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To the Graduate Council:

I am submitting herewith a thesis written by Olivera Lukajic entitled "The relationship between steps per day and bone variables in healthy postmenopausal women." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Exercise Science.

Dixie Lee Thompson, Major Professor

We have read this thesis and recommend its acceptance:

Edward Howley, David R. Bassett

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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recommend its acceptance:

David R. Bassett, Jr.

Edward T. Howley

Accepted for the Council:

Vice Chancellor and Dean of Graduate Studies

THE RELATIONSHIP BETWEEN STEPS PER DAY AND BONE VARIABLES IN HEALTHY POSTMENOPAUSAL WOMEN

A Thesis Presented
for the Master of Science Degree
The University of Tennessee, Knoxville

Olivera Lukajic

August 2004

DEDICATION

This thesis is dedicated to my mother and father who have always believed in me and supported me. Their hard work ethic and determination to survive inspire me to always give all I have and never to give up. I would also like to dedicate this to all of my friends back in Bosnia who due to the war were robbed of the opportunity to pursue their college dreams. This is for all of you; I love you and miss you every day.

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A very special thanks is extended to all of the women who participated in this research. Without you this would be impossible.

ABSTRACT

The primary purpose of this study was to examine the relationship between ambulatory physical activity (steps per day) and bone variables in healthy, Caucasian postmenopausal women. Additionally, we examined the relationship of body mass (BM), lean mass (LM), and fat mass (FM) with bone variables in this group of women. Average steps taken per day were compared to bone mineral density (BMD) in 93 postmenopausal women (60.8 ± 5.8 yrs). Ambulatory physical activity (steps per day) was measured for 14 consecutive days using a Yamax Digi-Walker SW-200. Additionally, current physical activity (PA) level was estimated using a Paffenbarger Physical Activity Index (PAI) and Seven Day-Recall Questionnaire (PAR). Total daily caloric intake was estimated by 3-day dietary record. When we examined all 93 subjects together ambulatory PA was negatively correlated with age, body mass index (BMI), and BM. There was a significant linear relationship between ambulatory PA and PAI ($P < 0.001$), but no significant relationship between daily steps and PAR. In addition, there was no significant relationship between ambulatory PA and any of the total or regional BMD or bone mineral content (BMC) values ($P > 0.05$). Body mass was associated with total BMD (TBMD), BMD_{LEG}, total BMC, and BMC_{LEG}, while FM was associated with only total BMD, BMD_{LEG}, and BMC_{LEG}. Lean mass was strongly associated with total and regional BMD and BMC. Age was negatively related to TBMD, BMD_{LEG}, and LM. Because of the strong relationship ob BM to bone variables, we expressed bone variables relative to BM. A modest, yet highly significant, relationship was then seen between daily steps and BMD and BMC. The participants were broken down based on steps taken

per day into 3 different activity groups: least active (< 5,500), moderately active (5,500 - 7,500), and most active (> 7,500). There was no significant difference in uncorrected total or regional BMD or BMC for the activity groups. When subjects were grouped according to reported hormone replacement therapy (HRT) use (HRT = yes HRT, NHRT = no HRT), we found that ambulatory PA was negatively correlated with age, BMI, and BM in NHRT, but in YHRT group this negative correlation was only seen between daily steps and age. We found that there was no significant relationship between daily steps and uncorrected total or regional BMD and BMC measured for either HRT group. In conclusion ambulatory PA has no significant effect on uncorrected BMD or BMC in postmenopausal women. However, BM, FM, and especially LM have significant effect on BMD in postmenopausal women. When bone variables are expressed relative to BM, ambulatory PA is significantly related to bone variables.

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CHAPTER 1

INTRODUCTION

The Mosby Medical Dictionary (49) defines osteoporosis as "a loss of normal bone density with thinning of bone tissue and the growth of small holes in the bone" (pg. 574). Osteoporosis is a major health problem in our society, affecting approximately 10 million Americans (43, 61). An additional 18 million people have low bone mass, known as osteopenia, which places them at high risk for developing osteoporosis (61). While osteoporosis affects both sexes; the majority of cases (80%) occur in elderly women, while only 20% of cases occur in men (9, 108). Sixteen percent of all women over the age of 50 have osteoporosis while approximately half of the women over the age of 50 have decreased bone mineral density (BMD) (9, 23, 108). In men over the age of 50, 18% have decreased BMD and only 2% have osteoporosis (9, 23, 108). According to the National Osteoporosis Foundation (90), it is estimated that the number of people with osteoporosis will increase to 12 million by 2010 and 14 million by 2020. It is also predicted that 30 to 40 years from now hip fractures will be three to four times more prevalent than they currently are (67).

Age-related bone loss occurs in all humans. Bone mass, which is the total amount of bone tissue one has, is fairly constant during young adult life. According to Hodgson (61) bone mass reaches its peak by the age 30. After age 30, both men and women experience bone loss of 3 to 5% per decade (61). However postmenopausal women experience the highest rate of bone loss (117). According to Hodgson (61) women may lose up to 20% of her total bone mass in the 5 to 7 years after menopause. By the age of

70-75 a woman may lose up to 35 to 50% of her bone mass (61, 69). This enormous bone loss may lead to fractures, which sometimes worsen to the point that they lead to loss of independence and possibly complications leading to death. There are a number of risk factors important in the development of osteoporosis, such as low body mass, family history of osteoporosis, certain medications (e.g., steroids), lack of physical activity, poor nutrition, smoking, and alcohol consumption (9, 108).

Osteoporosis is a major risk factor for bone fractures. An estimated total of 1.5 million fractures occur annually in the United States, with 700,000, 300,000, and 250,000 fractures of the vertebrae, hip, and wrist, respectively (61). Cumming et al. (34) projected that the cost of hip fractures in 2040 will be $16 billion. Chrischilles et al. (26) estimated that the total cost for 10 years due to osteoporosis will be as much as $96 billion. In the elderly population, a bone fracture can become a debilitating event, which can progress to loss of independence and in some cases even death. According to Lane (76) almost 24% of those who suffer a hip fracture will die within the first year of the fracture. The serious consequences of osteoporosis-related fractures point to the importance of finding ways of decreasing or even reversing the effects of osteoporosis.

Physical activity (PA) is thought to be important in maintaining a good BMD in both men and women of all ages, especially elderly. Several longitudinal investigators have examined the effects of walking and leisure-time physical activity (LTPA) on BMD and reported that exercise has a positive effect on bone mass (21, 40, 46, 74, 92, 139). Most of these studies have assessed PA by the use of self-report methods specifically looking at the effects of aerobic, resistance training, weight-bearing exercise programs

and/or walking programs on BMD (21, 40, 46, 74, 92, 139). Krall and Dawson-Hughes (74) showed that those who walked > 7 mi · week $^{-1}$ on a regular basis had higher BMD than those who walked less than one mile. In general, longitudinal studies (21, 40, 46, 74, 92, 139) and cross-sectional studies (42, 50, 66, 70, 100) have shown that the lumbar, trochanteric and the whole body BMD are significantly higher in exercisers compared to non-exercisers.

Douchi et al. (40) found that women who participated in physical activities such as walking, jogging, and tennis for at least 2 years, at least 2 hours per week had higher lumbar spine BMD ($P < 0.01$) as compared to the sedentary participants, however there was no significant difference in total body BMD between the exercise and sedentary group (40). Caplan and Ward (21) examined the effect of a twice-weekly aerobic weight-bearing program on BMD in 30 postmenopausal women. The results showed that there was no effect of the exercise program on femoral neck, Ward's triangle , and trochanteric BMD, while there was a positive effect on the exercise program on lumbar BMD between exercise and control group after completing the exercise program (21).

In a similar study by Graafmans et al. (50), the researchers found that each 5-point increase in PA score was associated with BMD comparable to a person ten years younger. Some of the studies (46, 50) suggest that those who are currently more active have lower risk of fractures. Feskanich et al. (46) showed that active women had a 55% lower risk of hip fractures as compared to sedentary women, however they did not report if there was any difference in the bone. In addition, they found that the risk of hip fractures decreased by 6% for every 3 MET-h · wk^{-1} increase in activity (46).

It is also important to mention that PA involvement throughout life, not just current activity, is positively associated with BMD (19, 36, 51). Investigators have looked at the effects of previous involvement in athletics and regular exercise for at least the past two years, compared to irregular exercise (40, 42, 66, 109). Those involved in sports and those who participated in regular PA had higher BMD than those who were not involved (40, 42, 66, 109).

A limitation to most research that has been done on PA and bone health is the reliance on recall of the activity by the participant. An alternative approach would be to use a motion sensor device such as a pedometer to measure ambulatory activity. Pedometers are designed to count steps taken, and their accuracy has been shown in previous studies (12, 13, 32, 93, 115). An advantage to using a pedometer is that it can provide an estimate of ambulatory PA without relying on the participant to recall what she has done. To date there are only two studies that have utilized pedometers to track steps per day and examine the relationship to BMD. Hutchinson et al. (64) used pedometers to examine the relationship between steps and BMD in 26-51 year old males, while Kitagawa et al. (70) examined postmenopausal female Japanese participants. The findings from these two studies are in conflict. Kitagawa et al. (70) found that daily steps have a positive effect on BMD in women, but Hutchinson et al. (64) found no correlation between steps taken per day and BMD in men. Given the limitations to questionnaire-based studies and the limited data that objectively measures ambulatory PA, the relationship between daily walking and BMD is unclear.

Purpose

The purpose of this study was to examine the relationship between ambulatory PA (steps per day) and bone variables in healthy Caucasian postmenopausal women.

Hypotheses

Based on previous PA research and its effect on bones in different populations, particularly postmenopausal women, we hypothesize that;

1. Postmenopausal women who take more steps per day will have greater BMD than their less active counterparts.

2. Postmenopausal women who take more steps per day will have greater regional BMD in the pelvis, leg, and spine.

CHAPTER 2

REVIEW OF LITERATURE

The purpose of the research performed was to examine the relationship between ambulatory physical activity (PA) and bone variables in postmenopausal women. Therefore, the main focus of this review of literature will be research that focused on postmenopausal women. A review of the current literature provides evidence that PA can affect changes in BMD and attenuate in bone loss that is often seen during and after menopause (40, 46, 50). The positive effects of exercise on cardiovascular disease, hypertension, diabetes and other diseases have been well established in both men and women (17, 79, 85, 95, 127). Due to an early lack of research examining women, there has been a recent increase in the number of articles concerning women's health, although there are still plenty of questions that remain unanswered. One area of increasing interest is the changes in health that occur when women go through menopause. One of major problems in postmenopausal women is an accelerated decrease in BMD, and a much higher risk for developing osteoporosis versus premenopausal women (23). Fortunately, research has shown that proper nutrition and exercise programs may slow down and even alter bone loss in postmenopausal women. Due to a lack of research in this area there is a need to understand the physiological changes of menopause as well as the outside factors that play a major role in affecting BMD.

Definition and Prevalence of Osteoporosis

Osteoporosis is a condition resulting from loss of bone that leads to skeletal weakness (76). Osteopenia is an intermediate point where bone loss has occurred but

skeletal weakness has not escalated to the point of fractures (76). Bone depends on bone mass which is the total amount of bone tissue one has and bone density which is how compacted that bone tissue is (61). Approximately 10 million Americans are affected by osteoporosis and an additional 18 million people have osteopenia, and therefore are at an increased risk to develop osteoporosis (43, 61). While both sexes can experience a decrease in BMD, 16% of women over the age of 50 have osteoporosis while about half of them have decreased BMD. Of men over the age of 50 18% have decreased BMD and only 2% have osteoporosis (9, 23, 108). Clearly there is a gender difference due to the fact that very few men have osteoporosis.

One of the most devastating outcomes of osteoporosis is a high rate of bone fractures. Even the smallest fracture can and often does lead to disturbing health outcomes as severe as death. After suffering from a fracture many people are not able to perform their daily tasks, which cause them to become dependent on others. For example, fractures of the hip can often lead to complete inactivity, bed rest and sometimes even death. An estimated total of 1.5 million fractures occur annually in the United States, with 700,000 vertebrae, 300,000 hip fractures, and 250,000 wrist fractures (61). It has been predicted that 30 to 40 years from now hip fractures will be three to four times more prevalent than they currently are (67). Chrischilles et al. (26) reported that the estimated health care cost for osteoporotic fractures in white women over the age of 45 will be $45.2 billion over the next ten years. Baron et al. (9) estimates that hip fractures have the greatest daily cost of $191.50 per person during the 40-week follow-up period. Baron et al. (9) also estimate, that in the year following a hip fracture, the cost to Medicare is approximately $15,294 per person, while the cost for the ten most common

fractures combined ends up costing Medicare $4.2 billion dollars per year (9). It is very obvious the damage and cost this disease can cause. Therefore, it is important to understand the menopausal effect on BMD, as well as factors critical in the prevention of and intervention with osteoporosis.

Measuring Bone

Bone strength is measured by determining the BMD and bone mineral content (BMC). An individual's bone density is compared to two standards, known as "age matched" (z-score) and "young normal" (t-score). The age-matched reading compares personal bone density to what is expected in someone of the same age, sex and size (33, 61, 76). Bone mineral density and BMC can be measured using various methods such as quantitative ultrasound (QUS), quantitative computed tomography (QCT), and dual energy X-ray absorptiometry (DXA).

Dual energy X-ray absorptiomerty is the most common and accurate method used to assess BMD and BMC (33, 61, 69, 76). The DXA has been shown to be safe, quick (5-6 min if using the fan beam array or 20-30 min if DXA uses a pencil beam), and has low radiation (69, 76). The low dose of DXA radiation involved is 10-30 μSv per test, while the sun exposure in the United States is 3000 μSv per year (69). The DXA radiation amount is approximately 0.03% of the sun exposure per year (69, 76). According to Kham et al. (69) this equipment uses a stable X-ray generator and two energy levels as the radiation source. Dual energy X-ray absorptiometry considers the body as two separate compartments, bone and non-bone compartment (69). By this method total BMD and total BMC are measured along with regional BMD and BMC.

Regional sites that are measured consist of head, arms, legs, trunk, ribs, pelvis, and spine. Osteoporosis is defined by the World Health Organization (WHO) as a DXA t-score of at least -2.5, while normal BMD is t-score of 0 measured by DXA. Osteopenia is a t-score between – 2.5 and -1.0 (33, 61, 69). One of the disadvantages of DXA is that it cannot distinguish the difference between trabecular and cortical bone. Overall, DXA is a very common and accurate method of measuring BMD and BMC while exposing patients to very little radiation (33, 61, 69, 76).

Dual X-ray absorptiometry is an ideal test for those seeking baseline measurements of BMD (61, 71). Validity of DXA was tested by Koo and colleagues (71) where DXA was to proven to be valid in testing BMD. According to Khan and associates (69) DXA provides accuracy, short-term precision, and long-term reliability. Patel et al. (99) examined long-term precision (7 years) and reproducibility of DXA when measuring BMD and found that DXA is a reliable tool to use. In addition, DXA is considered the gold standard for assessing regional and total BMD.

Bone loss increases after menopause; however the amount of bone loss depends on number of different factors. Factors affecting bone strength and bone loss in postmenopausal women are: body composition, smoking, alcohol, nutrition, and PA.

Menopause

Menopause is defined as the period when the menstrual cycle gradually ceases and eventually comes to a complete halt (138). It is important to include that menopause is not a disease but a very normal and natural phase of every women's life. Menopause normally occurs between the ages of 45-55, however some women may experience it as early as their 30s or as late as 60 years of age (138). It is very important to mention that

women who smoke generally reach menopause 1.5 to 2 years earlier than nonsmokers (61, 86). While most of the time menopause occurs naturally, many women go through a surgical procedure known as a hysterectomy, which causes a premature menopause to take place. The majority of women experience the general signs and symptoms of menopause, which include vasomotor symptoms such as hot flashes, night sweats, insomnia, anxiety, and mood swings (138). Menopause also results in a number of physiological changes such as hormonal changes (i.e., decrease in estrogen and progesterone), which can lead to weight gain in the abdominal region (101, 128, 131, 140), cardiovascular disease (28, 101, 131), and decreased bone mass, which can lead to decrease in BMD and osteoporosis (33, 61, 76).

Android Obesity

As women go through menopause they experience hormonal changes that affect fat distribution. Premenopausal women have high levels of estrogen, which maintains the bone remodeling cycle and helps women to store most body fat in the hip region. However, due to the body producing less estrogen during the years of menopause most women will experience an increase in abdominal fat rather than subcutaneous peripheral fat (82-84, 132). Zamboni et al. (140) used computerized tomography and abdominal circumference to measure body fat distribution in pre and postmenopausal obese women. They found that postmenopausal women had a higher visceral abdominal fat but lower subcutaneous fat as compared to premenopausal women. Several investigators have found that postmenopausal women experience an increase in abdominal fat rather than subcutaneous fat (82, 130, 140). Abdominal fat is known as an android obesity and it's

defined as the type of obesity characterized by body fat in the upper half of the body (52). Android obesity occurs more in men than women, however, postmenopausal women experience it more than premenopausal women (82). In males, it has been found that there is an association between android obesity and higher morbidity and mortality, and higher health risks such as hypertension, high cholesterol, diabetes, and cardiovascular disease (CVD) (4, 6, 55). In addition, android obesity is associated with CVD, which is a leading cause of death in men (65) and postmenopausal women (28, 101, 131). In order to minimize the health issues surrounding android obesity, such as CVD, we need to understand the nature of menopause and its influence on women and the development of android obesity.

Numerous studies have examined the relationship between android obesity and menopause. Ley and colleagues (82) measured body composition and regional body fat using DXA in 103 men, 61 premenopausal, and 70 postmenopausal women ages 19-63. They found that men had the greatest android obesity, 48.6% of their total body fat was abdominal fat. Android obesity was much lower in premenopausal women (38% of their total body fat was abdominal fat) than postmenopausal women (42.1%). They concluded that body fat distribution, measured by DXA, is affected by menopause, specifically in the abdominal region (82). Tremollieres et al. (132) and Svendsen et al. (124) conducted a similar study and found that premenopausal women have lower percent body fat in their upper body when compared to postmenopausal women. Additionally they also concluded that the change in percent body fat was related to menopause (124, 132).

Toth and associates (131) stated that cross sectional studies showed no effect of menopause on body fat distribution while longitudinal showed an association between

menopause and android obesity. In addition, six studies that used DXA to measure fat gain and body fat distribution showed an increase in abdominal fat in women after menopause (131). Toth et al. (130) examined the effect of menopause on weight gain and abdominal fat by using two groups; one group had 53 premenopausal women and a second group had 28 postmenopausal women. Total and regional body fat was measured by DXA while abdominal fat distribution was measured by computed tomography and then compared between the two groups. Trunk, subcutaneous, and intra-abdominal fat were higher in postmenopausal women by 36%, 22%, and 49%, respectively. The researchers concluded that menopausal changes are associated with increase in android fat (130). It is very important to note that high android fat is more associated with health issues such as hypertension, diabetes and cardiovascular disease than an increase in subcutaneous fat (130). Interestingly, previous studies did not take into account if any participants were on hormone replacement therapy (HRT). Hormone replacement therapy effectively minimizes the android obesity in postmenopausal women but does not prevent weight gain itself (106). Poehlman et al. (101) examined 35 healthy premenopausal women who had never received HRT. This was a prospective study that followed women for a period of 6 years. After the 6-year period, 18 women experienced menopause and 17 remained premenopausal. All of the women had their body fat determined by underwater weighing and their waist circumference measured. The 18 postmenopausal women experienced an increase in fat mass by 2.5 ± 2 kg while there was no change in the 17 premenopausal women (101).

There is an increasing quantity of research being conducted investigating the effects of menopausal on women's health. Toth and associates (131) conducted a literature review examining four cross sectional and longitudinal studies that used waist-to-hip ratio to analyze the effect of menopause on fat gain and body fat distribution. Current research provides evidence that menopause is related to increases in body mass and abdominal body fat in postmenopausal women (34, 82, 101, 124, 132). It is very clear that there is an increase in total central abdominal adiposity, which in turn increases the risk for CVD in postmenopausal women (28, 56, 101, 124, 128, 130, 140). With an increase in body fat, postmenopausal women also experience an increase in body mass. Interestingly, this increase in body mass has a positive effect on BMD in postmenopausal women. An increase in body mass places an increased load on the bones, which can result in a higher bone mineral density.

Role of Body Mass on Bone Health

Current research provides information showing an apparent positive relationship between body mass and BMD (25, 29, 57, 58, 89, 118). However, there is an existing debate over whether positive effects on BMD are caused by additional body fat (29, 89, 118), lean mass (25, 29), or body mass (57, 58). With additional body mass, regardless of the body composition, the bones are experiencing greater loading which in turn increases bone strength, and lowers the risk of fractures and osteoporosis.

Harris and colleagues (57) examined the relationship between percent ideal body mass (%IBW) and BMD in 288 postmenopausal women who were enrolled in a 2-year calcium supplement study. Bone mineral density of spine and femoral neck were measured by dual-photon absorptiometry while the radius was measured by single-photon

absorptiometry at one and two year follow-up. Percent IBW was calculated from weight/height tables (110). The results showed that BMD of the spine was inversely related to weight. More specifically, the women had a protective effect of bone loss from the spine when their IBW was between 89 and 110% of their IBW but not greater. Women greater than approximately 106% IBW had significant gains in BMD of the spine, but they did not have further protection from BMD loss. The researchers suggested that high body mass is positively related to BMD in postmenopausal women (57).

Harris and Dawson-Hughes (58) examined 261 postmenopausal women and the relationship between body mass, body composition, and BMD. Dual-energy X-ray absorptiometry was used to measure body mass, body fat, lean mass, BMD of spine, femur, and total body. The results showed a slight negative relationship between total BMD and lean mass (r = -0.12), while there was no relationship between spine and femoral BMD and lean mass (r = 0.01and 0.02, respectively). Also, there was a significant correlation between total BMD and body mass (r = 0.24) (58).

Murillo-Uribe et al. (89) examined the relationship between body fat distribution and BMD in 113 Hispanic postmenopausal women. Participants were divided into two groups based on their BMI; normal weight □27 (n = 75) and obesity group □27 (n = 38). The women were then further divided into groups based on their waist-to-hip ratio (WHR); 1) normal weight with lower-level body fat distribution (gynecoid), 2) obese women with lower-level body fat distribution, 3) normal weight with upper-level body fat distribution (abdominal or android), and 4) obese women with upper-level body fat

distribution. Lunar DPXL was used to measure bone mineral density of the lumbar spine, femoral neck, Ward's triangle and trochanter. The findings showed that when the participants were divided based on their BMI, those in the obese group had a significantly greater BMD than those in the normal weight group ($P < 0.009$). When the participants were divided based on their WHR and BMI, the lumbar spine BMD was higher in the group with obese women with upper level of body fat distribution. This suggests that there is a beneficial effect of the upper-level body fat on BMD for lumbar vertebra (89).

Chen and associates (25) examined the relationship between lean mass and BMD in 50 Caucasian postmenopausal women. The participants had either never been on HRT or stopped taking it at least 1-year before the start of the study. Bone mineral density of the total body, lumbar spine, femoral neck, Ward's triangle and trochanter were measured by DXA. In addition fat mass (FM), lean mass (LM) were also measured by DXA. The findings showed that among FM, %FM, LM, %LM, mass and height, greater body mass was the best predictor of total BMD ($P < 0.001$). Percent LM, when compared to FM, was inversely correlated with total BMD. Lean mass was a significant predictor for all BMD sites measured ($P < 0.001$). From these results the authors were able to suggest that LM, when compared to FM, is closely related to BMD in postmenopausal women while greater body mass is significantly associated with higher BMD (25). Similar findings were reported in a study conducted by Silveira-Marone et al. (118). They examined the influence of body mass, FM, LM on BMD in 61 Hispanic postmenopausal women. Dual energy X-ray was used to measure FM, LM, total body, lumbar spine, femoral neck, Ward's triangle, trochanter, arms, legs, pelvis and head BMD. The results showed that FM, LM, body mass were positively correlated with BMD in total body ($P <$

0.005, $P < 0.002$, $P < 0.002$, respectively), and the pelvis ($P < 0.001$, $P < 0.01$, and $P < 0.001$, respectively). When LM was compared to FM it was determined that LM is the strongest predictor of BMD at all sites ($P < 0.01$ vs. $0.2 < P < 0.5$, respectively). The findings suggest that LM is more important than FM as a predictor of BMD in Hispanic postmenopausal women (118).

Compston and colleagues (29) conducted a study investigating the effect of body fat and lean mass on BMD in 97 postmenopausal women. Lumbar spine and femur BMD along with FM and LM were measured by DXA. The findings showed a positive correlation between FM and all BMD sites measured ($P < 0.01$-0.001), while LM showed a weak correlation with BMD measured at all sites ($P < 0.05$). Based on the findings the authors concluded that FM and LM are both related to BMD while the FM had the strongest relationship (29).

Feskanich et al. (46) conducted a study that examined the risk of hip fractures in postmenopausal women based on their BMI and PA level (met-h $\cdot$ wk^{-1}). The women were placed into six different groups based on their BMI: <21, 21-22.9, 23-24.9, 25-26.9, 27-29.9, $\geq$30. The women in the BMI group of 23-24.9 were classified as the reference group and the results showed that those in the groups with BMIs between 25 and 29.9 did not have an increased relative risk (RR) of hip fractures versus those in the reference group. However, a BMI $\geq$ 30 kg $\cdot$ m^{-2} was associated with 50% less risk of a hip fracture, while those with a BMI <23 kg $\cdot$ m^{-2} had a significantly higher RR of hip fractures. More specifically, those with a BMI of 21-22.9 kg $\cdot$ m^{-2} were at a 45% greater risk of hip

fractures while those with a BMI <21 kg · m^{-2} had an 83% greater risk of hip fractures when compared against the reference group of 23-24.9 kg · m^{-2} (46).

In summary excess body mass, regardless of body composition, has positive benefits on BMD in postmenopausal women. In general, studies showed that body mass is significantly related to BMD in postmenopausal women (25, 29, 57, 58, 89, 118). This is achieved by the increased body mass placing a greater stress on the bones, which results in positive benefits in relation to increased BMD.

Role of Smoking on Bone Health

Smoking is very detrimental to general health as well as bone health. It has been reported that women who smoke experience menopause approximately two years earlier than those who do not smoke (61, 78, 86). Research has further proven that smoking accelerates bone loss in women (20, 61, 72, 73, 76). Smoking interferes with the production of estrogen and progesterone and it also interferes with calcium (Ca^{++}) absorption, allowing bone loss to accelerate (20, 61, 72, 73, 76). Postmenopausal women who smoke are at an even higher risk for developing osteoporosis and are two times more likely to have a fracture than those postmenopausal women who do not smoke (76).

Hooper and Seeman (63) studied the effects of smoking on bone density in 41 female pairs of identical twins between the ages of 27 and 73. The participants had their bone density measured by DXA at the lumbar spine, femoral neck, and femoral shaft. Smoking history as well as other medical history was obtained by questionnaire. Twenty pairs of twins had one sibling that was a heavy smoker. The twin that was the heavy smoker had a 9.3% lower spine BMD, 5.8% lower femoral neck, and 6.5% lower femoral shaft as compared to the twin that smoked less. Further findings were that for every 10

pack-year smoked the BMD decreased by 2% at spine, 0.9% lower at femoral neck, and 1.4% lower at the femoral shaft. The main conclusion of this article is that those who smoke one pack per day will have 5 to 10% lower BMD by the time of menopause as well as higher risk for fractures and osteoporosis (63).

Krall and Dawson-Hughes (72) examined the effect of smoking on BMD, and the rate of bone loss in 320 women (40-70 years of age) who were enrolled in 2-year Ca^{++} supplementation study. Bone mineral density was measured by DXA at baseline, after one year, and after 2 years of participation, while the amount of cigarettes per day were self-reported. Researchers found that bone loss from femoral neck, and spine was higher in women who smoked as compared to nonsmokers, also these findings suggest that smoking interferes with Ca^{++} absorption (72). These findings are in agreement with conclusions from a similar study conducted by these same authors (73).

Baron et al. (10) investigated postmenopausal women from Sweden. They had a control group (n = 3312) and a case group (n = 1328). The case group included women that had sustained a hip fracture between 1993 and 1995. The mean ages for the case and control groups were 72.5 and 70.5 years respectively. More women in the case group were current smokers compared with the control group (26.1% cases vs. 19.3% controls). The researchers compared current smokers to those who never smoked and found that current smokers had a 66% higher risk for hip fracture, while former smokers had 15% higher risk for hip fractures. Another finding was that the maximum number of cigarettes smoked was not related to hip fractures but the duration of smoking was. They also

stated that for each 5 years of smoking cessation there was a decrease in the risk of hip fractures by 2% (10).

Law and Hackshaw (78) conducted a meta-analysis of 29 studies that examined the relationship between smoking and BMD. The researchers did a Medline search for studies measuring BMD, and/or recorded the incidence of hip fractures in women according to their smoking habits. They excluded studies in which the participants were selected because they had a certain disease. The researchers found that smoking is one of the major causes of hip fractures in elderly women. Lifetime risk for fractures increased by 12-19% in women up to 85 years of age and 22-37% in 90 year olds. The meta-analysis also showed that the risk of hip fractures in smokers compared to nonsmokers is 17% higher at age 60, 41% higher at age 70, 71% higher at age 80 and 108% higher at age 90. Major conclusions of this meta-analysis were that smoking does not effect bone in premenopausal women but it does effect postmenopausal bone, as well as that postmenopausal smokers greatly increase their risk of suffering from a hip fractures in older age (78).

Role of Alcohol Consumption on Bone Health

The research on alcohol consumption and its effect on bone is contrdictory (45, 93, 112). Most studies found that moderate alcohol intake can actually benefit and protect BMD (44, 45, 61, 101) while few studies found that chronic alcohol intake increases bone mineral loss (27, 56). According to the U.S. Department of Agriculture and the U.S. Department of Health and Human Services moderate drinking is considered no more than one drink per day for women and no more than two drinks per day for men (113).

According to Hodgson (61) chronic alcohol drinking can increase the risk of developing osteoporosis. Hodgson states that alcohol interferes with the bone-building process while it may enhance the bone-removing process, which results in an increased bone loss (33, 59). Present literature also shows a relationship between consuming large amounts of alcohol and a tendency to eat an unhealthy diet and to be physically inactive which are both factors for developing osteoporosis (33, 59, 74, 109).

Hannan and associates (56) examined osteoporosis risk factors in 800 men and women (mean age 74 yrs) participating in the Framingham study, over a four year period. Bone mineral density was measured by Lunar densiometers at the hip, radius, and spine. Each participant had alcohol intake measured by questionnaire at baseline and following examinations every two years. Over those four years women had a greater bone loss than men (3.4 - 4.8% vs. 0.2 - 3.6%) at all bone sites. They also reported that women who drank at least 7 oz of alcohol per week had greater bone loss at the trochanter when compared to those who drank less than 1 oz $\cdot$ week^{-1} (56).

A study conducted by Clark et al. (27) examined BMD and fractures in women who are recovering from alcohol abuse. There were two groups of women ages 18-70; one group had no history of alcohol abuse (n = 447) and the other group was those in treatment (n = 228). Participants' femoral neck and lumbar spine BMD were measured by DXA. They found that the treatment group had a 7.7% lower femoral neck BMD and 6.3% lower lumbar spine BMD as compared to non-alcohol abusing group. In addition the women who were being treated for alcohol abuse and dependence had lower BMD that those with no history of alcohol use (27).

A large number of studies show that moderate consumption of alcohol is actually beneficial to bone health. Felson and colleagues (44) examined 1164 men and postmenopausal women every two years, who were participants in the Framingham Osteoporosis Study. Participants had their radius, femur, and spine BMD measured by single photon absorptiometer. They were also placed into one of four categories based on alcohol consumption; at least 1 oz, 1-3 oz, 3-7 oz, and more than 7 oz · week^{-1}. The findings showed that postmenopausal women who consumed more than 7 oz · week^{-1} had 4.2% higher radius density than those in the other three drinking categories. The postmenopausal women in the highest drinking category (more than 7 oz · week $^{-1}$) had approximately 5 to 10% higher BMD than nondrinkers (44). Holbrook and Barrett-Connor (62) had 267 women and 182 men ages 45 and older participate in a study examining the relationship between alcohol intake and bone density. Bone density of the radial shaft and wrist by a single photon absorptiometry scanner while femoral neck and lumbar spine were measured DXA. A questionnaire was used to recall alcohol intake in the previous week as well as the alcohol intake in the previous 24 hours. The results showed that, in women, high alcohol intake in the previous week was positively associated with higher bone mass of the spine, while high alcohol intake in the last 24 hours was positively associated with higher BMD of the radial shaft and spine. The researchers concluded that alcohol consumption is positively associated with BMD in women (62).

Another study examining postmenopausal women and the effect of moderate alcohol consumption was done by Feskanich et al. (45). They had a total of 188 postmenopausal Caucasian women (50 to 74 yrs) who were participants in the Nurses'

Health Study that started in 1976. Participants had their lumbar spine and femur BMD measured by DXA. Long-term alcohol intake was calculated and averaged from the food frequency questionnaires that were collected between the years of 1980 to 1990. Women who consumed at least 75 g · week^{-1} of alcohol had a higher BMD in their lumbar spine compared to those postmenopausal women who do not drink. Bone mineral density of the lumbar spine for women who consumed ≥ 75 g · week^{-1} of alcohol was 0.951 g · cm^{-2} while non-drinking women had lumbar spine BMD of 0.849 g · cm^{-2} (45).

Rapuri and colleagues (104) examined 489 postmenopausal women ages 65 to 77 years. They looked at the relationship between alcohol intake and BMD in the spine, mid-radius, and total body. Then women were placed into two groups; the drinking group (147 women), and the control group, which were non-drinkers (297 women). Bone mineral density was measured by DXA, while alcohol intake was established based on a dietary questionnaire. The women in the drinking group were further placed into one of six different categories based on alcohol intake; < 28.6, > 28.6, < 57.2, > 57.2, < 142.9, and > 142.9 g · week^{-1}. The women in the drinking group had a 10% higher BMD in the spine, 4.5% higher total body BMD, and a 6% higher mid-radius BMD than the control group. The findings stated that BMD at lumbar spine, total body, and mid-radius was significantly higher in drinkers when compared to non-drinkers ($P < 0.000$, $P < 0.001$, and $P < 0.014$, respectively). The researchers also reported that the maximum effect of alcohol intake was seen in those that had alcohol consumption between 28.6 and 57.2 g · week^{-1}, where BMD was 16% higher in spine, 12% higher in total body, and 14% higher in mid-radius when compared to the control group. Alcohol consumption tended to

improve BMD at all sites measured in > 57.2 to < 142.9 and > 142.9 g · week^{-1}, however alcohol consumption group of > 142.9 g · week^{-1} had BMD higher only in lumbar spine and total body when compared to non-drinkers (5.5% and 15% respectively). The researchers have concluded that moderate alcohol consumption is associated with higher BMD in postmenopausal women (104).

The findings on alcohol intake and its effect on BMD and osteoporosis in postmenopausal women are not definite. Further studies need to be conducted examining this relationship, as well as the amount of alcohol consumption needed for optimal bone health.

Role of Calcium (Ca^{++}) and Vitamin D on Bone Health

Ninety-nine percent of ingested Ca^{++} is stored in our bones, helping to maintain good bone strength (7, 59, 74). For this reason consuming inadequate amounts of Ca^{++} can result in a decreased peak bone mass, which in turn places individuals at an increased risk for fractures (7, 59, 74). Recommended Daily Allowance (RDA) of Ca^{++} for women older than 50 is 1200 mg · day^{-1} while vitamin D is 400 - 600 IU · day^{-1} (33, 59, 74). American women consume approximately 600 mg Ca^{++} per day, which is well below the recommended value (33, 59, 74). Due to inadequate Ca^{++} intake, older age, hormonal changes related to menopause, postmenopausal women have an even lower amount of Ca^{++} absorbed, which in turn places them at an even greater risk for bone fractures. One way to increase daily Ca^{++} intake is to eat food that is rich in this nutrient or to take Ca^{++} supplements. The research shows that preferred method of increasing daily Ca^{++} is through eating food rich in Ca^{++} rather than taking Ca^{++} supplements (33, 59). Studies have reported that alcohol intake interferes with calcium (Ca^{++}) absorption thereby

accelerating the bone loss process (33, 59, 74). Since alcohol intake, smoking, and Ca^{++} absorption are coupled it is very important to examine the effect of Ca^{++} on bone health and osteoporosis. Calcium and vitamin D are very important nutrients for bone health. Consuming adequate amounts of these nutrients allows us to maintain strong bones. As men and women age they have diminished ability to absorb Ca^{++}. In addition, inadequate vitamin D intake, and smoking decrease Ca^{++} absorption (20, 59, 74, 125). The hormonal changes of menopause further interfere with Ca^{++} absorption (20, 59, 74, 125).

Interestingly, the daily recommended intake of Ca^{++} is not the same for everyone and it depends on age, pregnancy, and the stage of women's life. Factors such as age and the stage of postmenopausal life can influence the rate of bone loss (37, 38). In hopes of determining the amount of sufficient Ca^{++} supplement instead of dietary Ca^{++} intake, Dawson-Hughes et al. (38) conducted a study examining the effect of Ca^{++} supplementation in 301 healthy postmenopausal women. Half of those participants had daily Ca^{++} intake of less than 400 mg per day, while the other half had an intake of 400 to 650 mg Ca^{++} per day. The participants were placed in either a placebo group or supplement group of 500 mg Ca^{++} per day (Ca^{++} carbonate or Ca^{++} citrate) for two years. Calcium carbonate has more calcium per tablet (40%) than Ca^{++} citrate which has 23% of Ca^{++} per tablet, however calcium citrate is absorbed better than calcium carbonate (33). Every six months dual-photon scanner measured BMD of spine, radius, and femoral neck, while Ca^{++} and vitamin D intake was estimated by questionnaire. The findings were that women who are at least 5 years past menopause experienced bone loss from the spine, and they did not benefit from Ca^{++} supplementation. However, those women that

have been postmenopausal for 6 or more years and received 500 mg · day^{-1} Ca^{++} experienced less rapid bone loss when compared to placebo group. Participants with low initial Ca^{++} intake that ingested Ca^{++} citrate experienced less bone loss when compared to the placebo group. Participants who consumed calcium carbonate and placebo group experienced a significant bone loss in the spine region. The changes in BMD in Ca^{++} citrate vs. placebo group in the femoral neck, radius, and spine were 0.87 ± 1.01% vs. –2.11 ± 0.93%, 1.05 ± 0.75% vs. –2.33 ± 0.72%, and -0.38 ± 0.82% vs. –2.85 ± 0.77%, respectively. The findings suggest that women that have been postmenopausal for at least 6 years can benefits from 500 mg daily Ca^{++} supplement (38).

The intake of 1000 mg of Ca^{++} per day in late postmenopausal women (≥ 5 yrs past menopause) has a positive effect on BMD. It has been shown that this amount of Ca^{++} intake slows down axial and appendicular bone loss (105). Reid et al. (105) examined the effect of 1000 mg · day^{-1} of Ca^{++} in 122 postmenopausal women who had a mean dietary Ca^{++} intake of 750 mg · day^{-1}. The participants were at least three years past menopause and were randomly assigned to either a treatment group that received 1000 mg · day^{-1} of Ca^{++} or a placebo group for two years. Participants had their total body, lumbar spine, and proximal femur BMD measured by dual-energy X-ray every six months. Their Ca^{++} intake was estimated by four-day food log at three and six months, and then every six months thereafter. The findings showed that the placebo group experienced approximately 1% bone loss per year, while the Ca^{++} group only lost 0.5% of the bone mass per year. It was also found that Ca^{++} supplementation of 1000 mg · day^{-1} for 2 years decreased bone density loss in the hip and eliminated loss in the spine (105).

While an adequate intake of Ca^{++} is important, the proper intake of vitamin D is also crucial. Baeksgaard and colleagues (8) examined the effect of a combined Ca^{++} carbonate and vitamin D supplement in 240 Danish postmenopausal women who already had a good intake of those nutrients (919 mg $\cdot$ day^{-1} and of 3.8 μg $\cdot$ day^{-1} of vitamin D). The participants were randomly placed in a placebo group, a group that received 1000 mg $\cdot$ day^{-1} of Ca^{++} and 560 IU of vitamin D, or a group that received 1000 mg $\cdot$ day^{-1} Ca^{++}, 560 IU vitamin D and an additional multivitamin containing the same amount of Ca^{++} and vitamin D. Bone mineral density at the hip and forearm were measured by DXA while Ca^{++} intake was estimated from a questionnaire at baseline and after 1 and 2 years in the study. The results stated that women in the Ca^{++} plus vitamin D group experienced an increase in lumbar spine BMD of 1.6% , which is significant, after 2 years, while the placebo experienced no changes. The researchers conclude that even those early postmenopausal women with a high initial Ca^{++} plus vitamin D intake can benefit from an additional Ca^{++} and vitamin D intake (8).

Increased PA levels and increased Ca^{++} intake have been shown to have a protective effect on BMD in postmenopausal women (92, 123). Nelson et al. (92) examined the effect of a 1 - year walking program (4 times $\cdot$ wk^{-1}, 50 min $\cdot$ $session^{-1}$) and increased daily Ca^{++} intake in 36 postmenopausal women. All participants were instructed to consume 800 mg of Ca^{++} per day through their meals. The participants were placed in either a high - Ca^{++} group which in addition to consuming 800 mg of Ca^{++} per day they also consumed milk drink of 831 mg $\cdot$ day^{-1}, or a low - Ca^{++} group which in addition to 800 mg of Ca^{++} per day consumed a placebo drink of 41 mg $\cdot$ day^{-1} of Ca^{++}.

Further distribution of participants was into exercise groups: 1) exercise, moderate dietary Ca^{++} (EXMOD), 2) exercise, high Ca^{++} (EXHI), 3) sedentary, moderate Ca^{++} (SEDMOD), and 4) sedentary, high Ca^{++} (SEDHI). Lumbar and femur BMD were measured by dual-photon absorptiomerty, while the food intake was estimated from 7-day food log. The findings of this study were that the bone mass of the femoral neck in the high Ca^{++} group increased by 2%, while there was a 1.1% decrease in the low Ca^{++} group (92).

Suleiman et al. (123) also examined the relationship between PA, Ca^{++} intake and BMD in 124 healthy white postmenopausal women who had never received HRT. All participants had their BMD measured by DXA at the lumbar spine, hip, left calcaneus, and total body. Physical activity level (PAL) and daily Ca^{++} intake was assessed by questionnaire and four different groups were formed based on those results. The groups were: 1) high Ca^{++} (> 700 mg · day^{-1}) high PAL (> 50 h · wk^{-1}), 2) high Ca^{++}, low PAL (□ 50 h · wk^{-1}), 3) low Ca^{++} (□700 mg · day^{-1}) and high PAL, and the last group was low Ca^{++}, low PAL. The results showed that postmenopausal women in high Ca^{++}, high PAL group had the best BMD at all sites when compared to those in low Ca^{++} , low PAL group. The researchers stated that high Ca^{++} intake and high levels of PA can protect bone mass in women who are 5 to 12 years postmenopausal (123).

To examine the relationship between BMD in postmenopausal women and the amount of Ca^{++} supplementation needed, which appears to depend on the number of postmenopausal years, Dawson-Hughes (37) conducted a review of controlled clinical trials. The findings showed that the maximal effect appears to take place with Ca^{++} supplement of 1000 mg of Ca^{++} per day in postmenopausal women. However, the further

findings were that spine is unresponsive regardless of the Ca^{++} amount (37). Another study by Dawson-Hughes et al. (39) investigated the effect of Ca^{++} and vitamin D supplementation on bone density over 3 years in 176 men and 213 women 65 years of age or older. Participants were randomly assigned into a placebo group or the treatment group daily consuming 500 mg $\cdot$ day^{-1} Ca^{++} citrate and 700 IU $\cdot$ day^{-1} of vitamin D. Bone mineral density in the hip, spine, and total body was measured every six months by DXA, while Ca^{++} intake was estimated from a food frequency questionnaire. The change in BMD in the Ca^{++} citrate plus vitamin D group vs. placebo group for femoral neck, spine, and total body were +0.50 ± 4.80% vs. -0.70 ± 5.03%, +2.12% ± 4.06% vs. +1.22% ± 4.25%, and +0.06% ± 1.83 vs. -1.09% ± 1.71%, respectively. The findings suggested that daily supplementation of 500 mg Ca^{++} citrate and 700 IU of vitamin D decreased bone loss when compared to placebo group.

The significance of Ca^{++} in prevention and treatment of osteoporosis is extremely important in postmenopausal women. Since American women already consume insufficient amounts of Ca^{++}, there is a need to find ways of increasing the Ca^{++} in the diet. The ways of doing this is through ingesting Ca^{++} in the diet (i.e., milk, yogurt, etc.) or through tablet supplementation (i.e., calcium citrate or carbonate). Regardless of how one increases her Ca^{++} intake, the final outcome is a positive benefit on bone health and BMD.

Role of Exercise on Bone Health

In addition to the use of prescription medications, the treatment and prevention of osteoporosis in women consists of ingesting enough Ca^{++}, not smoking, not consuming

excessive amounts of alcohol, and increasing levels of weight-bearing exercise (117). Exercise has been shown in general to have positive effects on BMD in postmenopausal women (41). Weight-bearing exercises such as weight-lifting, running, and jogging are much more effective on BMD than exercises not involving much loading on the bones (e.g., swimming) (42, 113, 117, 136).

Role of Resistance Training on Bone Health

Resistance training is not only beneficial for performance enhancement of athletes but is also beneficial to muscle and bone health of postmenopausal women. Muscle strength of older men and women responds considerably to resistance training (24, 48), which may improve balance and coordination perhaps leading to a decreased risk of falls and fractures (126). Intervention studies have examined the role of high and low-impact activities as well as a resistance training program in maintaining BMD (54, 102), as well as the improvements in BMD as a result of resistance training program participation (68, 91).

A study conducted by Pruitt et al. (102) examined the effects of resistance training on lumbar spine and femoral neck BMD in 17 postmenopausal women in the exercise group and 9 women in the control group. Resistance training program was 9 months long and the participants exercised $3 \cdot week^{-1}$. The researchers found that the lumbar BMD in the resistance training group increased $1.6 \pm 1.2\%$. This was significantly different from the change that occurred in the control group ($-3.6 \pm 1.5\%$) ($P < 0.01$). The resistance training program did not result in any difference for BMD at the femoral neck or wrist between the two groups (102).

Nelson and colleagues (91) examined femoral neck lumbar spine BMD (measured by DXA) in 40 postmenopausal women. Twenty women were in a 1-year resistance training program ($2 \cdot week^{-1}$) while the other 20 were in a control group. The results showed that femoral neck and lumbar spine BMD increased in the resistance training group (0.9% ± 4.5%, and 1.0% ± 3.6%, respectively) while the control group experienced a decline in these variables (-2.5% ± 3.8% and -1.8% ± 3.5%, respectively). The results suggest that high intensity resistance training program is beneficial in maintaining femoral and lumbar spine BMD in postmenopausal women (91).

A study by Kerr and associates (68) examined a relationship between a 2-year resistance training program and hip, lumbar spine, forearm, whole body, and total BMD in 126 postmenopausal women. Participants were divided into 3 different groups: strength (S), fitness (F), and control group (C). Group S and F performed the same 8 exercises (e.g. wrist curls, reverse curl, biceps curl, triceps pushdown, hip flexion, hip extension, latissimus dorsi pull down, and calf raises), three times per week. The F group in addition performed on a stationary bicycle. The findings showed no significant changes in forearm, lumbar spine, and whole body BMD, while there was a significant increase in total and hip BMD ($P < 0.05$ and $P < 0.01$, respectively) in the strength and fitness groups when compared to the control group (68). The findings of the studies above (54, 68, 91) suggest that resistance training is an effective pool for promoting bone health in postmenopausal women.

Role of Aerobic Activities Bone Health

Athletes have been observed to have higher BMD than non-athletes. Etherinton and associates (42) studied 83 former athletes, ages 40-65 and 585 age-matched controls. Out of 83 ex-athletes, 67 were distance runners and 16 of them were tennis players. They used modified Allied Dunbar Fitness Questionnaire Scale to assess levels of PA. The questionnaire was administered at baseline and then again 5-6 years later. Administering the questionnaire in this fashion allowed the researchers to assess current activity measured at baseline and current activity measured 5-6 years later. Original records of ex-athletes sporting associations were used to measure historical PA. Participants had their lumbar spine, femoral neck and forearm BMD measured by DXA. According to the result of the questionnaire they formed four PA groups: ex-athletes n = 83, active controls n = 22 (□1 h · wk^{-1} vigorous activity currently and in the past), low activity control n = 216 (inconsistent levels of PA), and inactive n = 347 (< 15 min · wk^{-1}). The investigators found that the ex-athletes, when compared to the controls, had a greater BMD in the lumbar spine (8.7%) and femoral neck (12.1%). The low active control group had a BMD that fell between the active control group and an inactive group. Femoral neck and lumbar spine BMD was higher in athletes when compared to control group (12.1% and 8.7% respectively). The results suggested that vigorous weight-bearing PA of 1h or longer per week is associated with an increase in BMD in women (42).

Bennell et al. (15) examined BMD in male and female (ages 17-26 yrs) power athletes (n = 27 and n = 23, respectively), distance runners (n = 31 and n = 30, respectively), and controls (n = 27 and n = 28, respectively). Total, upper limb, lumbar spine, femur, tibia/fibula, and foot BMD was measured at baseline and 12 months follow-

up. Baseline results showed that athletes had a greater BMD at all sites when compared to the control group, while power athletes had a greater lumbar spine BMD than endurance group at baseline. The results further showed that male and female power athletes had the higher lumbar spine and foot BMD than endurance and controls at baseline ($P < 0.01$ and $P < 0.05$, respectively). When BMD was examined at 12-month follow up the results showed that all groups experienced an increase to some degree in BMD (15).

Grove and Londeree (54) examined the effect of a 1-year high-impact (e.g., jumping jack, running in place) and low-impact (e.g., walking) exercise program in 15 postmenopausal women. Participants were randomly divided into high-impact exercise group (HI), low-impact exercise group (LO), and the controls (C). Lumbar spine BMD was measured by DPA at baseline, 6 months, and 12 months follow-up. The findings showed that the C group experienced a decrease in BMD ($P = 0.002$), while HI and LO groups had no significant improvement in BMD ($P = 0.853$ and $P = 0.308$, respectively). However, the results showed that HI and LO groups were able to maintain their BMD. Their pre BMD was 1.17 ± 0.10 g · cm^{-2} and 1.18 ± 0.10, while post BMD was 1.19 ± 0.10 and 1.18 ± 0.11 g · cm^{-2}, respectively (54).

Cycling is considered a non-weight bearing type of PA. It has been previously reported that cycling provides cardiovascular health benefits (1) but its effect on BMD is unclear (94). Most cyclists either participate in road cycling or mountain biking which require different skills and place different demands on the body. A major difference between the road and mountain biking is the mechanical loading, therefore it is important

to examine the difference between the two groups. Warner and colleagues (136) examined BMD in male mountain (n = 16) and road (n = 14) highly trained cyclists, ages 20-40 yrs. Their BMD was then compared to a recreationally active (no regular PA schedule) control group (n = 15). Total body, spine, and femoral neck BMD were measured by DXA. The findings showed that there was no difference in BMD between groups, however, when BMD was adjusted for body mass, mountain cyclists had a significantly higher BMD at all sites when compared to road cyclists and control group. The findings suggest that mountain cyclists might have a lower risk of developing osteoporosis at older age when compared to road cyclists and men that are not regularly active (136).

To better understand the effect of cycling on BMD in males Nichols et al. (94) conducted a study involving three different groups of men. One group was older cyclists (n = 27) ages 51.2 ± 5.3 yrs, the second group was young adults cyclists (n = 16), ages 31.7 ± 3.5 yrs, and the final group was non-athletes (n = 24) that were age and body mass matched to the older cyclists. Lumbar spine, proximal femur, and total body BMD was measured by DXA in all three groups. The results showed that older cyclists had a lower BMD at all sites measured when compared to young adult cyclists ($P < 0.03$) as well as non-athlete group. The researchers also reported that according to WHO criteria for osteopenia and osteoporosis 52% of older cyclists would be classified as osteopenic while 15% of them would be osteoporotic at spine and hip. The authors suggest that this may be due to the fact that cycling does not provide a great loading stimulus and impact on the bone (94).

In order to clearly understand the entire picture of osteoporosis and cycling we have to examine studies involving female participants. Unfortunately, only a couple studies examining cycling and BMD in women were found. Heinonen et al. (60) examined BMD in Finnish female orienteers, cross-country skiers, cyclists, weight lifters and a control group (n = 30, 28, 29, 18, and 25, respectively). Lumbar spine, femur, patella, tibia, calcaneus and radius BMD were measured by DXA. The results showed that the weight-lifter group had a higher BMD at all sites when compared to the control group, while out of the endurance groups the orienteers had the highest BMD at femur and tibia. The findings showed that cyclists had the lowest lumbar spine and lower extremities BMD among athlete groups, suggesting that non weight-bearing activities do not provide vertical weight-bearing (60). Another study conducted by Beshgetoor and associates (16) examined the effect of training mode on BMD in 12 female cyclists, 9 runners, and 9 controls (age 49.6 ± 7.9 yrs). Participants' lumbar spine and hip BMD were measured by DXA at baseline and 18 months later. The results showed a significant interaction between training time and femoral BMD in runners and cyclists ($P < 0.04$). Furthermore, runners and cyclists maintained femoral BMD while the control group experienced a decrease ($P < 0.05$). Also, the findings showed that runners maintained lumbar BMD while the cyclists and controls experienced a decrease ($P < 0.007$, and $P < 0.03$, respectively) (16).

In summary, mountain cycling seems to have more positive effect on BMD (136). Mountain cyclists are not consistently seated while cycling; constant up and down

movement of their body allows them to experience more loading than the road cyclists. This in turn provides more impact on bones leading to greater BMD (16, 60, 94, 136).

Role of Walking on Bone Health

Walking is recommended for achieving health benefits associated with PA, and for the elderly it is probably the safest activity (74). The findings of current literature showed that walking has enormous health benefits such as lower body fat, lower blood pressure (BP), decrease in stress level, and decrease in risk for developing cardiovascular disease or any heart disease (41, 88, 122, 133). Assessment of walking and its effect on BMD has been mixed. When examining walking cross-sectional studies the findings generally do not support a positive association between physical activity level and BMD (21, 31, 40), while some of the intervention studies, to some degree, do support a positive association between walking and BMD (74, 92, 139).

Krall and Dawson-Hughes (74) examined the relationship between walking and BMD in 239 healthy white postmenopausal women. Participants were already enrolled in a 1-year placebo-controlled trial of vitamin D supplementation, and none of the participants had taken estrogen during the trial. Participants had their whole body and lumbar spine BMD measured by dual-energy absorptiomerty at baseline, six months, and 1 year into the study. Levels of current PA such as miles walked per week, the amount of time spent in 14 different sports, and leisure time activities during the last month were assessed by self-reported method. Levels of historical PA were assessed by Historical Physical Activity questionnaire where 14 non-walking activities were listed. Time spent in those 14 non-walking activities was then divided into four age groups such as: ages 14-21, ages 22-34, ages 35-50, and from 50 till now. Postmenopausal women who walked >

7.5 miles · week^{-1} had higher whole body BMD ($P = 0.03$) when compared to those postmenopausal women who walked < 1 mile · week^{-1}. Women who were in a group that currently walked 3.5 to 13.4 miles · week^{-1} walked more ($P < 0.05$) during their younger years of 14 to 50 yrs when compared the women who are currently less active (current walking 1 to 3.4 miles · week $^{-1}$) (74).

Uusi-Rasi et al. (135) examined a relationship between walking and BMD in premenopausal women. The participants were 31 newspaper carriers and 30 office workers. Each participants had their lumbar spine, femoral neck, distal femur, patella, proximal tibia, calcaneous and distal radius BMD measured by DXA. On one shift the carriers were more active than office workers, 5926 m walked, 68 flights of stairs climbed vs. 1895 m and 10 flights of stairs, respectively. There was no significant difference in BMD at any site between these two groups which suggested that walking and stair climbing in premenopausal women may not be adequate to improve BMD (135).

Douchi et al. (40) examined the effect of PA on BMD in 57 (mean age 60.4 ± 6.4) postmenopausal women who were regular exercisers and 130 age - matched sedentary controls. Women in the exercise group were those who participated in physical activities for at least 2 hours per week for 2 years. Physical activities were: walking (n = 18), jogging (n = 14), volleyball (n = 7), tennis (n = 4), swimming (n = 3), aerobics (n = 3), and other activities (n = 8). Each participant had their lumbar and total BMD measured by DXA. The results showed that while there was a significant difference in lumbar

spine between these two groups ($P < 0.01$) that there was no significant difference in total BMD between the exercise and sedentary group (40).

Coupland and associates (31) examined 580 postmenopausal women (mean age 53.2 ± 3.8 y) who had no use of HRT in the last 3 months. Physical activity was assessed by the use of the Allied Dunbar National Fitness Survey that contained questions on heavy housework, heavy gardening, walking, cycling and sport activities over the past 4 weeks. Participants' lumbar spine, femur (neck and trochanter), radius (radius/ulna) and whole body BMD was measured by DXA. The results showed no relationship between BMD and total PA. Also, there was no relationship between duration of activities such as housework, swimming or cycling and BMD at any site measured. However, there was a relationship between walking pace and trochanteric and whole body BMD, $P = 0.013$ and $P = 0.045$, respectively. Also a significant relationship was seen between the number of flights of stairs climbed and trochanteric and whole body BMD, $P = 0.016$ and $P = 0.012$, respectively. The researchers stated that while total PA did not have any significant association with BMD at any sites measured walking pace and stair climbing yield a positive association (31).

In 2003, Kitagawa and colleagues (70) investigated the effect of daily steps on BMD in postmenopausal women. Their participants included 143 Japanese postmenopausal women, aged 61-87 years, which had no known history of bone disease, and were not taking estrogen or any other type of HRT. Quantitative ultrasound (QUS) was used to measure calcaneus BMD because it provides information on BMD as well as bone structure. Participants were given a pedometer (HJ-002, Omuron) and instructed to wear it at the waist all day for 7 consecutive days. They were also instructed to record

their steps taken per day as well as a brief description of their daily activities. The mean daily steps taken per day were 8,401 ± 3,404 steps · day^{-1}. Walking up to 12,000 steps · day^{-1} was positively associated with calcaneous BMD, while additional walking had no bonus benefit for calcaneous BMD in postmenopausal women. The researchers stated that steps taken per day may be suitable for examining a relationship between ultrasound parameters and PA in postmenopausal women, however further studies are need to determine and confirm the effect of walking on BMD and the rate of bone loss in postmenopausal women (70). One limitation to the study by Kitagawa and colleagues (70) was that it was conducted in Japanese women and therefore may not be generalizable to other races.

Caplan and Ward (21) examined the effect of a twice-weekly aerobic weight-bearing program on BMD in 30 postmenopausal women. The subjects were divided into two groups, an exercise group (n = 19) and a control group (n = 11). The exercise program consisted of a warm-up, 20-25 minutes of low impact aerobics, followed by 10 minutes of ball games for forty weeks divided into four terms of 10 weeks. Participants' lumbar, femoral neck, femoral trochanter, and Ward's triangle BMD was measured by dual photon absorptiomerty at baseline and post-study. The results showed that after completing the program there was no significant difference in femoral neck, Ward's triangle, and trochanteric BMD ($P = 0.84$, $P = 0.66$, and $P = 0.052$, respectively) between the exercise and the control group. However, the exercise group had a significantly higher lumbar BMD ($P = 0.031$) than the control group after completing the exercise

program. These results suggest that 20-25 minutes of low impact aerobics are beneficial to lumbar BMD in postmenopausal women (21).

White et al. (139) examined the impact of walking and aerobic dancing on BMC in 73 Caucasian postmenopausal women. Participants were randomly assigned to either a walking group (n = 27) or an aerobic dance group (n = 25), while a control group had 21 matched participants. The walking program was 26 weeks long and consisted of first walking 1 mile, 2 days per week, and then increased to walking 2 miles, 4 days per week. The aerobic dance program was also 26 weeks long with 2 dance performances 2 days · week^{-1} that progressed to 5 performances on 4 days · week^{-1}, while the control group was instructed not to perform any regular PA during 6-month experimental period. Bone mineral content and bone width of the radius was measured by Norland-Cameron Bone Mineral Analyser, while arm strength was measured isometrically at 115° of elbow flexion by a cable tensiometer. At the initial testing there was no significant difference in BMC between controls, walkers, and dancers, 0.81, 0.83, and 0.82, respectively. The results showed that there was a decrease in BMC in walking and control group, 1.7% and 1.6%, respectively. Bone width increased in the dance and walking groups, 1.3% and 1.6%, respectively, while dancers experienced an increase in arm strength. However, it's rather difficult to explain the changes that occurred in the radius even though there was no loading on this part of the body (139).

Nelson et al. (92) examined the effect of an increased daily Ca^{++} intake and a 1-year walking program in 36 postmenopausal women. The walking program consisted of supervised walking 4 times per week for total of 52 weeks. Each walking session lasted 50 min, and after 4 weeks participants wore weighted belts while walking, while

sedentary group was instructed not to engage in PA on a weekly basis. All participants were instructed to consume 800 mg of Ca^{++} per day through their meals. The participants were placed in either a high-Ca^{++} group which in addition to consuming 800 mg of Ca^{++} per day they also consumed milk drink of 831 mg $\cdot$ day^{-1}, or a low-Ca^{++} group which in addition to 800 mg of Ca^{++} per day consumed a placebo drink of 41 mg $\cdot$ day^{-1} of Ca^{++}. Participants were assigned to one of four groups: 1) exercise, moderate dietary Ca^{++} (EXMOD), 2) exercise, high Ca^{++} (EXHI), 3) sedentary, moderate Ca^{++} (SEDMOD), and 4) sedentary, high Ca^{++} (SEDHI). Lumbar and femur BMD were measured by dual-photon absorptiomerty (DPA) and by computed tomography (QCT), while the food intake was estimated from 7-day food log. Exercise group experienced an increase in lumbar spine measured by QCT by 0.5% while sedentary postmenopausal women experienced a decrease in this area by 7%. In addition, findings stated that the bone mass of the femoral neck in the high Ca^{++} group increased by 2%, while there was a 1.1% decrease in the low Ca^{++} group. However, neither the walking nor dietary Ca^{++} group experienced any effect on lumbar spine nor distal radius that was measured by DPA (92).

Another study that examined the effect of walking on BMD was an intervention study conducted by Cavanaugh and Cann (22). The researchers had 2 groups of postmenopausal women, walkers (n = 8) and non-walkers (n = 9). The walkers participated in 52-week long walking program that consisted of 15-40 min walking at heart rate (HR) between 60-85% of maximal age-adjusted HR, 3 times per week. Participants had their spinal BMD measured by quantitative computed tomography at baseline, 6, and 12 months. The findings showed that bone loss in walkers and non-

walkers was 5.6 ± 1.4%, and 4.0 ± 1.2%, respectively. From these results the researchers suggested that brisk walking does not prevent bone loss in postmenopausal women (22).

Feskanich et al. (46) examined the effect of walking and leisure-time PA on hip fractures in 61,200 postmenopausal women who were the participants in the Nurses' Health Study which was a 12 year follow up study. Participants reported hip fractures and levels of PA. Physical activity was reported in average time spent per week in walking, jogging, running, bicycling, racquet sports, lap swimming, and other aerobic activities. The results showed that active women (at least 24 MET-h $\cdot$ week^{-1}) had a 55% lower risk of hip fractures as compared to sedentary women (< 3 MET-h $\cdot$ week^{-1}). Postmenopausal women who walked for at least 4 h $\cdot$ week^{-1} had 41% lower risk of hip fractures when compared to those women who walked for less than 1 h $\cdot$ week^{-1} (46).

Ernst (41) conducted a meta-analysis of 21 articles examining exercise programs with women and the effect of those program on bone health. The conclusion of this meta-analysis stated that exercise is beneficial not only for maintaining good bone health but also improving it. Due to the wide range of activities included in the meta-analysis it is unclear what the most beneficial type of activity is for increasing BMD. Based on this meta-analysis, the author stated that weight-bearing exercises (5, 107) such as resistance training, jumping, and running are more effective for bone health than low loading exercises (114, 119, 121). The author reaches the conclusion that there is a need for further research not only to examine drug therapies that are beneficial, but also what are the most advantageous exercise programs to increase BMD (41).

Role of Lifetime Physical Activity on Bone Health

Lifetime PA and its effect on BMD in postmenopausal women has been examined by several investigators (19, 36, 51). One problem is that lifetime PA was assessed by using a self-reported method, which can be unreliable due to the individual's inability to accurately recall activities performed throughout life. A study conducted by Damilakis and colleagues (36) examined the effect of lifetime PA on BMD in 149 healthy Caucasian postmenopausal women. Participants were divided into two groups: control group (those that never participated in any organized sports/activities) (n = 78), and farmers (those that have been active all their life) (n = 71). Lifetime PA was assessed by a questionnaire developed by Kriska (75). The questionnaire asked about participating in leisure time PA during four past age periods: 14-21, 22-34, 35-50, and 50+ years. Lumbar spine and femoral neck BMD were measured by DXA, while broad-band ultrasound attenuation (BUA) and speed of sound (SOS) measurements were performed on the calcaneus. The results showed that farmers (active participants) had higher lumbar spine and femoral neck BMD ($P < 0.001$ for both). The authors stated that those which were physically active all throughout their life (i.e., farmers) had a positive relationship between levels of lifetime PA and BMD (36).

Another study was conducted by Greendale et al. (51), which examined the effect of lifetime PA on BMD in 1,014 postmenopausal women. Using a modified Paffenbarger questionnaire participants were asked to report PA sessions performed in an average week at different life stages such as: past year, the teenage years, age 30, and age 50 years. The results showed that there was a positive correlation between exercise in the

past year and BMD at the hip ($P = 0.001$) and hip components such as greater trochanter, intertrochanter and femoral neck ($P = 0.02$, $P = 0.001$, and $P = 0.001$, respectively). The findings also showed that lifetime PA and BMD had significant relationship at total hip and hip components ($P = 0.008$). The results suggest that current as well as lifetime PA have protective measurements on hip and hip components BMD in postmenopausal women (51).

Brahm et al. (19) examined the relationship between lifetime occupational and leisure-time PA and its effect on BMD in 61 Swedish women ages 23-84 yrs. Dual energy X-ray was used to measure lumbar spine, femoral neck, and total BMD while PA during childhood, young adulthood, and recent years was assessed by Mediterranean Osteoporosis Study Questionnaire (MEDOS). The findings showed that when controlled for age, weight and height women with higher occupational PA had greater lumbar spine BMD ($P < 0.03$) (19).

Use of Physical Activity Questionnaires to Assess Physical Activity

Physical activity patterns can be assessed by using questionnaires such as the Paffenbarger Physical Activity Index (PAI) from the College Alumnus Questionnaire and the Seven-Day Physical Activity Recall (PAR). Questionnaires are commonly used due to the low cost and the low burden on the participants (35). In addition, they can be quickly administered, allow large participant sample-size, and can capture quantitative and qualitative data (35). However, these traditional PA questionnaires have limitations such as the participant having to recall their physical activity resulting in inaccurate estimations of LTPA (11, 14, 35). Other problems that can arise is that participants may misunderstand the question and have difficulty recalling the intensity and frequency of

PA using self-reported methods (35), which makes it difficult to accurately categorize physical activities (69). Bassett et al. (13) reported that participants underestimated their daily walking distance by 2.74 km · day^{-1} using the PAI versus what was measured by a Yamax DW-500 pedometer. They also reported that the energy expenditure from walking was lower on the questionnaire versus an electronic pedometer 555 ± 405 and 1608 ± 640 kcal · wk^{-1}, respectively (13). Despite these limitations PA questionnaires are an acceptable method of assessing PA (35), although it may be beneficial to combine PA questionnaires with the use of an electronic pedometer for a more accurate assessment of historical as well as current leisure time PA, which will give a better understanding of its effects on BMD (11, 14, 47).

Paffenbarger Physical Activity Index from the College Alumnus Questionnaire (PAI)

Paffenbarger first developed the PAI in 1960s, which was used in the Harvard Alumni Study (95). This questionnaire is an accepted and highly used questionnaire, primarily designed to identify leisure-time physical activities associated with hypertensive cardiovascular disease in college alumni (98). The questionnaire is a self-administered questionnaire inquiring for information on city blocks walked each day as well as the number of stairs climbed. Participants are also asked to list all the recreational sports that they have participated in regularly over the past year, as well as the duration and frequency of those activities. Participants are also asked to report how much time they spend in four different activities (vigorous, moderate, light, sitting, and sleeping) during a 24 h day. The final outcome measured in this questionnaire is kcal · week^{-1} (98). Numerous studies have used the participants from the Harvard alumni group

and the PAI questionnaire to study PA influence on coronary heart disease (CHD) and risk of stroke in men (79, 80, 95-98, 116). LaPorte et al. (77) assessed PA in 76 postmenopausal women using a Large Scale Integrated activity monitor (LSI) and the PAI. In addition, a 3-day food log was used to assess caloric intake. While the food log was not a good predictor of activity index, LSI and the PAI were both found to be reliable and effective measures of PA (77).

Some of the studies using the PAI do not agree with the previous findings regarding the validity of energy expended measured by the PAI (2). Ainsworth et al. (2) examined the validity of PAI in 78 men and women. Energy expenditure was estimated from PAI and compared to energy expended measured by cardiorespiratory fitness, body fatness, motion detection, and physical activity records. Participants PA was recorded over 24 hours for each day of the week, including weekends. Energy expended in walking and stair climbing was underestimated on the PAI when compared to the physical activity records (2).

Seven-Day Physical Activity Recall Questionnaire (PAR)

Seven-Day Physical Activity Recall (PAR) is a self-reported PA questionnaire that can be administered by phone or an interview in person. The PAR questionnaire was first developed by Dr. Steven Blair in early 1980's to assess habitual PA in the Stanford Five City Project (111). Since habitual PA varies from day to day, Dr. Blair designed this questionnaire to examine habitual PA of the last seven days, five week days and two weekend days (53, 111, 112). These modifications included recording physical activities only if they were 15 minutes of continuous activity or longer, while work and leisure activities were recorded separately (111). In this questionnaire each participant is asked

to recall how many hours they spent sleeping and participating in three different PA categories (moderate, hard, and very hard) in the past seven days. Those PA hours are then added together and multiplied by MET values assigned for each activity based on energy expenditure (18). For example, sleeping is 1 MET, moderate activity is 4 METs (i.e., walking), hard activity is 6 METs (i.e., jogging), and very hard is 10 METs (i.e., running). The final outcome measured in this questionnaire is kcal $\cdot$ day^{-1}. The PAR is one of the most commonly used questionnaires to assess PA as well as total energy expenditure and it provides useful estimate of habitual PA (2, 3, 30, 53, 59, 103, 137).

Validity and reliability are always important areas of research regardless of what assessment tool is being used. While the PAR questionnaire has some limitations, such as difficulty in recalling PA, many studies have been conducted to examine the validity and reliability of the PAR to assess time spent in PA (2, 3, 30, 53, 59, 137). One study to use this is Blair et al. (18) where total of 1,206 women and 1,077 men were asked to provide the total amount of hours spent in sleep, moderate, hard and very hard PA. Participants were then instructed to complete a three-day food log, recording everything that they consumed. Energy expenditure was estimated from the PAR questionnaire and compared to energy intake from food log. The researchers suggested that the PAR is a good tool in estimating habitual PA (18).

A separate study by Ainsworth and colleagues (2) examined the accuracy of the PAR questionnaire in 75 men and women in white-collar jobs. The PAR questionnaire was used to measure energy expenditure and the total number of hours spent working per day along with the total number of hours spent in sleep, moderate, hard, and very hard

PA in the last seven days. Physical activity was also assessed by an indirect measure of maximal oxygen uptake, percent body fat, and forced expiration volume in 1 second. Kilocalories expended per day in occupational physical activities were estimated by accelerometry, while participants recorded occupational activities for six 2-day periods across one year. The findings showed that the PAR correlated the best with PA records (r = 0.11 to 0.47) (2).

Hayden-Wade et al. (59) conducted a study to test the validity of the PAR. They had 69 participants (25 men, 44 women) who completed the PAR questionnaire both by phone and in-person methods. Each participant wore an accelerometer (TriTrac-R3D) in a waist pouch for 10 days to measure PA, which was then compared to the PAR. According to Hayden-Wade et al. both methods of administering PAR, independent of age, body mass index, or PA level, were valid and had comparable estimates for total activities (r = 0.96). Also, moderate, hard, and very hard activities when examined separately were valid and had comparable estimates in phone and in-person methods (r = 0.94, r = 0.97, and r = 0.97, respectively) (59).

Numbers of studies have examined the validity of PAR questionnaire to estimate energy expenditure (30, 103, 137). Several of them compared values attained by the PAR questionnaire to values attained by doubly labeled water (103, 137). More recent study conducted by Washburn et al. (137) evaluated validity of the PAR questionnaire in 46 overweight young adults (men = 17, women = 29). Total daily energy expenditure (TDEE) along with PA energy expenditure (PAEE) was measured by the PAR and then compared to energy expenditure values measured by doubly labeled water. The results showed that there was no significant difference between TDEE nor PAEE measured by

the PAR and doubly labeled water. Total daily energy expenditure from the PAR vs. doubly labeled water was 11825 ± 1779, and 11922 ± 2516 kJ · day^{-1}, respectively (137).

Another study that had compared TDEE was conducted by Racette and associates (103). Total number of participants was 14 premenopausal obese women whose PA and TDEE were measured by the PAR and doubly labeled water. Following these tests all participants were placed on a 12-week weight reduction program. Total daily energy expenditure prior to weight loss measured by doubly labeled water (3.97 ± 1.23 MJ · day^{-1}) was not significantly different from that measured by PAR (4.79 ± 0.95 MJ · day^{-1}). The results showed that the PAR provides an accurate estimate for PA as well as TDEE in obese women (103). Most of the studies that examined the validity and accuracy of 7-day PAR are in agreement with one another stating that 7-day PAR is a accurate method of assessing PA and estimating TDEE (2, 3, 18, 53, 59, 103, 137), while some disagree (30).

Pedometers

Lifetime and current PA has been mainly measured by the use of questionnaires (13, 42, 46, 50, 74, 92, 100, 139). Current PA patterns are generally measured by "self-reported" PA questionnaires, but they tend to at times underestimate physical activity such as walking (13). Self-reported PA is a possibility to error due to the lack of participant's ability to recall how far they walked nor do they remember to include habitual activities (11, 14, 47). Therefore, there is a need more accurate, reliable as well as low cost devices such as pedometers.

Pedometers invention can be credited to Leonardo DaVinci approximately 500 years ago (87). However, electronic pedometers, according to Bassett and Strath (14) were developed in the last decade (pg. 164). Even Thomas Jefferson was intrigued by this device that he purchased in Paris (14). According to Bassett and Strath (14) Jefferson used it to "keep careful records of his walking". The use of pedometers in 1960 was mainly for measuring plots of land (14). Since those times the use of pedometers has expended dramatically. Currently, pedometers are used to measure steps taken per day and are fairly small size devices worn on the hip, secured on pants or belt. Electronic pedometers are triggered by vertical acceleration that occurs on the waist when walking. With each movement a lever arm moves up and down opening and closing and electrical circuit, and one step is recorded (47). It is very important to note that the pedometers have limitations such as inability to distinguish the difference between walking and running. Pedometers also do not provide information on the duration of exercise, frequency and intensity (11, 14, 47). Despite all of those limitation pedometers are useful in walking studies for measuring steps taken per day (11, 14, 47).

While some pedometers are very simple and only measure steps taken per day, others measure distance (km or miles) covered per day as well as energy expenditure (kilocalories). Researchers are beginning to take advantage of pedometers to assess PA (12, 13, 32, 115), kilocalories expended (32, 93), and miles walked per day (12, 32). Due to an increase in number of pedometer brands the validity of each has become an issue. Which pedometer to use in research as well as clinical settings causes a great amount of confusion among the general public as well as the researchers. Numbers of studies have been conducted in recent years to solve this issue and determine which pedometers are

more valid and reliable in counting steps, calories expended, and distance covered (12, 13, 32, 93, 115).

One of the studies done by Bassett et al. (12) looked at the accuracy of five electronic pedometers (Yamax, Accusplit, Freestyle Pacer, Eddie Bauer, and L.L. Bean) in measuring distance walked. Bassett et al. examined twenty-eight participants ages 18-65 years. In the first part, the participants walked a 4.88-km sidewalk course while wearing the same brand of a pedometer on each hip. The researchers reported that there were significant differences between pedometers ($P < 0.05$), with the Yamax being the most accurate pedometer in measuring the actual distance walked. In the second part of the study, the researchers wanted to examine the effect of the surface on the pedometer accuracy. The participants walked again around a 400-m rubberized track while wearing the same brand of a pedometer on each hip. Once again, the Yamax was shown to be the most accurate in measuring distance covered. The third part of this study examined the effects of walking speed on pedometer accuracy. The participants walked at 2, 2.5, 3, 3.5, and 4 miles per hour. The Yamax was found to be more accurate than any other pedometer for tracking the distance covered in slow to moderate speed (12).

A more recent study conducted by Schneider and colleagues (115) examined the accuracy and reliability of ten different brands of pedometers for measuring steps over a 400-m walk. Ten males and ten females walked around the 400-m track wearing the same brand of pedometer on each side of waistband or belt. The actual steps taken were determined by the use of a hand-tally counter carried by a researcher. While the findings reported that eight out of ten pedometers were not significantly different from the actual

steps counted, Kenz Lifecorder (KZ), New Lifestyles NL-2000 (NL), and Yamax Digi-Walker SW-701 (DW) were the most accurate in measuring steps taken within ± 3% of the actual steps taken (115). Nelson et al. (93) looked at the validity of the Yamax Digi-Walker DW-500 in estimating energy expended. Total of 24 participants walked at speeds of: 2.0, 2.5, 3.0, 3.5 and 4.0 mph. They showed that when the participants walked at speeds of 3-4 miles per hour Yamax provided valid results. However, when the participants walked at 2 mph or slower the Yamax significantly underestimated energy expended (93).

Crouter et al. (32) conducted a study in 2003 assessing steps, distance, and energy cost by the use of pedometers. Ten participants (five males, five females) walked on a treadmill at various speeds (54, 67, 80, 94, and 107 $m \cdot min^{-1}$) for 5-min stages wearing a pedometer on the right side and then the left side. While the participants were walking on a treadmill, a researcher was recording steps taken by a hand-tally counter and energy expenditure (kcal) was measured by indirect calorimetry. The researchers reported that most pedometers underestimated steps at slow pace (54 and 67 $m \cdot min^{-1}$) but the accuracy improved as the walking speed increased. At 80 $m \cdot min^{-1}$ and above, six models Yamasa Skeletone (SK), Omron (OM), Yamax Digi-Walker SW-701 (DW), Kenz Lifecorder (KZ), New Lifestyles 2000 (NL), and Walk4Life LS 2525 (WL) gave mean values that were within ± 1% of actual steps, while most of the pedometers overestimated kilocalories at every speed ($P < 0.05$) (32).

Leenders et al. (81) conducted a study to determine the ability of different PA monitors to detect movement during treadmill walking. Twenty-eight participants walked on a treadmill at 3.2, 4, 4.8, 5.6, and 6.4 $km \cdot h^{-1}$ with accelerometers and Yamax

on the waist measuring bodily movement and energy expended. The findings agree with previous research (32, 93) in that energy expenditure was significantly underestimated by the Yamax, while the bodily movements were significantly related to accelerometers and Yamax ($r = 0.47$ to 0.94). As stated in previous research, it is possible to estimate PA by steps and/or distance covered but it is harder to estimate energy expended at slow speeds (12, 13, 32, 93, 115).

Obviously the popularity of the pedometers is rapidly increasing among researchers as well as the general public. Given the variety of pedometer brand and wide ranges in prices it has become more difficult to decide which one to purchase to serve the best purpose. In general, it seems that the pedometers are most accurate in counting steps (12, 32, 115), less accurate in distance covered (12, 13, 32), and even less accurate in estimating energy expended (13, 32, 81, 93), as well as that they are accurate in people with different BMIs (normal, overweight and obese) (125). Despite the limitations of an electronic pedometer, the device is becoming more and more popular not only among the researchers but also among general public. In order to achieve health benefits associated with PA and walking it has been recommended to take 10,000 steps $\cdot$ day^{-1} (134). The pedometers are being used in health promoting programs such as one in Kansas City, MO school, where T-shirts were made reading "Digi walk today?" (11).

Summary

As discussed already, numerous factors such as exercise, calcium intake, alcohol, smoking, estrogen level, etc. can affect BMD in postmenopausal women. Several studies have shown that exercise can have positive effects on BMD in postmenopausal women

(15, 42, 54, 68, 91, 102), but the type of exercise can greatly influence the changes that occur in BMD. Since walking is an easy activity to track, several studies have used walking to assess the relationship between BMD and physical activity (22, 31, 40, 70, 74, 92), although only a few studies showed that walking has a positive effect on BMD in postmenopausal women (40, 70, 74, 92). Furthermore these improvements seen were not only in total BMD (74) but more so in regional (i.e., lumbar spine) BMD (40, 92). However, Cavanaugh and Cann (22) reported that brisk walking does not prevent bone loss in postmenopausal women. There is much left to learn about the relationship between physical activity and bone health.

CHAPTER 3

MANUSCRIPT

Abstract

PURPOSE: The primary purpose of this study was to examine the relationship between ambulatory physical activity (PA) (steps per day) and bone variables in healthy, Caucasian postmenopausal women. Additionally, we examined the relationship of body mass (BM), lean mass (LM), and fat mass (FM) with bone variables in this group of women.

METHODS: Ambulatory PA was compared to bone mineral density (BMD) in 93 postmenopausal women (60.8 ± 5.8 yrs). Ambulatory PA was measured for 14 consecutive days using a Yamax Digi-Walker SW-200. Additionally, current physical activity level was estimated using a Paffenbarger Physical Activity Index (PAI) and Seven Day Physical Activity Questionnaire (PAR). Total daily caloric intake was estimated by 3-day dietary record.

RESULTS: When we examined all 93 subjects together, ambulatory PA was negatively correlated with age (r = -0.340, $P = 0.001$), body mass index (BMI) (-0.417, $P < 0.001$), and BM (r = -0.363, $P < 0.001$). There was a significant linear relationship between ambulatory PA and PAI ($P < 0.001$), but no significant relationship between ambulatory PA and PAR. In addition, there was no significant relationship between ambulatory PA and any of the total or regional BMD or bone mineral content (BMC) values ($P > 0.05$). However, when we corrected for BM ambulatory PA was significantly correlated to all bone variables measured. Body mass was associated with total BMD, BMD_{LEG}, total

BMC, and BMC_{LEG}, while FM was associated with total BMD, BMD_{LEG}, and BMC_{LEG}. Lean mass was strongly associated with total and regional BMD and BMC. Age was negatively related to TBMD (r = -0.245, P = 0.018), BMD_{LEG} (r = -0.228, P = 0.028), and LM (r = -0.286, P = 0.005). The participants were divided based on steps taken per day into 3 different activity groups: least active (< 5,500), moderately active (5,500 - 7,500), and most active (> 7,500). There was no significant difference in uncorrected total or regional BMD or BMC for the activity groups. When subjects were grouped according to use of hormone replacement therapy (HRT) (HRT or no HRT), we found that ambulatory PA was negatively correlated with age, BMI, and BM in the no HRT group, but in the HRT group this negative correlation was only seen between ambulatory PA and age. We found that there was no significant relationship between daily steps and uncorrected total or regional BMD and BMC measured for either HRT group.

CONCLUSION: In conclusion, ambulatory PA has no significant effect on uncorrected BMD or BMC in postmenopausal women. However, after correction for BM ambulatory PA was positively correlated to all bone variables. In addition, BM, FM, and especially LM were significantly related to BMD in postmenopausal women. Both BM and ambulatory PA appear to impact bone variables in postmenopausal Caucasian women.

Key Words: DXA, PEDOMETER, WALKING, AMBULATORY PHYSICAL ACTIVITY, BODY MASS INDEX

Introduction

Osteoporosis is a major health problem in our society, affecting approximately 10 million Americans (43, 61). An additional 18 million people have osteopenia, which places them at high risk for developing osteoporosis (61). While osteoporosis affects both

sexes; the majority of cases (80%) occur in elderly women (9, 108). Sixteen percent of all women over age 50 have osteoporosis while approximately half of them have a decreased bone mineral density (BMD) (9, 23, 108). In men over the age of 50, 18% have a osteopenia with only 2% having osteoporosis (10, 23, 108). According to the National Osteoporosis Foundation (90), it is estimated that the number of people with osteoporosis will increase to 12 million by 2010 and 14 million by 2020. It is predicted that 30 to 40 years from now hip fractures will be three to four times more prevalent (67).

Physical activity (PA) is thought to be important in maintaining BMD in both men and women of all ages, especially the elderly. Several longitudinal investigations have examined the effects of walking and leisure-time physical activity (LTPA) on BMD and reported that exercise has a positive effect on BMD (21, 40, 46, 74, 92, 139), but the type of exercise can greatly influence the changes that occur. Since walking is a common physical activity, several studies have used walking to examine the relationship between BMD and PA (22, 31, 40, 70, 74, 92). Some studies (cross sectional and intervention studies) do show that walking has a positive effect on BMD in postmenopausal women (40, 70, 74, 92). Furthermore, these improvements were not only in total BMD (74), but more so in regional (i.e., lumbar spine) BMD (40, 92). However, Cavanaugh and Cann (22) reported that brisk walking does not prevent bone loss in postmenopausal women. It is also important to mention that PA involvement throughout life, not just current activity, is positively associated with BMD (19, 36, 51). Investigators have also looked at the effects of previous involvement in athletics, and regular exercise for the past two years compared to irregular exercise (40, 42, 66, 109). Those involved in sports and

those who participated in regular PA had higher BMD than those who were not involved (40, 42, 66, 109). Also those women that have higher body mass (BM) seem to have greater BMD. While some authors argued that this is due to increase lean mass (LM) (25, 29, 118), others state it is due to increase fat mass (FM) (29, 89).

Only one study has examined the relationship between steps taken per day and BMD in postmenopausal women (70), however the participants were Japanese women and the bone measured was limited to the calcaneous. Due to lifestyle, diet differences, and the fact that Kitagawa et al. (70) examined only BMD at the heel, a general application of the results is inappropriate. Therefore, the purpose of this study was to examine the relationship between steps per day and BMD in healthy Caucasian postmenopausal women. Based on PA research and its effect on bones in different populations, particularly postmenopausal women, we hypothesized that:

1. Postmenopausal women who take more steps per day will have greater BMD than their less active counterparts.
2. Postmenopausal women who take more steps per day will have greater regional BMD in the pelvis, leg, and spine.

Methods

Participants

Participants included healthy Caucasian postmenopausal women between the ages of 50 and 75 (60.9 ± 5.8 yr) recruited via flyers, internet postings, word of mouth, local newspaper advertisement, and visits to senior and church groups in the Knoxville, TN area. One hundred seventy women expressed interest in the study and were interviewed via telephone to insure that they met the inclusion criteria for the study. Participants were

excluded if they weighed more than 135 kg, were less than 2 years postmenopausal, had metal implants, reported a history of any bone disease, or reported use of estrogen or any other form of HRT within the past 2 years. In addition, any participants that reported current smoking and/or drinking more than 14 alcoholic drinks per week were excluded. Out of the 170 women screened, 93 women qualified and were included in the study.

Testing Protocol

After the initial screening, each participant visited the Applied Physiology Laboratory on the University of Tennessee campus. All testing was conducted during this visit, which lasted approximately one hour. Upon arrival at the laboratory, they read and signed an informed consent form approved by the University of Tennessee Institutional Review Board (Appendix A). Participants' questions regarding the informed consent or the study were encouraged and answered. Subsequently, each participant filled out a brief questionnaire including background information and medical history to assess health status (Appendix B). The questions asked provided additional screening to ensure that no participant had any diseases or orthopedic problems that would be contraindications to PA.

Total BMD, bone mineral content (BMC), along with specific sites: leg BMD and BMC, pelvis BMD and BMC, and spine BMD and BMC were measured by dual-energy X-ray absorptiometry DXA (Lunar DPX-NT, GELunar, Madison, WI). This device uses pencil-beam technology and a dual energy source to assess total and regional BMD and BMC. Total body scans were performed. The coefficient of variation determined from daily Quality Assurance scans was 0.29%.

Height was measured to the nearest 0.1 cm using a standard calibrated stadiometer (Seca Corp., Columbia, MD). Each participant had her BM measured to the nearest 0.1 kg using a calibrated load cell scale (Bod Pod Body Composition System, Life Measurement Instruments, Concord, CA). Body mass index (BMI) was calculated by dividing mass (kg) by height squared (m^2).

Body composition was determined by whole-body air displacement plethysmography using a Bod Pod Body Composition System (Life Measurement Instruments, Concord, CA). Before each test the Bod Pod was calibrated according to the manufacture's instructions. Each participant's body volume was measured sitting inside a sealed chamber with her hair completely covered with a swim cap and wearing a swimsuit. Body volume was corrected for thoracic gas volume, which was estimated based on gender, age, and height. Body density (D_b) ($kg \cdot L^{-1}$) was determined by body mass (kg) and body volume (L). Once the body density was known, percent body fat was determined by using the Siri equation (120).

Each participant completed two standard PA questionnaires: 1) The Paffenbarger PA Index Questionnaire (PAI) (Appendix C) is a self-administered questionnaire used to assess current levels of PA (98), and 2) The Stanford Seven Day Physical Activity Recall (PAR) (Appendix D) is an interview-based questionnaire administered by the researcher to assess the current levels of PA (111). After testing was complete, investigators trained participants in the use of an electronic pedometer. Participants were instructed to wear a Digi-Walker model SW-200 pedometer (NewLifestyles, Inc., Lees Summit, MO) at the midline of the right thigh on the waistband. Participants were asked to wear the pedometer at all times during the day except when swimming, showering and sleeping.

Before putting the pedometer on in the morning, the participants were instructed to reset the pedometer and also record the time that the pedometer was placed on the waistband. Every night, before going to sleep, the participants removed the pedometer and recorded the total number of steps on the pedometer for that day. They also recorded specific activities they engaged in during the day (Appendix E). While the participants were in the study they were asked not to alter their typical daily PA. This procedure was followed for 14 days.

Each participant was also responsible for keeping a three-day dietary record (two weekdays and one weekend day). Detailed instructions for completing the dietary record were provided (Appendix F) and the participants were encouraged not to modify their diet. The three-day food recall log was entered into a computer containing Nutritionist Pro software v1.3 (First DataBank, Inc., Baltimore, MD) and analyzed for total calories, fat, carbohydrates, protein, Ca^{++}, vitamin D, alcohol, fiber, and iron consumed per day.

Statistical Analyses

Statistical analysis was completed using SPSS 11.5 version for Windows (SPSS Inc., Chicago, IL). An alpha of 0.05 was used to denote statistical significance. Initially, Pearson bivariate correlations were conducted to examine the relationship between steps per day, and age, BMI, BM, total and regional BMD and BMC, t-score, z-score, PAI and PAR. To correct for BM we divided total and regional BMD and BMC values by participant's BM and then conducted Pearson correlations. In addition, we correlated age with total and regional BMD and BMC as well as with BM, LM, and FM. The participants were then divided into three categories based on their current physical

activity level: least active (< 5,500 steps per day), moderately active (5,500-7,500 steps per day), and most active (> 7,500 steps per day). A one-way analysis of variance (ANOVA) was then used to compare total and regional BMD and BMC, t-scores, z-scores, PAI, and PAR between physical activity groups.

The participants were then classified based on whether or not they have ever taken HRT. Subsequently, Pearson bivariate correlations were performed on each HRT group to examine the relationship between steps per day, age, BMI, BM, t-score, z-score, PAI and PAR, total and regional BMD and BMC. Also independent sample t-test was used to compare all variables mentioned above between these two HRT groups.

Results

Physical Characteristics

Ninety-three postmenopausal participants completed the study and were included in the analysis. All tables are presented in the appendix G. Descriptive characteristics of the participants are shown in tables 1 and 2. For all participants, ambulatory PA (steps per day) was negative correlated with age (r = - 0.340, $P = 0.001$), BMI (r = -0.417, $P < 0.001$), and BM (r = - 0.363, $P < 0.001$) (table 3). When the participants were classified into the physical activity groups (<5,500, 5,500-7,500, and > 7,500 steps per day) there were significant differences between the three groups for age ($P = 0.016$), BMI ($P < 0.001$), and BM ($P = 0.007$) (table 1). When all 93 participants were examined we found a significant relationship between ambulatory PA and PAI (r = 0.456, $P < 0.001$) however, we did not find a significant relationship between steps per day and PAR (r = 0.202, $P = 0.052$). There was also a significant difference in PAI among the 3 activity groups (table 1). When we examined the correlation between bone variables and calcium

(Ca^{++}), vitamin D, and alcohol intake we found no significant correlation (data not shown).

Tables 4 and 5 (Appendix G) show the relationship between ambulatory PA and the total and regional BMD and BMC for all 93 participants. When all 93 participants were examined together there was no significant association between ambulatory PA and any of the total or regional BMD or BMC values. Correlations between BM, LM, FM, and bone variables represented in tables 4 and 5, show a strong relationship between LM and TBMD ($r = 0.453$, $P < 0.001$), TBMC ($r = 0.529$, $P < 0.001$), as well as all regional sites of BMD and BMC measured. Because of the strong relationship of BM to bone variables we expressed bone variables relative to BM. This was achieved by dividing the total and regional BMD and BMC variables by the participant's BM. Interestingly, a modest, yet highly significant, relationship was seen between ambulatory PA and all BMD variables measured (table 6) and all BMC variables measured (table 7).

HRT Comparison

Table 8 shows the descriptive characteristics for the HRT groups. There were no differences between groups on any measured variable. Table 9 shows a negative relationship in the HRT group between ambulatory PA and age ($r = -0.376$, $P = 0.010$). However, the no HRT group had a negative relationship not only between ambulatory PA and age ($r = -0.320$, $P = 0.028$), but also between ambulatory PA and BMI ($r = -0.535$, $P < 0.001$), and BM ($r = -0.483$, $P = 0.001$) (table 10). The correlation between ambulatory PA and total and regional BMD and BMC for participants in the HRT groups was not significant (data not shown, r ranged from -0.27 to 0.28).

Discussion

The purpose of this study was to examine the relationship between ambulatory PA (steps per day) and bone variables in postmenopausal women. The study shows that there was no significant relationship between ambulatory PA (steps per day) and the raw scores of total and regional BMD and BMC. Because of the strong relationship between BM and bone variables and also to better examine the relationship between ambulatory PA and BMD, we corrected for BM by dividing total and regional BMD and BMC values by BM. Interestingly, we found a significant relationship between ambulatory PA and all corrected BMD and BMC variables measured. Even though we corrected for BM differently than Kitagawa et al (70) did, our findings were in agreement with their findings. Kitagawa et al. (70) reported positive association between walking up to 12,000 steps per day and calcaneous BMD in Japanese postmenopausal women. We found that those who accumulate more ambulatory PA daily (steps per day) have not only greater total and regional BMD but also total and regional BMC. The method used to measure BMD in Kitagawa's study was different from our method. They used quantitative ultrasound (QUS) to assess only calcaneous BMD while we used DXA and examined total and regional BMD. In addition our findings were in agreement with Krall and Dawson-Hughes (74) who found that those who walked > 7.5 miles per week had greater whole body BMD when compared to those who walked < 1 mile per week. Our findings do not agree with findings reported by Cavanaugh and Cann (22). They examined postmenopausal women 8 walkers and 9 non-walkers, and found that both groups experience similar bone loss (5.6% walkers vs. 4.0% non-walkers). From this they concluded that walking may not be sufficient to prevent bone loss in postmenopausal

women (22). Disagreement in results may be due to the fact that their participants were approximately 10 years younger than ours, and our sample size much larger (93 our women vs. 17 their women). Further, our findings were not in agreement with Uusi-Rassi et al. (135) who examined premenopausal women who were newspaper carriers and office workers. Even though their participants were premenopausal women the findings were not in agreement in that BMD did not differ between these two groups, suggesting that walking may not be adequate in increasing BMD in premenopausal women (135). This could be due to the fact that their participants were premenopausal women. Additionally, the authors did not correct for the influence of BM on bone variables.

There was a significant relationship between ambulatory PA and PAI in this group of women. This suggests that ambulatory PA (steps per day) is a general reflection of overall PA. Our findings are in agreement with LaPorte et al. (77) who assessed PA in 76 postmenopausal women using a Large Scale Integrated activity monitor (LSI) and the PAI. The LSI and the PAI were both found to be reliable and effective measures of PA.

Ambulatory PA was negatively correlated with age, BMI, and BM. These findings are expected and in agreement with findings reported by Thompson et al. who found that ambulatory PA had a significant relationship with BMI and other body composition variables in middle-aged women (129). Interestingly, in our women ambulatory PA was related to BMI only in no HRT women. This may be due to the artificial influence of HRT on body mass.

Other variables that have an effect on BMD are alcohol, calcium (Ca^{++}), and vitamin D intake. Holbrook and Barrett-Connor (62) examined women ages 45 and older

and found that alcohol consumption was positively associated with BMD in women. Baeksgaard and colleagues (8) reported that Ca^{++} plus vitamin D intake can be beneficial to BMD in postmenopausal women. However, when we examined Ca^{++}, vitamin D, and alcohol intake in our women we found no significant correlation between these variables and BMD. A 3-day dietary record may be ineffective in establishing the relationship between nutrient intake and bone variables.

When we examined the effect of BM, FM, and LM on BMD in postmenopausal women, we found that BM and FM have significant relationship with certain bone variables. These findings were similar with findings reported by Harris and colleagues (57) and Harris and Dawson-Hughes (58). They found that BM is positively related to total BMD, as did we. In addition, our findings on FM and its positive effect on BMD are in agreement with findings reported by other studies (29, 89). Our results showed that LM was strongly associated with total and all regional BMD and BMC sites measured. These findings are in agreement with findings reported by Compston et al. (29) as well as Chen and associates (25) who reported that LM is more important in predicting total and pelvis BMD in Caucasian postmenopausal women.

The present study does have some limitations. For instance, pedometers do not provide information on intensity duration or exercise. In addition, pedometers underestimate steps taken at slower walking pace at which majority of elderly function. Also, pedometers do no measure activities such as cycling and swimming and underestimate some moderate activities such as gardening. Nevertheless, pedometers do provide an accurate, objective method of quantifying accumulated ambulatory PA.

Overall, we concluded that ambulatory PA (steps per day), measured by the use of an electronic pedometer, when corrected for BM was significantly correlated to total and regional BMD and BMC after correction for BM, in Caucasian postmenopausal women. In addition, BM, FM, and LM were strongly related to all bone variables measured. The strong relationship between BM and bone variables masks the relationship between walking and bone. It may be that those who are heavier need fewer total steps to have the same impact on bone compared to those who weight less. Additional research is needed to help clarify this complex interaction among variables.

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APPENDICES

Appendix A

Informed Consent

INFORMED CONSENT

Title of Study: Relationship between physical activity and bone mineral density and body composition in healthy postmenopausal women.

Co-Investigator: Olivera Lukajic and Emily Krumm

Address: The University of Tennessee
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Faculty Advisor: Dr. Dixie L. Thompson

PURPOSE

You are invited to participate in a research study examining the relationship between physical activity and bone mineral density and body composition in healthy postmenopausal women. All the testing will take place at the University of Tennessee Applied Physiology Laboratory. Testing will take approximately one hour. Following the testing you will wear a step counter (pedometer) for 14 days and also record all that you eat and drink for three days.

PROCEDURES

1. Blood pressure measurement: a cuff will be placed around your upper right arm. This cuff will be inflated with air and then slowly deflated. By listening to the sound of the pulse in your arm, it is possible to determine your blood pressure.
2.
3. Health questionnaire and physical activity questionnaires will be used to assess health status, current physical activity, and diet.
4. Bone mineral density (BMD) will be measured by dual-energy X-ray absorptiometry (DXA). This is a common method for assessing bone mineral density. DXA is safe, low radiation dose, and it is also quick, approximately 30 minutes. The low dose of radiation involved is equivalent to being outside in the sun for about two hours.
5. Body fat distribution will be estimated by measuring waist and hip circumferences.
6. Body fat percentage will be determined by the use of the Bod Pod®. The Bod Pod® is a device that measures your body's composition as you sit inside it for

approximately 3 minutes. You will wear a bathing suit or your undergarments for this procedure.
6. You will be given an electronic pedometer to wear for 14 consecutive days. You will be asked to record your daily steps taken along with a brief description of your daily activity (e.g. walking, gardening, etc). You will also be responsible for keeping a three-day dietary record, which will allow you to record food and drinks that you consume for three days.

RISKS ASSOCIATED WITH PARTICIPATION

There are very few risks associated with this study. You are asked not to change your normal routine, so any exercise performed is reflective of your typical activity. There are no known risks to body composition measurements. There is a small amount of radiation exposure from the DXA. However, the radiation is equivalent to about two hours of sun exposure.

BENEFITS ASSOCIATED WITH PARTICIPATION

You will receive the results of your bone mineral density scan and body composition tests. This will provide you with information on your bone health and body composition. You may share this information with your primary physician for interpretation and diagnosis. You will also benefit by obtaining valuable information on your current physical activity levels and gain knowledge on some health benefits of exercise. All of this information will allow you to determine weather you need to increase your daily physical activity or that you are achieving recommended level. Nutritional benefits include knowledge of your total caloric intake per day, how many calories are coming from carbohydrates, fats, and proteins. You will also know what your Ca^{++} and iron intake are along with the rest of vitamins and minerals.

CONFIDENTIALITY

The information from this study will be treated as privileged and confidential and will consequently not be released to any person without your consent. All the information collected will be coded by a number assigned to each participant rather than your names. The data will be kept in a locked cabinet in 317 HPER. However, the information will be used in research reports and presentations, but your name and other identity will not be disclosed.

QUESTIONS

If you have any questions or concerns at any time during this study or after you have completed this study, you may contact either of the co-investigators. Olivera Lukajic can be reached at (865) 974-5091--her office is located in the HPER building in Room 317. You may reach Emily Krumm at (865) 974-4215 or visit her office in 349 HPER. You can also reach Dr. Dixie Thompson at (865) 974-8883. During this study if any events occur that will keep you from participating in this study you should inform either Olivera or Emily immediately. You are free to decide whether or not to participate in this study and are free to withdraw at any time. Before you sign this form, please ask

questions regarding any aspect of the study, which is unclear to you. You may also contact Research Compliance Services of the Office of Research at (865) 974-3466 if you have any questions about your rights as a participant.

CONSENT

By signing this paper, I am demonstrating that I fully understand and agree to take part in this research study.

_____ _____

Your signature Date

_____ _____

Researcher's signature Date

Appendix B

Health History Questionnaire

HEALTH HISTORY QUESTIONNAIRE

1. Have you ever been diagnosed with any of the following conditions? Please check the appropriate column.

__Asthma	__Gout	__Osteoarthritis	__Liver Problem
__Back Pain	__Heart Problems	__Osteoporosis	__Epilepsy
__Bronchitis	__Cancer	__Emphysema	__Metal in the Body
__Stroke	__Diabetes	__High Cholesterol	__Rheumatoid Arthr.
__Hypoglycemia	__Kidney Problems	__Thyroid Problem	__High Blood Pressure

2. Do you have any other physical conditions that may limit your ability to be physically active? If so, please describe:

_____

3. Are you currently taking any medications? Yes No
If yes, please list.

_____

_____

4. Do you currently smoke or have you quit within the last 6 months? Yes No
If yes, what type of tobacco products and how many per day?

_____

5. Do you currently consume more than 14 alcoholic drinks per week? Yes No

6. Are you currently taking hormone replacement therapy? Yes No
Have you ever been on hormone replacement therapy? Yes No
If yes, when did you stop? _____years
and how long did you take it? _____years

7. Of the following members of your family, please describe any cardiovascular disease, heart disease, stroke, or diabetes, along with the age of onset.

Father_____

Mother_____

Brother_____

Sister_____

Appendix C

Paffenbarger Physical Activity Index from the College Alumnus Questionnaire (PAI)

Paffenbarger Physical Activity Index Questionnaire

1. How many city blocks or their equivalent do you normally walk each day?
_____blocks/day (let 12 blocks = 1 mile)

2. What is your usual pace of walking? (Please check one.)
a.____casual or strolling (less than 2 mph) b.___average or normal (2 to 3 mph)
c____fairly brisk (3 to 4 mph) d.___brisk or striding (4mph or faster)

3. How many flights or stairs do you climb up each day?___flights/day (let 1 flight = 10 steps.)

4. List any sports or recreation you have actively participated in during the past year. Please remember seasonal sports or events.

Sport, Recreation, or Other Physical Activity	Number of Times/year	Average Time/Episode Hours	Minutes	Years Participation
a.				
b.				
c.				
d.				
e.				
f.				

5. Which on these statements best expresses your view? (Please check one).

a.__I take enough exercise to keep healthy b.__I ought to take more exercise
c.__Don't know

6. At least once a week, do you engage in regular activity akin to brisk walking, jogging, bicycling, swimming, etc. long enough to work up a sweat, get your heart thumping, or get out of breath?
___No Why not?_____ ___Yes How many time per week?___ Activity:_____

7.When you are exercising in your usual fashion, how would you rate your level of exertion (degree of effort)? (Please circle one number.)

0	0.5	1	2	3	4	5	6	7	8	9	10
normal	very very weak	very weak	weak	moderate	somewhat strong	strong		very strong		very very strong	max

8. On a usual weekday and a weekend day, how much time do you spend on the following activities? Total for each day should add to 24 hours.

	Usual Weekday Hours/Day	Usual Weekend Day Hours/Day
a. vigorous activity (digging in the garden, strenuous sports, jogging, aerobic dancing, sustained swimming, brisk walking, heavy carpentry, bicycling on hill, etc.		
b. moderate activity (housework, light sports, regular walking, golf, yard work, lawn mowing, painting, repairing, light carpentry, ballroom dancing, bicycling on level ground, etc.)		
c. light activity (office work, driving car, strolling, personal care, standing with little motion, etc.)		
d. sitting activity (eating, reading, desk work, watching TV, listening to radio, etc.)		
e. sleeping or reclining		

Appendix D

Seven-Day Physical Activity Recall Questionnaire (PAR)

The Seven-Day Recall

Interviewer_____Today is_____Today's Date_____

1. Were you employed in the last seven days? 0. No (skip to Q#4) 1. Yes

2. How many days of the last seven did you work? _____days

3. How many total hours did you work in the last seven days? _____hours last week

4. What two days do you consider your weekend days? _____
(mark days below with a squiggle)

DAYS

	SLEEP	1__	2__	3__	4__	5__	6__	7__
	Moderate							
	Hard							
	Very Hard							
	Moderate							
	Hard							
	Very Hard							
	Moderate							
	Hard							
	Very Hard							
Total Min Per Day	Strength: Flexibility:	____	____	____	____	____	____	____

Compared to your physical activity over the past three months, was last week's physical activity 1. More
2. Less 3. About the same

Appendix E

Step Record

Sunday Date Time On Time Off Total Steps Brief description of activities	**Monday Date** Time On Time Off Total Steps Brief description of activities	**Tuesday Date** Time On Time Off Total Steps Brief description of activities	**Wednesday Date** Time On Time Off Total Steps Brief description of activities	**Thursday Date** Time On Time Off Total Steps Brief description of activities	**Friday Date** Time On Time Off Total Steps Brief description of activities	**Saturday Date** Time On Time Off Total Steps Brief description of activities
Saturday Date Time On Time Off Total Steps Brief description of activities	**Monday Date** Time On Time Off Total Steps Brief description of activities	**Tuesday Date** Time On Time Off Total Steps Brief description of activities	**Wednesday Date** Time On Time Off Total Steps Brief description of activities	**Thursday Date** Time On Time Off Total Steps Brief description of activities	**Friday Date** Time On Time Off Total Steps Brief description of activities	**Saturday Date** Time On Time Off Total Steps Brief description of activities

Appendix F

Dietary Record

Dietary Record Instructions

1. Use the Dietary Record Forms provided to record everything you eat or drink for 3 consecutive days – two weekdays and one weekend day.
2. Indicate the name of the FOOD ITEM the AMOUNT eaten, how it was PREPARED (fried, boiled, broiled, etc.), and the TIME the food was eaten. If the item was a brand name product, please include the name. Try to be accurate about the amounts eaten. Measuring with measuring cups and spoons is best, but if you must make estimates, use the following guidelines:
   Fist is about 1 cup
   Tip of Thumb is about 1 teaspoon
   Palm of the hand is about 3 ounces of meat (about the size of a deck of cards)
   Tip of Thumb is about 1 ounce of cheese
3. Try to eat what you normally eat and record everything. The project will only be useful if you are HONEST about what you eat. The information you provide is confidential.
4. MILK: Indicate whether milk is whole, low fat (1 or 2%), or skim. Include flavoring if one is used.
5. VEGETABLES and FRUITS: One average serving of cooked or canned fruits and vegetables is about half cup. Fresh whole fruits and vegetables should be listed as small, medium or large. Be sure to indicate if sugar or syrup is added to fruit and list if any margarine, butter, cheese sauce, or cream sauce are added to vegetables. When recording salad, list items comprising the salad separately and be sure to include salad dressing used.
6. EGGS: Indicate method of preparation (scrambled, fried, poached, etc.), and number eaten.
7. MEAT/POULTRY/FISH: Indicate approximately size or weight in ounces of the serving. Be sure to include any gravy, sauce or breading added.
8. CHEESE: Indicate kind, number of ounces or slices, and whether it is made from whole milk, part skim, or is low calorie.
9. CEREAL: Specify kind, whether cooked or dry, and measure in terms of cups or ounces. Remember that consuming 8 oz. of cereal is not the same as consuming one cup of cereal. 1 cup of cereal generally weights about 1 ounce.
10. BREAD and ROLLS: Specify kind (whole wheat, enriched wheat, rye, etc.) and number of slices.
11. BEVERAGES: Include every item you drink excluding water. Be sure to record cream and sugar used in tea and coffee, whether juices are sweetened or unsweetened and whether soft drinks are diet or regular.
12. FATS: Remember to record all butter, margarine, oil and other fats used in cooking or on food.
13. MIXED DISHES/CASSEROLES: List the main ingredients and approximate amount of each ingredient to the best of your ability.

14. ALCOHOL: Be honest. Record amount in ounces. Specify with "light" or "regular" beer.

Dietary Record Form

Subject Number: _____
Date: _____ Please use a new copy for each day

Food Item	Amount	Time

Express approximate measures in cups (c), Tablespoons (T), teaspoons (t), grams (g), ounces (oz), pieces, etc.

Appendix G

Tables

Table 1: Descriptive characteristics of participants

		Step categories		
	Total	**< 5,500 steps · day^{-1}**	**5,500-7,500 steps · day^{-1}**	**> 7,500 steps · day^{-1}**
N	93	30	30	33
Steps · Day^{-1}	6813 ± (2955)	3623 ± (1414)*#	6541 ± (596)†#	9961 ± (1773)†*
Age (yr)	60.9 ± (5.8)	63.2 ± (6.7)#	60.4 ± (5.4)	59.2 ± (4.5)
BMI (kg · m^{-2})	27.6 ± (5.9)	30.5 ± (6.8)*#	28.2 ± (5.7)#	24.6 ± (3.3)
BM (kg)	75.1 ± (17.3)	82.2 ± (20.2)#	75.3 ± (15.1)	68.6 ± (14.1)
t-score	0.3 ± (1.2)	0.6 ± (1.3)	0.1 ± (0.9)	0.3 ± (1.3)
z-score	0.9 ± (1.0)	1.0 ± (1.0)	0.7 ± (0.8)	1.1 ± (1.2)
PAI (kcal · wk^{-1})	1967 ± (1563)	975 ± (828)*#	2197 ± (1700)†	2660 ± (1522)
PAR (kcal · d^{-1})	888 ± (382)	851 ± (282)	834 ± (227)	971 ± (538)

(BMI = body mass index)
(BM = body mass)
(PAI = Paffenbarger Physical Activity Index)
(PAR = Seven-Day Recall Questionnaire)
Values are Mean ± (SD)
† = Significant difference from least active group ($P < 0.05$)
* = Significant difference from moderate active group ($P < 0.05$)
# = Significant difference from most active group ($P < 0.05$)

Table 2: Bone variables of participants

		Step categories		
	Total	**< 5,500 steps · day^{-1}**	**5,500-7,500 steps · day^{-1}**	**> 7,500 steps · day^{-1}**
N	93	30	30	33
TBMD (g · cm^{-2})	1.150 ± (0.095)	1.171 ± (0.101)	1.135 ± (0.071)	1.146 ± (0.106)
BMD_{LEG} (g · cm^{-2})	1.168 ± (0.100)	1.184 ± (0.114)	1.148 ± (0.077)	1.172 ± (0.105)
BMD_{SPINE} (g · cm^{-2})	1.047 ± (0.128)	1.050 ± (0.159)	1.032 ± (0.073)	1.058 ± (0.137)
BMD_{PELVIS} (g · cm^{-2})	1.111 ± (0.120)	1.121 ± (0.136)	1.098 ± (0.082)	1.115 ± (0.135)
TBMC (g)	2443 ± (354)	2438 ± (379)	2425 ± (252)	2463 ± (416)
BMC_{LEG} (g)	903 ± (132)	933 ± (151)	903 ± (102)	875 ± (135)
BMC_{SPINE} (g)	226 ± (46)	216 ± (48)	225 ± (35)	235 ± (52)
BMC_{PELVIS} (g)	287 ± (74)	277 ± (93)	283 ± (51)	300 ± (71)

(TBMD = total bone mineral density)
(TBMC = total bone mineral content)
Values are Mean ± (SD)

Table 3: Pearson correlations between steps per day, age, BMI, and BM of all 93 participants

	Age (yr)	BMI ($kg \cdot m^{-2}$)	BM (kg)
Steps per day	-0.340 ($P = 0.001$)	-0.417 ($P < 0.001$)	-0.363 ($P < 0.001$)
Age (yr)		-0.164 ($P = 0.116$)	-0.149 ($P = 0.153$)
BMI ($kg \cdot m^{-2}$)			0.865 ($P < 0.001$)

(BMI = body mass index)
(BM = body mass)

Table 4: Pearson correlations between steps per day, BM, LM, FM, and BMD variables of all 93 participants

	TBMD ($g \cdot cm^{-2}$)	BMD_{LEG} ($g \cdot cm^{-2}$)	BMD_{SPINE} ($g \cdot cm^{-2}$)	BMD_{PELVIS} ($g \cdot cm^{-2}$)
Steps per day	-0.136 ($P = 0.194$)	-0.044 ($P = 0.673$)	-0.005 ($P = 0.962$)	-0.014 ($P = 0.896$)
BM (kg)	0.405 ($P < 0.001$)	0.387 ($P < 0.001$)	0.153 ($P = 0.141$)	0.191 ($P = 0.067$)
LM (kg)	0.453 ($P < 0.001$)	0.497 ($P < 0.001$)	0.304 ($P = 0.003$)	0.294 ($P = 0.004$)
FM (kg)	0.388 ($P < 0.001$)	0.325 ($P = 0.001$)	0.098 ($P = 0.352$)	0.162 ($P = 0.121$)

(TBMD = total bone mineral density)
(BM = body mass)
(LM = lean mass)
(FM = fat mass)

Table 5: Pearson correlations between steps per day, BM, LM, FM, and BMC variables of all 93 participants

	TBMC (g)	BMC_{LEG} (g)	BMC_{SPINE} (g)	BMC_{PELVIS} (g)
Steps per day	0.015 ($P = 0.884$)	-0.174 ($P = 0.096$)	0.163 ($P = 0.118$)	0.125 ($P = 0.233$)
BM (kg)	0.254 ($P = 0.014$)	0.562 ($P < 0.001$)	0.009 ($P = 0.933$)	0.111 ($P = 0.288$)
LM (kg)	0.529 ($P < 0.001$)	0.746 ($P < 0.001$)	0.260 ($P = 0.012$)	0.370 ($P < 0.001$)
FM (kg)	0.158 ($P = 0.129$)	0.490 ($P < 0.001$)	-0.063 ($P = 0.548$)	0.007 ($P = 0.948$)

(TBMC = total bone mineral content)
(BM = body mass)
(LM = lean mass)
(FM = fat mass)

Table 6: Pearson correlations between steps per day and BMD variables when corrected for BM of all 93 participants

	TBMD/BM ($g/cm^2/kg$)	BMD_{LEG}/BM ($g/cm^2/kg$)	BMD_{SPINE}/BM ($g/cm^2/kg$)	BMD_{PELVIS}/BM ($g/cm^2/kg$)
Steps per day	0.353 ($P = 0.001$)	0.393 ($P < 0.001$)	0.355 ($P < 0.001$)	0.373 ($P < 0.001$)

(TBMD/BM = Total bone mineral density divided by body mass)
(BMD_{LEG}/BM = bone mineral density of the leg divided by body mass)
(BMD_{SPINE}/BM = bone mineral density of the spine divided by body mass)
(BMD_{PELVIS}/BM = bone mineral density of the pelvis divided by body mass)

Table 7: Pearson correlations between steps per day and BMC variables when corrected for BM of all 93 participants

	TBMC/BM (g/kg)	BMD_{LEG}/BM (g/kg)	BMC_{SPINE}/BM (g/kg)	BMC_{PELVIS}/BM (g/kg)
Steps per day	0.373	0.315	0.400	0.388
	($P < 0.001$)	($P < 0.001$)	($P = 0.002$)	($P < 0.001$)

(TBMC/BM = Total bone mineral content divided by body mass)
(BMC_{LEG}/BM = bone mineral content of the leg divided by body mass)
(BMC_{SPINE}/BM = bone mineral content of the spine divided by body mass)
(BMC_{PELVIS}/BM = bone mineral content of the pelvis divided by body mass)

Table 8: Descriptive characteristics of participants that have never been on hormone replacement therapy (NHRT) and those previously on hormone replacement therapy (HRT)

	NHRT	HRT
N	47	46
Steps · day^{-1}	6860.7 ± 3401.0	6764.8 ± 2454.8
Age (yr)	60.5 ± 6.4	61.3 ± 5.1
BMI (kg · m^{-2})	27.7 ± 6.7	27.6 ± 5.0
BM (kg)	74.1 ± 19.5	76.2 ± 14.9
TBMD(g · cm^{-2})	1.149 ± 0.108	1.152 ± 0.079
BMD_{LEG} (g · cm^{-2})	1.163 ± 0.108	1.173 ± 0.091
BMD_{SPINE} (g · cm^{-2})	1.042 ± 0.144	1.052 ± 0.109
BMD_{PELVIS} (g · cm^{-2})	1.106 ± 0.133	1.116 ± 0.105
TBMC (g)	2391 ± 377	2495 ± 325
BMC_{LEG} (g)	890 ± 138	916 ± 125
BMC_{SPINE} (g)	219 ± 49	232 ± 43
BMC_{PELVIS} (g)	274 ± 73	300 ± 73
t-SCORE	0.3 ± 1.4	0.3 ± 1.0
z-SCORE	0.9 ± 1.1	0.9 ± 0.9
PAI (kcal · wk^{-1})	2099 ± 1718	1832 ± 1394
PAR (kcal · d^{-1})	872 ± 874	904 ± 393

Values are Mean ± SD

Table 9: Pearson correlations between steps per day, age, BMI, and BM of 46 participants previously on HRT

	Age (yr)	BMI ($kg \cdot m^{-2}$)	BM (kg)
Steps per day	-0.376 ($P = 0.010$)	-0.191 ($P = 0.204$)	-0.141 ($P = 0.349$)
Age (yr)		-0.276 ($P = 0.063$)	-0.171 ($P = 0.255$)
BMI ($kg \cdot m^{-2}$)			0.699 ($P < 0.001$)

(BMI = body mass index)
(BM = body mass)

Table 10: Pearson correlations between steps per day, age, BMI, and BM of 47 participants that have never been on HRT

	Age (yr)	BMI ($kg \cdot m^{-2}$)	BM (kg)
Steps per day	-0.320 ($P = 0.028$)	-0.535 ($P < 0.001$)	-0.483 ($P = 0.001$)
Age (yr)		-0.101 ($P = 0.501$)	-0.144 ($P = 0.333$)
BMI ($kg \cdot m^{-2}$)			0.960 ($P < 0.001$)

(BMI = body mass index)
(BM = body mass)

VITA

Olivera Lukajic was born in Maglaj, Bosnia in 1978. She attended elementary, middle and most of high school in Osnovna/Srednja - Škola Maglaj, Bosnia. In 1995 Olivera came abroad, finished her senior year of high school and Olivera attended the University of Tennessee, Knoxville, earning a Bachelor of Science degree in Exercise Science in May, 2001. While working on her Bachelor degree for four years Olivera work as a student assistant in Strength and Conditioning for the Lady Vols Athletics Department at the University of Tennessee, Knoxville. Olivera entered the graduate program in Exercise Science at the University of Tennessee, Knoxville in August 2002, and served as a Graduate Research Assistant during 2002-2003 and 2003-2004 school years. While at the University of Tennessee Olivera also assisted in a couple of pedometer studies. In August 2004 she received a Master of Science degree with an emphasis in Exercise Physiology.

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