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BODY COMPOSITION AND MUSCULAR STRENGTH AS PREDICTORS OF BONE MINERAL DENSITY IN AFRICAN AMERICAN WOMEN WITH METABOLIC SYNDROME

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Our cross-sectional study investigated the relationships between regional bone mineral density (BMD) and body composition variables, including total body lean mass (LM) and fat mass (FM), as well as muscular strength in overweight and obese African-American (AA) women with metabolic syndrome (MetS). Forty-four women ranging in age from 39 to 61 years participated. Upper and lower body strength measurements were assessed using chest press and leg extension exercises, respectively. Body composition and BMD of the total body, spine (L2-L4), hip, and radius were measured by dual-energy X-ray absorptiometry. LM was positively correlated with total body, spine, hip, and radius BMD (r=.338–.603, all P<.05), and FM was positively correlated with total body BMD (r=.343, P<.05). In multiple linear regression analyses after controlling for age, height, total energy, and calcium intake, LM was a significant positive determinant of BMD at various skeletal sites (P<.05), while FM was negatively related to BMD of total hip (P<.05). Our results indicate that LM is an independent predictor of total body, spine, hip, and total radius BMD. In contrast, FM is a negative predictor of total body and hip BMD in overweight or obese AA women with MetS (P<.05). Upper and lower body muscular strength measures were not associated with BMD at any skeletal sites. These results suggest an important role for LM in preventing the development of osteopenia and osteoporosis. (*Ethn Dis.* 2014;24[3]:356–362)

Key Words: Body Fat, Obesity, Lean Mass, Osteoporosis

INTRODUCTION

Obesity and osteoporosis are clinical and public health challenges worldwide.

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The 2009–2010 National Health and Nutrition Examination Survey (NHANES) data indicated that 69% of adults aged ≥20 years in the United States were either overweight or obese.[1] The relationship between obesity and osteoporosis, previously thought to be mutually exclusive, is getting increased attention and has been reviewed recently.[2] The protective effect of overweight/obesity on bone mass is commonly accepted, and overweight individuals tend to have a higher bone mineral density (BMD) compared to those who are normal-weight.[3] However, obesity is a condition also characterized by high fat mass (FM), low lean mass (LM), and metabolic disturbances that are associated with a high inflammatory state.[4] Some studies indicate that excessive adiposity might not lead to added benefits to bone.[5] Recently, the interrelationship between BMD and muscular strength loss has been investigated in older women because of the interest in the function of muscle and bone as a unit.[6] Muscular strength, reflecting skeletal muscle mass, has also been shown to be an independent predictor of BMD in healthy participants,[7,8] although some authors have reported no association between muscular strength and BMD.[9,10] A study examining older women showed that poor muscular strength relative to excessively high fat mass may be associated with lower BMD.[6] The ability of muscular strength in predicting BMD is unclear. Further research is needed to understand the roles of muscular strength in predicting BMD in overweight/obese women, especially when compared with LM and FM.

Obesity, especially abdominal adiposity, is associated with insulin resistance and other diagnostic correlates of metabolic syndrome (MetS) including elevated triglycerides, low high-density lipoprotein cholesterol (HDL-C), high fasting glucose concentrations, and elevated blood pressure.[11] Studies on the effect of MetS on BMD are extensive but the results are inconsistent. A study of the US population showed that femoral neck BMD was higher among participants with MetS after adjustment for age, sex, and other covariates.[12] In contrast, the Rancho Bernardo Study showed that men but not women with MetS had lower BMD after adjustment for body mass index (BMI).[13] In a study of Korean women, BMD of the spine was significantly lower in women with MetS after adjustment for age, weight, and height compared to women without MetS.[14] Race and sex differences and varied analytical methods may have influenced these study results as some studies adjusted for BMI[12,13] and others adjusted for weight.[14]

African American (AA) women, in comparison to women of other ethnic/racial backgrounds, have considerably higher BMI values.[1] High BMI values have been well accepted as indices for higher body fat percentages in the general population.[15] The most recent NHANES statistics show that 82% of non-Hispanic Black females in the United States are overweight, 59% are obese, and 18% are extremely obese with a BMI ≥40 kg/m^2.[1] Furthermore, 39% of adult AA women in the United States have MetS.[16] Whether or not overweight or obesity affects bone health in AA women with MetS is still unclear. To our knowledge, no study has examined the BMD of AA women with MetS and the association between BMD, LM, FM, and muscular strength

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METHODS

Participant Characteristics

Our study included 26 pre-menopausal, 1 peri-menopausal, and 20 post-menopausal AA women with MetS recruited from the local community in Tallahassee, Florida by using posted announcements, newspaper advertisements, email distribution lists, and word-of-mouth. Exclusion criteria included uncontrolled hypertension (≥160/100 mm Hg), diagnosed heart disease, uncontrolled diabetes, endocrine disease, anticoagulant therapy, bleeding disorders, history of stroke, thyroid disease, pregnancy/plan to become pregnant, smoking during the past 6 months, and any physical illnesses/orthopedic disability that would limit ambulation or the ability to complete upper and lower body strength testing. Participants were also not permitted into the study if they were currently participating in any type of exercise programs, special diets, or weight-loss programs. Interested women were prescreened via telephone interview for age, current physical activity level, and physical limitations. Those who successfully completed prescreening were scheduled for their laboratory measurements at which point they underwent additional screening for study inclusion. The women were only eligible to participate in the study if they had at least three of the following cardiovascular disease risk factors associated with MetS: waist circumference >88 cm, blood glucose ≥100 mg/dL, blood pressure ≥130/≥85 mm Hg, triglycerides ≥150 mg/dL, and/or HDL-C <50 mg/dL.[17] The study was approved by The Florida State University Institutional Review Board and all women signed an informed consent and completed a medical-history questionnaire before enrolling into the study.

Blood Pressure and Anthropometric Measurements

Resting blood pressure was taken in a quiet room after five minutes of rest. Two measurements were taken on the right arm. If the systolic or diastolic differed by more than 6 or 4 mm Hg, respectively, a third measurement was taken. The two measures that were closest were averaged for the criterion measure. Height without shoes was measured on a wall-mounted stadiometer, and weight in indoor clothing with a digital scale (Seca Corporation, Hanover, MD). Waist and hip circumferences were measured with a Gulick fiberglass measuring tape with a tension handle (Creative Health Products, Ann Arbor, MI). Circumference measurements were collected using the methods recommended by the American College of Sports Medicine.[18]

Body Composition

Dual-energy X-ray absorptiometry (iDXA, GE Medical Systems, Madison, WI) with software supplied by the manufacturer (encore 2006, version 13.11) was used to measure total body LM, FM, and BMD utilizing a whole body scan. The iDXA has a wider scan field and higher precision that can accommodate individuals up to 181 kg, avoiding the errors typically encountered when measuring overweight/obese individuals, and therefore providing a more accurate assessment of body composition.[19] Regions of interest, including lumbar spine (L2-L4), right and left femurs (total hip), and non-dominant forearm (total radius) were measured separately. Participant BMD results at the clinically relevant sites of the spine and hip were compared to age-, sex-, and ethnicity-matched reference populations provided by the manufacturer to generate T-scores. For spine and total hip BMD measurements, a score of >1 and <2.5 standard deviation (SD) below the young normal mean (T-score), and <2.5 SD below the young normal mean (T-score) were considered clinically diagnostic of osteopenia and osteoporosis, respectively. Lean mass refers to the total body mass less bone and fat. Measurements were completed according to the manufacturer's specifications by a certified X-ray technician. The coefficients of variation for precision were .7%, .8%, 1.0%, and .9% for total body BMD, LM, FM, and % body fat, respectively. The precision coefficients of variation for total hip, spine, and total forearm BMD were .4%, 1.6%, and 1.1%, respectively.

Muscular Strength

Upper and lower body strength was assessed using chest press and leg extension machine exercises (MedX™; Orlando, FL), respectively. After a warm-up, participants were progressed towards the maximum weight that they could lift one time through a full range of motion, also called a one-repetition maximum (1-RM). All measurements were recorded within approximately 5 maximal attempts. Participants were given 3–5 minutes of rest between each attempt.[18]

Physical Activity and Dietary Intake

Participants received a New Lifestyles Digi-Walker SW-200 pedometer (New Lifestyles, Inc.; Lees Summit, MO;[20] and were instructed to record the total number of steps taken each day for seven days on a provided activity log. Participants were instructed not to make any changes to their typical daily routine of work and leisure activity. Participants were also given a food log and instructed by a registered dietitian on how to record their complete dietary consumption for three consecutive days, including two weekdays and one weekend day. Participants were instructed to remain consistent with their typical dietary habits and to record items and consumption quantities as specifically as possible. Dietary intake records for each day were analyzed using Nutritionist Pro™ analysis software (Axxya Systems; Stafford, TX). Average energy and calcium intakes for the three days were calculated to provide an estimate of each participant's typical daily consumption.

Blood Analysis

Fasting venous blood samples were collected into vacutainer tubes treated with sodium fluoride for blood glucose, sodium heparin for HDL-C, and EDTA for total cholesterol and triglycerides. Total cholesterol, HDL-C, triglycerides, and fasting blood glucose were quantified using colormetric reagents and standards in a Sirrus Clinical Chemistry Analyzer (Stanbio Laboratory; Boerne, TX). All blood variables were measured in duplicate.

Statistical Analysis

Data were analyzed with SPSS version 18 (SPSS Inc.; Chicago, IL). All values are presented as mean ± standard deviation. Pearson's correlation coefficients were used to examine the associations of muscular strength, BMD, and body composition. Multiple linear regression models were used to investigate the independent effects of LM, FM, and muscular strength on BMD of total body and various skeletal sites. Regression models were adjusted for age, height, total energy, and calcium intake. Body weight was not included in the multiple regression models due to the collinearity with LM and FM. Significance was considered at $P<.05$.

RESULTS

Of the fifty-six women who underwent the initial assessment, seven did not meet the inclusion criteria and two women did not complete the upper and lower body strength tests. Participant characteristics are presented in Table 1. The participants were 48.7 ± 5.6 years old, obese (total body fat percentage: 45.6 ± 5.7%; BMI: 34.7 ± 5.5 kg/m^2), and categorized as sedentary (average steps/day: 5,909 ± 3,494;[21] BMI ranged from 25.1 to 45.1 kg/m^2. Based on BMI,[22] 16% of women were overweight and 84% were obese. Participants were categorized as having MetS as each had at least 3 abnormal cardiovascular disease risk factors. Abnormal mean values for the entire sample included: waist circumference, 104.3 ± 13.5 cm; diastolic blood pressure, 85 ± 8 mm Hg; blood glucose, 121 ± 48 mg/dL; and HDL-C 37 ± 11 mg/dL. Fourteen women were pre-diabetic and 24 women were non-diabetic (pre-diabetics were defined by an HbA1c of 5.7 to 6.4% and controls by HbA1c <5.7%).[23] Mean systolic blood pressure was elevated nearly to the threshold for MetS (127 ± 12 mm Hg), while triglyceride levels were within normal concentrations (92 ± 48 mg/dL). Only 17% of participants achieved the recommended daily intake of calcium (800 mg) through diet alone. Both osteopenic and osteoporotic prevalence was low. Osteopenia at either hip or spine was present in 2 participants (2/47, 4.3%), whereas osteoporosis was present only in one participant in the spine (1/47, 2.1%).

Correlations between body composition, muscular strength, and BMD are shown in Table 2. Lean mass was significantly and positively correlated with total body and regional BMD (r=.338–.603, all $P<.05$). Fat mass was only positively correlated to total body BMD (r=.343, $P<.05$). Upper and lower body strength did not correlate with BMD at any skeletal regions. There was no relationship of any of the blood parameters and total or regional BMDs (data are not shown).

Table 3 shows multiple regression analysis results. Lean mass was an independent and strong predictor of total body, spine, hip, and radius BMD ($P<.05$). The association remained significant after either upper body strength or lower body strength was added to the model (Models 2 and 3, respectively). Fat mass was a negative predictor of total body and hip BMD and the association remained significant after upper body strength was added to the model ($P<.05$). After adding lower body strength in the regression model, the negative effect of FM on total body BMD disappeared, but the negative association between hip BMD and FM remained ($P<.05$). Neither upper nor lower body strength was an independent predictor of total body, spine, hip, or radius BMD.

DISCUSSION

Our study showed that sedentary overweight or obese AA women with MetS had a low rate of osteopenia or osteoporosis in the spine and hip, possibly due to their excessive body weight.[24] We found that LM was the

We found that LM was the strongest predictor of total body, spine, hip, and radius BMD after adjustment for age, height, energy intake, and calcium intake.

Table 1. Participant Characteristics, *N*=47

Variables	Mean ± SD	Range, Min-Max
Age, yrs	48.8 ± 5.6	39–61
Menopausal age, yrs	44.4 ± 7.1	34–50
Height, cm	164.5 ± 5.4	153.0–177.5
Weight, kg	93.9 ± 15.7	59.9–133.2
Body mass index, kg/m^2	34.7 ± 5.5	25.1–45.1
Systolic blood pressure, mm Hg	127 ± 12	105–155
Diastolic blood pressure, mm Hg	85 ± 8	66–105
Steps/day	5909 ± 3494	1839–15958
Energy intake, kcal/day	1905.6 ± 547.9	1049.7–3415.0
Dietary calcium intake, mg/day	623.3 ± 297.3	323.0–2082.3
Waist circumference, cm	104.3 ± 13.5	82.3–135.0
Hip circumference, cm	120.4 ± 13.0	93.0–143.0
Lean body mass, kg	47.4 ± 6.1	35.1–60.4
Fat body mass, kg	42.8 ± 13.0	20.2–74.3
Total body fat percentage, %	45.6 ± 5.7	34.6–55.5
Total body BMD, g/cm^2	1.295 ± .118	.971–1.561
Spine L2-L4 BMD, g/cm^2	1.231 ± .149	.846–1.524
Spine T-score	1.3 ± 1.6	−2.3–6.9
Total hip BMD, g/cm^2	1.149 ± .147	.915–1.537
Hip T-score	1.2 ± 1.2	−1.4–4.2
Total radius BMD, g/cm^2	.573 ± .047	.468–.736
Upper body strength, kg	99.7 ± 15.9	72.7–140.9
Lower body strength, kg	102.1 ± 22.6	50.0–140.9
Blood glucose, mg/dL	121 ± 48	92–386
HDL-C, mg/dL	37 ± 11	19–61
LDL-C, mg/dL	153 ± 28	103–210
Triglycerides, mg/dL	92 ± 48	36–232
Cholesterol, mg/dL	209 ± 32	145–276
LDL-C/HDL-C	4.5 ± 1.6	2.2–9.3
Cholesterol/HDL-C	6.1 ± 2.1	3.4–12.5

BMD, bone mineral density; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol.

T-score = standard deviation from young-normal, sex-matched population BMD.

strongest predictor of total body, spine, hip, and radius BMD after adjustment for age, height, energy intake, and calcium intake. Correlations between muscular strength and BMD measures were not significant, suggesting that AA women with MetS in our study may have lacked the ability or were not familiarized enough with the modality of exercise (chest press and leg extension) to fully recruit motor units to produce force.[25] Perhaps using a simpler device like the handgrip dynamometer would have been a better modality to access strength.[26] In addition, it has been suggested that the relationship between muscle mass and muscular strength may not be linear.[27] In accordance with these findings, our study did not find an association between muscular strength and BMD, but a relationship between LM and BMD at various sites (all $P<.05$). In contrast, FM was a significant negative predictor of total hip BMD. These findings imply that maintaining LM is critical to maintaining bone mass in overweight or obese AA women with MetS.

The findings of our study were in accordance with previous results reporting a significant positive effect of total body LM on BMD of various sites in healthy women.[28,29] A study by Winters and Snow[30] reported that LM was a robust predictor for total body, femoral neck, and total hip BMD in premenopausal women. Similarly, Ilich and Brownbill[28] showed that LM had a predominant effect on total body, femoral neck, total femur, and spine BMD in slightly overweight postmenopausal women. These studies support the concept that the effect of body composition on BMD is primarily mediated through the mechanical pull of LM on the skeleton, but not by the static loads, such are exerted by FM.[31] Although both LM and FM have similar relative contributions to gravitational loading on weight-bearing sites (spine, femur, and total body), LM exerts greater effect on the skeleton via regional muscle pull.

This study clearly demonstrated a negative effect of FM on total body and hip BMD. The observed negative association between FM and BMD was in accordance with some previous studies.[5,32] Recently, Zhao et al[29] showed that when controlling for mechanical loading of body weight, FM was negatively related to weight-adjusted BMD, suggesting that a higher FM may not increase BMD. In a study of a large-cohort of Chinese pre- and postmenopausal women by Hsu et al,[32] a negative association between FM and bone mass across quartiles of FM in 5-kg strata of weight was found. A smaller study with 84 Chinese perimenopausal

Table 2. Pearson's correlation coefficients between muscular strength, body composition and bone mineral density, *N*=47

	Total Body BMD	Spine BMD	Total Hip BMD	Total Radius BMD
Total body fat percentage	.120	.127	−.041	.122
Fat mass	.343[a]	.252	.240	.105
Lean mass	.603[b]	.471[b]	.524[b]	.338[b]
Upper body strength	.075	.051	.169	.268
Lower body strength	−.163	−.287	−.057	.214

BMD, bone mineral density.

[a] $P<.05$.

[b] $P<.01$.

Table 3. Multiple linear regression for the independent effect of body composition and muscular strength on bone mineral density, *N*=47

	Total Body BMD	Spine (L2-L4) BMD	Total Femur BMD	Total Radius BMD
	B	*B*	*B*	*B*
Model 1[a]				
Fat mass	−.003	−.004	−.005[b]	−.001
Lean mass	.017[c]	.016[c]	.021[c]	.004[b]
Model $R_{(adj)}^2$	.335	.149	.359	.162
Model 2[a]				
Fat mass	−.003[b]	−.003	−.004[b]	−.001
Lean mass	.017[c]	.016[c]	.021[c]	.004[b]
Upper body strength	.0003	.0002	.001	.0003
Model $R_{(adj)}^2$	.327	.128	.377	.185
Model 3[a]				
Fat mass	−.003	−.003	−.004[b]	−.001
Lean mass	.015[c]	.015[c]	.021[c]	.005[c]
Lower body strength	.0001	−.001	.0003	.0003
Model $R_{(adj)}^2$	.319	.168	.364	.203

BMD, bone mineral density.
[a] All models are adjusted for age, height, total energy, and calcium intake. In Models 2 and 3, upper and lower body strength variables were entered, respectively.
[b] $P<.05$.
[c] $P<.01$.

women showed that body fat was inversely associated with BMD of all skeletal sites after adjusting for body weight and height.[5] The participants in our study averaged about 46% body fat compared to 25% in the normal-weight women.[33] It is well established that fat tissue produces adipocyte-derived hormones[34] or inflammatory factors[35] that have a negative effect on bones. Inflammatory cytokines play an important role in stimulating osteoclast activity and in developing osteoporosis.[4] A decreased adiponectin level[36] and increased interleukin-1, interleukin-6, and tumor necrosis factor-alpha levels[37] were previously shown to be positively correlated with bone loss. The negative association between FM and BMD yields an important clinical implication that losing fat tissue and maintaining LM are beneficial not only to decrease risks for metabolic diseases but also to prevent osteoporosis.

Our findings are contrary to previous studies that did find muscular strength to be a BMD predictor in various populations including older Caucasian, AA, and Asian women[7] and young Caucasian, Hispanic, and Asian women.[8,38] The conflicting results may be due to bone site differences (each having different muscle attachments) and differential loading or type of strain. It has been suggested that the muscle contraction stimulates bone remodeling by pulling at the site of attachment of the tendon into the bone,[39] and that the skeleton adapts to the increased magnitude of loading by depositing bone.[40] Bevier et al[41] found that isometric back strength correlated with higher spine BMD, demonstrating a site-specific relationship between muscular strength and adjacent BMD sites. In addition, Kerr el al[39] reported that the load threshold for osteogenesis in women is much lower for the upper than lower limbs. Lower limb BMD is mainly influenced by mechanical loading such as gravity, muscle mass, and muscular strength.[7] In this study, however, the total body lean tissue (which includes internal organs and connective tissues that do not contribute to muscular strength) was used as a proxy to assess the relationship between BMD of various skeletal sites and muscle groups.

Our participants were sedentary, overweight or obese, and had MetS. Based on the mean pedometer-measured activity levels (5,909 ± 3,494 steps/day), the participants did not engage in high levels of walking that required lower limb movement. Therefore, we did not see strong lower limb muscular strength predicting hip BMD. It appears that although there is a general trend for LM to predict BMD, the strength of predictability depends on the population tested, the bone site measured (each having different muscle attachments) and the combination of variables used in regression models. The above factors may have led to the discrepancy between LM having a relationship with bones, but not the upper or lower body muscular strength. In addition, different techniques for measuring muscular strength have been used such as isokinetic dynamometers,[6] isotonic or variable resistance machines,[38] and isometric dynamometers.[42] These different modalities and the complexity of movements could have contributed to the variation in results. Future research should examine different muscular strength measurement modalities and different types of muscle groups to identify which assessment modality and muscle groups have the best association with BMD measurements.

Our study has some limitations including the relatively small sample size (although based on the power calculation, the sample was adequate) and the fact that the participants were not actively engaging in any form of resistance or aerobic exercise. The population was also relatively healthy since it did not include individuals with overt health issues such as heart disease, cancer, diagnosed osteoporosis, and diabetes. With an additional group that included active participants, we could provide a prospective on the uniqueness of the study population and could compare the relationship between muscular strength and BMD in sedentary vs exercising women. There was a big variation in caloric intake among participants. Participant may have changed their food patterns during the recording period although we suggested not changing their diet. Another reason can be that the portion size they reported had a discrepancy between what we commonly consider as a normal portion size.[43] Furthermore, underreporting of food intake is common in obese participants.[44] The degree of underreporting is positively correlated with BMI and is one of the obstacles to assess dietary intake. Our interest was to investigate the effect of body composition and muscular strength on BMD in AA women with BMI≥25 and MetS. We did not stratify AA women with MetS into overweight or obese groups. Therefore, there could be differences between those two groups. Furthermore, because of the cross-sectional nature of the study, the causal effect, or lack of it, of the association between muscular strength and BMD in these particular participants cannot be addressed. Since our sample was not randomly selected, our results may not be applicable to all AA women or individuals from other races/ethnicities and sex.

In conclusion, ours is the first study to examine the relationship between body composition, muscular strength, and BMD in overweight and obese AA women with MetS. Our findings indicate that LM is a strong independent predictor of total body, spine, hip, and total radius BMD in African-American women. In contrast, FM was a negative predictor of total hip BMD. Consequently, losing FM and maintaining or increasing LM in this population may have a positive effect on BMD and could prevent the development of osteopenia and osteoporosis. Muscular strength was not related to any of the BMD sites. Future research in larger groups and perhaps osteopenic/osteoporotic women could help clarify this relationship.

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