating in mountain cycling (23). However, the osteogenic benefits of mountain cycling for women are unknown.

Statement of problem

Women are at greater risk of low BMD, osteopenia, osteoporosis, and bone fractures compared to men (13, 24, 25). Today, more women than ever before are participating in mountain cycling, and they are starting at an earlier age; thus, research examining the osteogenic effects of mountain cycling for women is necessary (26, 27). Two studies have examined the relation between mountain cycling and BMD in men, but to our knowledge no studies have examined the relation between road cycling and BMD in women. Therefore, additional research is necessary to elucidate the relation of both types of cycling (mountain and road) and BMD in women in order to fill the current gap in the literature.

Statement of purpose

The purpose of this study is to determine if the vibrational and muscular contraction aspects of mountain cycling have a significantly greater osteogenic effect compared with road cycling and running in women. The relation between BMD and BMD/weight in women mountain cyclists, road cyclists, and runners will be analyzed to determine if there are

differences in these variables between groups. In addition, a secondary purpose is to examine the relation between muscle strength and BMD, and to test whether controlling for the effects of muscle strength impacts the magnitude of the differences in BMD between these 3 groups.

Significance of study

This study will generate data on BMD in women mountain cyclists, road cyclists, and runners. Women athletes are an under-represented population in this area of exercise science research. As cycling is growing in popularity and osteopenia and osteoporosis are becoming more prevalent, a better understanding of the relation between cycling and BMD is vital for women's health who partake in these activities. Similarly, this study will give medical professionals a better understanding about the osteogenic outcomes of cycling in women.

CHAPTER II: REVIEW OF LITERATURE

Introduction

Osteoporosis and osteopenia are becoming more prevalent in the United States. The National Center for Health Statistics provided a data brief in 2005-2008 showing 9% of adults aged 50 and over have steoporosis within their femur neck or lumbar spine in the United States (28). The World Health Organization (WHO) diagnoses osteoporosis and osteopenia based on the BMD at either the femur neck region of the proximal hip or the lumbar spine. The WHO diagnoses patients with osteopenia when their BMD t-score of the hip or spine is between -1 and -2.5 while osteoporosis is diagnosed when their BMD t-score of the hip or spine is below -2.5 (9). The ability to precisely measure BMD in the skeleton has significantly improved with the widespread availability of the dual energy x-ray absorptiometry (1).

In a 2012 National Center for Health Statistics 2005-2008 data brief, women showed an increase in prevalence of osteoporosis for each decade beyond 50 years of age, whereas in men this decline does not begin until 80 years of age. The prevalence of osteoporosis at either skeletal site (femur neck or lumbar spine) for women was 7% during ages 50-59 years, 10% during ages 60-69 years, 27% during ages 70-79 years, and 35% during 80 years of age and older. For men, prevalence of osteoporosis at either skeletal site (femur neck or lumbar spine) was between 3-4% during ages 50-79 years and increased to 10% during 80 years of age and older. Similarly, in 2005-2008 the prevalence of osteopenia for women remained higher during each age range than the prevalence of osteopenia for men. The prevalence of osteopenia was 54% in women aged 50-59 years and increased to 65-68% for women aged 60 years and older. The prevalence of osteopenia in men 50-69 years of age was 32%; this is less than the prevalence (45%) in men aged 70-79 years and the prevalence (60%) in men 80 years of age and older. Therefore, the highest age-specific prevalence of osteopenia in men (occurring at 80 years and older) was still

less than the prevalence of osteopenia occurring in women 50 years of age and older. After adjusting for age, the prevalence of osteoporosis and osteopenia at the femoral neck and lumbar spine was 16% and 61%, respectively, for women and 4% and 38%, respectively, for men (28).

The United States is experiencing a growth in the older adult population due to the "baby boom" era and lengthening of life expectancy (29). Therefore, an increase in the prevalence of osteoporosis and osteopenia is shown through data collected in 2017-2018 and the trend is expected to continue. In 2017-2018, the National Center for Health Statistics reported 12.6% of adults aged 50 and over in the United States have steoporosis within their femur neck or lumbar spine or both. Therefore, a 3.6% increase in the prevalence of osteoporosis in the United States' population of adults 50 years of age and older occurred over the span of approximately 10 years. Additionally, the average prevalence of osteoporosis in women aged 50 years and older increased from 14% in 2007-2008 to 19.6% in 2017-2018. The average prevalence of osteoporosis in men aged 50 years and older saw no significant change and remained lower at about 4%. Between 2007-2008 and 2017-2018, the prevalence of osteopenia remained consistent without significant changes at about 43% for all adults aged 50 and over, 51% for women aged 50 and over, and 33% for men aged 50 and over. As of March 2021, the prevalence of osteoporosis in adults aged 50 years and older at the femoral neck was 6.3%. This falls short of the Healthy People 2020 goal of 5.3% or less (10).

According to the International Osteoporosis Foundation, in 2016 an estimated 200 million people worldwide were suffering from osteoporosis with 1 in 3 women aged 50 years and older and 1 in 5 men aged 50 years and older expected to experience an osteoporotic fracture during their lifetime (12). Specifically, in the United States, the National Osteoporosis Foundation estimates 10 million Americans are suffering from osteoporosis while osteoporosis-

related or osteoporotic fractures are estimated to total between 1.5 and 2 million annually (29). In 2004, the total opportunity cost, including the medical sector, patient and family sector, and research and development sector, was estimated at 34 billion USD and projected to increase to 41.4 billion USD in 2025. The medical sector includes incident fracture care, continuing post fracture care, screening tests, and pharmacological treatment. The patient and family sector in 2004 was estimated at 1.3 billion USD and was only generated from informal care costs (family homecare), but some studies will also include formal home healthcare visits and patient productivity costs from work absence (30). According to Becker et al (2010), the annual direct medical costs are estimated between 17 to 20 billion dollars for osteoporosis financial burdens with over half of the costs coming from inpatient care expenses. Hip fractures, despite being 14% of incident fractures, account for 72% of the total cost estimate. In 2005, the most common sites of fracture include vertebral fractures, wrist fractures, hip fractures, and "nontraditional skeletal sites" (femur, clavicle, fingers, patella, etc.). Using the data from 2005, the projected medical costs of osteoporotic fractures would reach 25.3 billion in 2025 with 87% of these costs originating from adults aged 65 and over (29).

The development of osteoporosis or osteopenia can result from low levels of peak BMD at physical maturity, failure to maintain peak BMD through the third and fourth decades of life, and/or bone loss after the fourth decade of life (24). Non-modifiable and modifiable risk factors play a major role in these causes of the development of osteoporosis or osteopenia. Therefore, the prevalence of osteoporosis, osteopenia, and osteoporotic fractures in adults are associated with the non-modifiable and modifiable risk factors.

Non-Modifiable Risk Factors

The non-modifiable risk factors include sex, age, genetics, and ethnicity or race (11). The following sections are focused on the non-modifiable factors.

Sex: Overall, women suffer from osteoporosis and osteopenia more than men; an estimated 8 million women in the United States are affected by osteoporosis. Women show higher rates of osteoporosis than men due to lower bone mass and bone size, longer life span, and the hormonal effects of menopause. Men reach about a 10-12% higher peak bone mass and bone size compared to women during the years of peak bone density (13). Since osteoporosis is a multi-faceted disease, a combination of endocrine and chronic inflammatory factors influence bone strength, mineral density, geometry, microstructure, mineralization, and properties. The onset of menopause and estrogen deficiency (endocrine factors) coincides with changes in bone such as increased osteoclast-mediated bone resorption, endocortical thinning, and increased cortical porosity (25, 31). The ability to offset the loss of bone mass due to the increase in remodeling intensity is insufficient in women but not men (31). In a population study of 1715 men and women, women 67 to 69 years of age had a loss of bone mass two to five times greater than men with similar bone sizes (13).

In a review by Pietschmann et al. (25), several molecules impact the balance between osteoclasts for bone formation and osteoblasts for bone resorption. Inflammation will cause the immune system to produce greater amounts of T cells which increase the production of bone-resorbing cytokines that inhibit new bone formation. Also, inflammation can produce cytokines that stimulate osteoclasts and inhibit osteoblasts which results in exaggerated systemic bone loss (25). The crucial point is that inflammatory cells are more abundant in early postmenopausal and postmenopausal women experiencing estrogen deficiency (31). Postmenopausal women are at

the highest risk of osteoporosis, osteopenia, and fractures related to both low bone density diagnoses. Half of all postmenopausal women will experience a osteoporotic-related fracture in their lifetime, a forth will experience a vertebral deformity, and 15% will experience a hip fracture (32).

Age: Menopause and advancing age accelerate the imbalance between bone formation and resorption rates and increase the risk of bone fractures (12). Aging is associated with increased inflammation; therefore, inflammation is the major contributor of the reduction in bone health in the aging population (25, 31). Along with the National Center for Health Statistics, studies show a BMD decrease after 45 years of age in women along with a small decrease in hip BMD and an insignificant trend in spine BMD (33). In women, there is a 15% drop in BMD per decade after menopause, and since women live longer than men, there are greater reductions in bone mass (8). Peak BMD in Mexican-American, Non-Hispanic White, and Non-Hispanic Black women occurs between the ages of 30-39 years. On the other hand, peak BMD for Mexican-American, Non-Hispanic White, and Non-Hispanic Black males occurs between 20-29 years of age (8).

According to a review on the pathogenesis of osteoporosis by Seeman (31), bone material and structural properties degrade with age because the modeling and remodeling mechanisms deteriorate. The mechanisms deteriorating with age include periosteal osteoblast function, osteocyte signaling, and overall deficiency of osteoclasts. Over time, remodeling mechanisms deposit less bone than they remove, therefore, causing bone loss, trabecular thinning, loss of connectivity, cortical thinning, and porosity. Older, more mineralized bone accumulates microdamage due to being distant from remodeling mechanisms on the bone surface. At the same time, surface bone remodeling mechanisms are creating negative bone balance and less

mineralized bone (31). Studies show an increase in osteoporotic and any bone fracture with age among men and women (34).

Ethnicity or Race: The National Center for Health Statistics found the prevalence of osteoporosis and osteopenia significantly differed by race and ethnicity. Data from 2005-2008 show the age-adjusted prevalence of osteoporosis at either skeletal site was lower in non-Hispanic white men at 4% compared to other races, which included primarily Hispanics and multiracial persons, at 9%. However, the age-adjusted prevalence for osteopenia at either skeletal site was lower in non-Hispanic black men at 24% than non-Hispanic white men at 39%. For women, the age-adjusted prevalence of osteoporosis at either skeletal site was lowest in non-Hispanic black women at 9% compared to non-Hispanic white women at 15% and Mexican-American women at 26%. The age-adjusted prevalence of osteopenia in either skeletal site was also lowest in non-Hispanic black women at 44% compared to non-Hispanic white woman at 62% and other races at 72% (28). Therefore, in all adults the prevalence of osteoporosis and osteopenia at either skeletal site was lowest in non-Hispanic black persons when compared to non-Hispanic white persons, Mexican-Americans, and other races; these results agree with reports by the National Osteoporosis Foundation (14, 28). Wright et al. estimated that in 2010, 7.7 million non-Hispanic white, 0.5 million non-Hispanic black, and 0.6 million Mexican Americans had osteoporosis, and 33.8, 2.9, and 2 million more had low bone mass, respectively (14). According to Becker et al., the prevalence between different race and ethnic groups stayed consistent with the lowest prevalence seen in Blacks (16.5%) compared to Whites (30.7%), Hispanics (32.4%), and Asian Americans (38.9%) (29).

Genetics: Genetics is estimated to account for 60-80% of optimal bone mineralization and 50-85% of the variance in peak bone density (35-38). Evidence in twin and family studies show that

differences in skeletal traits are largely attributed to differences in genes and not differences in environmental exposures (31, 33). Ralston et al. discussed the heritable phenotypes linked to the pathogenesis of osteoporosis, such as ultrasound properties of bone, biochemical markers of bone turnover, and bone geometry. While there is a heritable contribution to age-related bone loss and bone fracture, the contribution to both is weaker than for peak bone density (36). A Swedish study found a decrease in the heritability of hip fractures with age; they observed a 68% heritability below the age of 65 years but constant decrease until a near zero heritability by the age of 80 years. Another study found 71% of premenopausal women with a family history of osteoporosis had low bone mass (39). For site specific BMD and heritability, Harris et al (1998) found a heritability of 77% for the lumbar spine and 72% for the femoral neck (40).

Since BMD regulation and osteoporosis-related phenotypes are polygenic, a single gene mutation would not cause severe osteoporosis or abnormally high bone mass (36). Some studies found the vitamin D receptor (VDR) gene encoding a nuclear hormone receptor to be associated with BMD in the femur and vertebrae but not the forearm (41). The VDR plays a role in regulating calcium homeostasis by being able to increase the absorption of calcium. The estrogen receptor-alpha and -beta (ESα and ESß) gene polymorphisms which mediate the action of estrogen in bones are associated with BMD as well, however some studies only show a relationship between BMD and the ESα (37). According to Chew and Clarke (2017), the collagen 1 alpha 1 (COL1A1) gene polymorphisms are associated with a significant increase in risk of osteoporosis fracture, especially vertebral fractures, and a modest decrease in BMD (41).

Modifiable Risk Factors

The modifiable negative risk factors that increase an individual's risk for osteopenia and osteoporosis include tobacco use, alcohol abuse, being underweight, low sex hormones, low

calcium, low vitamin D intake or absorption, excessive caffeine intake, and physical inactivity (11). The following sections are focused on the modifiable negaitve factors.

Tobacco Use: Studies have established an association between smoking and decreased BMD in postmenopausal women and men (1, 42). While evidence shows smoking has no effect on premenopausal women, an additional 0.2% of bone loss each year is observed in postmenopausal women who habitually smoke. There is a 50% increase in lifetime risk of hip fracture due to excess bone loss over decades in smokers, and one in eight hip fractures in women are attributed to smoking (43). In current smokers and individuals who have ever smoked after 50 years of age, there is a significant increase in osteoporotic and any bone fracture for men and women (34). It is estimated that women smokers increase their likelihood of a spine fracture by 13% and a hip fracture by 31%. Smoking has adverse effects on ovarian function and estrogen metabolism which contribute to the negative effects on BMD with tobacco use (44). A study performed by Bjarnason and Christiansen on 153 early postmenopausal women found a 4% lower BMD in smokers compared to non-smokers (45).

Alcohol Abuse: Excessive alcohol consumption can affect multiple mechanisms in the body and be detrimental to bone health. Predisposition to falls, calcium deficiency, and chronic liver disease, which causes vitamin D deficiency, are results of alcohol abuse. A dose-dependent relationship is present between alcohol intake and fracture risk with a daily intake of three or more units of alcohol associated with fracture risk, including any fracture, osteoporotic fracture, and hip fracture, for both men and women (12). Kanis et al. (46) found no significant increase in osteoporotic fracture risk with a daily intake of two or less units of alcohol for men and women, and risk ratios were not significantly higher in men or women.

Milena et al. (47) found that alcohol-related bone disorders depend on volume and type of drink and drinker sex. Alcohol disrupts bone remodeling and accretion by decreasing osteoblast activity and serum osteocalcin levels and, similar to aging, increases inflammation (47). Turner (48) discusses the opposing effects of alcohol on young men and postmenopausal women; the alcohol-induced decrease in bone remodeling in postmenopausal women slows bone loss since bone resorption is also decreased. In young men, when bone resorption predominates there is an imbalance in bone formation and gradual bone loss occurs (48). Thus, moderate levels of alcohol below two units or less (one unit equals 14 grams of pure alcohol) are shown to stimulate calcitonin secretion which inhibits resorption and increases bone accretion (47, 48).

Being Underweight: Having a BMI less than 21 kg/m^2 is a significant risk factor for all osteoporotic fractures, including hip and forearm, but is a protective factor for lower leg fracture (12, 49). Being underweight can be the outcome of an eating disorder or inability to take in enough food to meet the body's energy demands. The Relative Energy Deficiency in Sport (RED-S) and Female Athlete Triad (Triad) models both explain the negative impacts on bone health when low energy deficiency occurs (50). Energy deficiency is relative to the balance between dietary energy intake and energy expenditure required for the body's homeostasis functioning, carrying out daily tasks, and performing physical activities (51). Skeletal health is impacted by poor nutrition which coincides with not eating enough food and being underweight (1). Additionally, low energy availability due to poor nutrition and/or being underweight is linked to low vitamin D and calcium levels (19).

One way to observe the negative effects of being underweight is through individuals with an eating disorder (e.g., anorexia nervosa). There is an increased prevalence of osteoporosis, osteoporotic fractures, and osteopenia in individuals with a history of or currently with anorexia

nervosa (52-55). More than 85% of women with anorexia nervosa have a bone mineral density at least one standard deviation below their age group's mean and a 7-fold increase in risk of bone fracture (54, 56). There is a 57% elevated incidence of fracture years after treatment of anorexia nervosa (56). In a study on adolescent girls diagnosed with anorexia nervosa, no improvements in BMD were observed at the beginning treatment (when nutritional status improves) due to insufficient weight gain. After 21 months of treatment, a significant increase in lumbar and total body BMD was observed as sufficient weight gain had occurred and an improvement in nutritional status remained (52). Anorexia nervosa is shown to have a high relapse rate and can affect older women (57, 58). A study performed on twenty-one women 45-48 years of age and diagnosed with anorexia nervosa found the mean baseline lateral spine bone mass was three standard deviations below their age group's mean (56).

Several studies found body weight positively correlates with BMD in men and women. In postmenopausal women, weight is the strongest predictor of femoral and lumbar BMD (59). In a study performed by Bjarnason and Christiansen on 153 early postmenopausal women, participants in the lowest tercile of body mass index (BMI) had 10% lower BMD compared to participants in the highest tercile (45). Since body weight includes fat mass and lean mass, it is important to note that fat mass does not protect against bone loss while lean mass, which measures muscle mass, positively influences and is a predictor of BMD. Healthy (not excessive) levels of fat mass are shown to positively influence BMD in postmenopausal women and sedentary individuals (47). In a study of Chinese women 20-39 years or age, low body weight and delayed menarche were the two major risk factors for low bone mass (6).

Low Sex Hormone Levels: Estrogen stimulates bone cell proliferation via estrogen receptors on osteoblasts and osteoclasts. After menopause, there is a down-regulation in the estrogen

receptors which reduces bone cell proliferation, and the effectiveness of mechanical strain on bone growth is reduced because the proliferative effects from strain act though the estrogen receptors as well. Therefore, postmenopausal women experience a loss of bone mass and deterioration of bone structure due to their loss of estrogen receptors from estrogen withdrawal (1, 31, 60). Studies on postmenopausal women have shown estrogen and progestin replacement therapy reduces bone turnover by 50% and hip fractures by 34%; however, an increased risk in coronary heart disease, stroke, breast cancer, and thromboembolic events is seen with estrogen and progestin replacement therapy too. Therefore, current recommendations suggest a limit of 5 years of estrogen and progestin replacement therapy during the perimenopausal phase (1, 61).

One way to observe the negative effects of low sex hormone levels is through individuals with amenorrhea, eumenorrhea, or oligomenorrhea. A study conducted on athletes 17 to 39 years of age with amenorrhea found lower BMD at the lumbar spine, femoral neck, Ward triangle, intertrochanteric region, femoral shaft, and tibia. Out of the 29 female athletes in this study, 7 were diagnosed with osteoporosis and 14 were diagnosed with osteopenia despite being an age where optimal BMD normally occurs and a majority being runners (62).

The RED-S and Triad models demonstrate the negative effects energy deficiency has on menstrual function and bone health. Through the literature, hypoestrogenism has been linked to low energy availability, and therefore, a major part of the Triad model (50). Southmayd et al. (63) found a combination of energy deficiency and estrogen deficiency was the most detrimental to bone health, and only treating hypoestrogenism without treating undernutrition to meet energy demands is likely inadequate prevention for maintaining and recovering bone health. Williams et al. (64) found that a caloric restriction with exercise producing a shortage of calories between 470 and 810 per day over three menstrual cycles induces menstrual disturbances.

Low Calcium: A dietary supply of calcium is required to maintain serum calcium levels in the body; low serum calcium levels cause bone resorption rather than bone accretion. Aging increases calcium requirements and the Institute of Medicine (IOM) recommends a daily intake of 1000 mg per day for men aged 50-70 years and 1200 mg per day for women aged over 50 years and men aged over 70 years. Optimal calcium absorption occurs when the dosage does not exceed 500-600 mg and there is little to no intake of oxalate, which is in some food products and prevents calcium absorption by binding with it (12).

Many studies show an inadequate intake of dietary calcium over a lifetime increases the risk of developing osteoporosis. Throughout the years of skeletal maturity there is a heightened importance on meeting dietary calcium needs in order for bone accretion and optimized peak bone mass to occur (8). Kemper et al. (65) found a positive relationship between calcium intake and lumbar BMD in adolescence (ages 13-16) but not adulthood in their longitudinal study on men and women. In a population-based study on middle-aged men, dietary calcium intake was an independent predictor of BMD (59).

Low Vitamin D Intake or Absorption: Vitamin D is necessary for calcium absorption, bone health, muscle performance, and balance, and the IOM recommends for adults to consume 15 micrograms (ug) (600 IU) per day until 70 years of age and 20 ug (800 IU) per day over 70 years of age. It has been shown that a daily intake of 20 ug/day reduces falls and fractures significantly. When vitamin D levels are sufficient, the need for calcium intake is reduced because absorption of calcium is more efficient (1).

Heaney (66) found 90% of the vitamin D utilized by the body was from cutaneous sources rather than dietary intake, which only accounted for 5 ug/day. Multiple studies report one minimal erythema dose of UV-B radiation to the total body produces 250 to 625 ug of

cholecalciferol (also known as Vitamin D_3) (67). However, from 20 to 80 years of age the skin content of 7-dehydrocholesterol, which is the immediate precursor to pre-vitamin D, is reduced by 50% (68). Therefore, older adults need to have greater amounts of sun exposure than accounted for when they were younger to meet vitamin D recommendations (69).

With aging there are increases in the probability of malabsorption issues, intestinal diseases, increased gastric acidity, pernicious anemia, inhibition to proton pumps, and increased usage of medications and glucocorticoids; all of which decrease the ability to absorb and breakdown vitamin D in the body (12). Bischoff-Ferrari et al. (70) found that among all patient groups studied, patients with hip fractures have the lowest vitamin D levels. Vitamin D deficiency also causes severe myopathy with loss of muscle strength (primarily type-2 muscle loss) and coordination; therefore, the disposition for falls increases (1). Osteomalacia is the weakening of bones through vitamin D deficiency; patients have trouble walking due to pain in their bones and hips with osteomalacia (71).

Excessive Caffeine and Non-Nutrient Drinks Intake: Some studies show a relationship between caffeine consumption and fracture risk; therefore, a commonly advised rule for caffeine intake is to consume less than one to two servings of an 8-12 ounce serving size (12). Hallstrom et al. (72) found increased risk of osteoporotic fractures with a high caffeine intake (>330 mg) and coffee consumption (>600 ml) only when paired with low calcium intake (<700 mg/day) in women 40-76 years of age. Caffeine intake has been shown to increase with age therefore making aging more of a risk factor for low BMD (73). Tucker et al. (74) found intake of regular and diet cola (a caffeinated beverages) in women but not men significantly reduced BMD in the hip and not in the spine; decaffeinated cola had similar results and other carbonated beverages were not associated with low BMD.

Whiting et al. found that milk consumption decreased with increased consumption of low nutrient dense beverages (e.g., juice, cola, carbonated drinks), and adolescent girls had reduced BMD only when low nutrient dense beverages replaced milk beverages. Adolescent boys did not demonstrate this relationship because they had higher calcium intake and higher activity levels (75). Smith et al. (76) found adult women had no short-term negative effects from high carbonated beverage consumption and suggested milk replacement causes low calcium intake and reduced BMD levels. Older, well-nourished women showed no affect with carbonated beverage intake and BMD (77). Fitzpatrick and Heaney (78) explain that a small impairment in calcium absorption occurs with caffeine intake, but the impairment is irrelevant in the presence of adequate dietary calcium intake.

Physical Inactivity: Evidence supporting the relationship between physical activity and bone health is seen throughout cross sectional, cohort, and intervention studies (7, 12, 17, 79). There is a deleterious effect of physical inactivity shown throughout the literature in prolonged periods of bed rest or non-weight-bearing activity, general lifestyle inactivity, and prolonged spaceflight (80). It is known that weight-bearing physical activity (i.e., running, gymnastics, soccer) provides more osteogenic stimulation than non-weight-bearing physical activity (i.e., swimming, road cycling), and the weight-bearing sites of the body experience the most BMD regulation (18, 19). Although nutritionally deficit, women and girls with anorexia nervosa are shown to improve their femoral neck bone mineral by engaging in more vigorous physical activity (81).

Regular weight-bearing exercise along with back and posture exercises should be advocated throughout life starting in childhood and through young adulthood because they are essential for normal skeletal development to achieve and maintain peak bone mass (24). These exercises will also help adults as they age with balance, muscle strength, and reduced bone loss

from disuse (1, 12). Studies show weight-bearing physical activity throughout childhood and adolescence optimizes peak bone mineral density (38). Individuals who regularly participate in physical activity have a favorable biochemical profile, i.e., lower parathyroid hormone level, that enhances their bone metabolism (59).

Skeletal Loading and Muscular Strength

Engaging in exercise during skeletal growth rather than skeletal maturity has greater osteogenic results and is an important factor in determining the state of bone health in later life (4, 5, 7, 82). With exercise, bone strength increases due to an increase in bone mineral content and significant alterations in the size and shape of bones (6). During childhood and adolescent years, there are a greater proportion of active osteoblasts allowing for periosteal expansion. Periosteal expansion improves bending and torsional strength of the bone, and since periosteal surface rarely undergoes remodeling in adult years, BMD is not reduced within that layer of bone. Studies show vigorous exercise during childhood and adolescent years reduces fracture risk in later decades of life (83). A systematic review by Bielemann et al. (7) found there is a greater association between physical activity and bone mass when physical activity is performed all the way from childhood throughout adulthood. Also, involvement in sports during adolescence is related to higher physical activity levels in adults. Previous studies have found difficulty with the relationship between physical activity and bone mass in women due to less overall participation in sports involving high peak strain or vigorous physical activity (7). However, there is evidence showing the incorporation of weight-bearing exercise in postmenopausal women is associated with improving femoral neck and lumbar spine BMD (84).

The adaptive process of bone responding to mechanical loading is called mechanotransduction, and for this mechanism to be activated, there are two parts: (a) physical

signal and (b) cellular response. The physical signal requires the bone to undergo a dynamic stress that must exceed a minimum threshold. On the cellular side, the bone cells must be in a receptive state in which they are not desensitized to the mechanical stimulus (82).

Hert et al. (85) was one of the first scientists to discover physical activity and exercise involving dynamic loading but not static loading produced osteogenic benefits. Dynamic loading, unlike static loading, creates shear stresses in the bone from fluid movement in the lacunar-canalicular network system which stimulate osteocytes, osteoblasts, and bone lining cells. The osteogenic index (IO) estimates bone formation with exercise and depends on the exercise intensity and degree of desensitization. Intensity of exercise is found by multiplying the peak magnitude of load or stress with the loading frequency. When translating this equation to exercise, increasing the rate and amount of ground reaction force will increase intensity (83).

Colletti et al. (18) found that muscle strengthening exercises performed by men 19-29 years of age for at least a year are associated with higher BMD and increased bone mass at the weight-bearing sites, when compared to non-exercising age-matched controls. Studies found isometric dynamometry of back or grip strength was a predictor of BMD for the lumbar spine and forearm, respectively, in men (18).

Physical Activity and Sport as Osteogenic Stimulants

Studies have shown that high impact sports maximize bone mass accretion and maintenance and reduce bone loss in the later decades of life for men and women (7). While medications, such as hormone replacement therapy, calcitonin, bisphosphonates, and selective estrogen receptor modulates, have been used to prevent and treat osteoporosis, the high costs of these drugs only provide limited benefits with unpleasant side effects. Dynamic and high mechanical strain exercise or sport have the potential to provide more osteogenic benefits

without the drug-induced negative side effects (86). Overall, strength- and power-trained athletes have higher BMD than endurance-trained athletes due to the difference in the magnitude of mechanical strains (87).

Kemper et al. (65) used ground reaction forces (GRF) to classify physical activities into four categories: score 3 is activities with a GRF greater than four times body weight, score 2 is activities with a GRF between two and four times body weight, score 1 is activities with a GRF between one and two times body weight, and score 0 is activities with a GRF less than one times body weight. The same study measured BMD at the lumbar spine, femoral neck, and distal radius. Table 1 and the following section list physical activities and sports with their scores and provides a summary about each physical activity's influence on BMD, bone fracture risks, and osteogenic benefits.

Dynamic and High Mechanical Strain:

Power Lifting and Weight-lifting: Since weight-lifters achieve some of the highest absolute and relative peak power outputs in the literature, significant mechanical strain and torque are placed on the muscles and compressive and shear forces are placed on the bones of the body (88). Therefore, biochemical indicators of bone formation are elevated by up to 35% in competitive weight-lifters (men and women) with site specific increases occurring in the vertebrae (13-42%), femoral neck/trochanter (12-24%), tibia (9-12%), and radius (10%) compared to untrained, healthy adults (89, 90). Karlsson et al. (91) found after 30 years of retirement from weightlifting, individuals 50-64 years of age maintain a significantly higher bone mass than compared to age-matched controls. However, retired weightlifters past 65 years of age and following more than 30 years of retirement had no lasting BMD benefits, which indicates that maintaining adequate physical activity levels is necessary for preventing a decrease in bone health and BMD (91).

Table 1. The estimated mechanical strain of physical activities and their score according to the amount of ground reaction force (GRF).

Recreated from Kemper et al. (2002) (65)

Physical Activities	**Mechanical Strain (GRF)**	**Score**
Yoga	0.5-1	0
Volleyball	5-10	3
Bicycling	0.5-1	0
Soccer, Field Hockey	3-5	2
Skating	1-3	1
Running	1-3	1
Swimming	0.5-1	0
Basketball	5-10	3

Note the mechanical strain amount provided is the GRF as a multiple of body weight created in the physical activity.

Studies show the BMD of the spine is significantly higher in male power lifters (18). In an article by Nguyen et al. (92), weight-lifting, particularly squats and deadlifts, was found to increase lean muscle mass and BMD at the hip and lumbar spine. Cussler et al. (86) found through a one-year weight-lifting interventional study in 140 women 44-66 years of age that the weight lifted (summation of the amount of weight lifted in a particular exercise) in a seated leg press and military press, separately, correlated to femoral trochanter BMD. Therefore, the study found regional muscular loading with an absence of direct muscle targeting at the hip site still stimulated osteogenic benefits (86).

Soccer and Field Hockey: Soccer demands a large volume of running, ranging from 9000 to 12,000 meters per game (for men and women), which is a considerably greater amount of running than in basketball, handball, and volleyball (93). In a meta-analysis by Taylor et al. (93), high-intensity running accounted for 5.1-18.2% in men and 4.8% in women of the total distance traveled per game. Within one game of soccer for men and women, an average of between 1379-1459 activity changes (significant change in time-motion analysis data) occurred; this shows the dynamic and irregular pattern of strain on the body that soccer requires. The same meta-analysis reported that only two studies measuring jumping in soccer players; an average of 10.4 ± 5.4 jumps per game were reported in elite men soccer players while junior men performed 0.9-3.6 jumps per game (93).

Taylor et al. (93) also found studies on field hockey that showed a similar volume of running in men and women ranging from 6000 to 10,000 meters. Of total game time, high-intensity running accounted for 1.2% in elite men, and elite women performed more episodes of high-intensity running with a similar total distance (93). Comparable to soccer, Lythe and Kilding (94) reported 1148 ± 128.9 activity changes (which require a acceleration/deceleration

component) per game in elite men field hockey players. Kemper et al. (65) scored soccer and field hockey a 2 with GRF varying between three and five times a player's body weight.

Basketball: Basketball requires a higher ratio of high-intensity running and sprinting and more lateral movement than soccer and volleyball with upwards of 300 lateral movements per game (93). Additionally, the frequency of jumping in basketball is about 41-56 jumps per game for men and 19-43 jumps per game in women; consequently, high-impact strain is frequent with an average of one jump per minute (93). Basketball is also primarily played on hardwood surfaces whereas soccer and field hockey are on turf; therefore, the GRFs of basketball are greater and produce more osteogenic stimuli (95). A meta-analysis including 15 studies on adolescent boys and girls found basketball athletes have a greater total and regional (spine, upper limbs, lower limbs, pelvis, and trunk) BMD compared to non-athletes and swimming, soccer, and volleyball athletes. The differences between the basketball athletes and compared groups was greater in men than women (96). Kemper et al. (65) scored basketball a 3 with GRF greater than four times a player's body weight.

Jallai et al. (97) studied adolescent boy basketball players with an average of 8 years of vigorous training experience and average training load of 9 hours per week compared to training- and age-matched soccer players; the study found the basketball had more lean body mass and, after adjusting for height, significantly higher BMD values in total body, lumbar spine, both arms, and right proximal femur. The largest differences were in the upper extremities (25-28%), and no differences were seen in the head, left leg, and left proximal femur (97).

Volleyball: In both court and beach volleyball, multi-directional demands and frequent lateral movements construct the high-impact physical activity which Kemper et al. (65) scored a 3 with GRF greater than four times a player's body weight (93). Tillman et al. found women volleyball

players jumped an average of 22.5 times per game, and mostly jumped off two legs (84% of jumps on offense and 99% of jumps on defense) and landed in a mixed pattern between the legs (about half the time landing bilaterally) (98). Sheppard et al. (99) reported men volleyball players performed 1-19 block jumps, 0-15 spike jumps, and 0-21 jump sets per game depending on position; Cortell-Tormo et al. (100) reported lateral movements in men's volleyball accounting for 67.8% of offense plays and 11.3% of defense plays. Therefore, both men's and women's volleyball contain high levels of jumping which is a high mechanical strain activity and osteogenically stimulating.

Tennis: Tennis consists of rapid accelerations and decelerations with full body twisting components that act on the spine and femoral neck. Due to the high-intensity movements and hard courts, tennis can produce GRFs of 5-10 times an individual's body weight (101). Additionally, tennis provides a unique opportunity to compare loading effects on bone health between a dominantly used "playing arm" with a less used "nonplaying arm" while observing lower body impact (102). Ireland et al. (103) observed muscle strength and size and BMD in 50 elite junior tennis players (boys and girls) and found significant correlation between muscle size and bone size. In line with previous literature, there are large, site-specific differences in bone strength and muscle size between the racket and nonracket arm (103). Ducher et al. (104) reported an 8-14% exercise-induced bone mineral content gain in the playing arm of women and a 13-22% exercise-induced bone mineral content gain in playing arm of men.

Studies found college women tennis players to have higher total BMD than age-matched swimmers and non-exercisers (18). At the professional tennis level, Calbet et al. (101) found 11% greater femoral neck BMD and 15% greater lumbar spine BMD compared to sedentary age-matched controls which is similar increases to other weight-bearing physical activities.

Improvements in BMD at these clinically significant sites support tennis being a preventative activity to low BMD and bone fractures (101).

Judo: Contrarily to ball sports and physical activities, judo is a contact physical activity primarily consisting of demanding full body movements and technical-tactical skills. Judo is comprised of various throwing and falling techniques which, when practiced consistently, impact bone structure (105). A study on the effects of weight cycling on bone metabolism in elite judoists found the increased bone formation rate of the weight-bearing activity protected BMD (106). In a meta-analysis, five studies reported BMD among judoists or judokas; Bozkurt (107) found significantly higher L1-L4 BMD in men judokas compared to runners, and Matsumoto et al. (108) reported significantly higher total BMD in men and women judokas compared to long-distance runners and swimmers (109). Andreoli et al. (110) found significantly higher trunk and total BMD in men judokas but no significant difference in leg BMD compared to controls, runners, and karate athletes. Additionally, Bozkurt (111) found no significant difference in trochanter, intertrochanter, and Ward's triangle BMD of men judokas compared to runners, karate athletes, and wrestlers (109). Therefore, evidence shows judo has osteogenic benefits for the total body and spine in men and women.

Skating: Ice dancing has a ballroom dancing influence with few lifts and jumps. On the other hand, single and pair skating involves frequent lifting and jumping with significant landing forces and mechanical loading. Similarly to tennis, skating provides an opportunity to compare the "landing leg" to the "takeoff leg"; Burt et al. (112) found higher BMD, larger and stronger bones in the landing leg compared to the takeoff leg which is consistent with previous findings. In the same study, skaters were reported to have average BMD at the tibia and below average BMD at the radius compared to age- and sex-matched normative data (112).

Speed skating is the other form of skating researched in the literature, and Kemper et al. (65) scored skating (figure and speed) a 1 with GRFs between one and two times a person's body weight. Speed skating has an irregular movement pattern, specifically short track speed skating, and generates a high magnitude of load due to high speeds of more than 50 kilometers per hours (113). Therefore, other studies would argue that Kemper's score is inaccurately low because evidence shows skating produces enough GRF to stimulate bone accretion.

Running: Endurance and distance runners, when compared to sprinters, gymnasts, and ball sport athletes, consistently have lower BMD due to higher possibilities of reduced muscular strength training and/or energy availability. Although running is a weight-bearing activity, these risk factors have been shown to negatively influence BMD in runners, especially in women. With the exception of adolescent women, running is generally associated with equivalent or slightly higher BMD than sedentary controls (114).

Although Kemper et al. (65) scored running a 1 with GRFs between one and two times a person's body weight, most studies show positive associations between running and BMD (65). In a study on elite Norwegian endurance cyclists and runners, none of the runners (11 women and 10 men) had low BMD although previous studies show evidence of low BMD in distance runners. The study cited the possibility of low energy availability as a possible reason for low BMD due to the common occurrence of elite runners relying on a weight-to-power ratio (19). In a cross-sectional study by Tenforde et al. (115), adolescent runners were found to be at risk for low BMD if there was presence of the following risk factors: for girls lower android to gynoid fat ratio, being shorter, menstrual irregularity, history of fracture, and for boys lower android to gynoid fat ratio, lower BMI, and belief that being thinner was better for performance.

Greene et al. (116) evaluated 20 elite adolescent boy runners and found higher lean body mass was associated with higher BMD. Wilks et al. (117) used peripheral computed tomography and found that there was greater bone strength in sprinters than in distance runners. Therefore, evidence shows running can be act as an osteogenic stimulant if a healthy weight is maintained and muscular strengthening exercises are implemented.

Static and Low Mechanical Strain:

Swimming: Similar to astronauts, swimmers spend hours in a hypogravity or low-gravity environment with low levels of tension transmitting through their muscular system. The reduced levels of muscular strain and absence of impact forces prevent osteogenic benefits from occurring in swimmers. However, when an additional physical activity is incorporated into a swimmer's schedule, improved bone mass is observed (118, 119). Skerry et al. (120) found when swimmers consistently perform at low mechanical loads, their threshold for bone remodeling to occur decreases and therefore makes it easier for lower impact and mechanical straining sports to positively effect BMD.

Kemper et al. (65) scored swimming a 0 with GRFs less than one times a person's body weight. Multiple studies have found swimmers to have similar BMD as non-exercisers and lower levels of BMD than other physical activities including tennis, weight-lifting, cycling, running, and soccer (18, 19). A meta-analysis including fourteen studies on childhood and adolescent swimmers found swimmers have similar BMD levels as sedentary individuals and lower BMD levels, specifically in the femoral neck and lumbar spine, as high-impact sports. The meta-analysis also found the difference between BMD in swimmers and other athletes increases with age; therefore, incorporating osteogenic exercises particularly during childhood and adolescent years will help swimmers reach a more optimal peak BMD (121). One study found that

swimmers (men and women) with a training volume of equal to or greater than 12 hours per week had higher BMD values in the upper limbs and spine compared to non-exercisers (122).

Yoga: Fishman (123) presented the importance of yoga for increasing range of motion and improving posture, balance, strength, and coordination which potentially help individuals overcome the fear of falling and occurrence of fractures during more osteogenic stimulating activities (i.e., walking). While Kemper et al. (65) scored yoga a 0 with GRF less than one times a person's body weight, the benefits of yoga are seen with a reduction of risk of lower limb and hip fracture, primarily among postmenopausal women, due to improvements in balance (124). A systematic review and meta-analysis including 591 women 45-78 years of age throughout randomized controlled trials (RCTs), non-RCTs, and pre-post studies, found no significant improvements in BMD compared with controls. These findings are in agreement with previous literature stating yoga is not an exercise modality appropriate for the bone remodeling process (125).

Cycling as an Osteogenic Stimulant

Several studies (Table 2) have examined the negative and neutral effects of road cycling on BMD, and fewer studies (Table 3) have examined the positive effects of mountain cycling on BMD. Ultimately, only two studies exist that measure BMD in mountain cyclists, and both studies are performed on men. Regarding studies on road cyclists, more studies on men exist, but there are multiple studies on women. Since women have an increased risk for osteoporosis and osteopenia, it is important to have equal representation in the literature for mountain cycling to better understand the physical activity's role with bone health.

Road Cycling: Similarly to elite runners, power-to-weight ratio is one of the most important performance markers for elite cyclists and can come at the expense of reduced energy intake and

Table 2. BMD and bone health in men and women road cyclists compared to sedentary and active controls

Recreated from Nagle and Brooks (2011) (126) and Olmedillas et al. (2012) (22).

Study	Groups and Physical Activity	BMD Results
Duncan et al. N=75 women (127)	Runners (N=15), 8.4 ± 1.2 h/wk Triathletes (N=15), 16.2 ± 4.7 h/wk Road Cyclists (N=15), 15 ± 4.9 h/wk Swimmers (N=15), 15 ± 4.8 h/wk Sedentary Controls (N=15), < 2 h/wk	No difference at LS & FN between cyclists and controls. Runners greater FN than all groups and greater LS than triathletes.
Maimoun et al. N= 38 men (128)	Road Cyclists (N=11), 10.6 ± 3.9 h/wk Swimmers (N=13), 10.7 ± 3.2 h/wk Triathletes (N=14), 15.2 ± 4.3 h/wk Sedentary Controls (N=10), < 2 h/wk	No difference at LS, TH, & FN between cyclists and controls. No LS difference between groups.
Medelli et al. N=103 men (129)	Pro/elite Road Cyclists (N=73), 22-25 h/wk for 25.8 ± 4.3 yr Sedentary Controls (N=30), < 1 h/wk	Cyclists lower LS & FN than controls with higher calcium intake.
Heinonen et al. N = 105 women (130)	Road Cyclists (N=29), 556 ± 338 h/yr Active Controls (N=25), 202 ± 135 h/yr Weight Lifters (N=18), 429 ± 129 h/yr Other Athletes[a] (N=33)	Adjusted for weight, no difference in LS & FN between cyclists and controls.
Nichols et al. N = 67 men (16)	Older Road Cyclists (N = 27, 40-60 yr), 12.1 ± 3.9 h/wk Young Road Cyclists (N = 16, 25-35 yr) 15.8 ± 3.8 h/wk Active Controls (N=24), 4.5 ± 2.6 h/wk	Older cyclists LS & TH lower than young cyclists and controls. Older cyclists lower FN than young cyclists.
Nikander et al. N = 285 women (131)	Road Cyclists (N=29), 10.2 ± 6.8 h/wk Sedentary Controls (N=30), 2.9 ± 2 h/wk Swimmers (N=27), 13.5± 4.5 h/wk Other Athletes[b] (N=199)	No difference in FN between cyclists, swimmers, and controls. All other sports higher FN than controls.
Rector et al. N = 43 men (132)	Road Cyclists (N=27), 13 ± 1.2 h/wk Runners (N=16), 11.4 ± 1.5 h/wk	Adjusted for age, weight, bone loading, runners greater LS than cyclists.
Rector et al. N= 42 men (133)	Road Cyclists (N=19), ≥ 6 h/wk Runners (N=10), ≥ 6 h/wk Resistance trainers (N=13), ≥ 6 h/wk	Adjusted for LBM, runners greater LS than cyclists.
Sabo et al. N = 61 men (134)	Tour de France Cyclists (N=6), Active Controls (N=21), 2.4 h/wk Other Athletes[c]	Cyclists had a nonsignificant lower AP and LS than controls.

Note BMD=bone mineral density, FN=femoral neck, LS=lumbar spine, TH= total hip, AP=anterior-posterior, h=hour, d=day, wk=week, yr=year, LBM=lean body mass, pQCT=peripheral quantitative computed tomography

Table 2 Continued

Study	Groups and Physical Activity	BMD Results
Smathers et al. N = 62 men (135)	Road Cyclists (N=32), 13 ± 0.7 h/wk Active Controls (N=30), 3 d/wk	Adjusted for body fat, LBM, and fat mass, cyclist lower AP LS than controls.
Smathers et al. N = 62 men (135)	Road Cyclists (N=32), 13 ± 0.7 h/wk Active Controls (N=30), 3 d/wk	Adjusted for body fat, LBM, and fat mass, cyclist lower AP LS than controls.
Andersen et al. N = 40 men and women (19)	Road Cyclists (N=7 female, 12 male), 909 ± 124 h/yr Runners (N=11 female, 10 male), 549 ± 170 h/yr	Cyclists had lower LS, FN, and total body BMD than runners.
Hinrichs et al. N= 382 men and women (136)	Road Cyclists (N=16), 15 h/wk Runners (N=37), 12.5 h/wk Sedentary Controls (N=61) Other Athletes[d] (N=268), 7.5-27 h/wk	Cyclists had lower LS and FN than all other groups.
Nevill et. al. N = 111 men (137)	Road Cyclists (N=16), > 4 h/wk Active Controls (N=15) Other Athletes[e] (N=90), > 4 h/wk	Cyclists had no difference compared to controls, and all the other sports did.
Olmedillas et al. N = 44 men (138)	Road Cyclists (N=21), 10 h/wk Active Controls (N=23), 4 h/wk	Cyclists had lower pelvis, total body BMD, FN, and TH than controls.
Penteado et al. N = 59 men (139)	Road Cyclists (N=31), 21 h/wk Sedentary Controls (N=28), 0 h/wk	No difference in cyclists compared to controls.
Stewart et al. N = 62 men (140)	Road Cyclists (N=14), 8.7 h/wk Runners (N=12), 10.7 h/wk Runners + cyclists (N=13), 9.4 h/wk Sedentary Controls (N=23), 0 h/wk	Cyclists had lower LS than controls. Runners + cyclists had a higher total body BMD than controls.
Wilks et al. N = 103 men (117)	Sprint Cyclists (N=52), < 2 h/wk Distance Cyclists (N=19), < 2 h/wk Active Controls (N=32), < 2 h/wk	Using pQCT, cyclists had a higher tibial bone mineral content than controls.

[a]Other athletes studied include orienteers and cross-country skiers
[b]Other athletes studied include volleyball, hurdling, squash, soccer, speed skating, step-aerobics, weight-lifting, orienteering, and cross-country skiing
[c]Other athletes studied include weight-lifters and boxers.
[d]Other athletes studied include team sports and triathletes
[e]Other athletes studied include triathletes, upper-body, keep-fit, strength, running, rugby, rowing, and racket sports

Table 3. BMD and bone health in men and women mountain cyclists compared to sedentary and active controls.

Study	Groups and Physical Activity	BMD Results
Warner et al. N = 45 men (17)	Mountain Cyclists (N=16), ≥ 10 h/wk Road Cyclists (N=14), ≥ 10 h/wk Sedentary Controls (N=15), < 2 h/wk	Adjusted for weight and age, no difference between road cyclists and controls. Mountain cyclists higher FN & LS than others.
McVeigh et al. N = 30 men (20)	Road Cyclists (N=10), 13.5 ± 6.2 h/wk Mountain Cyclists (N=10), 13.6 ± h/wk Sedentary Controls (N=10), < 2 h/wk	Using pQCT, mountain cyclists had higher bone content at the radius than road cyclists and controls.

Note BMD=bone mineral density, FN=femoral neck, LS=lumbar spine, h=hour, wk=week, & pQCT=peripheral quantitative computed tomography

availability. Low body mass and energy deficiency are risk factors for low BMD (19). In addition to those risk factors, road cycling, similar to swimming, is a weight-supported activity. In cycling, the spine is suspended evenly between the seat and handlebars and involves minimal strain (114, 140). Kemper et al. (65) scored road cycling a 0 with GRFs less than one times a person's body weight.

Andersen et al. (19) found that elite Norwegian road cyclists (7 women and 12 men) had significantly lower BMD than runners, and a logistic regression found no significant relationship with independent variables except type of sport. Ten of the nineteen road cyclists were classified to have low BMD according to the American College of Sport Medicine criteria (Z-score $\leq$ -1). The prevalence of low BMD in the road cyclists was site specific, occurring in the lumbar spine and femoral neck, which are both high-risk areas of low BMD (19). Rector et al. (132) found that men road cyclists were 7.4 times more likely to have osteopenia in the spine compared to runners after adjusting for age, weight, and bone-leading history (other physical activities). The same study reported 60% of the sampled men road cyclists they studied had osteopenia of the spine, and the road cyclists had significantly lower BMD than the runners who had similar stature, weight, and body composition as the cyclists (132). Smathers et el. (135) found that men road cyclists had lower spine BMD than untrained controls without any group differences in testosterone.

Mountain Cycling: Kemper et al. (65) did not score the GRFs of mountain cycling, however studies show the GRFs are much greater in mountain cycling than road cycling (17). Mountain cycling requires riding over a variety of rougher surfaces including rocks, gravel, sand, dirt, logs, drop-offs, etc. at multiple levels of speed and inclines. This variation in terrain produces a dynamic system of vibrations, intensities, and frequencies that act on the arms and legs. Due to

the balancing component, using a dropper post, and more time spent with two points of contact (hands and feet), greater mechanical strains are placed on the legs from the pedals Approximately 70-80% of a rider's body weight is placed on the legs from the pedals when a rider is standing up whereas in road cycling (where a rider spends more time in the sitting position) there is only 50% of a rider's body weight acting on the legs (141).

Additionally, mountain cycling requires isometric contractions in the arm and leg muscles for stabilization over uneven and steep terrain. Therefore, greater indices of bone strength and structure are observed in mountain cyclists which coincides with greater bone mineral content in the radius (17, 20). McVeigh et al. (20) found that male mountain cyclists have greater exercise-induced muscle hypertrophy and upper-body muscular strength which provides evidence of a greater osteogenic stimulus than road cycling. Warner et al. (17) reported a positive relationship between muscle strength and BMD in male mountain cyclists. However, these two studies are the only evidence of osteogenic benefits in mountain cycling. McVeigh et al. (20) studied 10 male mountain cyclists between 20-31 years of age and Warner et al. (17) studied 16 male mountain cyclists between 21-31 years of age. Both studies reported mountain cycling to provide osteogenic benefits, but there is no evidence if these results are the same in women mountain cyclists.

CHAPTER III: MANUSCRIPT

Introduction

The National Osteoporosis Foundation (2019) estimates that 54 million Americans have osteoporosis or osteopenia, and osteoporotic fractures are estimated at 2 million annually. As the aging population grows and people live longer, this public health crisis will grow as well. Women have a higher risk of being diagnosed with osteoporosis and suffering an osteoporotic fracture, because women have lower bone mass and bone size, longer life span, and negative hormonal effects from menopause. Bone mineral density (BMD) is the amount of minerals per square centimeter of bone and is an indirect risk indicator of osteoporosis and bone fractures. Attaining and maintaining optimal peak BMD throughout life is a key component to avoiding low BMD and preventing bone fractures. Healthy bone growth and maintenance requires a combination of calcium formation and resorption in bone tissue through biochemical and mechanical factors (122). There are multiple factors that influence the maintenance of BMD including: age, sex, genetics, race, nutrition, alcohol consumption, weight, hormone levels, and physical activity. In terms of mechanical stimuli, physical activity promotes the most osteogenic benefits by creating muscular forces to act on bones in the body.

Studies show weight-bearing physical activity with dynamic and high mechanical strain stimulate bone growth while static and low mechanical strain activities do not improve bone health. Multiple studies have looked at various high impact sports (i.e., soccer, weight-lifting, running) and low impact sports (i.e., swimming, yoga, cycling) to assess the effects on BMD within the population. There is evidence showing women experience a positive relationship between weight-bearing physical activity and BMD, however; more studies on the relationship of all physical activities and sports and BMD in women are needed. Cycling is an activity that has increased in popularity among women over the past 10 years, and little is known about the

relationship between mountain cycling and BMD in women. Previously only two studies have assessed the effects of mountain cycling on BMD, and both studies examined men.

Two primary forms of cycling exist, road and mountain cycling. Previous studies on men and women found road cycling to have little to no osteogenic benefits due to the repetitive motion of the activity and low strain on the body. The predictability of paved roads and generally staying in the seated position on a road bike are a couple reasons for the static and low mechanical strain characteristics. Mountain cycling, on the other hand, requires the rider to maneuver over rocks and roots while adjusting their body weight on their legs and arms. Mountain terrain is also more likely to involve drops, jumps, or steep sections of trail requiring higher levels of force to be exerted and, therefore, impact forces that must be absorbed by the body. These factors lead to greater bone strain in mountain cycling, compared to road cycling.

Therefore, the purpose of this study is to determine if the dynamic and high mechanical strain aspects of mountain cycling provide an osteogenic benefit in women. Additionally, this study will determine if mountain cycling has a significantly greater osteogenic effect compared to road cycling and running in women. Since there are multiple factors that influence BMD, as many of these factors as possible were controlled or accounted for, in order to isolate the effects of the physical activity mode.

Methodology

Participants

All participants were healthy, non-smoking, 20- to 40-year-old women who were screened for medical and medication history that could affect bone health or testing. Exclusion criteria included: being pregnant or trying to become pregnant, significant amounts of metal in the body,

i.e., throughout their spine, hips, or legs, and currently amenorrheic or oligomenorrheic (past menstrual inconsistency was accepted). Cyclists and runners were recruited simultaneously. Forty-six women volunteered to take part in the study; two were excluded after data collection. Cyclists (n=27) were currently riding when recruited and had been riding for at least 3 years for ≥ 6 hours per week and for ≥ 10 months per year. Twelve of the cyclists were primarily as road cyclists (RC) and 15 of the cyclists were primarily as mountain cyclists (MC). Runners (R) (n=17) were currently running when recruited and had been running for at least 3 years for ≥ 3 hours per week and for ≥ 10 months per year. All participants engaged in less than 2 months per year of resistance training or heavy impact sports (besides running for runners). Each volunteer provided written consent and the study was approved by the Institutional Review Board of the University of Tennessee.

Recruitment and Screening

Recruitment occurred within the local community of Knoxville, Tennessee and surrounding areas, including Chattanooga (TN), Athens (GA), Johnson City (TN). Flyers were posted on the researcher's social media platforms, including Instagram and Facebook, as well as at local bike, running, and coffee shops. Some participants further shared the research study with their social groups and teams. Interested participants contacted the research team and were sent a screening questionnaire prior to scheduling a visitation that determined eligibility through the inclusion and exclusion criteria. Once a participant was determined eligible, the participant was scheduled to visit the University of Tennessee Health, Physical Education, and Recreation (HPER) Building's Knoxville Applied Physiology Laboratory, preferably between 7:00-10:00 am. Participants were instructed to refrain from eating and drinking 4 hours before visiting the lab which is why the morning hours were preferable. A few exceptions were made for participants to come in during

the afternoon. At the visitation, a health history form was completed by the participant to assess medical conditions or diseases, and a pregnancy test (Mom Med, Co-Innivation Biotech Co.Ltd) was completed by the participant to confirm the participant was not pregnant. All participants met the World Health Organization Physical Activity Guidelines of at least 150 minutes per week of moderate physical activity, 75 minutes per week of vigorous physical activity, or a combination of the two (11).

Dietary Analysis

All participants completed a food frequency questionnaire analyzing vitamin D, calcium, and caffeine dietary intake for a typical day within the previous year. The individual questionnaires making up the full food frequency questionnaire are validated in Schliep et al., 2013, One et al., 2017 , and Glabska et al. , 2015, respectively. The participants were asked to fill out a page including any supplements or foods with caffeine that are regularly included in their diet. The amount of vitamin D, calcium, and caffeine intake per day (µg and mg) was calculated in Excel by the researcher using nutritional amounts from the U.S. Department of Agriculture's FoodData Central ("Nutritional Access Tool", 2013, USA).

Physical Activity and Training History

All participants completed a lifelong physical activity questionnaire that consisted of the time spans between 12-19, 20-29, 30-39, and 40-49 years (for 40 years of age had to be included) of age. Within each time span type of sport or activity, period (years and months), weeks per year, sessions per week, hours per session, and intensity (light, moderate, and high) were recorded by the participant for each exercise. The participant indicated which activities were performed competitively. If the participant traveled by foot or bike to work and/or school then activity to school or work, period (years and months), days per week, minutes per day, and intensity (light,

moderate, and high) were recorded within each age bracket as well. The participants were instructed to include individual sports, team sports, and planned physical activity and exercise. If clarification was needed, the researcher was available to answer questions.

Anthropometrics

Body height (to the nearest inch) and weight (to the nearest pound) were measured with a stadiometer on a mechanical scale. Both measurements were taken with participants wearing athletic clothing (short sleeves and short pants or tights) and without shoes. Age and ethnicity were self-reported and recorded.

Bone Density and Body Composition Measurements

Bone density measurements were obtained using dual-energy X-ray absorptiometry (DXA; software encore version 13.60, GE Lunar iDEXA, GE Healthcare, Madison, WI). Manufacturer-suggested calibration for quality assurance was performed prior to each test. Three separate scans were performed all in standard mode on each participant: total body, non-dominant, anteroposterior forearm, and non-dominate, proximal femur. The regions of interest were total body, total spine, total hips, radial bone, and femoral neck. The total body scan was used for assessment of the total spine and hips, lean and fat tissue mass, body fat %, and body mass index (BMI) calculation. DXA calibration and acquisition were performed by the same experienced technician for all participants.

Muscular Strength Measurements

Two 1-repetition-max (1-RM) strength tests were conducted to determine the maximal strength at two significant sites. A hand dynamometer (Creative Health Products Inc., Takei Scientific Instruments Co. LTD., Japan) was used to assess 1-RM by following the American College of Sports Medicine's Guidelines for Exercise Testing and Prescription (10^{th} edition) static handgrip

strength test procedure (142). Briefly, the participant was in the standing position and the arm used to hold the hand dynamometer was kept in-line with the thigh. Participants were then asked to warm-up on a stationary bike and stretch, if necessary, for 5-10 minutes. A leg press (Body-Solid Leg Press & Hack Squat, Forest Park, IL) with removable weight plates was used to assess 1-RM strength of the lower body by following the American College of Sports Medicine's Guidelines for Exercise Testing and Prescription (10^{th} edition) test procedure for measurement of muscular strength (142). The participant was instructed to achieve a 90-degree bend in the knees for each leg press, and the researcher present verified this. Both tests were demonstrated and explained by the researcher beforehand. Consistency was assured by having the same researcher conduct the tests for all participants.

Statistical Analysis

Statistical analyses were performed with IBM SPSS statistics software version 27.0 (IBM, Armonk, NY). First the data was tested for normality via Kolmogorov-Smirnov and Shapiro-Wilk tests of normality. The vitamin D and sport hours per week data were the only data sets not normally distributed; the means for all the other descriptive data was determined and the median, maximum, and minimum for the nonparametric data was determined. Data was then analyzed using one-way ANOVAs and significant data was then analyzed using Tukey's Post Hoc Test. Nonparametric data was analyzed using the Independent-Samples Kruskal-Wallis Test. Type 1 error was controlled for by running multivariate tests and tests of between-subjects effects. The data was then analyzed using 2-way ANOVAs (age group x classification). Correlations were analyzed using Pearson Correlation tests and Spearman's rho (for nonparametric data). The alpha level remained at 0.05 for all comparisons. Effect size was analyzed using univariate analysis of variance for all data.

Results

The characteristics of the three groups of participants are shown in Table 4. Eleven of the mountain cyclists, eight of the road cyclists, and five of the runners reported that they raced competitively. Ten participants, four mountain cyclists, two road cyclists, and four runners had a BMI classification of overweight. One runner was classified by their BMI as obese, and the other participants were of normal weight. Riding volume (hours) was comparable between the mountain and road cyclists. Runners trained fewer hours per week, as expected. Assessment of history in the sport found that runners had three more years of involvement in the sport than both groups of cyclists. The only significant ($p \leq 0.05$) difference between the groups was calcium intake; mountain cyclists had significantly higher levels of calcium intake than road cyclists and runners. Road cyclists and runners did not meet the recommended daily guideline of calcium (1000 mg/day) for young women while mountain cyclists did meet the guideline. Caffeine intake was low among the participants and below the high caffeine intake amount of 330 mg/day set by Hallstrom et al. (2006) (72). Vitamin D intake for all groups was below the Institute of Medicine's daily recommendation of 15 micrograms; however, vitamin D synthesized by sunlight was not assessed.

The data from the strength tests of the three groups of participants is shown in Table 5. There were no significant differences in handgrip and leg strength and no significant differences when accounting for lean body mass between the groups. The handgrip 1-RM score equals the maximum weight in kilograms of the left and right hands added together. The leg press ratio is defined as the 1-RM weight divided by body weight. Both the handgrip 1-RM score and leg press ratio follow the American College of Sports Medicine's Guidelines for Exercise Testing and Prescription (10^{th} edition) (142) static handgrip strength test scoring protocol.

Table 4. Descriptive characteristics of participants (mean ± SD).

	MC	*RC*	*R*
n	15	17	12
Age (years)	31.7 ± 5.7	31.5 ± 6.6	29.2 ± 4.8
Height (m)	1.67 ± 0.05	1.65 ± 0.07	1.68 ± 0.06
Body mass (kg)	64.7 ± 8.0	62.9 ± 9.0	65.4 ± 8.1
BMI (kg/m^2)	23.0 ± 2.2	22.9 ± 1.7	23.1 ± 3.1
Lean Body Mass (kg)	45.7 ± 4.7	43.8 ± 5.8	44.9 ± 4.2
Body Fat (%)	26.4 ± 4.7	27.8 ± 5.2	28.5 ± 6.8
Sport history (years)	7.8 ± 4.9	8.5 ± 3.5	11.5 ± 4.9
*Sport hours (hrs/wk)**	9.4 (5.5-20)[a]	8.2 (5.5-15)[c]	4 (3-10)[a,c]
*Vitamin D Intake (ug/day)**	2.2 (0.88-9.6)	2.7 (0.97-9.4)	2.5 (0-12.9)
Calcium Intake (mg/day)	1101 ± 449[a,b]	604 ± 220[b]	659 ± 275[a]
Caffeine Intake (mg/day)	128 ± 73	143 ± 85	133 ± 80

Note: MC=mountain cyclist, RC=road cyclist, R=runner, hrs=hours, wk=week, m=meters, kg=kilogram, BMI=body mass index, mg=milligrams, & ug=micrograms.
*Nonparametric data reported by "median (minimum – maximum)".
[a]Significant ($p \leq 0.05$) difference between MC and R; [b]Significant ($p \leq 0.05$) difference between MC and RC;
[c]Significant ($p \leq 0.01$) difference between R and RC.

Table 5. Muscular strength variables in the participants (mean ± SD).

Strength Factors	*MC*	*RC*	*R*
Handgrip 1-RM Score (kg)	63.9 ± 6.9	64 ± 9.6	61.8 ± 8.2
1-RM/LBM	1.4 ± 0.18	1.5 ± 0.15	1.4 ± 0.18
Leg Press 1-RM (kg)	248 ± 44	210 ± 45	218 ± 44
Leg Press Ratio	3.8 ± 0.53	3.4 ± 0.87	3.3 ± 0.53
1-RM/LBM	5.4 ± 0.61	4.8 ± 1.13	4.9 ± 0.91

Note: 1-RM=1-repetition max, MC=mountain cyclist, RC=road cyclist, R=runner, LBM=lean body mass, kg=kilograms, handgrip score=dominate hand max+ nondominate hand max, & leg press ratio= 1-RM (kg) / body weight (kg).

The total body, spine, wrist (radial and ulna combined), and femoral neck BMD data of each group of participants is shown in Table 6. Since there were no significant differences in body weight between the groups, BMD was not adjusted for weight. Only femoral neck BMD was significantly ($p \leq 0.05$) different between the mountain cyclists and runners, with runners having significantly greater femoral neck BMD than mountain cyclists. Correlations of BMD and descriptive characteristics are shown in Table 7. High strain physical activity included involvement in basketball, soccer, tennis, weight-lifting, running, gymnastics, cheerleading, color guard, dance, volleyball, ultimate frisbee, ice hockey, softball, equestrian, and climbing (65, 93). Body mass was positively correlated with all BMD variables (total body, spine, wrist, and femoral neck) ($p \leq 0.05$). Lean body mass and handgrip strength were positively correlated with total body, spine, and wrist BMD ($p \leq 0.05$). Fat mass was positively correlated with wrist BMD. All other variables showed no association with BMD at the tested sites.

Participants were broken into two age groups, 20-30 and 31-40 years of age, to test for significant differences in BMD. The 20-30 age group (N=22) had six mountain cyclists, five road cyclists, and 11 runners. The 31-40 age group (N=22) had nine mountain cyclists, seven road cyclists, and six runners. The BMD at all sites (total body, spine, wrist, and femoral neck) did not significantly ($p \leq 0.05$) differ between the age groups. Prior to the previous three years, road cyclists were involved with 8.1 ± 4.2 years of dynamic, high strain physical activity, mountain cyclists were involved with 7.0 ± 3.3 years, and runners were involved in 7.7 ± 5.4 years. Overall, only two runners displayed osteopenia at the wrist and 1 mountain cyclist displayed osteopenia at the femoral neck. None of the participants had osteoporosis.

Table 6. Bone mineral density (g/cm^2) (mean ± SD) at each of the tested locations.

	MC	*RC*	*R*
Total Body BMD	1.145 ± 0.070	1.184 ± 0.089	1.208 ± 0.082
Spine BMD	1.044 ± 0.091	1.079 ± 0.135	1.125 ± 0.107
Wrist BMD	0.650 ± 0.045	0.679 ± 0.037	0.652 ± 0.044
Femoral Neck BMD	0.999 ± 0.112[a]	1.039 ± 0.078	1.104 ± 0.133[a]

Note: MC=mountain cyclist, RC=road cyclist, R=runner, BMD=bone mineral density, wt=weight, g=grams, cm=centimeters, & kg=kilograms.
[a]Significant ($p \leq 0.05$) difference between MC and R.

Table 7. Correlations between bone mineral density (g/cm^2) and collected variables.

	Total Body	*Spine*	*Wrist*	*Femoral Neck*
Body mass (kg)	0.388[a]	0.416[a]	0.423[a]	0.324[a]
LBM (kg)	0.333[a]	0.395[a]	0.325[a]	0.237
Fat mass (kg)	0.224	0.235	0.336[a]	0.258
Handgrip Score (kg)	0.362[a]	0.432[a]	0.456[a]	0.119
Leg press 1-RM (kg)	0.076	0.065	0.239	0.137
Identified Sport History (yrs)	-0.137	-0.101	-0.287	-0.163
High Strain PA History (yrs)	0.061	0.054	0.252	-0.147
Vitamin D Intake (ug/day)	0.090	0.101	0.212	0.308
Calcium Intake (mg/day)	-0.063	-0.064	-0.014	-0.150
Caffeine Intake (mg/day)	0.019	-0.015	-0.059	-0.008

Note: LBM=lean body mass, kg=kilograms, handgrip score=dominate hand max+ nondominate hand max, yrs=years, PA=physical activity, 1-RM=1-repetition max, mg=milligrams, & ug=micrograms.
[a]Significance ($p \leq 0.05$).

Discussion

The only significant BMD difference between the groups was the femoral neck BMD of the runners being significantly higher than the mountain cyclists. Duncan et al. (127) also found women runners to have higher femoral neck BMD than triathletes, road cyclists, swimmers, and sedentary controls. Although Warner et al. (17) and McVeigh et al. (20) found male mountain cyclists to have greater BMD and bone strength and size, respectively, our study did not find similar results. A reason for the lack of significance may be attributed to the lesser number of hours per week of riding for the women mountain cyclists in our study (9.4 (5.5-20) hours per week) compared to the 11.2 $\pm$ 2.2 and 13.6 $\pm$ 4.6 hours per week of mountain cycling from Warner et al. and McVeigh et al., respectively. The women's involvement in mountain cycling in the present study (7.8 $\pm$ 4.9 years) was more than that of the male mountain cyclists in two previous studies (5.9 $\pm$ 2.8 years in Warner et al. and 5.8 $\pm$ 4.8 years in McVeigh et al.). However, the mountain cyclists in this study only were required to perform at least 6 hours per week of mountain cycling for the previous three years (and 10 months out of the year). Therefore, it is possible the volume of mountain cycling was insufficient to create a significant osteogenic benefit.

This study also found that road cyclists did not have low BMD and their BMD levels were comparable to mountain cyclists and runners. This finding is not consistent with those of Penteado et al. (139) and Maimoun et al. (128) who found that male road cyclists had similar BMD values as sedentary controls. Additionally, Stewart et al. (140) and Medilli et al. (129) found that male road cyclists had lower lumbar spine and femoral neck BMD than sedentary controls. Olmedillas et al. (138) found that adolescent male road cyclists had lower pelvic, total body, femoral neck, and total hip BMD than active controls, Hinrich et al. (136) found that men

and women road cyclists to have lower lumbar spine and femoral neck BMD than runners and sedentary controls, and Anderson et al. (19) found that men and women road cyclists had lower lumbar spine, femoral neck, and total body BMD than runners. Since in the present study the road cyclists had an average of 8.1 $\pm$ 4.2 years of prior involvement in dynamic, high strain physical activities, the osteogenic benefits of those years of training may be the cause of comparable BMD levels as runners and mountain cyclists. This finding agrees with studies showing that weight-bearing physical activity throughout childhood and adolescence is optimal for developing peak bone mineral density (7, 38). The effects of involvement in dynamic, high strain physical activity during childhood and adolescence may also be evident in our runners who averaged 7.7 $\pm$ 5.4 years of involvement in dynamic, high strain physical activity. Other than two runners who were found to have osteopenia at the wrist, runners had healthy BMD at the wrist which is a skeletal site that experiences no osteogenic stimulus while running. Since this study did not test women past the age range of peak BMD, it is unknown if road cycling, mountain cycling, and running can maintain healthy BMD after menopause.

The positive association between BMD and body mass is consistent with previous literature in men and women. Recently, there has been a focus on Relative Energy Deficiency in Sport (RED-S) and Female Athlete Triad (Triad). These models show the negative impact of energy intake deficiency on bone health (50). Since no participants had low total body BMD and only three participants had low BMD at site specific locations, this study found women with normal BMI to also have healthy BMD. Other studies that found women athletes to have low BMD had lower BMI values (21). Skeletal health is impacted by low energy deficiency and poor nutrition which occurs when not consuming enough calories and/or being underweight (1). Huuskonen et al. (59) found that the femoral and lumbar BMD levels of postmenopausal women

were most strongly predicted by body weight. Bjarnason and Christiansen (45) found in 153 early postmenopausal women, participants in the lowest tercile of BMI had 10% lower BMD compared to participants in the highest tercile. Our study also found a positive association between wrist BMD and fat mass. This finding is consistent with the discussion by Fini et al. (15) in which women are shown to have a positive association between healthy levels of fat mass and BMD, as long as they are not classified by their BMI as obese. It is known that at least five participants in the current study had a history of an eating disorder, and their current BMD levels were within the normal range. Therefore, years after recovery from an eating disorder, bone health can be restored to normal levels, which is seen in previous literature, as well (52, 81).

Conclusion

Recreational and competitive women mountain cyclists display similar levels of BMD as recreational and competitive women road cyclists. Recreational and competitive women runners have a higher femoral neck BMD than recreational and competitive women mountain cyclists. Body mass is the most important determinant of BMD in women cyclists and runners. Therefore, underweight women athletes need to take extra precautions when performing physical activities (such as mountain or road cycling) that involves an increased risk of bone fracture from injury, due to falling or crashing. Additionally, underweight women athletes need to implement weight-bearing physical activity, a diet that meets calcium and vitamin D recommendations, reduce caffeine intake, and avoid tobacco use in order to optimize and maintain BMD levels. Prior involvement in dynamic, high strain, or weight-bearing physical activity throughout childhood and adolescence is important for optimizing peak BMD. Bone mineral density can then be maintained by road cycling, running, and mountain cycling (as well as other physical activities)

in the adult years. Further research is needed to identify the relationship between BMD in women and mountain cycling to determine if mountain cycling has an osteogenic benefit.

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APPENDIX A: RECRUITMENT MESSAGE

THE UNIVERSITY OF TENNESSEE KNOXVILLE

Interested in being a participant in a research study on female cyclists and runners?

The purpose of this study is to examine the effects of cycling on bone health in female cyclists and compare the findings to female runners and non-active controls. We are looking for female road cyclists, mountain bikers or off-road cyclists, and runners between the ages of 20-40 years. **You will receive your personal bone health, strength, and nutrition data as a benefit.**

The research study requires one visitation to the Health and Physical Education Building and a total duration of three hours plus your drive time.

Please contact University of Tennessee researcher Sierra Sims at ssims15@vols.utk.edu for more information. The advisors for this research study are Dr. David Bassett (dbassett@utk.edu) and Dr. Jessica Kutz Fleming (jkutz2@utk.edu).

APPENDIX B: SCREENING QUESTIONNAIRE

SCREENING QUESTIONNAIRE

1. Are you a female within 20-40 years of age?
2. Are you pregnant or trying to become pregnant*?
3. Do you have any metal in your body from a surgery?
4. Choose if you identify currently **only as** a (1) mountain cyclist, (2) road cyclist, (3) runner, or (4) non-exerciser and only answer that section's questions next to the "A". Please include information to clarify your answers when necessary.

    1) Mountain (Off-Road) Cyclist
        i. Have you been riding **at least 3 years with 8 hours per week** for at least 10 months out of year? (If no, *explain* about how much you do.)
            A.
        ii. Have you been doing **less than 2 months per year of resistance training** or inconsistent resistance training less than 4 times per month for the last 3 years? (Please state yes or no *and* explain.)
            A.
        iii. Have you been participating in **less than 2 months per year in heavy impact sports** (i.e., soccer, basketball, tennis, running, football, skiing, gymnastics) in the last 3 years or have inconsistently participated? (Please state yes or no *and* explain.)
            A.
        iv. Are you *currently* **amenorrheic** (absence of menstruation) or **oligomenorrheic** (infrequent menstruation)? (yes or no) *Further*, please include if past amenorrheic or oligomenorrheic.
            A.
        v. Do you take **medications** related to bone health?
            A.
        vi. Do you currently **smoke**, or have you consistently smoked (more than 5 times a week for over 6 months at a time) within the last 3 years?
            A.
    2) Road Cyclist
        i. Have you been riding **at least 3 years with 8 hours per week** for at least 10 months out of year? (If no, *explain* about how much you do.)
            A.
        ii. Have you been mountain biking **more than 3 hours a week** within the past 3 years?
            A.
        iii. Have you been doing **less than 2 months per year of resistance training** or inconsistent resistance training less than 4 times per month for the last 3 years? (Please state yes or no *and* explain.)
            A.

        iv. Have you been participating in **less than 2 months per year in heavy impact sports** (i.e., soccer, basketball, tennis, running, football, skiing,

gymnastics) in the last 3 years or have inconsistently participated? (Please state yes or no *and* explain.)

A.

v. Are you *currently* **amenorrheic** (absence of menstruation) or **oligomenorrheic** (infrequent menstruation)? (yes or no) *Further*, please include if past amenorrheic or oligomenorrheic.

A.

vi. Do you take **medications** related to bone health?

A.

vii. Do you currently **smoke**, or have you consistently smoked (more than 5 times a week for over 6 months at a time) within the last 3 years?

A.

3) <u>Runner</u>

i. Have you been running for **at least 3 years with at least 3 hours a week** for at least 10 months out of the year? (If no, *explain* about how much you do.)

A.

ii. Have you been doing **less than 2 months per year of resistance training** or inconsistent resistance training less than 4 times per month for the last 3 years? (Please state yes or no *and* explain.)

A.

iii. Have you been participating in **less than 2 months per year in heavy impact sports** (i.e., soccer, basketball, tennis, football, skiing, gymnastics) *besides running* in the last 3 years or have inconsistently participated? (Please state yes or no *and* explain.)

A.

iv. Are you *currently* **amenorrheic** (absence of menstruation) or **oligomenorrheic** (infrequent menstruation)? (yes or no) *Further*, please include if past amenorrheic or oligomenorrheic.

A.

v. Do you take **medications** related to bone health?

A.

vi. Do you currently **smoke**, or have you consistently smoked (more than 5 times a week for over 6 months at a time) within the last 3 years?

A.

4) <u>Non-Active</u>

i. Do you perform **less than 150 minutes per week of moderate-light physical activity or 75 minutes per week of vigorous physical activity**?

A.

ii. Have you been doing **less than 2 months per year of resistance training** or inconsistent resistance training less than 4 times per month for the last 3 years? (Please state yes or no *and* explain.)

A.

iii. Have you been participating in **less than 2 months per year in heavy impact sports** (i.e., soccer, basketball, tennis, football, skiing,

gymnastics, running) in the last 3 years or have inconsistently participated? (Please state yes or no *and* explain.)

A.

iv. Are you *currently* **amenorrheic** (absence of menstruation) or **oligomenorrheic** (infrequent menstruation)? (yes or no) *Further*, please include if past amenorrheic or oligomenorrheic.

A.

v. Do you take **medications** related to bone health?

A.

vi. Do you currently **smoke**, or have you consistently smoked (more than 5 times a week for over 6 months at a time) within the last 3 years?

A.

*If screened into this study, you will be required to do a pregnancy test during your visit for your safety.

APPENDIX C: CONSENT FOR RESEARCH PARTICIPANTS

Consent for Research Participation

Research Study Title:

Researcher(s): Sierra Sims, UTK Graduate Student, David R. Bassett, Jr. PhD, UTK, Jessica Kutz Fleming, PhD, UTK

Why am I being asked to be in this research study?

We are asking you to be in this research study because you meet the criteria to be a participant in the study as indicated from the screening questionnaire. You are either a female road cyclist, off-road cyclist, runner, or a non-active control with little to no resistance training and a history in your identified category (sport or inactive) of at least 3 years. You are between the ages of 20-40 years. You are not amenorrheic (currently experiencing inconsistent or no menstruation), do not take medications related to bone health, do not smoke or had not consistently smoked in the previous 3 years, have no metal in your body from surgery(s), and are not pregnant or trying to become pregnant. If your pregnancy test shows you are pregnant (positive result) then you will be excluded from the study. If you are a cyclist or non-active control you have little to no history of heavy impact or strain sports (i.e., gymnastics, running) and ride at least 8 hours a week. If you are a runner, you have little to no history of heavy impact or strain sports (i.e., gymnastics, tennis) excluding running and run at least 3 hours a week. If you are a road cyclist, you do not participate in more than 3 hours of mountain biking a week.

What is this research study about?

The purpose of this study is to examine the effect of cycling on bone mineral density in female cyclists and compare their data to female runners as the control. The long-term effects of off-road cyclists, road cyclists, and runners on bone health in females will be assessed by studying females who have been cycling or running for three or more years without consistent resistance training.

Who is conducting this research study?

This study is being conducted by researchers at the University of Tennessee, Knoxville.

How long will I be in the research study?

Participation in this study requires 1 visit lasting about 3 hours. The amount of time it takes you to drive to and from the University visitation location is also required.

What will happen if I say “Yes, I want to be in this research study”?

If you agree to be in this study, we will ask you to plan the following visit with our research team and complete the procedures, surveys, and tests under the visit. Before the visitation we will verbally or through UT Vault send you this reminder: "Being in this study is up to you. You can say no now or leave the study later. Either way, your decision won’t affect your relationship with the researchers, the University of Tennessee, or myself."

Visit #1: (HPER 318 & 309)

You will arrive at the Health and Physical Education (HPER) building and complete a health history form and be given a pregnancy test that must be returned as negative (not pregnant) before continuing the visit procedures. Then you will complete a familiarization protocol and food frequency and training questionnaire with the research personnel. The research personnel will measure your height, weight, and record your age. Last, you meet Pam Andrew, DEXA Technician, and follow her to the DEXA lab (Room 309) to complete your scan before meeting the research personnel back in the lab (Room 318) to do your two 1-RM tests. You may freely use the restroom and drink water during this visit. All the following tests will bring no cost to you as they are all covered by the research personnel.

• Health history form
  ○ This will be completed with the help of research personnel to determine if any previous injuries, medical conditions, or diseases are present. If you have a condition or disease affecting your bone health, you will be excluded from the study.

• Pregnancy test
  ○ This is a safety precaution for you since you will be doing a DEXA scan.

• Familiarization protocol
  ○ This protocol is conducted to familiarize you with the study area. The research personnel will explain all parts of the lab space that you will be using or would possibly need to use (i.e., bathrooms).
  ○ The research personnel will show you where the restrooms and water fountains are located. The research personnel will walk you through the lab space where the anthropometric measurements and 1-Repetition max (1- RM) tests will take place. Lastly, the research personnel will show you where the Dual-energy X-Ray Absorptiometry (DEXA) room is and emergency exits.

• Food frequency and training questionnaires
  ○ These will be used to determine dietary calcium, caffeine, and vitamin D intake. The questionnaires are validated in Schliep et. al., 2013, One et. al., 2017, and Glabska et. al., 2015. Additionally, questions about the participant's training frequency in years and hours per week, type of sport, and intensity will be included.

• Anthropometric measurements
  ○ Height, weight, and age will be recorded.

• Dual-energy X-Ray Absorptiometry (DEXA) scans
  ○ You will wear loose clothing and remove all metal. With the research personnel and Pam Andrews (research coordinator within Kinesiology department who has agreed to perform the tests) present, you will lie down on the DEXA table. This is an open table with a scanning bar that runs the length of the table. Once comfortable, you will be asked to stay as still as possible. The DEXA scanner will be overhead and scan over the entire body (total body scan). Additionally, 2 separate scans will occur, one over the non-dominate forearm and one over the femur on the non-dominate side.

  ○ The DEXA scans will give the percent body fat and lean tissue mass of each participant. The 3 areas being scanned are as follows: total body, forearm, and femur. The bone mineral density of the total body, hips (via total body scan), radial bone (via forearm scan), spine (via total body scan), and femoral neck (via femur scan) will be determined.

- A DEXA scan is similar to an X-Ray and will give off a small amount of radiation (i.e., total body scan= 0.03 mrads, lumbar spine scan= 1.46 mrads, femur scan= 1.46 mrads). A single chest X-Ray gives off 1 mrad per scan and, typically, multiple scans are done during chest examinations in clinical/hospital settings to provide multiple viewpoints of the area. DEXA scans are often performed during middle- or older-aged primary care check-ups to measure bone mineral density. A low bone mineral density is a safety risk because the risk of fracturing a bone through everyday activities increases.

1-Repetition max (1-RM) tests
- A 1-RM test is conducted to find the maximal strength and/or power of the selected muscle. A warm-up protocol with multiple minutes of rest is followed to prepare for the maximal exertion. Before any physical exercise is done with the equipment, the research personnel will demonstrate correct form and explain the goal of the exercise.

- Leg strength and power will be found with a leg press.
- Hand strength will be found with a hand dynamometer.
- A research personnel will be present to guide you through correct 1-RM protocol for both 1-RM tests.

Copies of your data from these tests will be shared with you immediately after collection. Research personnel will explain the data and answer questions about your data.

What happens if I say "No, I do not want to be in this research study"?

Being in this study is up to you. You can say no now or leave the study later.

Either way, your decision won't affect your relationship with the researchers or the University of Tennessee.

What happens if I say "Yes" but change my mind later?

Even if you decide to be in the study now, you can change your mind and stop at any time.

If you decide to stop before the study is completed, contact the PI or any other study- related contact. Your data will be destroyed once you have withdrawn. The research personnel will inform you if your data cannot be withdrawn i.e., the data has already been submitted to a journal or organization.

Are there any possible risks to me?

It is possible that someone could find out you were in this study or see your study information, but we believe this risk is small because of the procedures we use to protect your information. These procedures are described later in this form. The DEXA scans will give off a small amount of radiation which can increase the risk of cancer. The ionizing radiation from a DEXA scan is similar to what a person would receive during cross-country airplane flight or sitting outside on the bleachers for lunch on a sunny day. A much larger dose of radiation would be received from a dental X-Ray. A DEXA scan is commonly performed during a routine check-up with a primary care physician for middle-aged and older-aged adults to ensure safety to perform daily activities as low

bone mineral density carries an increased risk of bone fractures. Three of the scans are on small areas of the body with minimal radiation exposure.

Also, the 1-repetition maximal tests (1-RM tests) can cause physical harm to participants if performed with poor form or if done unsupervised due to the use of heavy weights and forces. Therefore, when you are performing the 1-RM tests, the principal investigator (PI) will be observing the test and you will be educated on proper technique beforehand.

Are there any benefits to being in this research study?

This study will generate data specific to female cyclists which is sparse within the scientific literature. Most of the data on bone health in athletes and in the physically active population focuses on males with little focus on females. This study will give medical professionals a better understanding about the osteogenic outcomes of mountain biking.

You will benefit from this study by learning more about your bone health. Any unknown Osteopenia or Osteoporosis will be identified which will allow you to take further steps to prevent future injury by following up with your personal care physician about the health issue. The copy provided for you of your DEXA scan can be taken to your primary care physician to include in your health record.

There is no compensation provided from participating in this study.

Who can see or use the information collected for this research study?

We will protect the confidentiality of your information by assigning a participant number and storing the identifiable data under your number (not your name) in files that contain any collected data. The only place the name will be stored is in a file that contains all consent forms which are signed and on a participant number key sheet that links names with participant numbers. The data will be stored on a secured database with authentication necessary and within a secure network.

Electronic copies of the collected data will be deidentified and kept for the duration of the study. After 2 years, the consent forms will be de-identified and destroyed. All data will be de-identified and retained by the investigator for future research use for 3 years after collection.

If information from this study is published or presented at scientific meetings, your name and other personal information will not be used.

We will make every effort to prevent anyone who is not on the research team from knowing that you gave us information or what information came from you. Although it is unlikely, there are times when others may need to see the information we collect about you. These include:

- People at the University of Tennessee, Knoxville or the University of Tennessee, Knoxville Medical Center oversee research to make sure it is conducted properly.
- Government agencies (such as the Office for Human Research Protections in the U.S. Department of Health and Human Services), and others responsible for watching over the safety, effectiveness, and conduct of the research.
- If a law or court requires us to share the information, we would have to follow that law or final court ruling.

What will happen to my information after this study is over?

We will keep your information to use for future research. Your name and other information that can directly identify you will be deleted from your research data collected as part of the study.

We will not share your research data with other researchers.

Will it cost me anything to be in this research study?

If you agree to be in this study, you will need to pay for your transportation to and from the study visit. No furthers costs are necessary for participation. Researchers will ensure no costs are placed on you for parking.

What else do I need to know?

About 45 females will take part in this study. Because of the small number of participants in this study, it is possible that someone could identify you based on the information we collected from you.

We may need to stop your participation in the study without your consent if there is a decline in the safety of your participation, you do not follow study instructions, or if the study is stopped for any reason.

If we learn about any new information that may change your mind about being in the study, we will tell you. If that happens, you may be asked to sign a new consent form.

We use procedures to lower the possibility of these risks happening. Even so, you may still experience problems or injury, even when we are careful to avoid them. Please tell the researcher in charge, Sierra Sims (865-566-5989), about any injuries or side effects or other problems that you have during this study.

If physical injury or psychological injury occur, our research personnel are first aid trained and can assist with additional help to our ability. Please seek medical attention from their health care provider and inform the researcher as soon as possible if an injury occurs after the study procedures.

The University of Tennessee does not automatically pay for medical claims or give other compensation for injuries or other problems.

Who can answer my questions about this research study?

If you have questions or concerns about this study, or have experienced a research related problem or injury, contact the researchers, Sierra Sims at 865-566-5989 or at **ssims15@vols.utk.edu** or Dr. David Bassett at **dbassett@utk.edu**.
For questions or concerns about your rights or to speak with someone other than the research team about the study, please contact:

Institutional Review Board
The University of Tennessee, Knoxville 1534 White Avenue
Blount Hall, Room 408
Knoxville, TN 37996-1529
Phone: 865-974-7697
Email: utkirb@utk.edu

STATEMENT OF CONSENT

I have read this form and the research study has been explained to me. I have been given the chance to ask questions and my questions have been answered. If I have more questions, I have been told who to contact. By signing this document, I am agreeing to be in this study. I will receive a copy of this document after I sign it.

Name of Adult Participant Signature of Adult Participant Date

Researcher Signature (to be completed at time of informed consent)

I have explained the study to the participant and answered all of his/her questions. I believe that he/she understands the information described in this consent form and freely consents to be in the study.

Name of Research Team Member Signature of Research Team Member Date

APPENDIX D: HEALTH SCREENING QUESTIONNAIRE

Exercise Pre-participation Health Screening Questionnaire for Exercise Professionals

Asses your client health needs by marking all true statements.

Step 1

SYMPTOMS
Does your client experience:
__ chest discomfort with exertion
__ unreasonable breathlessness
__ dizziness, fainting, blackouts
__ ankle swelling
__ unpleasant awareness of a forceful, rapid or irregular heart rate
__ burning or cramping sensations in your lower legs when walking short distance

If you **did** mark any of the statements under the symptoms, **STOP**, your client should seek medical clearance before engaging in or resuming exercise. Your client may need to use a facility with a **medically qualified staff.**

If you **did not** mark any symptoms, continue to steps 2 and 3

Step 2

CURRENT ACTIVITY

Does your client currently perform planned, structured physical activity at least 30 min at moderate intensity on at least 3 days per week for at least the last 3 months?

Yes☐No ☐ Continue to Step 3

Step 3

MEDICAL CONDITIONS
Has your client had or do they currently have:
__ a heart attack
__ heart surgery, cardiac catheterization, or coronary angioplasty __ pacemaker/implantable cardiac defibrillator/rhythm disturbance __ heart valve disease
__ heart failure
__ heart transplantation
__ congenital heart disease
__ diabetes
__ renal disease

Evaluating Steps 2 and 3:

- If you **did not mark any of the statements in Step 3**, medical clearance is not necessary.
- If you marked Step 2 "**yes**" and **marked any of the statements in Step 3**, your client may continue to exercise at light to moderate intensity without medical clearance. Medical clearance recommended before engaging in vigorous exercise.
- If you marked Step 2 "**no**" and **marked any of the statements in Step 3,** medical clearance is recommended. Your client may need to use a facility with a **medically qualified staff.**

APPENDIX E: LIFE-LONG PHYSICAL ACTIVITY QUESTIONNAIRE

The following document is to examine your past and current physical activity. When the document says “sport” this refers to any planned physical activity (i.e., walking, running, cycling). The term “sport” does not have to be a team sport (i.e., track team, swim team) that you were involved in but would be a planned physical activity that should be included if you were involved in team sports.

Please ask the research personnel if you have any questions or need clarification.

Age 12 – 19 years

Did you perform exercise in the age period 12 – 19 years?

- ❑ *Yes (then fill in the table below)*
- ❑ *No (continue with the next question)*

Type of Sport	Time period	How many weeks per years	How often per week *(times per week)*	How long *(hours per session)*	Intensity *(light, moderate, high)**
E.g.: Doubles tennis	*2 years 6 months*	*40 weeks*	*2 times per week*	*1 hour per session*	*moderate intensity*

Light intensity: activities that cost little effort and are easy to perform.
Moderate intensity: activities that (slightly) increase breathing and heart rate.
High intensity: activities that greatly increase breathing and heart rate.

Which of the activities above did you perform competitively in the age period 12 – 19 years?

_____

Did you travel by foot or by bike to school and/or work in the age period 12 – 19 years?

- ❑ *Yes (then fill in the table below)*
- ❑ *No (continue with the next question)*

Activity to school or work	Time period	How often per week *(number of days per week)*	How long per day *(back and forth)*	Intensity *(light, moderate, high)**
For example: Cycling	*6 years*	*5 days per week*	*30 minutes per day*	*moderate intensity*

Light intensity: activities that cost little effort and are easy to perform.
Moderate intensity: activities that (slightly) increase breathing and heart rate.
High intensity: activities that greatly increase breathing and heart rate.

Age 20 – 29 years

Did you perform exercise in the age period 20 – 29 years?

- ❑ *Yes (then fill in the table below)*
- ❑ *No (continue with the next question)*

Type of Sport	Time period	How many weeks per years	How often per week *(times per week)*	How long *(hours per session)*	Intensity *(light, moderate, high)**
E.g.: Doubles tennis	*2 years 6 months*	*40 weeks*	*2 times per week*	*1 hour per session*	*moderate intensity*

Light intensity: activities that cost little effort and are easy to perform.
Moderate intensity: activities that (slightly) increase breathing and heart rate.
High intensity: activities that greatly increase breathing and heart rate.

Which of the activities above did you perform competitively in the age period 20 – 29 years?

_____

Did you travel by foot or by bike to school and/or work in the age period 20 – 29 years?

- ❑ *Yes (then fill in the table below)*
- ❑ *No (continue with the next question)*

Activity to school or work	Time period	How often per week *(number of days per week)*	How long per day *(back and forth)*	Intensity *(light, moderate, high)**
For example: Cycling	*8 years*	*5 days per week*	*30 minutes per day*	*moderate intensity*

Light intensity: activities that cost little effort and are easy to perform.
Moderate intensity: activities that (slightly) increase breathing and heart rate.
High intensity: activities that greatly increase breathing and heart rate.

Age 30 – 39 years

Did you perform exercise in the age period 30 – 39 years?

- ❑ *Yes (then fill in the table below)*
- ❑ *No (continue with the next question)*
- ❑ *Age category not yet reached (please proceed to the final page of the questionnaire)*

Type of Sport	Time period	How many weeks per years	How often per week *(times per week)*	How long *(hours per session)*	Intensity *(light, moderate, high)**
E.g.: Doubles tennis	*2 years 6 months*	*40 weeks*	*2 times per week*	*1 hour per session*	*moderate intensity*

Light intensity: activities that cost little effort and are easy to perform.
Moderate intensity: activities that (slightly) increase breathing and heart rate.
High intensity: activities that greatly increase breathing and heart rate.

Which of the activities above did you perform competitively in the age period 30 – 39 years?

_____

Did you travel by foot or by bike to school and/or work in the age period 30 – 39 years?

- ❑ *Yes (then fill in the table below)*
- ❑ *No (continue with the next question)*

Activity to school or work	Time period	How often per week *(number of days per week)*	How long per day *(back and forth)*	Intensity *(light, moderate, high)**
For example: Cycling	*8 years*	*5 days per week*	*30 minutes per day*	*moderate intensity*

Light intensity: activities that cost little effort and are easy to perform.
Moderate intensity: activities that (slightly) increase breathing and heart rate.
High intensity: activities that greatly increase breathing and heart rate.

Age 40 – 49 years

Did you perform exercise in the age period 40 – 49 years?

- ❑ *Yes (then fill in the table below)*
- ❑ *No (continue with the next question)*
- ❑ *Age category not yet reached (please proceed to the final page of the questionnaire)*

Type of Sport	Time period	How many weeks per years	How often per week *(times per week)*	How long *(hours per session)*	Intensity *(light, moderate, high)**
E.g.: Doubles tennis	*2 years 6 months*	*40 weeks*	*2 times per week*	*1 hour per session*	*moderate intensity*

Light intensity: activities that cost little effort and are easy to perform.
Moderate intensity: activities that (slightly) increase breathing and heart rate.
High intensity: activities that greatly increase breathing and heart rate.

Which of the activities above did you perform competitively in the age period 40 – 49 years?

_____

Did you travel by foot or by bike to school and/or work in the age period 40 – 49 years?

- ❑ *Yes (then fill in the table below)*
- ❑ *No (continue with the next question)*

Activity to school or work	Time period	How often per week *(number of days per week)*	How long per day *(back and forth)*	Intensity *(light, moderate, high)**
For example: Cycling	*8 years*	*5 days per week*	*30 minutes per day*	*moderate intensity*

Light intensity: activities that cost little effort and are easy to perform.
Moderate intensity: activities that (slightly) increase breathing and heart rate.
High intensity: activities that greatly increase breathing and heart rate.

End of questionnaire

This is the end of the questionnaire.

If you have any additional information, you can place it in the box below:

APPENDIX E: FOOD FREQUENCY QUESTIONNAIRE

Group of products	Products	Serving size	Frequency	Number of servings
Fresh and smoked fish →	Salmon, rainbow trout, herring, eel	50 g (deck of cards)	monthly	
→	Halibut, mackerel, brook trout, sole, tuna	50 g (deck of cards)	monthly	
→	Cod, flounder, plaice, pollock, hake, bass, zander, pike	50 g (deck of cards)	monthly	
Fish products →	Herrings, sardines and tuna products	100 g (e.g. 2 rollmopses, small can of tuna, 2/3 of can of herrings)	monthly	
→	Other fish products	100 g (e.g. 1/3 of can of fish stew)	monthly	
Dairy products	Milk and milk beverages (yoghurt, kefir, buttermilk, cream)	250 g (1 glass)	weekly	
	Rennet cheese	20 g (1 slice)	weekly	
	Blue and soft penicillium cheese	150 g (1 package)	weekly	
	Feta cheese	15 g (1 slice)	weekly	
	Cottage cheese	50 g (1 thick slice, 2 tablespoons)	weekly	
	Processed cheese	25 g (1 slice, 1 spoon, 1 triangle serving)	weekly	
	Homogenized cheese, dairy desert	150 g (1 package)	weekly	
	Dairy ice cream	40 g (1 scoop)	monthly	
Eggs	Egg	50 g (1 medium egg)	weekly	
	Egg yolk	20 g (1 yolk)	weekly	
Meat		100 g (palm of small hand)	weekly	
Meat products		15 g (thin slice of ham, 3 slices of sausage)	weekly	
Cereals	White wheat and confectionery bread	35 g (1 slice, small roll)	weekly	
	Cooked egg pasta	100 g of cooked (1 glass)	weekly	
Fats	Butter, butter products, pork fat	5g (1 teaspoon)	daily	
	Margarine	5g (1 teaspoon)	daily	

How often (on average) have you eaten the following items during the *past month*?

Food item	Never	Servings per month	week	day	Serving size	
Milk **fortified with calcium** to drink	☐	_____	_____	_____	☐ 125 ml ☐ 250 ml ☐ 375 ml	(0.5 cup) (1 cup) (1.5 cups)
Milk **fortified with calcium** in cereal	☐	_____	_____	_____	☐ 60 ml ☐ 125 ml ☐ 250 ml	(0.25 cup) (0.5 cup) (1 cup)
Milk to drink	☐	_____	_____	_____	☐ 125 ml ☐ 250 ml ☐ 375 ml	(0.5 cup) (1 cup) (1.5 cups)
Milk in cereal	☐	_____	_____	_____	☐ 60 ml ☐ 125 ml ☐ 250 ml	(0.25 cup) (0.5 cup) (1 cup)
Milk/Cream in tea/coffee	☐	_____	_____	_____	☐ 15 ml ☐ 30 ml ☐ 60 ml	(1 tbsp) (2 tbsp) (4 tbsp)
Alternative milk to drink – **fortified with calcium** *(☐ soy, ☐ almond, ☐ rice, ☐ hemp, ☐ oat)*	☐	_____	_____	_____	☐ 125 ml ☐ 250 ml ☐ 375 ml	(0.5 cup) (1 cup) (1.5 cups)
Alternative milk in cereal – **fortified with calcium** *(☐ soy, ☐ almond, ☐ rice, ☐ hemp, ☐ oat)*	☐	_____	_____	_____	☐ 125 ml ☐ 250 ml ☐ 375 ml	(0.5 cup) (1 cup) (1.5 cups)
Alternative milk in tea/coffee – **fortified with calcium** *(☐ soy, ☐ almond, ☐ rice, ☐ hemp, ☐ oat)*	☐	_____	_____	_____	☐ 15 ml ☐ 30 ml ☐ 60 ml	(1 tbsp) (2 tbsp) (4 tbsp)
Soy beverage to drink – <u>not</u> fortified with calcium	☐	_____	_____	_____	☐ 125 ml ☐ 250 ml ☐ 375 ml	(0.5 cup) (1 cup) (1.5 cups)
Soy beverage in cereal – <u>not</u> fortified with calcium	☐	_____	_____	_____	☐ 60 ml ☐ 125 ml ☐ 250 ml	(0.25 cup) (0.5 cup) (1 cup)
Evaporated milk	☐	_____	_____	_____	☐ 15 ml ☐ 45 ml ☐ 125 ml	(1 tbsp) (3 tbsp) (0.5 cup)
Sweetened condensed milk	☐	_____	_____	_____	☐ 15 ml ☐ 30 ml ☐ 60 ml	(1 tbsp) (2 tbsp) (4 tbsp)
Milk desserts – homemade *(ex: tapioca, rice pudding)*	☐	_____	_____	_____	☐ 125 ml ☐ 250 ml	(0.5 cup) (1 cup)
Milk desserts – prepared/pre-packaged *(ex: tapioca, rice pudding)* *(1 small container = 113 g)*	☐	_____	_____	_____	☐ 125 ml ☐ 250 ml ☐ 1 container	(0.5 cup) (1 cup) (small)

Food item	Never	Servings per month	week	day	Serving size	
Milk desserts – homemade (**with fortified alternative milk**)	□	_____	_____	_____	□ 125 ml □ 250 ml	(0.5 cup) (1 cup)
Milk desserts – prepared/pre-packaged (with fortified alternative milk) *(ex: tapioca, rice pudding)* *(1 small container = 112 g)*	□	_____	_____	_____	□ 125 ml □ 250 ml □ 1 container	(0.5 cup) (1 cup) (small)
Cream soups prepared with milk	□	_____	_____	_____	□ 125 ml □ 160 ml □ 250 ml	(0.5 cup) (2/3 cup) (1 cup)
Cream soups prepared with alternative milk – **fortified with calcium**	□	_____	_____	_____	□ 125 ml □ 160 ml □ 250 ml	(0.5 cup) (2/3 cup) (1 cup)
Ice cream, ice milk or frozen yogurt	□	_____	_____	_____	□ 125 ml □ 250 ml □ 375 ml	(0.5 cup) (1 cup) (1.5 cups)
Greek yogurt *(plain or flavored)* *(1 small container = 100 g)*	□	_____	_____	_____	□ 60 ml □ 125 ml □ 200 ml □ 250 ml □ 1 container	(0.25 cup) (0.5 cup) (0.75 cup) (1 cup) (small)
Yogurt to eat or drink - regular *(plain or fruit flavored)* *(1 small container = 100 g)*	□	_____	_____	_____	□ 60 ml □ 125 ml □ 200 ml □ 250 ml □ 1 container	(0.25 cup) (0.5 cup) (0.75 cup) (1 cup) (small)
Cottage cheese *(1 small container = 113 g)*	□	_____	_____	_____	□ 125 ml □ 175 ml □ 250 ml □ 1 container	(0.5 cup) (0.75 cup) (1 cup) (small)
Fresh, soft or cream cheese *(brie, camembert, goat, ricotta, feta)*	□	_____	_____	_____	□ 14 g □ 28 g □ 56 g	(0.5 oz) (1.0 oz) (2.0 oz)
Firm or processed cheese *(including in sandwich or mixed dish)* *(blue, fontina, cheddar, Swiss, gouda, colby, edam, provolone, brick)*	□	_____	_____	_____	□ 14 g □ 28 g □ 56 g	(0.5 oz) (1.0 oz) (2.0 oz)
Hard cheese *(gruyère, romano, parmesan)*	□	_____	_____	_____	□ 15 ml □ 30 ml □ 45 ml	(1 tbsp) (2 tbsp) (3 tbsp)
Pizza *(medium 12", 1/8 = 1 slice, approx. 100 g)*	□	_____	_____	_____	□ 1 slice □ 2 slices □ 3 slices	

Food item	Never	Servings per month	Servings per week	Servings per Day	Serving size
Pasta with cream or cheese sauce	☐	_____	_____	_____	☐ 250 ml (1 cup) ☐ 375 ml (1.5 cups) ☐ 500 ml (2 cups)
Lasagna *(1 piece = 7.5 cm x 9 cm)*	☐	_____	_____	_____	☐ 0.5 piece ☐ 1 piece ☐ 1.5 piece
Pasta stuffed with cheese *(ex. tortellini, ravioli)*	☐	_____	_____	_____	☐ 250 ml (1 cup) ☐ 375 ml (1.5 cups) ☐ 500 ml (2 cups)
Oranges *(1 fruit = 1 medium sized fruit)*	☐	_____	_____	_____	☐ 0.5 fruit ☐ 1 fruit ☐ 2 fruits
Orange juice – **fortified with calcium**	☐	_____	_____	_____	☐ 125 ml (0.5 cup) ☐ 160 ml (2/3 cup) ☐ 250 ml (1 cup)
Canned salmon or sardines **with bones**	☐	_____	_____	_____	☐ 28 g (1 oz) ☐ 56 g (2 oz) ☐ 84 g (3 oz)
Salmon – canned or fresh without bones	☐	_____	_____	_____	☐ 56 g (2 oz) ☐ 84 g (3 oz) ☐ 112 g (4 oz)
Other fish	☐	_____	_____	_____	☐ 56 g (2 oz) ☐ 84 g (3 oz) ☐ 112 g (4 oz)
Broccoli – cooked or raw	☐	_____	_____	_____	☐ 60 ml (0.25 cup) ☐ 125 ml (0.5 cup) ☐ 250 ml (1 cup)
Dark leafy greens – cooked *(bok choy, kale, gailan (chinese broccoli), collards, dandelion or beet greens, spinach)*	☐	_____	_____	_____	☐ 60 ml (0.25 cup) ☐ 125 ml (0.5 cup) ☐ 250 ml (1 cup)
Dark leafy greens – raw *(bok choy, kale, gailan (chinese broccoli), collards, dandelion or beet greens, spinach)*	☐	_____	_____	_____	☐ 60 ml (0.25 cup) ☐ 125 ml (0.5 cup) ☐ 250 ml (1 cup)
Dried (or canned) beans or peas *(navy, pinto, kidney, chick peas, lentil, etc.)*	☐	_____	_____	_____	☐ 60 ml (0.25 cup) ☐ 125 ml (0.5 cup) ☐ 250 ml (1 cup)
White bread, buns, rolls, bagels, pita, tortilla	☐	_____	_____	_____	1 serving = 1 slice ½ bagel ½ pita
Whole wheat bread, buns, rolls, bagels, pita, tortilla	☐	_____	_____	_____	1 serving = 1 slice ½ bagel ½ pita

Food item	Never	Servings per month	week	day	Serving size
Pancakes, waffles *(1 small piece = 10.2 cm diameter)*	☐	_____	_____	_____	☐ 1 piece ☐ 2 pieces ☐ 3 pieces
Tofu, firm *(prepared with calcium sulfate)*	☐	_____	_____	_____	☐ 60 ml (0.25 cup) ☐ 125 ml (0.5 cup) ☐ 250 ml (1 cup)
Tofu, silken	☐	_____	_____	_____	☐ 60 ml (0.25 cup) ☐ 125 ml (0.5 cup) ☐ 250 ml (1 cup)
Almonds	☐	_____	_____	_____	☐ 30 ml (2 Tbsp) ☐ 60 ml (0.25 cup) ☐ 125 ml (0.5 cup)
Margarine	☐	_____	_____	_____	☐ 5 ml (1 tsp) ☐ 15 ml (1 tbsp) ☐ 45 ml (3 tbsp)
Egg, large (with yolk)	☐	_____	_____	_____	☐ 1 egg ☐ 2 eggs ☐ 3 eggs
Liver *or liver pâté*	☐	_____	_____	_____	☐ 56 g (2 oz) ☐ 112 g (4 oz) ☐ 168 g (6 oz)
Deli meat *(salami, bologna, luncheon meat)* *(1 slice = 1 oz)*	☐	_____	_____	_____	☐ 1 slice ☐ 2 slices ☐ 3 slices
Meat *(pork, poultry, beef, sausage, bacon)*	☐	_____	_____	_____	☐ 56 g (2 oz) ☐ 112 g (4 oz) ☐ 168 g (6 oz)
Energy bars *(ex: Cliff, Luna bars, SlimFast, PowerBar)* *(small bar = 48g, large bar = 60 g)*	☐	_____	_____	_____	☐ 0.8 bars (small) ☐ 1 bar (large)
Meal replacement drink *(ex: Ensure, Boost, etc.)* *(1 bottle = 235 ml)*	☐	_____	_____	_____	☐ 0.5 bottle ☐ 1 bottle ☐ 1.5 bottle

Supplement Beverages	Never	Servings per month	week	day	Serving size
Decaffeinated coffee (Instant & brewed)					S: 4 oz M: 8 oz L:12 oz
Instant coffee, not decaffeinated (Including flavored types)					S: 4 oz M: 8 oz L:12 oz
Brewed coffee, not decaffeinated					S: 4 oz M: 8 oz L:12 oz
Decaffeinated espresso and espresso drinks (Latte, Mocha, Americano)					S: 4 oz M: 8 oz L:12 oz

Espresso and espresso drinks, not decaffeinated (Latte, Mocha, Americano)			S: 4 oz M: 8 oz L:12 oz
Herbal or decaffeinated tea (Instant, bottled, and brewed)			S: 4 oz M: 8 oz L:12 oz
Green tea (Not decaffeinated-instant, bottled, and brewed)			S: 4 oz M: 8 oz L:12 oz
Black tea such as Lipton, or Earl Grey (Not decaffeinated-instant, bottled, and brewed)			S: 4 oz M: 8 oz L:12 oz
Jolt, Mountain Dew, Red Bull and other highly caffeinated sodas			S: 8 oz M: 12 oz L:16 oz
Regular colas and root beer (With caffeine, not diet)			S: 8 oz M: 12 oz L:16 oz
Diet colas and diet root beer (With caffeine)			S: 8 oz M: 12 oz L:16 oz
Regular colas and root beer (Caffeine free, not diet)			S: 8 oz M: 12 oz L:16 oz
Diet colas and diet root beer (Caffeine free)			S: 8 oz M: 12 oz L:16 oz

Are there any other foods not mentioned above that you usually eat <u>at least once per week</u>?

Other foods that you usually eat at least once per week	Usual serving size	Servings per week
(a)		
(b)		
(c)		
(d)		
(e)		

For the above section, please include all supplements with caffeine (i.e., gels, bars, energy gummies)

VITA

Sierra Sims grew up in Farragut, Tennessee with her parents and two younger brothers. When she graduated from Farragut High School, she then attended the University of Tennessee, Knoxville. Sierra was an engineering major for the first three years of undergraduate school and an honors and honors engineering student. She worked as an undergraduate research student her junior year researching urban runoff and stormwater. Sierra decided to switch into Kinesiology to pursue her passion for exercise, health, and youth sport. After graduating with her Bachelor of Education degree, Sierra stayed at the University of Tennessee to complete her Master of Science in Kinesiology with a focus in Exercise Physiology.