THE ASSOCIATIONS AMONG BODY COMPOSITION, HISTORICAL AND RECENT PHYSICAL ACTIVITY, AND BONE STATUS IN POSTMENOPAUSAL WOMEN

by

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(Under the Direction of Ellen M. Evans)

ABSTRACT

The association between historical bone loading physical activity (PA) and bone mineral density (BMD) and the relative importance of lean soft tissue mass (LSTM) or fat mass (FM) as the primary independent predictor of BMD, controlling for historical or recent PA, has not been extensively studied in postmenopausal women. Women (n = 67, mean age 58.1 ± 3.9, range 49-65 years old) were assessed for PA habits subjectively via questionnaires and objectively using a pedometer. Bone status and body composition measured were assessed using dual-energy x-ray absorptiometry. No significant relationships were found between any reported historical PA and BMD although recent PA, measured either from self-report or step counts, were weakly related. LSTM, not FM or recent PA, was the only significant independent contributor to whole body and femoral neck BMD other than hormone replacement therapy when age and months in menopause were controlled.

INDEX WORDS: bone mineral density, lean soft tissue mass, fat mass, physical activity, postmenopausal women
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CHAPTER 1
INTRODUCTION

1.1 Significance

Osteoporosis, defined with low bone mineral density (BMD), causes approximately 1.5 million fractures per year in addition to 500,000 hospitalizations, 800,000 emergency room visits, 2.6 million physician visits, and 180,000 nursing home enrollments [1]. In 2002, the health care costs associated with osteoporosis were $12-18B [2]. In 2025, the projected health care cost associated with osteoporosis and fractures is $25.3B in the US [3]. BMD is affected by several factors including nutrition, physical activity (PA), hormonal status, and body composition. Early BMD development during childhood and adolescence is influenced 60-80% by genetics [4]. Other important modifiers for children and adolescents are nutrition and PA [4]. The establishment of high levels of BMD early in life and maintenance throughout the lifespan are preventative measures for osteoporosis [4].

With regard to females, estrogen is a primary anti-resorption agent [2]. The perimenopausal period normally begins during the mid-40s with the average age of menopause being 51 [5, 6]. BMD tends to decline at an accelerated rate during the menopausal transition and early menopause due to the drastic decline in estrogen due to ovarian failure [7]. Estrogen replacement therapy as well as calcium and vitamin D all contribute to the preservation of BMD in postmenopausal women [2, 8]. Weight is related to osteoporosis with thin women being at higher risk [9]. More specifically regarding body composition, lean soft tissue mass (LSTM) has been shown to be the strongest correlate to BMD in healthy postmenopausal women [10-16];
however, other studies have found the associations between BMD and fat mass (FM) to be stronger [17-21].

In this context, the primary objectives of this study were to 1) evaluate the associations between lifetime and recent PA and bone status and 2) to determine the relative strength of the independent contribution of LSTM and FM on BMD in early postmenopausal women. Lifetime PA has been reported to be associated with bone status in young and premenopausal women; however, it has not yet been researched in healthy postmenopausal women using questionnaires that quantify loading activities. Moreover, the relative independent strength of association between the primary soft tissue body composition components, LSTM and FM, and bone status is not completely established in the literature in the early postmenopausal population. The specific aims of this investigation are as follows:

1.2 Specific Aims and Hypotheses

Specific Aim 1: To determine the relative and independent associations of historical (past) and recent subjectively and objectively measured PA on bone status as indicated by BMD and bone mineral content (BMC) of the whole body (WB), proximal femur (PF), femoral neck (FN), and lumbar spine (LS) in early postmenopausal women. It was hypothesized that historical and recent PA would both have a significant positive relation to the bone variables.

Specific Aim 2: To investigate the relative independent associations between LSTM and FM on the WB, PF, FN, and LS BMD and BMC in postmenopausal women, while taking into account the potential influence of historical and recent subjectively and objectively measured PA. It was hypothesized that although both LSTM and FM would be significantly related to
BMD and BMC, especially of the WB and PF, LSTM would be the primary independent predictor even after controlling for PA.

1.3 Public Health Significance

Previous research on healthy postmenopausal women has attempted to determine if LSTM or FM contributes more to BMD. It has been suggested LSTM is more strongly correlated with bone health compared to FM [10-16], although other studies suggest FM has a stronger association to bone health [17-21]. Several studies have also stated as women age FM plays a larger role for BMD status [11, 14, 17, 22] suggesting the relative contributing factor changes along the lifespan even with regard to earlier and later menopausal stage. It is important to understand the primary contributing factors of BMD so it can be maintained or positively influenced in this population.

It is also important when determining the primary relative contributor of LSTM and FM to BMD to consider PA. It is well established that PA is known to affect body composition, the main effects of increased PA for postmenopausal women are small decreases in FM [23, 24]. The lack of consideration of PA or sub-optimal measurement of PA in published studies may be contributing to the discrepancy and mixed results that are seen within investigations of body composition and bone status [23, 24]. Some published studies to date found no associations between PA and BMD so PA was not controlled for in their analysis [15, 20] or when controlling for PA, found that it strengthened the relation between FM and BMD although LSTM was still more important than FM for bone status [14]. Two studies used objectively measured PA and found negative correlations with BMD [13, 18]. In their analysis on body composition and BMD they either did not control for PA or did not find PA to be a significant independent variable [13,
Only one study found a significant correlation between PA and bone status and took PA into account in their analysis determining that LSTM was a greater contributor of BMD compared to FM [16]. Importantly, limited research exists exploring this topic using objective measures of PA, such as accelerometer or pedometer, and that which is published found mixed results for determining a relation between LSTM or FM and BMD [13, 16, 18].

In addition, the literature is lacking in the area of past or historical PA predicting bone status for healthy postmenopausal women. This is important as it is established that nearly 90% of the bone mass is formed by the 3rd decade of life [4]. One study investigating the effects of past PA on BMD in postmenopausal women using a series of 10 questions to assess past activities found no significant correlations [25]. However, the questions used did not attempt to quantify bone loading on the skeleton which is important when BMD or BMC is an outcome variable [26]. Two questionnaires have been used to demonstrate past bone loading activities and their correlation to BMD. The bone loading history questionnaire (BLHQ) estimates of bone loading PA has been determined to be significantly related to the FN BMD [27]. The current activity portion of the bone-specific physical activity questionnaire (BPAQ) has been shown to be correlated to WB, LS, and FN BMD in men [26]. The past activity of the BPAQ predicts the calcaneal broadband ultrasound attenuation, a measure associated with BMD [26].

The present study will add to the literature for postmenopausal women regarding the relation of PA to BMC and BMD of the WB and regional measures of PF, FN, and LS. Importantly, both past and recent PA will be assessed using bone specific questionnaires, and recent PA will be further assessed using an objective measure. Moreover, the present study will control for past and recent PA (if determined to be significant), when investigating the relationship between LSTM, FM and bone status variables.
1.4 References


2.1 Osteoporosis

Osteoporosis is characterized by low BMD, decrease in bone strength, lack of architectural structure, and risk of fracture [1-3]. As women age, their risk for osteopenia (the precursor for osteoporosis) and osteoporosis increases [4]. It is extremely important to reach an adequate level of peak bone mass (PBM) at a young age to prevent osteoporosis later in life [5]. An increase in PBM by one standard deviation may decrease fracture risk by 50% later in life [6]. In addition to low PBM a number of other risk factors exist for increased osteoporotic fractures including low estrogen levels, low body mass index, prior fragility fracture, premature menopause, long-term secondary amenorrhea, glucocorticoid therapy, and maternal history of hip fracture, and genetics [7, 8].

Osteoporosis causes ~1.5 million fractures, 500,000 hospitalizations, 800,000 emergency room visits, 2.6 million physician visits, and 180,000 nursing home enrollments per year [4]. It is thought by year 2025 the estimated costs associated with osteoporosis will be around $25.3B [9]. In the US in 2011 more than 40 million people had osteoporosis or were at high risk due to low bone mass [8]. It is estimated one in two women over the age of 50 are at a high risk for developing an osteoporosis-related fracture [8]. In addition it is estimated that 30% of Caucasian American women have osteoporosis and among them two thirds have vertebral fractures that remain undiagnosed and 25% have a vertebral deformity [10-12]. Fractures cause a gradual decline in survival rates compared to someone the same age without a fracture [13]; 20% of
people over the age of 50 die the year following a fracture [8]. The primary sites for osteoporosis related fractures for females are the wrists, LS, and hips [14]. The hip fracture has the most impact on a person’s life as most require hospitalization and surgery, some people require nursing home placement, and 50% will be unable to walk without assistance [8]. Vertebral fractures can cause serious back pain and disability [8]. Those with vertebral deformities are at higher risk for back pain and height loss as well [11]. Osteoporosis and the fractures that are caused is not only a burden due to its health care costs but it also decreases a person’s quality of life [8]. It is important to understand the contributing factors to bone mass so that it can be maintained as people age to prevent osteoporosis in late life.

2.2 Bone Status: Factors across the Lifespan

Hormones

Women’s BMD is dependent on several factors throughout their lifetime including their hormonal state. Menopause, due to the reduction in the hormone estrogen, is a major player in lowered BMD and the subsequent development of osteoporosis as women age [7, 14]. Menopause is defined as the permanent cessation of menstruation (12 months consecutively of amenorrhea) due to the loss of ovarian follicular activity [15, 16]. Menopause occurs between the ages of 45 and 55 [8]. On average, menopausal transition (or perimenopause) occurs during the mid-40s during which menstrual cycle irregularity occurs [15]. The menopausal transition time before the final menstrual period can be broken down into an early and late stage [15-17]. Follicle stimulating hormone (FSH) increases moving from the early to late stage [16]. Estrogen decreases across the two stages [16]. Thus, postmenopause a significant decrease in estrogen and an increase in follicle stimulating hormone are present [16]. The rapid reduction in BMD for
early postmenopausal women is directly related to decreased levels of estrogen with an accelerated loss occurring four to eight years after menopause [8, 14]. Hormone replacement therapy (HRT) specifically estrogen replacement, for up to seven years during postmenopause is effective at maintaining BMD [18]. HRT also helps in the prevention of osteoporotic fractures [19]. Thus, it is important to consider hormonal status (i.e. perimenopausal, postmenopausal) and HRT use when investigating BMD.

Nutrition

Nutrition is a modifiable lifestyle factor for preventing osteoporosis and maintaining BMD [7]. Nutrition, namely calcium and vitamin D, plays a major role in preventing fractures in subjects with osteoporosis [14, 20]. An adequate level of calcium is the most important lifestyle factor for attaining and maintaining bone mass [7]. Vitamin D helps to absorb intestinal calcium, as people age serum concentrations of 35-hydroxyvitamin D decrease [21]. Studies on postmenopausal women have found different results regarding calcium and vitamin D’s influence on BMD depending on how many years past menopause. Menopause is broken down into early (within five years of menopause) and late menopause (equal to or greater than five years postmenopause) [22, 23]. According to USDA’s Dietary reference intake women in early and late menopause should consume 1,200 mg of calcium a day. Calcium has little effect on BMD when early menopausal women are not vitamin D deficient [22]. When early menopausal women have a low intake of calcium, subsequent calcium and/or vitamin D supplementation significantly slows BMD loss at several sites except the spine [24-27]. There is no sustained benefit with Calcium supplementation to the spine in early menopausal women [23, 28, 29].

Women in late menopause are able to reduce bone loss through calcium supplements especially when their dietary intake is less than 400 mg Ca/d [30]. Slowing of the reduction in
LS and FN BMD has been shown with increasing calcium intake [28]. A study on postmenopausal women (mean age 62 years old) also found calcium and vitamin D improved hip BMD [31]. Overall, studies have found calcium and vitamin D supplementation to be beneficial for maintaining BMD in early and late menopause. Therefore, calcium and vitamin D supplementation are also important considerations when evaluating BMD of postmenopausal women.

*Physical Activity*

PA plays an important role in bone development and BMD maintenance through the lifespan [7]. The foundation for BMD is established early in life; by ~30 years of age, women have reached their PBM [32]. It is important during childhood and pubertal stages to partake in PA and continue this habit into young adulthood to maximize PBM [5, 33]. Intervention studies conducted on children as part of school programs found children who participated in high impact jumping and calisthenics increased their bone mass more so than those in normal activities [34-39]. Overall research suggests exercise during childhood causes gains in bone mass which can be maintained into adulthood conferring long lasting effects on bone health [40]. Physically active young adult women who tended to be active younger in life achieve and maintain a higher PBM than sedentary women [33]. High impact exercise is the best mode to maximize BMD in young adult women [33]. Some physical activities that are able to produce high impact loading forces include plyometrics, gymnastics, and high intensity resistance training [40]. A review in 2000 discussed the effects of impact exercise programs on FN BMD and found 1.0% of bone loss was prevented in postmenopausal women and 0.9% was prevented in premenopausal women [41]. However, notably, it is important to continue to exercise after PBM is established to increase or maintain BMD.
Physical activities conducted recently may increase or preserve bone health in postmenopausal women, potentially regardless of childhood activity levels [42-44]. Many cross-sectional research studies have investigated relationships between bone status and recent PA (within at least a year) measured through subjective means [42, 45-50]. The data were collected through recall questionnaires in five studies [42, 46, 48-50] or participants were recruited based off of their recent exercise habits [45]. One cross-sectional study also investigated past PA through a questionnaire asking briefly about work and leisure time PA in a series of 10 questions [51].

Overall, mixed results were found between the studies. In a study with older postmenopausal women (70-85 years old) the highest PA tertile, established by greater than 169 kcal/day using a PA questionnaire, had statistically greater PF, trochanter, FN, and intertrochanter BMD than those who were in lower tertile classifications [46]. In postmenopausal women (43-72 years old) on calcium supplements a significant linear trend was found between self-reported miles walked/week and WB BMD measured at three time points (baseline, 6 months, and 1 year) [50]. In addition, women who walked less than 1 mile/week had significantly lower LS BMD compared to women reporting 7.5 miles/week [50]. In contrast, two studies, one including women aged ≥ 60 years old and the other with postmenopausal women (45-71 years old), found no correlations or inconsistent correlations, respectively, between PA assessed recently through questionnaires and bone status [48, 49]. Another study using a recall questionnaire found no significant association between BMD and total PA or sporting activity in postmenopausal women (45-61 years old); however, there were significant positive correlations between stair climbing and walking pace to BMD at the trochanter BMD and WB BMD [42]. In women with a fast walking pace the PF BMD was positively associated
with frequency of walking at least a mile demonstrating that walking has a positive influence on BMD at the PF for postmenopausal women [42]. A different study found the active (5.1 hours/week of PA low to moderate intensity composed of walking or aerobics) postmenopausal women (64 years old on average) had significantly higher WB, LS, and trochanter BMD compared to sedentary and endurance athletes (5.5 PA hours/week training competitively for endurance events) [45]. Finally another study did not find a significant relationship between past and recent PA and BMD in 75 year old women [51]. Overall mixed results exist for subjectively based recent and past PA and BMD. This may be a result of the inability of the questionnaires used within these studies to quantify bone loading activities [52].

Other cross-sectional studies have investigated the relationship between bone health measures and objectively measured PA [53-57]. In these studies, accelerometers [54, 56] or pedometers [53, 55, 57] were used to measure PA. In perimenopausal women (40-54 years old) recent exercise, greater than 488 kcal/day as determined by accelerometer, was significantly associated with bone status of the LS [56]. It was also determined for each additional increase of 100 kcal/day in PA; LS BMD increased 0.012 g/cm² [56]. In contrast another study using accelerometers determined that a small statistically significant negative partial correlation ($r = -0.22$) existed between steps/day and FN BMD when age was controlled for in women with an average age of 63 [54]. In a study with 56 to 72 year old women, a positive relationship between pedometer determined ambulatory activity and LS BMD was determined [53]. Another study with middle-aged women, average age 49.2 ± 5.4, found PA, assessed by pedometer, explained 19.9% of the variance for WB BMD independent of body composition and hormonal status [57]. In the middle age group PA was also significantly positively related to WB and FN BMD when LSTM and FM were controlled [57]. The same study found a negative correlation between
recent PA and bone measures for the older women (mean age 68 years old) [57]. Another study found average walking steps/day determined through a pedometer was weakly negatively correlated with trunk, lower extremities, and total BMD in a sample including 107 premenopausal women (mean age 42.7 ± 7.2) and 71 postmenopausal women (mean age 56.1 ± 4.6) [55]. In summary, mixed results exist for cross-sectional studies exploring the relation between objectively determined PA and bone status, specifically BMD, which may be due to the inability of the devices to quantify the loading forces placed on the bone [52].

Numerous training studies have also been performed in an attempt to determine exercise effects on BMD in this age group of interest [58-66]. The types of exercise included high impact training [59], resistance training [58, 60, 61], walking/endurance [62-65], or a mix of different exercises [66]. One high impact training study through a jumping program found no significant difference between the postmenopausal women and the control group at baseline, 12 months, and 18 months [59]. Another high impact and low impact training study found both exercise types over the course of a year were able to maintain BMD in postmenopausal women [67]. A one year resistance training program designed to stress the ipsilateral forearm and hip region on one side of the body with an endurance group (more reps) and a strength group (less reps) was conducted on postmenopausal women (40-70 years old) [60]. The strength group had a significant increase in PF and radius BMD compared to the untrained side, while the endurance group only increased radius BMD highlighting the importance of peak load in postmenopausal women [60]. Another resistance training study with postmenopausal women (44-66 years old) lasting one year found a linear relationship between BMD changes at the femur trochanter and total and exercise-specific weight lifted [58]. These results reinforce the positive correlation between weight lifting and BMD [58]. In peri- and postmenopausal women (45-65 years old)
comparing walking with weight training [61], a significant group difference was not found in LS BMD; in the walking group there was a significant decrease in lumbar BMD by 1.3% that was not seen in the weight training group [61]. Mixed results exist for high ground reaction/impact interventions whereas more resistance training studies have found positive results for exercise on BMD in this age group.

Most of the interventions using endurance or walking training programs have determined that the intervention maintains or increases BMD. The maintenance of BMD occurred in a yearlong brisk walking study in women older than 65 years old at the LS and calcaneus whereas it significantly decreased in the control group [63]. Another intervention incorporating four days a week of at least 8,000 steps/day at 50% of VO2max using a target heart rate during outdoor walking over a 12 month period on postmenopausal women 49-75 years old with osteopenia/osteoporosis found LS BMD increased in the exercisers compared to the control group [65]. No significant change was found in LS, PF, trochanter, or intertrochanter BMD in a group who walked 10,000 steps/day and a group who walked 10,000 steps/day and performed 10 vertical jumps a day [64]. However a significant increase in bone formation markers in the walking and the combined walking and jumping group was found. The combined group had a more substantial increase suggesting that it has a more positive influence on bone metabolism [64]. In postmenopausal women 50 to 75 years old with an exercise intervention composed mostly of cycling and walking found no significant change in total BMD or BMC after one year of training compared to controls [62]. This study did find a significant effect between the participants over 60 and under 60; the older age group significantly increased total body BMD [62]. Finally in a study involving aerobic, weight lifting, and weight bearing exercise over a 12 month period three times a week found a significant increase in trochanteric BMD [66]. It is
clear that there are more studies that have found beneficial effects of exercise on BMD. An American College of Sports Medicine position stand on PA and bone health concluded that several types of exercise can preserve skeletal health in older women when examining two meta-analyses [40].

2.3 Menopause: Implications of Body Composition for Bone Status

Body composition in women varies with age and menopausal stage [68] and there are a significant number of women who gain weight during the menopausal transition [69]. During the menopausal transition women seem to have a significant increase in weight that is not related to the linear increase seen with normal aging but rather due to physiological changes that occur due to menopause [69]. A hormonal shift occurs; less estrogen is produced by the ovaries and with the cessation of ovulation, progesterone production also decreases [15, 70]. This increase in weight is also related to an increase and redistribution of FM with the central depots becoming more preferred [71]. Another potential reason for the increase in weight is transitional changes during this stage of life occur including parental care giving, children leaving home, and preparation for retirement (i.e. social stresses) [69].

Three body composition related factors associated with BMD are body weight, LSTM, and FM. It has been well established that body weight is a strong determinant of BMD [14]. A possible mechanism for the effect of body weight on BMD is the stress on the skeleton from mechanical loading during ambulation [14]. Soft tissues (LSTM and FM) also influence BMD [72]. LSTM effects on BMD stems in part from potential genetic association [73]. Increased PA and exercise may also positively contribute to BMD through LSTM [73, 74]. Greater LSTM and BMD may be a result from increased levels of PA which will lead to increased bone mass and
bone mineralization may be enhanced through the additional electrical kinetic potential of increased LSTM [75, 76]. LSTM may increase BMD through mechanical loading of the skeleton [54].

FM has two possible mechanisms to explain its effects on BMD: non-weight bearing and weight bearing [77]. Non-weight bearing effects occur through hormones excreted from the pancreatic beta cells including insulin, amylin, and preptin secreted from pancreatic beta cells [78]. Estrogen and leptin secreted from the adipose tissue are other hormones contributing to BMD [78]. These are all bone-active hormones [72]. There is an association between increased amounts of adipose tissue and hormonal circulation in obese women which leads to a greater conversion of adrenal androgens to estrogens [14]. The weight bearing effects are due to bone loading as greater amounts of FM are linked to greater body mass [78]. It has been suggested that the correlations between BMD and FM are influenced more from non-weight bearing than weight bearing mechanisms [77]. Reproductive stage of a woman’s life influences the associations between BMD and LSTM and/or FM.

Pre- and Perimenopause

During pre- or perimenopause phases most of the literature has determined that LSTM has a stronger correlation with BMD compared to FM. Some studies have found moderately strong associations between LSTM and BMD or BMC at the PF, FN, LS, and WB [79, 80]. LSTM had a significantly greater contribution to BMD compared to FM at each site as well [80]. Other studies have demonstrated LSTM to be a stronger predictor and/or significant contributor to BMD at just the FN site [81, 82]. LSTM was also a greater predictor of WB, PF, FN, and LS BMC and BMD than FM and after adjusted analysis, namely controlling for PA, FM was not significantly positively associated with the bone measures at all [57]. In premenopausal women
LSTM was a significant determinant of LS BMD [83]. LSTM is also positively correlated and the principal determinant of BMD at the WB and LS sites [74]. Another study found LSTM was the major determinant of bone mass compared to FM [84]. Some studies found FM to be more strongly correlated to BMD measures. FM was the principal determinant and had a stronger correlation with WB BMD compared to LSTM [85]. Another study found, after controlling for menopausal state, FM has a positive correlation with total and regional BMD (upper and lower extremities and trunk) but non-fat tissue mass did not [55]. In summary, more associations have been determined between LSTM and bone variables compared to FM in pre- and perimenopausal women; however, mixed results do exist in the literature.

*Postmenopause*

When considering postmenopausal women several studies have determined FM to have a stronger correlation to bone measures compared to LSTM. FM had positive correlations with total and regional BMD and was a significant predictor of total BMD [49, 55]. Other studies have found FM to be the significant determinant at specific BMD sites [86]. FM was the significant determinant of LS and FN BMD [86]. FM was the strongest anthropometric determinant of LS BMD [87].

Conversely, in postmenopausal women studies have also found that LSTM has a stronger correlation and is a better predictor of BMD. LSTM was a greater independent contributor at the LS and FN sites compared to FM [88]. One study came to the same conclusion with postmenopausal women as they did with pre- and perimenopausal women; namely that LSTM was a greater predictor of the WB, PF, FN, and LS BMC and PF, FN, and LS BMD [57]. After adjusted analysis FM was not significantly positively associated with bone measures [57]. LSTM was the stronger predictor of BMD at FN [48, 82] and PF compared to FM [54]. Another
study also found LSTM to be the stronger predictor compared to FM of the LS BMD [48]. LSTM (28-52%) was the major determinant and explains a greater percentage of variability compared to FM (12-21%) of postmenopausal bone mass [84]. LSTM was more closely related to bone mineral mass than FM as indicated by BMC and BMD measures [89].

**Summary**

Some literature suggests that during later menopausal years FM appears to be more important for BMD [89]. Several studies have observed a similar trend as women age; FM is more important to BMD but not necessarily the major independent predictor [74, 82-84]. During pre- and early menopause LSTM is an important contributor to BMD especially at the PF [90]. Overall the literature is inconclusive about which is the primary independent body composition predictor, LSTM or FM, of BMD during early menopause [88].

### 2.4 Effect of Walking on Body Composition in Postmenopausal Women

There are a multitude of intervention studies that examined the effects of exercise and PA for early postmenopausal women and found reductions in weight and reduced FM [91]. Walking was the most common mode of PA in the randomized controlled trials examined for early postmenopausal women [91]. Studies have demonstrated decreased fat or weight using walking as an intervention [63, 92-94]. The recommended 10,000 steps/day has been shown to be associated with favorable body composition and BMI in two cross-sectional studies – Krumm, Dessieux, Andrews, and Thompson (2006) postmenopausal women aged from 50-75 mean age 60.9 ± 5.8 years old and Hornbuckle, Bassett, and Thompson (2005) women aged from 40-62 mean age 51.4 ± 5.4 years old [95, 96]. In addition Krumm et al., (2006) found an inverse relationship between steps/day and adiposity variables including percent body fat, trunk fat,
20

BMI, waist and hip circumference, and waist/hip ratio [95]. Hornbuckle et al., (2005) found similar results except waist/hip ratio was not significant and trunk fat was not a measure used [96].

2.5 Assessment of Body Composition, Bone Mineral Density, and Bone Mineral Content

Dual-energy x-ray absorptiometry (DEXA) is a precise and safe way to measure soft tissue composition and bone measures [97]. The DEXA measures bone in BMC (g) and BMD. Notably, DEXA does not measure BMD as a true volumetric density but rather algorithms corrected for individuals of different bone and body size generating a two-dimensional areal BMD measure (g/cm²) [97]. DEXA is regarded as the gold standard for diagnosing osteoporosis [98]. There are thresholds that include people with osteoporotic fractures as well as thresholds that assess future risk of fracture [99]. The DEXA is able to measure the most commonly used sites for diagnosing osteoporosis including the anterior-posterior spine and hip scans (PF, FN or trochanter) [100].

2.6 Assessment of Physical Activity Level using Pedometer and Bone Loading Questionnaires

Walking is the most common PA performed by women in the US adult population [101]. It is an important variable to measure when assessing PA objectively. The pedometer used in this study, the NL series, is highly studied and determined to be accurate in assessing step counts [102]. Crouter, Schneider, Karabulut, and Bassett (2003) found the Kenz Lifecorder, New Lifestyle NL-2000, and Yamax Digi-Walker SW-701 to be the most accurate for counting the number of steps taken [102]. The NL series pedometer is commonly utilized in interventions and
some consider it an industry standard [103]. The New-Lifestyles NL-1000 has been used in a research setting as a standard of care comparison variable [103].

Bone relevant loading is important to consider when investigating PA effects on bone measures [52]. Force and loading rate are elements that need to be considered when examining physical activities [52]. Pedometers and questionnaires thus far in postmenopausal women have failed to capture these elements [52]. Two questionnaires have been developed and used in premenopausal women that capture load factors – the BLHQ and BPAQ [52, 104]. Both capture mechanical loads placed on the skeleton throughout a person’s life instead of only recently [52, 104].

The BLHQ has three different variables that are used to calculate the total and recent bone loading exposure scores [104]. The questionnaire takes into account unique bone loading units for the hips versus spine and uses them within the calculations for the hip and spine algorithms. The BLHQ used experts who considered ground reaction forces and forces applied by the muscle attachments when they rated the load magnitude. The load magnitude rating from each individual expert was averaged to get the load score. The bone loading unit was calculated from the loading score and a loading rate score. The product of the predetermined bone loading unit, seasons, years, and frequency are summed for each activity within each time period (elementary, junior high, high school, young adult, adult, and early postmenopause) to determine the total BLHQ score. The raw total BLHQ scores are divided by the number of years assessed by the questionnaire to calculate the total bone loading exposure. The raw recent BLHQ scores are divided by the number of years assessed during the most recent time period in order to calculate the recent bone loading exposure. The final measurements attained are the hip – total and recent and the spine – total and recent [104].
The BPAQ is able to calculate a current, past, and total score [52]. The past score is calculated from each activity evaluating the years of participation, age, weight factor, and effective load stimulus for each activity. The current score uses the same components as the past except the years of participation is replaced with the frequency/week for each activity. The total score is the product of the past and current score [52].

The BPAQ unlike the BLHQ used direct measures of forces from ground reaction forces measured on a force plate to calculate the loading forces [52]. The BPAQ used the ground reaction force score and determined an effective load rating [52]. All the effective load ratings were normalized relative to gymnastics which has the highest ground reaction forces and bone mass associated with it [52]. The BLHQ was able to determine an association between FN BMD with the historical bone loading activities captured by the questionnaire [104]. The BPAQ past component has been shown to predict calcaneal BUA in women [52].
2.7 References


57. Hinriksdottir, G., et al., Lean soft tissue contributes more to bone health than fat mass independent of physical activity in women across the lifespan. Maturitas, 2013.


CHAPTER 3

LEAN SOFT TISSUE MASS IS A STRONGER PREDICTOR OF BONE MINERAL DENSITY THAN FAT MASS INDEPENDENT OF PHYSICAL ACTIVITY IN POSTMENOPAUSAL WOMEN

Abstract

In young and premenopausal women historical bone loading has been associated with bone mineral density (BMD) but it has not been studied in postmenopausal women. Additionally, mixed results exist as to whether lean soft tissue mass (LSTM) or fat mass (FM) is the major independent contributor of BMD or bone mineral content (BMC) in postmenopausal women, especially when controlling for physical activity (PA). This study aimed to determine 1) the magnitude of the relation between PA, specifically bone loading activities and recent subjectively and objectively measured PA, to whole body (WB) and regional BMD and BMC in early postmenopausal women and 2) the relative independent contribution of LSTM and FM on BMD and BMC after controlling for PA. Women (n = 67, mean age 58.1 ± 3.9, range 49-65 years old) were assessed for PA via global physical activity questionnaire (GPAQ), bone-specific physical activity questionnaire (BPAQ), bone loading history questionnaire (BLHQ), and a pedometer that determined steps/day. WB LSTM, WB FM, WB BMD and BMC, proximal femur (PF) and femoral neck (FN) BMD and BMC, and lumbar spine (LS) BMD and BMC were assessed via dual-energy x-ray absorptiometry. Significant negative correlations were found between FM and steps/day, GPAQ measured total PA min/week, BPAQ current, BLHQ recent hip and spine (r range = -.400 to -.519, p < 0.01). LSTM was negatively correlated with BLHQ recent hip and spine (r = -.268 and -.276, respectively, p < 0.05). PA, as measured by steps/day and BLHQ recent hip and spine, was significantly negatively associated with WB and FN BMD (r range = -.281 to -.368, p < 0.05).

Both FM and LSTM were positively correlated with all of the bone variables (r range = .337 to .569, p < 0.01) except LS BMD and BMC and FN BMC (FM only). PA was not an independent contributor of BMD after age, months in menopause, hormone replacement therapy
estrogen and progesterone (HRT E and P), LSTM, and FM were controlled for using multiple linear regression. LSTM and HRT E and P (both p < 0.05) were the only significant predictors of BMD. LSTM and HRT E and P explained 40.3%, 50.4%, and 50.1% of variance in WB BMD when steps/day, BLHQ recent hip and spine were controlled, respectively. Similarly, LSTM and HRT E and P explained 47.1% and 46.4% of the variance in FN BMD when BLHQ recent hip and spine were controlled for, respectively. In conclusion LSTM appears to be the primary body composition determinant of BMD in postmenopausal women when considering recent PA measures. Although PA appears to be negatively related to bone status, in women this significant relation is present in part by the confounding relation with FM. Past bone loading questionnaires may not be appropriate to use in this population, in part due to potential recall error.

**Key words:** bone mineral density, bone mineral content, lean soft tissue mass, fat mass, physical activity, postmenopausal women
### 3.1 Introduction

As people age, especially women, their risk for fracture increases in part due to declines in bone mineral density (BMD) with the risk of fracture doubling every 5 to 10 years after the age of 50 [2]. Low BMD, decrease in bone strength, lack of architectural structure, and an increased risk of fracture are all characteristics of osteoporosis [3-5]. By the year 2025 the estimated costs associated with osteoporosis in the US are anticipated to be around $25.3B [6]. It is important to understand the contributing factors to skeletal health so that osteoporosis can be prevented in older women.

Several factors are associated with BMD in postmenopausal women including nutrition, hormonal status, physical activity (PA), weight status, and body composition [7]. Dietary intake, especially vitamin D and calcium have been associated with attaining and maintaining bone mass [8]. Substantial declines in the hormone estrogen which occur after menopause, is a major factor in lowered BMD and the development of osteoporosis as women age [7, 8]. PA also plays an important role in maximizing bone mass during childhood, maintaining it during adulthood, and slowing bone loss as people enter older adulthood [9].

Although it has been well established in the literature that weight significantly contributes to BMD and subsequent risk for osteoporosis, with low weight being a risk factor for fracture [7, 10], what is less well established is the independent contributions of lean soft tissue mass (LSTM) and fat mass (FM) to bone status in postmenopausal women. Additionally, the potential confounding influence of PA, past and recent, on the body composition relationship to bone status is not well established. When investigating the relation between body composition and BMD it is important to consider both past and recent PA. For example, a cross-sectional study investigating the associations of past and recent PA on bone mass in postmenopausal women did
not find significant correlations; however, the authors did not consider elements of force and loading rate associated with PA [11, 12]. When considering bone status it is important to assess loading aspects of an activity and most PA questionnaires do not capture this factor [13]. For example, significant correlations were found between past and recent PA and BMD in premenopausal women when the questionnaires assessed loading factors [12, 13]. To date a historical bone loading questionnaire has not been used in postmenopausal women to consider the relation of past and recent PA to BMD or bone mineral content (BMC). These PA related factors need to be controlled for when investigating the relationship between body composition and bone health due to potential confounding effects.

Inconclusive findings also exist between body composition outcomes (LSTM and FM) and BMD in postmenopausal women. Several research studies have examined these relative associations and have concluded that LSTM is more strongly correlated to BMD [14-19] or BMC [20]; or alternatively, FM has a stronger association to BMD [21-25]. A major limitation in several of these studies is that PA was not considered [15, 19, 20, 22, 23, 25]. Other studies used questionnaires [14, 17, 24] or objective measures [16, 21] to assess PA. However PA was not a significant variable [21], was not controlled for in the analysis to reach their conclusion regarding body composition and BMD [16, 17, 24], or strengthened the relation between FM and BMD but still concluded that LSTM was more important for bone status [14]. One study which controlled for PA determined LSTM to be the strongest independent predictor, compared to FM, of BMD and BMC variables in postmenopausal women [18]. Historical PA is also important to consider, and no studies to date have controlled for past PA when investigating the relationships between LSTM, FM and bone status in postmenopausal women.
The aim of this study was to determine the magnitude of the relationships of past reported PA and recent subjectively and objectively measured PA on BMD and BMC in postmenopausal women. An additional aim was to determine the primary independent body composition (LSTM or FM) predictor of BMD and BMC, controlling for historical and recent PA (if deemed significant).

3.2 Materials and Methods

Participants

Sixty seven postmenopausal women (mean age 58.1 ± 3.9, range 49-65 years old; 95.5% Caucasian) participated in the study. Exclusion criteria included self-reported current smoker, COPD including severe allergies or asthma, current use of corticosteroids, HIV, uncontrolled diabetes, other diagnosed endocrinological abnormalities, current or prior mental illness or clinical depression, severe arthritis, symptomatic joint abnormalities, symptomatic nervous system disorders, medical conditions that may affect balance, traumas requiring medical attention in the last year or any conditions which would preclude completion of physical testing. Women were recruited from the Athens community and surrounding areas through the Osher Lifelong Learning Institute, UGA Department of Kinesiology Fitness Center, university email, fliers, local print media, community postings and contact with community groups. Participants completed two visits within a 7-10 day period. The first visit lasted two hours and the second three hours. The study was approved by the University of Georgia Institutional Review Board and all participants signed an informed consent document prior to enrollment.

Health History Questionnaire

Participants’ general health and medical history data was collected in between visits to allow for assessment of age, months in menopause, and current medication use.
**Anthropometric Measures**

Body weight was measured using a calibrated electronic scale with subjects wearing light clothing and no shoes (Tanita, Model WB100). Barefoot standing height was measured to the nearest 0.1 cm with a digital stadiometer (SECA 424).

**Body Composition and Bone Measures**

Whole body (WB) soft tissue compositions were measured by dual-energy x-ray absorptiometry (DEXA, GE iLunar). WB LSTM and WB FM were used in the analysis. BMD and BMC of the left hip (proximal femur (PF) and femoral neck (FN)), lumbar spine (LS), and WB were assessed. Participants removed their shoes and any metal objects for the scans. Participants that had metal implants in the hip and spine were excluded from all analysis. The scans were analyzed by the same technician with subsequent review by an additional technician for quality control.

**Physical Activity**

*Objective.* Current step counts and activity minutes were measured using the New Lifestyles, NL1000 Pedometer over a seven day period. Participants were instructed to wear the pedometers on their hip during all waking hours, except swimming or bathing, for seven days. The participant recorded the time the monitor was put on and removed. In order for the steps/day to be considered valid the device was worn for at least one weekend day and four week days. The device also had to be worn for at least 10 hours/day in order for it to be considered a valid day. The devices’ memory stored the past seven days of steps and activity minutes which were recorded. The average number of steps/day was used in the final analysis.

*Subjective.* Measures of subjective PA were collected using the global physical activity questionnaire (GPAQ), bone loading history questionnaire (BLHQ), and bone-specific physical
activity questionnaire (BPAQ). These questionnaires were completed in between visits. The GPAQ includes 16 questions gaining information regarding total minutes of PA, work related PA, recreational activity, and sedentary time within a typical week. The total minutes of PA conducted in a typical week was used in the final analysis as this unit of measure most closely matches the pedometer unit of measure. The BLHQ and BPAQ assessed past and recent bone loading activities. The BLHQ uses the number of years, seasons, frequency, and a bone loading unit (specific to either the hip or spine) to calculate a bone loading score. It was used to determine a total bone loading exposure score for the hip and spine from different time periods of life (elementary, junior high, high school, young adult, adult, and early postmenopausal) and a recent bone loading exposure score for the hip and spine (early postmenopausal time point). An excel spread sheet was used to make all calculations as directed by the equations in Dolan, Williams, Ainsworth, and Shaw (2006) [13]. The recent bone loading exposure scores (BLHQ recent hip and spine) and total bone loading exposure scores (BLHQ total hip and spine) were used in the final analysis.

The BPAQ assessed all past, current (within the past year), and total PA. The variables included in the past score algorithms are an effective load stimulus derived from ground reaction force testing, years of participation, and age for each activity [12]. The current score variables for the calculations include the effective load stimulus derived from ground reaction force testing, frequency of participation per week, and age for each activity [12]. The total score is calculated from the products of the past and current PA algorithms [12]. The online BPAQ calculator V1 was used to score the BPAQ. Within the final analysis the current, past, and total BPAQ scores were used.
Statistical Analysis

Statistical analysis was performed using SPSS statistical software, version 20 for Windows. The data was inspected for normality and outliers. Total months in menopause and the GPAQ measure of total PA min/week were not normally distributed and were normalized by natural log transformations. BPAQ current, BPAQ past, and BPAQ total were non-normally distributed and did not respond to log transformations; thus spearman’s rho correlations were used to assess the relations between these measures and BMD, BMC, and body composition outcomes. Pearson partial correlations were calculated between all other PA and bone and body composition variables (body weight, LSTM, and FM). Analyses involving BMD and BMC were controlled for age, hormone replacement therapy estrogen and progesterone (HRT E and P), and months in menopause. BMC analysis was also controlled for height due to the known relation between skeletal size and BMC. Multiple linear regression analysis was performed to determine the relative independent association of LSTM, FM, and PA (historical and recent) to BMD, controlling for age, months since menopause, and HRT E and P.

3.3 Results

The participants’ characteristics are presented in Table 3.1. Minimal usage of hormone replacement therapy, osteoporotic medications, or vitamins were reported with the following: 1.6% HRT progesterone, 4.7% HRT estrogen, 7.8% HRT E and P, 1.6% HRT estrogen and testosterone, 15.6% vitamins/mineral supplements, and 1.6% osteoporosis medications. The sample exhibited a range of PA levels (Table 3.2). As expected, based on BMI, on average, our sample was overweight. The descriptive statistics for the BMD and BMC measurements are presented in Table 3.3.
Relationships between Past and Recent Physical Activity, Body Composition, and Bone Measures

All PA measures were negatively correlated to FM (r range = -.400 to -.519, p < 0.01) except BPAQ past and total and BLHQ total hip and spine (Table 3.4). The BLHQ recent hip and spine were negatively correlated with LSTM (r = -.268 and -.276, respectively, p < 0.05). Steps/day and BLHQ recent hip and spine were significantly negatively correlated with WB BMD (r range = -.281 to -.368, p < 0.05). The BLHQ recent hip and spine were significantly negatively correlated with FN BMD also (r = -.317 and -.289, respectively p < 0.05). The WB BMC also had significant negative correlations with BLHQ recent hip and spine (r = -.348 and -.332, respectively, p < 0.05). The FN BMC had a significant negative correlation with BPAQ past (r = -.294, p < 0.05). None of the other PA objective or subjective measures were significantly correlated with bone outcomes.

Relationships between Body Composition and Bone Measures

As expected weight, LSTM, and FM were moderately positively correlated with BMD and BMC of the WB and PF (Table 3.5). Similarly, weight, LSTM, and FM were moderately positively correlated to FN BMD (r range = .412 to .499, p < 0.01). Body composition did not significantly relate to LS BMD or BMC.

Regression analysis was performed to examine the independent contribution of LSTM, FM, and PA to WB and FN BMD (Tables 3.6 and 3.7). PA outcomes of interest were significant correlates as presented in Table 3.4 (steps/day, BLHQ recent hip, and BLHQ recent spine, respectively). Regardless of the PA measure used, LSTM and HRT E and P were the only independent predictors and the model explained 40.3%, 50.4%, and 50.1% of the variance for
WB BMD. Similarly, LSTM and HRT E and P explained 47.1% and 46.4% of the variance in FN BMD; BLHQ recent hip and spine were not significant factors (all p < 0.05).

3.4 Discussion

Historical PA does not appear to be related to bone status in postmenopausal women. The observed significant negative relations between objectively and subjectively measured recent PA and BMD measures were rendered insignificant after controlling for body composition. The other major finding of this study was that LSTM was the only significant body composition independent predictor of WB and FN BMD, even after controlling for subjectively and objectively measured recent PA. Most of the PA variables did not correlate with the BMD or BMC variables. The lack of association for the GPAQ measured total PA min/week with the bone variables may suggest that bone loading is an important aspect to take into account when using a questionnaire to account for PA [12]. Notably, the GPAQ is not a bone loading specific questionnaire. Moreover, since bone responds slower to PA than other biological systems an increased time frame (over a year) should be assessed by a PA questionnaire; the GPAQ assesses a typical week [13].

The main significant negative correlations for PA measured using the bone loading questionnaires were outcomes that tapped recent bone loading activities, specifically the BLHQ recent hip and spine. The BPAQ estimates of current, past, or total bone loading PA did not relate to any bone measures except for the BPAQ past which was related to FN BMC (r = -.294, p < 0.05). This contrasts with studies that originally developed the BPAQ and BLHQ [12, 13], which found a positive relation between BLHQ recent spine and FN BMD [13].
It is important to note that the negative relation between recent PA and bone status in our study appears to be due, at least in part, to the confounding negative relation between PA and FM. When using regression analyses, after controlling for body composition, PA was no longer an independent contributor of BMD variables. This finding parallels findings by Hinriksdottir, Arngrimsson, Misic, and Evans (2013) who reported in postmenopausal women (mean age 68.3 ± 6.4) when body composition was controlled using partial correlations PA was no longer associated with LS BMD suggesting that FM may confound the relation between PA and bone status in older women [18].

None of the historical questionnaire subsections for the BLHQ total or the BPAQ past and total correlated with any of the BMD variables. The BPAQ past has been demonstrated to predict calcaneal BUA ($R^2 = .48$, $p < 0.001$); however this was determined in young adult women with a mean age of 25.1 ± 2.8 years old [12]. These findings suggest recall may be too difficult for an older individual and they cannot accurately recount the main activities they participated in throughout their lifetime. Alternatively, other bone factors (e.g. weight changes, estrogen status over the life course, and current PA) that have larger effects on bone status may obscure the relative impact of historical loading on BMD. Due to the self-report nature of the historical loading studies to date, this remains unknown. Our findings parallel an additional study that also did not find a significant relationship between past or recent PA in 75 year old women [11]. These authors contributed this in part to questions not being detailed enough and not permitting accurate recall causing a skewed distribution of answers [11]. A skewed distribution was also present in the BPAQ scores which may also be due to questions not being detailed enough or potentially the sample including women who participated in activities that do not cause high levels of bone loading (i.e. walking).
Our additional finding that LSTM was found to be the only body composition variable to be an independent predictor of BMD, compared to FM and independent of PA, is similar to another study in the postmenopausal population [18]. There are a multitude of studies that have also attempted to isolate either LSTM [14-20] or FM [21-25] as the major contributor of BMD or BMC in postmenopausal women with mixed results.

The multiple linear regression analysis revealed LSTM to be the only body composition variable with independent contribution to BMD variables when controlling for the effects of PA. PA is important to adjust for because it is known to affect both primary components of body composition (LSTM and FM) and also BMD [9, 26]. Several studies in the literature did not have PA as a measured variable [15, 19, 25] or used sedentary controls [22]. Some research has investigated PA measured subjectively but found no correlation or did not control for PA in their analysis to determine the major independent body composition predictor (i.e., LSTM or FM) of BMD [17, 24]. One study used questionnaire based PA assessment and found after adjustment for PA, the relation of FM to BMD was strengthened; however, overall they reported that LSTM was the stronger predictor of FN BMD [14]. Three studies assessed PA objectively [16, 18, 21]. One of these studies found a significant negative partial correlation between steps/day and FN BMD; however, PA was not controlled for in the analysis between body composition and bone measures [16]. Another study found weak significant negative correlations between steps/day and BMD [21]. Steps/day was not chosen as a significant variable to be used in multiple linear regression where they found FM as the stronger independent predictor [21]. Hinriksdottir et al., (2013) controlled for recent PA (measured objectively) and found LSTM to be the main contributor to bone status in postmenopausal women [18]. Collectively, it appears that when
recent PA is measured well and subsequently controlled in the analyses, LSTM is the primary determinant of BMD, compared to FM, in healthy postmenopausal women.

Although our results are of interest, limitations are inherent in our study design. The cross-sectional design and lack of an intervention will not allow for interpretation of causality. As participants had to be willing to attend two study sessions on the UGA campus, results may not represent all postmenopausal women due to the time commitment involved. Participants were not excluded on the basis of medications such as hormone replacement therapy, supplements such as calcium and vitamin D, and other co-morbid conditions, although hormone replacement therapy and supplement usage were controlled for in the analysis. Finally, there is no objective way to measure past/historical PA therefore recall error will exist.

In conclusion, the findings from the present research suggest that 1) PA is not an independent contributor of BMD after controlling for body composition, and 2) LSTM, and not FM, is the primary determinant of BMD in healthy relatively high functioning postmenopausal women. Moreover, historical PA is either not measured well using recall questionnaires or alternatively is not a major contributor to bone status in postmenopausal women.
3.5 References


Table 3.1 Participant characteristics

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean ± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Months in menopause‡</td>
<td>118.0 ± 84.8</td>
<td>24 - 420</td>
</tr>
<tr>
<td>Age (years)</td>
<td>58.1 ± 3.9</td>
<td>49 - 65</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>70.9 ± 13.8</td>
<td>49.1 - 109.1</td>
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<tr>
<td>Height (cm)</td>
<td>163.8 ± 6.1</td>
<td>150.5 - 181.6</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>26.4 ± 4.6</td>
<td>18.1 - 38.3</td>
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<tr>
<td>Lean soft tissue mass (kg)</td>
<td>40.5 ± 5.3</td>
<td>31.7 - 53.2</td>
</tr>
<tr>
<td>Fat mass (kg)</td>
<td>28.4 ± 9.2</td>
<td>14.1 - 57.4</td>
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<tr>
<td>Body fat percent (%)</td>
<td>39.0 ± 6.0</td>
<td>27.7 - 52.8</td>
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‡n=66; BMI: body mass index.
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<td>Steps/day (n=62)</td>
<td>8,736.3 ± 3,683.1</td>
<td>954.3 - 21,275</td>
</tr>
<tr>
<td>GPAQ (min/week) (n=61)</td>
<td>479.5 ± 785.3</td>
<td>0 - 4,500</td>
</tr>
<tr>
<td>BPAQ current (n=52)</td>
<td>3.3 ± 6.2</td>
<td>0 - 29.9</td>
</tr>
<tr>
<td>BPAQ past (n=57)</td>
<td>121.9 ± 89.7</td>
<td>26.5 - 482.9</td>
</tr>
<tr>
<td>BPAQ total (n=51)</td>
<td>61.2 ± 46.3</td>
<td>13.5 - 254.6</td>
</tr>
<tr>
<td>BLHQ recent hip (n=56)</td>
<td>32.3 ± 22.2</td>
<td>1.4 - 80.9</td>
</tr>
<tr>
<td>BLHQ total hip (n=48)</td>
<td>36.5 ± 21.3</td>
<td>7.1 - 93.2</td>
</tr>
<tr>
<td>BLHQ recent spine (n=56)</td>
<td>27.4 ± 19.6</td>
<td>1.0 - 69.0</td>
</tr>
<tr>
<td>BLHQ total spine (n=48)</td>
<td>31.7 ± 18.9</td>
<td>5.3 - 81.0</td>
</tr>
</tbody>
</table>

GPAQ: global physical activity questionnaire; BPAQ: bone-specific physical activity questionnaire; BLHQ: bone loading history questionnaire.
Table 3.3 Bone mineral density and bone mineral content measures

<table>
<thead>
<tr>
<th>Variables (n=67)</th>
<th>Mean ± SD</th>
<th>Range</th>
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<tr>
<td><strong>Bone mineral density (g/cm²)</strong></td>
<td></td>
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<tr>
<td>Whole body</td>
<td>1.13 ± 0.115</td>
<td>0.856 - 1.43</td>
</tr>
<tr>
<td>Proximal femur</td>
<td>0.933 ± 0.135</td>
<td>0.684 - 1.33</td>
</tr>
<tr>
<td>Femoral neck</td>
<td>0.887 ± 0.130</td>
<td>0.620 - 1.23</td>
</tr>
<tr>
<td>Lumbar spine†</td>
<td>1.16 ± 0.163</td>
<td>0.863 - 1.59</td>
</tr>
<tr>
<td><strong>Bone mineral content (g)</strong></td>
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<tr>
<td>Whole body</td>
<td>2,265.8 ± 306.1</td>
<td>1,600 - 3,059</td>
</tr>
<tr>
<td>Proximal femur</td>
<td>29.2 ± 4.8</td>
<td>19.1 - 39.5</td>
</tr>
<tr>
<td>Femoral neck</td>
<td>4.1 ± 0.8</td>
<td>2.0 - 6.5</td>
</tr>
<tr>
<td>Lumbar spine†</td>
<td>62.7 ± 12.0</td>
<td>42.4 - 103.3</td>
</tr>
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†n=65
Table 3.4 Correlations between past and recent physical activity, body composition, bone mineral density, and bone mineral content measures

<table>
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<tr>
<th>V</th>
<th>PD</th>
<th>GPAQ</th>
<th>BPAQ current</th>
<th>BPAQ past</th>
<th>BPAQ total</th>
<th>BLHQ recent hip</th>
<th>BLHQ total hip</th>
<th>BLHQ recent spine</th>
<th>BLHQ total spine</th>
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<tr>
<td>W (kg)</td>
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<td>-.372**</td>
<td>-.320*</td>
<td>-.092</td>
<td>-.045</td>
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<td>-.126</td>
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<td>-.073</td>
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<td>-.480**</td>
<td>-.144</td>
<td>-.477**</td>
<td>-.139</td>
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<tr>
<td>BMD</td>
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<tr>
<td>WB (g/cm²)</td>
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<td>-.062</td>
<td>.011</td>
<td>-.143</td>
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<td>-.368**</td>
<td>-.084</td>
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<td>-.194</td>
<td>-.072</td>
<td>.039</td>
<td>-.098</td>
<td>-.123</td>
<td>-.233</td>
<td>-.041</td>
<td>-.203</td>
<td>.016</td>
</tr>
<tr>
<td>FN (g/cm²)</td>
<td>-.223</td>
<td>-.131</td>
<td>.057</td>
<td>-.208</td>
<td>-.251</td>
<td>-.317*</td>
<td>-.161</td>
<td>-.289*</td>
<td>-.148</td>
</tr>
<tr>
<td>LS (g/cm²)</td>
<td>-.266</td>
<td>.033</td>
<td>.136</td>
<td>-.107</td>
<td>-.089</td>
<td>-.221</td>
<td>-.014</td>
<td>-.195</td>
<td>.015</td>
</tr>
<tr>
<td>BMC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WB (g)</td>
<td>-.244</td>
<td>.055</td>
<td>.036</td>
<td>-.161</td>
<td>-.149</td>
<td>-.348*</td>
<td>-.115</td>
<td>-.332*</td>
<td>-.086</td>
</tr>
<tr>
<td>PF (g)</td>
<td>-.116</td>
<td>.099</td>
<td>.148</td>
<td>-.213</td>
<td>-.209</td>
<td>-.170</td>
<td>-.073</td>
<td>-.139</td>
<td>-.029</td>
</tr>
<tr>
<td>FN (g)</td>
<td>-.119</td>
<td>.034</td>
<td>.205</td>
<td>-.294*</td>
<td>-.267</td>
<td>-.071</td>
<td>-.128</td>
<td>-.034</td>
<td>-.083</td>
</tr>
<tr>
<td>LS (g)</td>
<td>-.197</td>
<td>.104</td>
<td>.204</td>
<td>-.130</td>
<td>-.091</td>
<td>-.139</td>
<td>-.024</td>
<td>-.116</td>
<td>.012</td>
</tr>
</tbody>
</table>

V: variables; PD: pedometer (steps/day); GPAQ: global physical activity questionnaire (min/week); BPAQ: bone-specific physical activity questionnaire; BLHQ: bone loading history questionnaire; BC: body composition; W: weight; LSTM: lean soft tissue mass; FM: fat mass; BMD: bone mineral density; WB: whole body; PF: proximal femur; FN: femoral neck; LS: lumbar spine; BMC: bone mineral content. BMD and BMC controlled for age, months in menopause, hormone replacement therapy estrogen and progesterone in addition BMC also controlled for height. BPAQ measures were run using spearman’s rho correlations.

* p < 0.05; ** p < 0.01
Table 3.5 Correlations between weight, body composition, bone mineral density, and bone mineral content measures

<table>
<thead>
<tr>
<th></th>
<th>Weight (kg) r</th>
<th>Lean soft tissue mass (kg) r</th>
<th>Fat mass (kg) r</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bone mineral density (g/cm²)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole body</td>
<td>.536**</td>
<td>.519**</td>
<td>.468**</td>
</tr>
<tr>
<td>Proximal femur</td>
<td>.531**</td>
<td>.535**</td>
<td>.459**</td>
</tr>
<tr>
<td>Femoral neck</td>
<td>.486**</td>
<td>.499**</td>
<td>.412**</td>
</tr>
<tr>
<td>Lumbar spine</td>
<td>.160</td>
<td>.156</td>
<td>.123</td>
</tr>
<tr>
<td><strong>Bone mineral content (g)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole body</td>
<td>.499**</td>
<td>.506**</td>
<td>.417**</td>
</tr>
<tr>
<td>Proximal femur</td>
<td>.490**</td>
<td>.569**</td>
<td>.384**</td>
</tr>
<tr>
<td>Femoral neck</td>
<td>.203</td>
<td>.337**</td>
<td>.108</td>
</tr>
<tr>
<td>Lumbar spine</td>
<td>.080</td>
<td>.094</td>
<td>.046</td>
</tr>
</tbody>
</table>

Bone mineral density and bone mineral content controlled for age, months in menopause, hormone replacement therapy estrogen and progesterone in addition bone mineral content also controlled for height.

* p < 0.05; ** p < 0.01
Table 3.6 Linear regression analysis of independent predictors of whole body bone mineral density

<table>
<thead>
<tr>
<th>Bone mineral density</th>
<th>R²</th>
<th>P value</th>
<th>ΔF</th>
<th>Variables</th>
<th>Standardized β</th>
<th>P value</th>
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</thead>
<tbody>
<tr>
<td>Whole body (g/cm²)</td>
<td>.165</td>
<td>.019</td>
<td></td>
<td>Meno M</td>
<td>-.156</td>
<td>.214</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Age</td>
<td>-.083</td>
<td>.502</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>HRT E P</td>
<td>.475</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>.403</td>
<td>.001</td>
<td></td>
<td>FM</td>
<td>.080</td>
<td>.682</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>LSTM</td>
<td>.371</td>
<td>.031</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Steps/day</td>
<td>-.197</td>
<td>.171</td>
</tr>
<tr>
<td>Whole body (g/cm²)</td>
<td>.270</td>
<td>.001</td>
<td></td>
<td>Meno M</td>
<td>-.203</td>
<td>.109</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Age</td>
<td>-.124</td>
<td>.315</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>HRT E P</td>
<td>.504</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>.504</td>
<td>.000</td>
<td></td>
<td>FM</td>
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<td>.493</td>
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<td></td>
<td></td>
<td></td>
<td>LSTM</td>
<td>.317</td>
<td>.029</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BLHQ recent hip</td>
<td>-.181</td>
<td>.129</td>
</tr>
<tr>
<td>Whole body (g/cm²)</td>
<td>.270</td>
<td>.001</td>
<td></td>
<td>Meno M</td>
<td>-.205</td>
<td>.106</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td>Age</td>
<td>-.126</td>
<td>.311</td>
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<tr>
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<td></td>
<td></td>
<td>HRT E P</td>
<td>.504</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>.501</td>
<td>.000</td>
<td></td>
<td>FM</td>
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<td>.467</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>LSTM</td>
<td>.314</td>
<td>.031</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>BLHQ recent spine</td>
<td>-.169</td>
<td>.160</td>
</tr>
</tbody>
</table>

Meno M: months in menopause; HRT E P, hormone replacement therapy estrogen and progesterone; FM: fat mass; LSTM: lean soft tissue mass; BLHQ: bone loading history questionnaire. All regression analyses were run in the following order: Step 1, Meno M, Age, HRT E P; Step 2, FM, LSTM, and physical activity measure.
<table>
<thead>
<tr>
<th>Bone mineral density</th>
<th>R²</th>
<th>P value</th>
<th>Variables</th>
<th>Standardized β</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femoral neck (g/cm²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td>.008</td>
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<td>.174</td>
</tr>
<tr>
<td></td>
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<td>Age</td>
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<td>.344</td>
</tr>
<tr>
<td></td>
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<td>HRT E P</td>
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<td><strong>.000</strong></td>
</tr>
<tr>
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<td>.471</td>
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<td>.786</td>
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<td><strong>.005</strong></td>
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<tr>
<td></td>
<td></td>
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<td>BLHQ recent hip</td>
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<td>.219</td>
</tr>
<tr>
<td>Femoral neck (g/cm²)</td>
<td></td>
<td></td>
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<td>.207</td>
<td>.008</td>
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<td></td>
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<td>Age</td>
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<tr>
<td></td>
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<td>HRT E P</td>
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<td><strong>.000</strong></td>
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<td></td>
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<td>.000</td>
<td>FM</td>
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<td>.691</td>
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<td></td>
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<td>LSTM</td>
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<td><strong>.006</strong></td>
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<td></td>
<td></td>
<td></td>
<td>BLHQ recent spine</td>
<td>-.113</td>
<td>.359</td>
</tr>
</tbody>
</table>

Meno M: months in menopause; HRT E P: hormone replacement therapy estrogen and progesterone; FM: fat mass; LSTM: lean soft tissue mass; BLHQ: bone loading history questionnaire. All regression analyses were run in the following order: Step 1, Meno M, Age, HRT E P; Step 2, FM, LSTM, and physical activity measure.
Body composition (LSTM and FM) and bone status variables (WB BMD and BMC, PF BMD and BMC, FN BMD and BMC, and LS BMD and BMC) were assessed in 67 postmenopausal women. Past bone loading activities across a lifetime were assessed using the BLHQ and BPAQ. The GPAQ was used to assess recent PA over a typical week. A pedometer (steps/day) was an objective PA measure assessing behavior over seven days. Expected significant correlations existed for BMD and BMC and revealed age, HRT E and P, and months in menopause should be controlled for (in addition to height for BMC analyses). The partial correlations controlling for age, HRT E and P, and months in menopause determined significant negative relationships between PA and BMD and BMC with PA measured using a pedometer, BLHQ, and BPAQ. LSTM and FM were partially positively correlated with BMD and BMC. Using multiple linear regression the independent predictors of BMD were LSTM and HRT E and P. The variance explained was 40.3%, 50.4%, and 50.1% for WB BMD, when steps/day, BLHQ recent hip, and BLHQ recent spine were controlled for respectively. The variance explained for FN BMD was 47.1% and 46.4% when BLHQ recent hip and spine were controlled, respectively. In conclusion, the findings from the present research suggest that 1) PA is not an independent contributor of BMD after controlling for body composition, and 2) LSTM, and not FM, is the primary determinant of BMD in healthy relatively high functioning postmenopausal women. Moreover, historical PA is either not measured well using recall questionnaires or alternatively is not a major contributor to bone status in postmenopausal women.
Future research should be directed towards developing a validated recall method for a historical bone loading PA questionnaire for postmenopausal women. Accurate recall for past PA in postmenopausal women may be lacking as suggested in our study and in the literature. Research should also use a different objective measure other than steps/day to assess PA on bone health. Future research technologies may be developed that would permit objective measurement of bone loading activities. Perhaps load sending accelerometers may be developed. Cross-sectional research is limited in their conclusions and confirmation of results in a longitudinal setting will give cause and effect interpretation to the findings. A prospective study should be conducted across a woman’s lifetime to assess the dominant contributor (LSTM or FM) to BMD assessing other important variables including nutrition, disease, hormonal status, PA, child birth, medications, and supplements. The relationships among LSTM, FM, PA, nutrition, and hormones with regard to bone status in older women remain of high public health interest due to our aging society and the epidemic of obesity.