

Socioeconomic status and bone mineral density in adults by race/ethnicity and gender: the Louisiana osteoporosis study

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Abstract

Summary Low bone mineral density (BMD) and osteoporosis have become a public health problem. We found that non-Hispanic white, black, and Asian adults with extremely low education and personal income are more likely to have lower BMD. This relationship is gender-specific. These findings are valuable to guide bone health interventions.

Introduction The evidence is limited regarding the relationship between socioeconomic status (SES) and bone mineral density (BMD) for minority populations in the USA, as well as the relationship between SES and BMD for men. This study explored and examined the relationship between SES and BMD by race/ethnicity and gender.

Methods Data ($n = 6568$) from the Louisiana Osteoporosis Study (LOS) was examined, including data for non-Hispanic whites ($n = 4153$), non-Hispanic blacks ($n = 1907$), and non-Hispanic Asians ($n = 508$). General linear models were used to estimate the relationship of SES and BMD (total hip and lumbar spine) stratified by race/ethnicity and gender. Adjustments were made for physiological and behavioral factors.

Results After adjusting for covariates, men with education levels below high school graduate experienced relatively

low hip BMD than their counterparts with college or graduate education ($p < 0.05$). In addition, women reporting a personal annual income under \$20,000 had relatively low hip and spine BMD than their counterparts with higher income level(s) ($p < 0.05$).

Conclusions Establishing a conclusive positive or negative association between BMD and SES proved to be difficult. However, individuals who are at an extreme SES disadvantage are the most vulnerable to have relatively low BMD in the study population. Efforts to promote bone health may benefit from focusing on men with low education levels and women with low individual income.

Keywords Bone mineral density · Gender · Race/ethnicity · Socioeconomic status

Introduction

As the world's population ages more rapidly, osteoporosis has emerged as a serious public health concern. Characterized by low bone mass and micro-architectural deterioration of bone tissue, osteoporosis can lead to an increased risk of bone fractures [1, 2], with the cost of treatment creating a financial burden for those involved and the society. For example, in the USA, the cost of treatment for osteoporotic fractures was projected to rise from US\$17 billion in 2005 to US\$25.3 billion in 2025 [3]. In addition, fractures can dramatically decrease mobility, increase functional disability, affect quality of life, and lead to a higher mortality rate [4, 5]. Effective and efficient strategies designed to target the most vulnerable populations are urgently needed.

Socioeconomic status (SES) has been reported to be associated with a variety of both acute and chronic diseases [6]. Recent studies suggest that a relationship may exist between

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SES and osteoporosis/bone mineral density (BMD) [7, 8]. The underlying mechanisms may involve some known modifiable risks and preventive behavioral factors, including but not limited to body mass index (BMI), physical exercise, cigarette smoking, calcium intake, alcohol consumption, and menopausal hormone therapy [7–13].

However, the reported relationship between SES and osteoporosis/BMD in currently available literature remains controversial. Overall, findings are more consistent in women. It was reported that lower education and/or income were associated with lower BMD in elderly Canadian, postmenopausal Korean, and elderly Australian women [14, 15]. However, in an Australian female cohort, BMD was the highest in the mid quintiles of SES [17]. For men, the results have been relatively inconsistent. An early study conducted in New Zealand reported that osteoporosis was a disease of higher SES in Caucasian men [17]. In contrast, education and household income were positively associated with BMD in Korean men [14]. Meanwhile, a study in Australia reported no relationship between SES and BMD in older men [15]. In another male Australian cohort, after adjusting for age, weight, and lifestyle factors, spine BMD was the highest in participants in the mid quintiles of education for men younger than 60 years old; the pattern of adjusted spine BMD was reversed in men age 60 and older [18]. These inconsistent findings may be partly caused by the cross-sectional nature of these studies, and different study populations and regions.

In the USA, race/ethnicity is an important factor when examining health disparities, but evidence documenting an association between SES, BMD, and race/ethnicity is scarce. In the USA, one study showed that after adjusting for covariates, including race and gender, education was positively associated with spine BMD, but not with femoral neck BMD [19]. The study also documented that current financial advantage was not related to either spine or femur neck BMD [19]. Another study examining NHANES III data of postmenopausal women revealed that after adjusting for age, weight, height, and years since last menstrual period, education and/or income were positively associated with total hip BMD in both black and white women, but not in Mexican-American women. However, the association was eliminated when accounting for calcium intake, physical activity, and smoking [20].

Overall, the evidence is limited regarding the relationship between SES and BMD for minority populations in the USA, as well as the relationship between SES and BMD for men. Therefore, the aim of this study was to examine the relationship between SES (education and personal annual income) and BMD by race/ethnicity (non-Hispanic whites, non-Hispanic blacks, and non-Hispanic Asians) and gender.

Methods

Study population

We used data from the Louisiana Osteoporosis Study (LOS) [21], a cross-sectional study with ongoing recruitment which began in 2011. It was designed to build a large sample pool (with ~20,000 subjects) and database for use in investigating genetic and environment risk and protective factors for osteoporosis in Southern Louisiana. Subjects age 18 and over were recruited in New Orleans, Baton Rouge, and surrounding areas in Louisiana, USA. The inclusion criteria for the LOS were (1) be at least 18 years of age; (2) be willing to participate in the study, have a bone densitometry exam, and blood drawn; and (3) speak and understand spoken English. The exclusion criteria were (1) female subjects who are, or could be pregnant; (2) female subjects who have had bilateral oophorectomy; (3) serious residuals from cerebral vascular disease; (4) diabetes mellitus, except for those controlled under medication; (5) chronic renal failure; (6) chronic liver failure; (7) significant chronic lung disease; (8) alcohol abuse as defined by those who cannot limit drinking, regularly become intoxicated, and cannot fulfill major responsibilities at work, school, or home; (9) chronic obstructive pulmonary disease (COPD); (10) corticosteroid therapy at pharmacologic levels for more than 6 months duration; (11) treatment with anticonvulsant therapy for more than 6 months duration; (12) evidence of other metabolic or inherited bone disease such as hyper- or hypoparathyroidism, Paget's disease, osteomalacia, osteogenesis imperfecta or others; (13) rheumatoid arthritis (except for minor cases that involve only hand joint and wrist); (14) collagen diseases (i.e., Osteogenesis imperfecta and Hypochondrogenesis); and (15) chronic gastrointestinal diseases including celiac disease, postgastrectomy, Crohn's disease, ulcerative colitis, liver transplant, and cirrhosis.

A total of 11,795 subjects who met the inclusion and exclusion criteria were recruited from 2011 to 2015. For this study, we excluded subjects of race/ethnicity with small sample size from the data analysis, including Hispanic/Latino, Native American/Pacific Islander, and other. We also excluded the data of participants who did not provide information regarding education and/or income status, both of which are optional questions in the questionnaire survey, with 27.1 and 36.9% missing for education and income, respectively. Ultimately, the data of 6568 participants who had complete survey information and valid anthropometric and scan measurements were included in the current study, including non-Hispanic whites ($n = 4151$), non-Hispanic blacks ($n = 1907$), and non-Hispanic Asians ($n = 508$). Consent forms were signed by each participant before any data collection, and the study was approved by the Tulane University Institutional Review Board (IRB).

Bone mineral density

We used hip and spine BMD (g/cm^2) in the current study. BMD of total hip (combined BMD of femoral neck, trochanter, and intertrochanteric region) and spine (combined BMD of L1–L4) were measured with a dual-energy X-ray absorptiometry (DXA) machine (Hologic Inc., Bedford, MA, USA) by trained and certified research staff. The machine was calibrated daily, and software and hardware were kept up-to-date during the data collection process. More details on data quality control including the usual covariation for repeated measures can be found in earlier publications [22].

Physiological, behavioral, and social factors

Body mass index (BMI) was calculated by dividing weight (kg) by height squared (m^2). Height was measured in a standing position using a calibrated Health-O-Meter Professional height and weight scale without shoes. Weight was measured with a balance beam, calibrated Health-O-Meter Professional height and weight scale.

Questionnaires were used to collect data including age, gender, race/ethnicity, SES, menopausal status, and behavioral factors. Self-reported race/ethnicity was identified by selection from the following groups: African-American/Black, Asian, Caucasian/White, Hispanic/Latino, Native American/Pacific Islander and other. SES was measured by education level and personal annual income; specifically, for education participants could select from: eighth grade or less, some high school, high school graduate, some college, college graduate, and graduate degree. We condensed education into the following four categories: less than high school graduate, high school graduate, college (including some college and college graduate), and graduate level. Participants selected personal annual income from five scales—under \$20,000, \$20,000–39,999, \$40,000–59,999, \$60,000–79,999, and \$80,000 or more. The five income categories were referred to as Levels 1, 2, 3, 4, and 5, respectively with higher levels indicating higher income. Menopausal status was assessed with a “yes/no” question. Specifically, a response of yes to “Are you postmenopausal (If perimenopausal, has it been more than 12 months without a period)?” was considered as post menopause.

Behavioral factors included regular exercise, smoking, milk consumption, alcohol use, and hormone replacement therapy. Regular exercise was measured by responding to, “Do you currently exercise on a fairly regular basis?” “Do/did you smoke cigarettes? — Past history or current use of tobacco should be YES” was used to assess smoking status. Milk consumption was assessed by the question, “Do you drink milk (including fortified soy, rice, almond milks, etc.)?” “Do you have a history of alcoholism or a drinking problem?” was used to assess alcohol use. A response of yes to the question was considered as having a drinking problem.

Menopausal hormone therapy was measured by asking, “Do you routinely accept hormone replacement therapy?” Although questions, such as duration and intensity, were asked for behavioral factors, the responses rate was relatively low. In addition, behavioral factors were treated as covariates, not the main factors. Therefore, behavioral factors were expressed as “yes/no,” and were coded as yes = 1 and no = 0.

Statistical analysis

Continuous and categorical variables were reported as means and percentages. Analysis of variance and Chi square/Fisher’s exact test were adopted to test the association of SES to physiological and behavioral factors by race/ethnicity and gender. Statistically significant interactions were found between gender and race/ethnicity, gender and SES, and race/ethnicity and SES for both skeletal sites in this study (not shown). Thus, we did a multiple comparisons of BMD across SES by race/ethnicity and gender. General linear models provided a statistic approach used to determine whether the means of two or more groups differ. The flexibility of general linear models to incorporate both factors and covariates is a good fit for this study to explore BMI differences across different levels of SES while considering covariates [23]. Therefore, general linear models were used to assess the Least Squares Means of BMD across SES level by race/ethnicity and gender, as well as the p -value for linear trends across SES, adjusting for age, plus menopause status for women.

The preliminary results demonstrated that the BMD of individuals with the lowest education or income disadvantage was minimal in a majority of subpopulations compared with their counterparts with higher SES. Therefore, general linear models were also adopted to further analyze significant differences in the association of SES with BMD by race/ethnicity and gender. The independent variables included in Model 1 were SES, age and BMI for men, plus menopausal status for women; Model 2 included variables in Model 1 and behavioral factors. Participants with less than high school graduate education or income less than \$20,000 (the lowest income category in the survey), both of which were considered extreme SES disadvantage, were used as reference groups in Models 1 and 2. All the statistical analyses were performed with SAS software, version 9.4 and stratified by race/ethnicity and gender, and $p < 0.05$ was considered statistically significant.

Results

Physiological and behavioral factors across SES of participants

In this study sample, 37.4% of the respondents were men. Of all the participants, 63.3% were non-Hispanic whites (32.2%

were men), 29.0% were non-Hispanic blacks (48.6% were men), and 7.7% were non-Hispanic Asians (37.4% were men) and 12.2% of the population sample had less than a high school education, while 18.7% had completed graduate school. Of the total, 43.9 and 15.1% reported being in the lowest and highest income, respectively (not in Table 1). For non-Hispanic blacks and whites, men of higher education were more likely to be older than their counterparts of lower education (see Table 1). Meanwhile, for both genders, older non-Hispanic white and black participants tended to have higher individual income. For non-Hispanic Asians, participants with lower education were generally older ($p < 0.01$), while those with lower income were generally younger ($p < 0.01$).

The mean BMI of non-Hispanic blacks and white men in both the lowest and highest income levels were lower than their middle level counterparts. Non-Hispanic white women

with lower education or income were more likely to have higher BMI when compared with their counterparts having higher education or income ($p < 0.001$). For non-Hispanic whites, the highest proportion of postmenopausal women was found in those with high school graduate education (76.4%), while the lowest proportion was found in those with extreme low income (43.8%). The higher proportion of postmenopausal status was found in non-Hispanic Asian women with lower education level ($p < 0.05$). No proportional differences across SES were found in non-Hispanic black women.

Most behavioral factors (see Table 2) differed across education levels in men and across income levels in women. Specifically, for all sub-groups, participants of higher education and/or higher income were more likely to engage in regular exercise, while less likely to report being current or past smokers. Milk consumption behavior differed across education, but not income, in men of each race/ethnicity. The higher

Table 1 Physiological characteristics of the study population across socioeconomic status by race/ethnicity and gender

	Education					Income ^a					
	Less than high school graduate	High school graduate	College	Graduate	<i>p</i> value	Level 1	Level 2	Level 3	Level 4	Level 5	<i>p</i> value
NHW											
Male (<i>n</i> = 1339)											
Age (years, mean)	46.6	47.8	49.4	53.9	***	44.5	50.2	54.7	60.9	56.5	***
BMI (kg/m ² , mean)	27.1	27.3	27.6	27.9	NS	26.8	28.4	28.6	28.4	28.1	***
Women (<i>n</i> = 2814)											
Age (years, mean)	51.0	58.1	50.9	49.9	***	45.1	53.4	52.2	55.0	54.1	***
BMI (kg/m ² , mean)	29.5	29.7	26.8	25.5	***	28.3	27.5	27.3	27.0	25.4	***
Post (yes, %)	57.7	76.4	56.7	51.5	***	43.8	61.3	60.9	68.2	61.7	***
NHB											
Men (<i>n</i> = 927)											
Age (years, mean)	47.2	47.2	47.5	48.6	NS	47.1	47.0	48.1	51.5	56.9	**
BMI (kg/m ² , mean)	26.3	27.5	28.3	29.4	**	27.1	29.4	31.5	30.1	28.5	***
Women (<i>n</i> = 980)											
Age years, mean)	47.8	46.3	45.6	49.9	*	44.8	48.4	48.2	51.0	52.5	***
BMI (kg/m ² , mean)	31.0	32.1	32.8	31.4	NS	32.2	32.4	33.3	30.0	30.2	NS
Post (yes, %)	46.7	42.0	42.3	54.3	NS	40.6	48.3	48.0	51.0	58.3	NS
NHA											
Men (<i>n</i> = 190)											
Age (years, mean)	50.0	54.0	40.5	42.3	**	40.1	46.3	46.9	56.7	56.2	**
BMI (kg/m ² , mean)	24.3	24.1	26.1	24.9	*	24.6	25.3	25.8	25.9	25.4	NS
Women (<i>n</i> = 318)											
Age (years, mean)	50.4	48.4	41.4	39.1	***	42.0	43.2	46.6	43.0	51.4	*
BMI (kg/m ² , mean)	24.9	24.1	23.2	23.4	*	23.3	23.4	25.3	24.0	24.8	NS
Post (yes, %)	57.8	39.2	30.4	21.5	***	35.0	30.0	3.33	23.1	58.3	NS

NHW non-Hispanic white, NHB non-Hispanic black, NHA non-Hispanic Asian, Post Post menopause status, NS non-significant

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

^a level 1 = <\$20,000; level 2 = \$20,000–39,999; level 3 = \$40,000–59,999; level 4 = \$60,000–79,999, level 5 = \geq \$80,000

Table 2 Behavioral characteristics of the study population across socioeconomic status by race/ethnicity and gender

	Education					Income ^a					
	Less than high school graduate	High school graduate	College	Graduate	<i>p</i> value	Level 1	Level 2	Level 3	Level 4	Level 5	<i>p</i> value
NHW											
Men (<i>n</i> = 1339)											
Exercise (yes, %)	69.5	70.9	76.2	81.6	*	74.8	70.8	74.5	67.7	83.9	*
Smoker (yes, %)	86.2	77.7	59.6	31.9	***	78.9	61.3	43.2	39.4	33.2	***
Milk (yes, %)	83.5	87.0	82.0	77.8	*	85.1	81.7	82.6	77.8	77.5	NS
Alcohol (yes, %)	19.3	11.0	9.0	5.4	***	14.1	9.5	5.5	2.0	4.8	***
Women (<i>n</i> = 2814)											
Exercise (yes, %)	57.7	48.1	71.0	79.3	***	65.6	64.9	64.6	69.5	78.1	***
Smoker (yes, %)	49.4	42.6	40.3	36.5	*	48.0	39.9	42.5	36.2	34.0	***
Milk (yes, %)	82.1	74.7	76.0	75.4	NS	78.0	77.7	74.5	75.1	74.4	NS
HT (yes, %)	6.4	10.9	10.1	9.8	NS	4.3	7.3	12.9	12.2	13.6	***
Alcohol (yes, %)	3.9	2.4	2.8	1.5	NS	5.5	2.6	2.0	1.4	0.7	***
NHB											
Men (<i>n</i> = 927)											
Exercise (yes, %)	68.9	70.0	78.6	87.2	**	72.5	75.7	70.4	84.6	88.9	NS
Smoker (yes, %)	83.5	78.6	72.1	43.6	***	80.3	61.2	66.7	30.8	33.3	***
Milk (yes, %)	82.2	86.6	81.2	69.2	*	83.8	82.5	85.2	76.9	50.0	*
Alcohol (yes, %)	15.8	11.6	11.2	2.6	NS	12.8	7.8	14.8	7.7	5.6	NS
Women (<i>n</i> = 980)											
Exercise (yes, %)	46.9	59.7	56.7	74.6	***	53.8	60.4	68.3	66.0	66.7	*
Smoker (yes, %)	55.2	39.9	30.0	20.5	***	44.1	25.6	21.7	20.0	16.7	***
Milk (yes, %)	69.9	77.6	77.0	72.1	NS	76.1	78.0	63.3	78.0	88.9	**
HT (yes, %)	0.0	0.9	2.5	4.9	*	1.1	1.8	4.2	2.0	11.1	**
Alcohol (yes, %)	2.2	2.2	2.1	0.8	NS	2.1	3.1	0.1	0.0	0.0	NS
NHA											
Men (<i>n</i> = 190)											
Exercise (yes, %)	33.3	55.3	71.7	80.3	**	64.1	64.2	70.1	100.0	86.4	NS
Smoker (yes, %)	66.7	44.7	28.3	21.0	**	31.5	39.6	29.4	33.3	18.2	NS
Milk (yes, %)	66.7	57.9	73.6	82.7	*	75.0	66.0	64.7	100.0	83.4	NS
Alcohol (yes, %)	0.0	2.7	0.0	0.0	-	1.1	0.0	0.0	0.0	0.0	-
Women (<i>n</i> = 318)											
Exercise (yes, %)	56.3	46.0	64.3	65.2	NS	62.1	47.2	70.0	75.0	70.8	*
Smoker (yes, %)	0.0	2.0	7.1	3.3	NS	2.0	2.3	10.0	8.3	8.3	*
Milk (yes, %)	60.1	66.0	62.5	89.1	***	73.2	61.8	70.0	100.0	70.8	NS
HT (yes, %)	0.0	2.0	1.8	1.1	NS	0.0	0.0	5.0	8.3	4.2	**
Alcohol (yes, %)	0.0	0.0	0.0	0.0	-	0.0	0.0	0.0	0.0	0.0	-

NHW non-Hispanic white, NHB non-Hispanic black, NHA non-Hispanic Asian, Exercise self-reported regular exercise, Smoker self-reported current or past smokers, Milk self-reported milk consumption, Alcohol self-reported drinking problem, HT menopausal hormone therapy, NS non-significant * *p* < 0.05; ** *p* < 0.01; *** *p* < 0.001

^a level 1 = <\$20,000; level 2 = \$20,000–39,999; level 3 = \$40,000–59,999; level 4 = \$60,000–79,999; level 5 = ≥ \$80,000

proportion of participants who had a drinking problem was found in participants with lower education and/or income for non-Hispanic whites; while no difference was found across SES in non-Hispanic blacks. In contrast, very few non-Hispanic Asians reported having drinking problems.

The participants with higher education and/or income were more likely to use menopausal hormone therapy in both non-Hispanic white and black women. Very few non-Hispanic Asian women reported ever having had hormone replacement therapy.

Association of SES with BMD

Figure 1 displays adjusted mean distribution of total hip BMD and lumbar spine BMD across education and income by race/ethnicity and gender. After adjusting for age, positive linear relationship was only found (1) between education and hip BMD as well as income and spine BMD in non-Hispanic white men, (2) between education and hip BMD in non-Hispanic

Asian men, and (3) between education and both hip and spine BMD in non-Hispanic black women. For the rest, the association between SES and BMD varied. Specifically, the highest hip and/or spine BMD were found in the middle levels of SES in a majority of the other sub-groups (e.g., hip BMD of non-Hispanic white women with middle income levels and hip BMD of non-Hispanic black men with middle education and income levels). Meanwhile, there was no clear pattern or

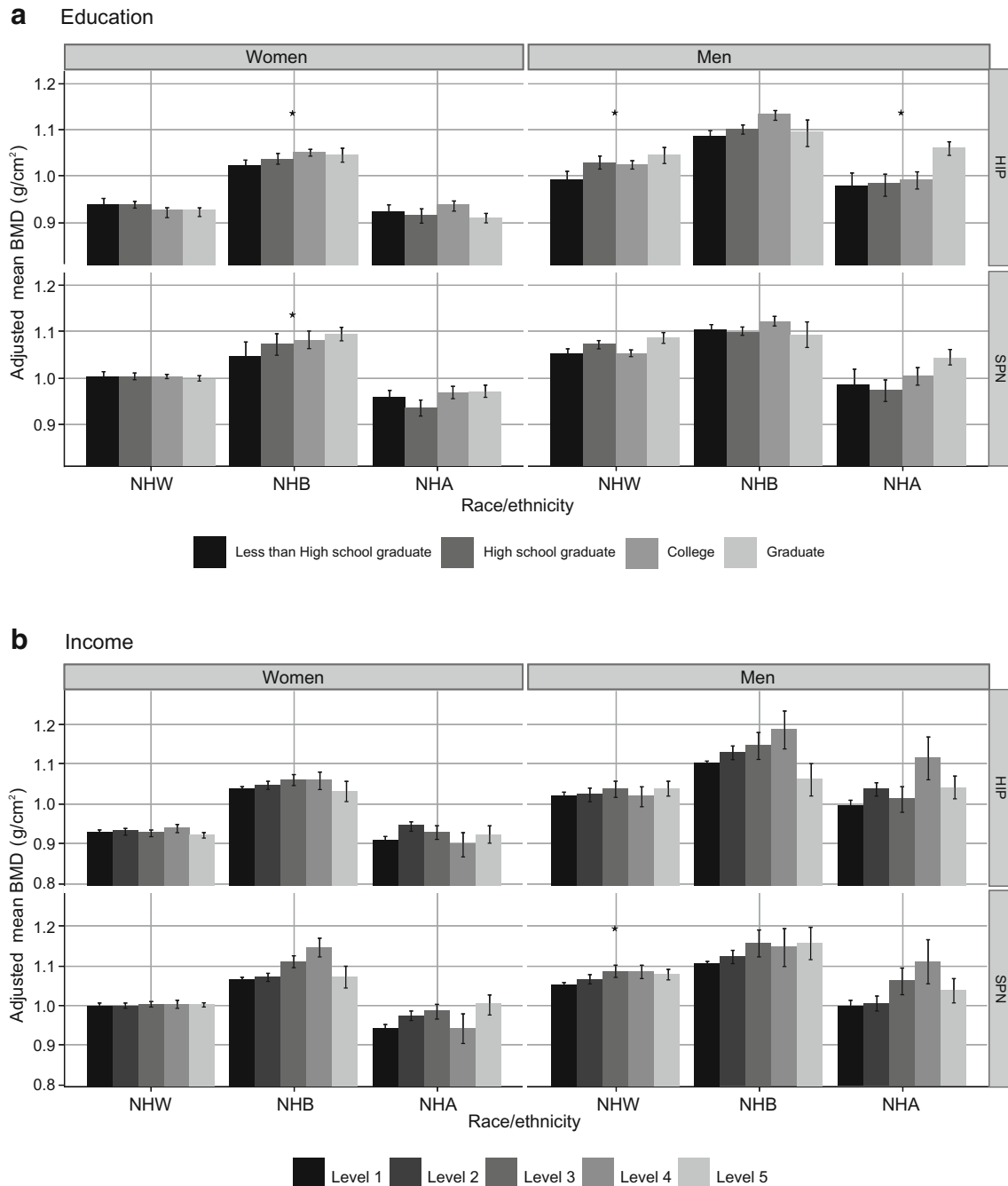


Fig. 1 Adjusted mean hip/spine bone mineral density (BMD) across a education, and b income by race/ethnicity and gender. Adjusted for age in men, plus menopause status in women. *HIP* Total hip BMD, *SPN* Spine BMD, *NHW* non-Hispanic white, *NHB* non-Hispanic black, *NHA* non-

Hispanic Asian. *Level 1* = <\$20,000; *Level 2* = \$20,000–39,999; *Level 3* = \$40,000–59,999; *Level 4* = \$60,000–79,999, *Level 5* = ≥ \$80,000; **p* < 0.05; ***p* < 0.01; ****p* < 0.001; *NS* non-significant

directionality to the associations between BMD and SES in some participants (e.g., spine BMD across education and hip BMD across income in non-Hispanic white men). For example, consider the odd relationship between spine BMD and education for non-Hispanic white men. Two groups (those who either did not graduate from high school or had a college education) had lower spine BMD when compared with two contrasting

groups (either high school graduates or those with graduate education). The BMD of individuals with extreme SES disadvantage was the lowest for a majority of sub-groups when compared to their counterparts with higher SES level(s).

Using the lowest education or lowest income level as the reference group, the relationship between SES and BMD is shown in Fig. 2. After controlling for physiological factors

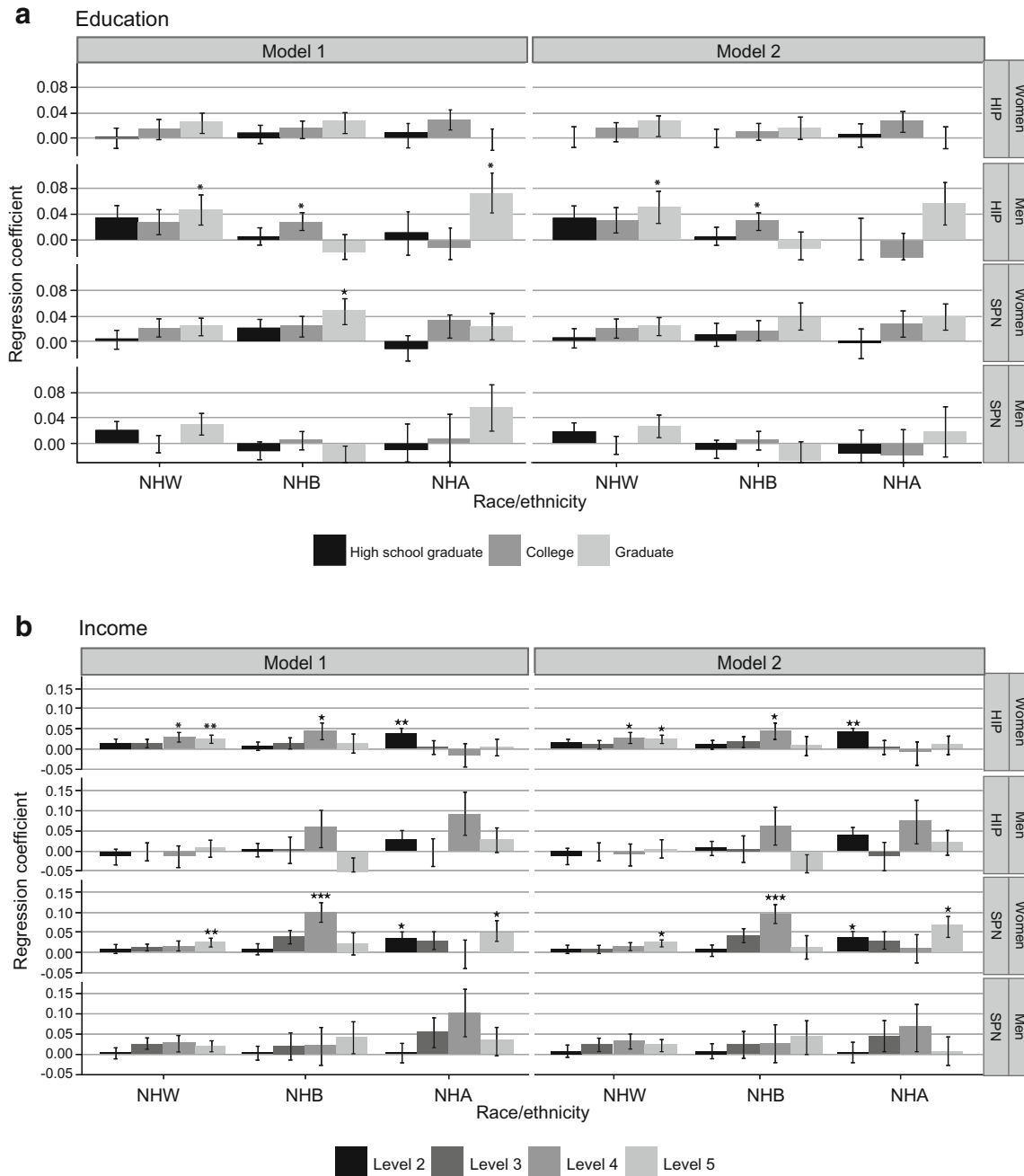


Fig. 2 Adjusted regression coefficient of hip/spine bone mineral density (BMD) and **a** education, and **b** income by race/ethnicity and gender. Model 1 adjusted for age and body mass index in men, plus menopause status for women. Model 2 adjusted for variables in model 1, exercise, smoking, milk consumption, and drinking problem in men, plus menopausal hormone therapy in women. *HIP* Total hip BMD, *SPN*

Spine BMD, *NHW* non-Hispanic white, *NHB* non-Hispanic black, *NHA* non-Hispanic Asian. Reference group for education: less than high school graduate; Reference group for income: level 1 = <\$20,000; level 2 = \$20,000–39,999; level 3 = \$40,000–59,999; level 4 = \$60,000–79,999, level 5 = ≥ \$80,000; **p* < 0.05; ***p* < 0.01; ****p* < 0.001

(Model 1), non-Hispanic white men with extreme low education had significantly lower hip BMD when compared with those with a college education (Regression coefficient = 0.048; 95% confidence interval (CI) = (0.003, 0.09); Fig. 2a). That is, while holding physiological factors in Model 1 constant, the mean hip BMD of non-Hispanic white men with college education was 0.048 (g/cm²) higher than their counterparts who had not graduated from a high school. Meanwhile, non-Hispanic black men with extreme low education had lower hip BMD than their counterparts who have graduate education (Regression coefficient = 0.028; 95% CI = (0.007, 0.059). The regression coefficients for both increased slightly when adding behavioral factors (Model 2). In non-Hispanic Asian men, a significant difference was found between the reference group and those with a graduate education (Model 1; Regression coefficient = 0.073; 95% CI = (0.028, 0.146), but the difference was eliminated after adjusting for behavioral factors (Model 2). No difference in spine BMD was observed between the reference group and higher education level(s) in men, and no spine BMD difference was observed between the lowest education level and higher level(s) in women.

Non-Hispanic whites and non-Hispanic black women with an income of \$60,000–79,999 and/or \$80,000 or more have higher BMD compared to their counterparts with income under \$20,000 in both the hip and spine after controlling for physiological factors (Fig. 2b). The differences remained but decreased slightly when adding behavioral factors. For non-Hispanic Asian women, those with incomes of \$20,000–39,999 and/or \$80,000 or more had higher hip and spine BMD than their reference counterparts. All the differences existed, but increased slightly after taking behavioral factors into account. In addition, no BMD difference at either site was found between the reference income group and higher income level(s) for men of all races/ethnicities.

Discussion

This study explored the relationship between SES and BMD across non-Hispanic populations of whites, blacks, and Asians. Overall, we were unable to conclude a generalizable positive or negative association between education/income and hip/spine BMD. However, we did find that individuals with extreme SES disadvantage have lower BMD than their counterparts with higher SES level(s) after controlling for physiological and behavioral factors, and the association was gender-specific. That is, for every race/ethnicity in the study population, education was more relevant to hip BMD in men, while income was relevant to hip and spine BMD in women. The results of this study may provide important information for prevention and management of osteoporosis. It also provides some implications for research scholars and practitioners in this field.

When adjusting for age for men, plus menopause status for women, only a few positive linear trend associations between BMD and SES were found at either hip or spine in each race/ethnicity and gender group, but for most sub-populations, SES was not linearly associated with BMD at either site. In fact, previous reports in Australia found that the highest BMD was found in people of mid-range SES [16, 18]. These findings reflect the complexity of osteoporosis, which is a multifactorial disease. For instance, the literature has shown that BMI was negatively related to SES [24] but positively associated with higher BMD [25]. The complex relationship between SES, BMI, and BMD makes osteoporosis unlike other chronic diseases (e.g., cardiovascular diseases) the higher prevalence of which is linked to lower SES [26, 27]. Meanwhile, the available literature has documented that more than 60% of the variation in BMD was attributable to genetic factors [28]. Given this, BMD may not be easily modified by behavioral factors which are assumed to be associated with SES. Although an earlier study reported that variation in body composition, diet, and socio-demographic factors could explain much of the racial/ethnic differences of bone mass and density [7]; genomic studies have shown that there was more genetic diversity within racial groups than between those groups [29]. However, it remains unclear how genetic traits interact with environmental factors such as behavioral factors (e.g., physical activity and calcium intake), that are closely related to SES.

Notably, by using participants with extreme SES disadvantage as the reference group, the relationship between BMD and SES showed gender-specific characteristics. Specifically, men with the lowest education had lower hip BMD than men with higher education level(s) for each sub-group when controlling for physiological factors. The differences remained in non-Hispanic whites and blacks after adding behavioral factors, but disappeared in non-Hispanic Asians. We would argue first that education matters in men more than women for BMD outcomes. In particular, men with an extreme education disadvantage may be at greater risk of developing osteoporosis. It has been widely accepted that education is consistently positively related to protective factors (e.g., regular exercise) and negatively associated with risk behaviors (e.g., smoking), and that women are at greater risk to have lower BMD and develop osteoporosis [30]. Thus, a majority of existing preventive and management interventions have been targeted toward women, but rarely toward men. Consequently, as men with higher educational attainment may be exposed to knowledge relevant to osteoporosis [31] frequently. Thus, in terms of encouraging healthy behaviors, men with extremely low educational attainment are left behind.

Meanwhile, when adjusting for both physiological and behavioral factors, individuals with extreme income disadvantage had both lower hip and spine BMD in women, but not in men. This confirms prior reports that income was positively related to BMD in women, and could possibly be explained by healthy behaviors related to income [14, 15, 20]. Further, compared to

education, personal income appeared to be more relevant to both hip and spine BMD in women. We would like to bring intra-household bargaining, a concept used to study feminist economics, into our discussion. Intra-household bargaining occurs between members of a household in order to arrive at decisions (e.g., daily needs) regarding the household unit [32]. Women's bargaining power has been widely reported to be associated with health outcomes, such as maternal health [32] and children's health [33–35]. However, bargaining power is not equally distributed and is actually determined by a variety of factors including gender and women's current annual or lifetime earnings [36, 37]. For those women who earn extremely low income, we do not know the extent to which they can choose their own behaviors that are relevant to BMD. Although examining the relationships between women's personal income, intra-household bargaining power, and BMD is beyond the objective of this study, the current findings may suggest a possible association, and this topic is worthy of further study.

In addition, unlike the remaining differences in non-Hispanic white and black men, for non-Hispanic Asian men, hip BMD differences between individuals with extremely low education and higher education disappeared when considering behavioral factors. Similarly, unlike the decreased BMD differences between income levels found in non-Hispanic white and non-Hispanic black women, BMD differences increased after adding behavioral factors in non-Hispanic Asian women. Previous research has documented that when compared with non-Hispanic whites and blacks, a majority of non-Hispanic Asians were immigrants from foreign countries [38]. Their earlier behaviors in their home countries may be very different from current behaviors in the USA, and the patterns of BMD differences across SES may also be different from those who were born in the USA. Even the patterns of their current behaviors across SES differed from non-Hispanic whites and blacks as identified in this study. Therefore, we would suggest that more studies related to osteoporosis/BMD are needed in minorities, especially those who migrate from foreign countries, who have rarely been studied.

In this study, selected physiological and behavioral factors could not fully explain BMD differences between individuals with extreme SES disadvantage and those of higher SES. This may be partially because of the multifactorial nature of BMD. It may also reflect the fact that BMD is shaped over one's lifespan [39]. Childhood and adolescence are very important to building peak BMD and are especially relevant to adult bone health [19, 40, 41]. Therefore, longitudinal studies tracking SES through life course, and how BMD may vary based on change of SES, are warranted [42].

Both gender and race/ethnicity are biological and psychosocial contributors to a variety of health outcomes, including BMD [26, 43]. Consequently, gender and race/ethnicity add complexity to the relationship between SES and BMD. In this study, we tried to minimize the confounding influences of these factors and

stratified our analyses by gender, as well as race/ethnicity. It is well documented that women and minority populations have lower SES than men and whites, respectively [35, 43–46]. Therefore, further research is needed to evaluate the interaction influences of gender, race/ethnicity, and SES on BMD.

There are some limitations of this study. First, this is a cross-sectional study, which cannot draw a causal relationship, nor can it capture BMD differences shaped before the study began. Second, the study population is not a representative sample, because participants were recruited from a single southern state in the USA. The situation may be different from other regions. For example, the prevalence of a drinking problem, one of the risk factors of osteoporosis/low BMD, in the study state, is higher than the national level [47]. Therefore, the results may not be easily generalized to other regions. Third, this study examined individual income, which may not capture the financial status of the household. Future studies examining the different associations between household income and personal income with BMD would be very meaningful. Fourth, the time frame was not available for behavioral factors and they were all treated as dummy variables. Although they were covariates in the study, some information may be missing without examining the intensity or duration of behavioral factors. Fifth, the amount and regularity of dietary calcium was not available in the study, and we used milk consumption as the proxy for dietary calcium intake. Milk consumption is a major source of calcium intake. Although it may be arbitrary to only assess responses of yes/no to milk consumption, this method can capture baseline data related to dietary calcium consumption habits. In fact, we did find a significant association between milk consumption and hip/spine BMD by running a simple regression. Therefore, we think it is important to control milk consumption behavior when assessing the relationship between SES and BMD. Lastly, the data of participants who did not provide education and/or income status were excluded, which was a high proportion of the study sample. This might introduce bias to the results. However, no significant BMD differences were observed between participants whose SES data were missing and participants who were included in the current study. Therefore, we assumed that the data were missing at random and only analyzed the remaining data, which is a common approach to minimize the bias of study results [48].

Conclusions

In conclusion, BMD is a complex bone health indicator that is influenced by multiple factors. Deciding whether a positive or negative association exists between BMD and SES has proved to be difficult; however, people with extreme SES disadvantages were most vulnerable to have lower hip and/or spine BMD in the study population, and this was gender-specific. That is, hip BMD for men from the lowest education level as well as both hip and spine BMD of women with the lowest income were significantly

lower when compared with their counterparts from higher SES level(s). Additional community education and efforts related to providing osteoporosis knowledge and prevention information should be targeted for men, especially for those with extremely low education levels. In addition, differences in bone health with respect to household income and individual income have never been previously reported. If this is a valid concern, then considering a women's individual income is important when examining the relationship between SES and health outcomes. Third, as the population of the USA ages at an unprecedented rate and with increasing diversity in race/ethnicity, more studies relevant to bone health are needed for minority populations. Finally, to our knowledge, available literature examining SES and BMD only provide cross-sectional studies exclusively. Longitudinal studies examining how SES and behaviors through one's life course influence BMD could provide promising results.

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Compliance with ethical standards

Conflict of interest None.

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