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Ethnic Variations in Serum 25(OH)D Levels and Bone Ultrasound Attenuation Measurements in Blacks and Whites

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Abstract

Vitamin D deficiency is more common in Blacks, yet Blacks have lower prevalence of bone fragility fractures or osteoporosis than Whites. Broadband ultrasound attenuation (BUA) has been used to explore the association between serum 25(OH)D levels and bone quality in White and non-white populations. We investigated serum 25(OH)D status with corresponding BUA measurements assessed cross sectionally in a cohort of 232 Blacks and 260 Whites, aged 30–95 years who were part of the calibration study of the large Adventist Health Study-2 (AHS-2). At the calibration clinics, calcaneal BUA was measured and blood drawn for serum 25(OH)D assessment. In multivariable analyses, BUA was negatively associated with age (β -coefficient = -0.38 ; $p < 0.0001$) and positively associated with body mass index (BMI) ($p_{\text{trend}} < 0.0001$) and positively, but non-significantly, associated with serum 25(OH)D levels. Also, as expected, females had lower BUA (β -coefficient = -5.19 ; $p < 0.05$) and Blacks had higher BUA (β -coefficient = 4.26 ; $p < 0.05$). Gender and race modified the relationship of serum 25(OH)D on BUA with a positive association in males ($p_{\text{trend}} = 0.05$), but no significant association in females after also controlling for menopausal status and hormone therapy. After also controlling for serum 25(OH)D levels, Black males had higher BUA than White men, but such differences were not found among the females. When stratifying on race, a positive association between serum 25(OH)D levels and BUA ($p_{\text{trend}} = 0.05$) was found in Blacks, but not among Whites. Further studies are needed to understand how racial/ethnic differences in serum 25(OH)D levels influence bone health.

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Conflict of Interest Sakamoto, R. has continued to use the seed grant from AHS-2 Calibration Study and received \$500.00 from APU. Authors Thorpe, D., Knutsen, R., Knutsen S., and Beeson, L. each declare no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the study.

Authors' Contributions Authors' roles: Study design: RS, DT, RK, LB and SK. Study conduct: RS, SK, DT, LB, RK. Data collection: RS, SK, DT, LB, and RK. Data analysis: DT, SK, LB and RK. Data interpretation: SK, DT, LB, RK and RS. Drafting manuscript: RS, DT, RK, LB, and SK. Revising manuscript content: RS, DT, SK, LB and RK. Approving final version of manuscript: RS, SK, RK, DT, and LB.

Keywords

Vitamin D; BUA; Serum 25-hydroxyvitamin D; Bone health; Race; Ethnicity

Introduction

National health goals include a focus on prevention of injuries such as fractures, especially in the older population. Osteoporosis is a skeletal disease characterized by low bone mineral density (BMD) and structural deterioration of bone leading to bone fragility and increased susceptibility to fractures with a 6:1 female to male ratio [1]. Findings from the 2003–2004 National Health and Nutrition Examination Survey (NHANES) suggest that ethnic differences exist in the association between serum 25(OH)D levels and BMD. Investigators found that when serum 25(OH)D declined among Whites, BMD decreased significantly, but this did not occur among Blacks ($p < 0.01$) [2]. Studies report that more than 90% of those with hyperpigmented skin have vitamin D insufficiency and that Blacks have the highest prevalence of vitamin D deficiency [3–5]. This is attributed to the hyperpigmented skin that leads to the reduction of the conversion of pre-vitamin D₃ (cholecalciferol) to its active state calcitriol [4, 6].

Vitamin D deficiency or hypovitaminosis D has been known to affect bone health [7–9]. Studies of serum 25(OH)D status and bone health commonly use dual energy X-ray absorptiometry (DXA) considered as the gold standard in ascertaining the risk of osteoporotic fractures [10, 11]; but access to having DXA remains low, especially among ethnic groups [12, 13]. Broadband ultrasound attenuation (BUA) estimate subjects' bone quality and are used to predict risks for osteoporosis [14–17] and the most common broadband ultrasound attenuation (BUA) measurement is calcaneal quantitative ultrasound (QUS) [15, 18]. BUA has been recommended as an acceptable surrogate for BMD measurements [15, 18, 19] and is a FDA-approved tool for screening women at risk for osteoporosis [15, 19]. Meta-analyses showed that BUA is a viable alternative tool to measure the different physical properties of the bone complementary to that known from BMD when using DXA [20, 21] and is also able to predict fractures in other body parts such as the hip and other non-spine fractures [22, 23]. Although there are studies of bone health determinants in Blacks and Whites, there are few studies that have examined their differences in the same population. Studying such will most likely reduce the number of potential cultural differences between the races that influence health outcomes and that are difficult to identify and thus cannot be accounted for in studies. The aim of this study was to (1) explore the relationship of serum 25(OH)D status with calcaneal BUA measurements in Blacks and Whites and (2) assess whether low serum 25(OH)D status predicts BUA in both Blacks and Whites in an essentially healthy population.

Materials and Methods

Study Participants

The calibration study is a sub-study of the large Adventist Health Study-2 (AHS-2), a cohort study of about 96,000 subjects. Enrollment procedures and the cohort profile of the AHS-2

have been described elsewhere [24]. The 485 subjects, aged 32–96, in this study are part of the AHS-2 calibration study where subjects were randomly selected from the full 96,000 subjects and which was conducted 2–3 years following the enrollment into the larger AHS-2. At enrollment into the AHS-2 study, all 485 subjects in our study reported that they had never been doctor diagnosed with osteoporosis. All had valid BUA measurements and serum 25(OH)D assessments from the calibration study and were either White or Black race. The calibration clinics were conducted from November 2003 to May 2006 except during February, June, and July at the time when people were likely taking vacation or weather changes. Clinic protocols were similar to those used in the church pilot clinics of the AHS-2 [25] and included blood pressure measurement, anthropometrics, calcaneal BUA, venipuncture, and collection of overnight 12-h urine. The study was approved by the Loma Linda University Human Subjects Committee Review Board in compliance with 1964 Helsinki declaration and its later amendments.

Lifestyle Questionnaire

Each calibration study participant completed the 50-page baseline lifestyle questionnaire at enrollment into the AHS-2. The questionnaire included self-reported demographic and health history data including age, gender, race, educational and income status, smoking, health history, including self-reported doctor-diagnosed osteoporosis and a female section. As part of the calibration study, a large food-frequency questionnaire was completed which was validated using six 24-h recalls [26].

Serum 25(OH)D Levels

At the calibration clinics, blood samples were collected after 8-h fasting. After blood was drawn from the subjects, plasma and cells were separated immediately by centrifuge and then transported on frozen gel packs overnight to reach the lab at Loma Linda University, CA. Blood was aliquoted and then stored in liquid nitrogen. Samples of frozen serum were later couriered on dry ice from Loma Linda laboratory to the Reproductive Endocrine Research Laboratory, Department of Obstetrics and Gynecology, University of Southern California Keck School of Medicine. Radioimmunoassay (DiaSorin, Stillwater, MN) was used for serum 25(OH)D level determination. Laboratory methods including correlation coefficient determinations are described in detail elsewhere [27].

Bone Ultrasound Attenuation Measurements

During the clinic visits, BUA was assessed on the dominant foot at the calcaneal site using a contact ultrasound bone (CUBA) system analyzer to measure the bone quality consistent with assessment procedure of cortical and cancellous bone [17]. These BUA (dB/MHz) measurements were used in this study.

Data Analysis

We divided the serum 25(OH)D levels into three strata based on the current scientific literature as follows: deficiency (<20 ng/ml); insufficiency (20–30 ng/ml); sufficiency (>30 ng/ml) [28–31] although the Institute of Medicine (IOM) declares that bone health is attained at 20 ng/ml. Univariate analyses between serum vitamin D and potential

confounders or known predictors of BUA were conducted using the chi-square test for categorical variables. To compare quantitative variables by serum D levels, we compared the mean intakes of total calcium and total vitamin D, and mean sun exposure in hot and cold weather by the three serum 25(OH) levels, we used analysis of variance (ANOVA). Student's t test was used to compare the mean values of serum vitamin D and BUA levels between the two race groups (i.e., Whites vs. Blacks) within gender. Multiple linear regression analyses were used to model the effects of serum vitamin D and race on BUA while controlling for covariables. After analyzing all subjects combined, we then chose to stratify the regression analyses on gender due to studies that have shown different determinants of bone strength (fracture risk) for males and females within the same race [32–34]. And finally, we used a similar model to assess the independent effect of serum vitamin D and gender on BUA, stratified on race since Blacks and Whites seem to have different predictors of bone health and fracture risk. SAS version 9.4 (SAS Institute, Cary, NC) was used for all statistical analyses.

Results

Table 1 presents descriptive subject data according to the three serum 25(OH)D levels. A larger proportion of Blacks than Whites had deficient serum 25(OH)D levels (60.4 vs. 15.0%, respectively) ($p < 0.0001$). The gender difference in serum 25(OH)D is less clear. The proportion of females was larger than the proportion of males in both the deficient and sufficient groups ($p = 0.03$) whereas a higher proportion of males had insufficient levels, 39.7 vs. 28.3% in women ($p = 0.0002$). As expected, those with the highest body mass index (BMI) were more likely to have deficient serum 25(OH)D, 46.3 vs. 26.4%, among those with normal BMI. Physical activity seemed to be inversely associated with serum 25(OH)D levels with those with the lowest level of physical activity being most likely to be in the deficient or insufficient range of vitamin D (73.4%) vs. (67.2%) among those with the highest level of physical activity ($p = 0.02$). Dietary intakes of calcium and vitamin D increased in a dose-response fashion across the three serum vitamin D categories ($p < 0.0001$) with the highest intakes in the sufficient vitamin D category. The proportion of vegetarians was about one-half of the population which consists of lacto-ovo, pesco, and semi-vegetarians (those who eat meat <1/week) and vegans. The nature of the association with age was less clear, with those in the deficient and sufficient categories being younger than those in the insufficient ($p = 0.001$). There was no difference in BUA between ever and never smokers nor between those with a history of minor trauma fractures or no such history and educational level and hours spent outdoors/week was not associated with serum 25(OH)D levels. Among the females, there was no association with menopausal status or with use of estrogen therapy. Finally, there was no clear association between BUA levels and serum 25(OH)D levels.

When comparing serum 25(OH)D levels and BUA by gender and race (Table 2), White females had higher mean serum 25(OH)D levels than their Black counterparts ($p < 0.0001$), but Black women had significantly higher mean BUA levels ($p = 0.03$). Male subjects showed the same trend for their serum 25(OH)D levels in that White males had significantly higher serum 25(OH)D levels than their Black counterparts ($p < 0.0001$). However, Black males had only slightly higher mean BUA scores (86.2 db/MHz) than Whites (84.8 db/

MHz) and the difference was not statistically significant ($p = 0.56$). BUA for Blacks: *mean* 85.2 dB/MHz; range from 22.0–144 dB/MHz, Whites: *mean* 80.5 dB/MHz; range 23.0–146 dB/MHz. Males had higher BUA scores: 85.6 dB/MHz vs. females: 79.8 dB/MHz. The higher the BUA scores, the higher is the bone quality.

In the multivariable regression model, age, race, BMI, history of fracture, and race were all significantly related to BUA (Table 3). However, when assessing the associations in stratified analyses, the relationships varied by gender. Age, as expected, was a strong predictor of BUA in women (β -coefficient = -0.61) ($p < 0.0001$), but less so in men (β -coefficient = -0.28) ($p < 0.001$). For each additional year of age, BUA decreases by 0.61 dB/MHz in women, whereas in men, BUA is decreased by 0.28 dB/MHz, provided all of the other variables in the models are held constant. Serum 25(OH)D was an independent predictor of BUA in men ($p_{\text{trend}} < 0.05$), but less so, and not significant, in females. Among men, those with serum 25(OH)D greater than 30 ng/ml had 5.35 dB/MHz higher BUA than those with serum 25(OH)D less than 20 ng/ml when holding other variables constant. BMI showed a positive and similar effect on BUA in both men and women. However, the positive effect of BMI was somewhat stronger in women than in men as shown by the coefficients of regression for the highest two categories. Having a history of fracture was a strong predictor of lower BUA in women but not in men, whereas smoking was inversely associated with BUA in men only. Surprisingly, after adjusting for the relevant covariables, there was no longer any significant difference in BUA between Black and White females. But the difference among Black and White males seemed to persist with a higher BUA in Blacks indicated by a regression estimate of 6.95. For the other covariables, including physical activity, there was no longer an association with BUA levels in either gender. When stratifying the same model on race (Table 4), we found a significant inverse association between age and BUA which was stronger in Blacks [β -coefficient = -0.52 ($p < 0.0001$)] than in Whites [β -coefficient = -0.28 ($p < 0.05$)]. Serum 25(OH)D was an independent predictor of BUA in Blacks ($p_{\text{trend}} < 0.05$), but not in Whites. Although the effect of BMI on BUA was strongly positive in both groups, it was stronger in Whites than in Blacks. A history of fracture was negatively associated with BUA in Whites [β -coefficient = -7.29 ($p < 0.05$)], but not in Blacks. There was no independent effect on BUA of gender among the Blacks, whereas White females had significantly lower BUA [β -coefficient = -7.53 ($p < 0.05$)] than White males.

Discussion

In this cross-sectional study, age, race, BMI, smoking, and serum 25(OH)D were independent predictors of BUA in men whereas serum 25(OH)D levels was not independently associated with BUA levels in women. As far as we can ascertain, few, if any, studies have controlled for both gender and race in the same study when assessing the role of serum 25(OH)D on bone health. When we did so, the association between serum 25(OH)D and BUA was positive, but no longer significant. It has been well documented that a significant proportion of Blacks are vitamin D deficient, yet have higher bone quality than Whites [2, 4, 30, 35, 36].

Relationship of Serum 25(OH)D to BUA/BMD Among Races in Men and Women

Only a few other studies have reported an association between serum 25(OH)D and BUA [32, 37], but a significant number of studies have investigated this association with BMD as the outcome [2, 36, 38–45]. The reports on this association do not agree across studies. Kauppi, et al., [32] found serum 25(OH)D status to be an independent determinant of BUA in a large study of White Finnish population. Low levels of serum 25(OH)D significantly reduced quantitative ultrasound measurements in both men and women. These findings are in line with our findings among males and Blacks, but less so in females and Whites in general. Thus, our findings among Whites are more in line with Zochling et al. [37] who found, among institutionalized White older adults, that serum 25(OH)D was not related to QUS in either gender.

For BMD, the NHANES study reported that serum 25(OH)D was positively associated with BMD in younger and older adults among both Blacks and Whites of both genders [36]. And in an Italian study of premenopausal women [38], serum 25(OH)D levels were also found to be positively associated with spine BMD. Another NHANES study [2], however, reported that BMD significantly decreased when serum 25(OH)D declined among Whites, but not among Blacks. This paradoxical finding is consistent with that of others [46, 47]. Aloia et al. [46] explained that the differences or advantages of Blacks having lower bone loss is not only due to their skeletal resistance to parathyroid hormone, but that also Blacks have superior renal calcium conservation. A previous study among Black versus White children concurred on the findings of lower urinary calcium excretion among Black children [48] whereas Dawson et al. [49] found another possible reason that Blacks have favorable bone health, the possibility of Blacks' gut resistance to 1,25(OH)₂D (calcitriol).

In line, our findings showed that serum 25(OH)D levels among Blacks to be positively associated with BUA levels whereas the association is weaker and non-significant among Whites. In a study on behavioral and physical characteristics related to 25(OH)D status, Pasco et al. [39] reported that White Australian women with higher serum 25(OH)D levels also had higher BMD in whole body scans. In the Multi Ethnic Study of Atherosclerosis (MESA) [40], however, and contrary to our findings, researchers found that the positive associations of serum 25(OH)D with BMD was strong only among Whites and not among Blacks, similar to the findings of Hannan et al. [42].

In a study of young physicians with 75% female participants, Manickam et al. [43] reported that serum 25(OH)D levels were not statistically associated with BMD. Interestingly, Barbour et al., [44] in a bi-ethnic male population with Whites from the USA and Blacks from Tobago, showed that in White males, serum 25(OH)D was positively associated with cortical BMD at both the radius and tibial sites. In the African ancestry, there was an inverse association between serum 25(OH)D and the cross-sectional area. Race modified the association between serum 25(OH)D and total BMD, cross-sectional area, and trabecular BMD of the radius. Martin et al. [45], on the other hand, noted that serum 25(OH)D was positively associated with BMD only at certain bone sites: cortical volume at the cortical and femoral neck and shaft among US elderly men.

Studies that Show Racial Differences in BUA/BMD in Women

Cauley et al. [50] reported that age-adjusted BUA was higher among African-American (AA) women 65+ years of age as compared to Caucasian women of the same age (69.1 and 66.2 dB/MHz, respectively) ($p = 0.12$). This is in line with findings from other studies [46, 47] reporting on paradoxical findings in AA with low serum 25(OH)D yet higher overall BMD status as compared to Whites. In a study of postmenopausal South Asian and Caucasian women [51], it was found that South Asian women had lower serum 25(OH)D levels than Caucasian women, but no significant association was found between serum 25(OH)D levels and bone resorption parameters, nor with reduced bone quality. The findings of these studies mimic our study with regards to Black women in our study having the lowest serum 25(OH)D levels, yet having higher BUA levels. Also, in our multivariate analyses, the association between serum 25(OH)D levels and BUA was positive, but did not reach significance among females.

Studies that Show Racial Differences in BUA/BMD in men

In a cross-sectional study using MrOS data, Cauley et al. [52] noted that African-American men had 6 to 11% higher BMD than Caucasian men independent of other potential covariates. Frost et al. [53] studied the relationship between serum 25(OH)D and BMD in younger men and noted a positive association for all measured sites. Another study among young men [54] found different associations for different serum 25(OH)D measurements with 25(OH)D₃ being an independent predictor of BMD of the total body and spine while 25(OH)D₂ was found to be a negative predictor of these same sites. Interestingly, Ahkter, et al. [55] reported in their study of African men that there was no correlation between serum 25(OH)D and BMD at any site. However, among vitamin D-deficient participants (those with < 15 ng/ml), results showed a positive association with BMD at various sites. Our study supports findings that Black men have lower serum 25(OH)D levels than White men and yet Black men have higher calcaneal BUA levels. The higher BUA among Blacks remain significant even after adjusting for a number of factors in multivariable analyses.

Vitamin D Deficiency and Health Disparities

African Americans tend to have sturdier bones than their White counterparts, but studies [56–58] show poorer health outcomes that could be attributed to vitamin D deficiency's non-skeletal effects. Roberts et al. [59] reviewed evidence of vitamin D deficiency among Blacks and questioned what currently appears to be a pandemic of vitamin D deficiency in the Black population. They argued that there is no evidence of higher-than-normal rates of common complications and symptomology of true vitamin D deficiency. Many possible mechanisms have been suggested to explain [60] the complexity of health disparities among Blacks [61–65]. Recent studies [66, 67] have corroborated these risks with respect to the observed higher mortality rates among Blacks, and this was also reflected in a recent review of evidence of the multisystem effects of vitamin D [64].

Most recently, Pludowski et al. [68] published vitamin D supplementation guidelines for the general population that highlighted the need to individualize recommended dosages based on age, body weight, ethnicity, and latitude of residence. Of importance, these authors emphasized disease-specific recommendations with clear tolerable upper limits that posed

no adverse events using higher cut-off levels and/or dosages than previously recommended by IOM [60]. Pludowski's group and Grant et al. [69] concur with the importance of vitamin D supplementation to offset the global health crisis of vitamin D deficiency.

Strengths/Limitations—A major strength of this research is that Blacks were well represented in this study and both Blacks and Whites were recruited from the same parent population of Adventists, thus reducing the possibility of confounding by unknown factors. Subjects were mostly never smokers, and among past smokers, more than 50% had quit smoking more than 20 years ago. Also, the majority of the AHS-2 subjects do not drink alcohol. Thus, our study is essentially free from the effects of these two major confounders. A limitation of this study is its cross-sectional design resulting in BUA and serum 25(OH)D levels being assessed at the same time. However, at enrollment into the parent AHS-2, all subjects had reported that they did not have doctor-diagnosed osteoporosis, and so, any low levels of BUA would be unknown to the subjects [2, 4, 30, 35, 36]. Another possible limitation is that we did not differentiate between various degrees of African heritage and this could have influenced our findings. Blacks in our study self-reported their race on the initial enrollment questionnaire as either African-American or African-Caribbean and the Blacks were recruited from “Black” churches. Thus, we believe they had a significant degree of African heritage even though it would have been useful to be able to adjust for degree of such heritage.

Although BUA is not the gold standard test for bone mineral density, other studies support its usability for screening purposes. In addition, we did not have information on PTH levels and this could be valuable since longstanding low serum 25(OH)D levels would potentially lower serum calcium and increase serum PTH levels and thus mobilize calcium from the bones resulting in low BUA levels. However, our findings of Blacks having the highest proportion of subjects with vitamin D deficiency makes this potential confounding factor less likely since the Blacks also had the highest BUA levels.

Conclusion

BMI and age were the most consistent predictors of BUA among both Blacks and Whites of both genders. We found that serum 25(OH)D was positively associated with bone quality as measured by BUA in males after controlling for common bone strength determinants such as age, race, BMI, smoking, history of fracture, physical activity, and calcium intake. A higher proportion of Blacks have hypovitaminosis D than Whites, and mean age-adjusted serum 25(OH)D levels are about 10 ng/ml lower in Blacks than in the Whites in both genders. In spite of this, Blacks have higher age-adjusted BUA than Whites, especially among the females. However, after adjusting for other relevant covariables in multivariable analyses, a positive association between serum 25(OH)D levels and BUA was only present in Blacks. Our findings raise several questions. First, should serum 25(OH)D and BUA reference levels be different for Blacks and Whites and for males and females within each race? And second, are low levels of BUA associated with later fracture risk among Blacks? Prospective studies consisting of both Blacks and Whites and with fractures as the outcome are necessary to elucidate these questions. Longitudinal studies, as well as clinical trials, with both Black and White subjects, are necessary to ascertain what modifiable factors, other than serum

25(OH)D levels and BMI, can reduce risks for bone fractures or maintain bone health among different races/ethnicities.

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Table 1

Participants' characteristics by vitamin D status

Serum 25(OH)D (ng/ml)							
Category	Deficiency(<20 ng/ml)(<i>n</i> = 175)		Insufficiency(20–30 ng/ml)(<i>n</i> = 163)		Sufficiency(>30 ng/ml)(<i>n</i> = 146)		<i>P</i>
	<i>n</i>	%	<i>n</i>	%	<i>n</i>	%	
Race:							
Whites	39	15.0	105	40.4	116	44.6	<0.0001
Blacks	136	60.4	59	26.2	30	13.3	
Gender:							
Male	79	33.3	94	39.7	64	27.0	0.03
Female	96	38.9	70	28.3	81	32.8	
BMI(kg/m ²):							
<20	13	35.1	5	13.5	19	51.4	0.0002
20–24	38	26.4	54	37.5	52	36.1	
25–29	62	36.5	57	33.5	51	30.0	
30	62	46.3	48	35.8	24	17.9	
Smoking:							
Never smoker	143	35.8	135	33.7	122	30.5	0.57
Ever smoker	32	39.5	29	35.8	20	24.7	
Minor accident fracture							
No	149	36.8	141	34.8	115	28.4	0.23
Yes	26	32.9	23	29.1	30	38.0	
Physical activity (walk/run/jog)							
Level 1 (<120 min/wk)	136	38.4	124	35.0	94	26.6	0.02
Level 2 (120–<180 min/wk)	21	30.0	17	24.3	32	45.7	
Level 3 (≥180 min/wk)	18	29.5	23	37.7	20	32.8	
Estrogen usage (female):							
Never	42	43.3	23	23.7	32	33.0	0.51
Current	10	30.3	11	33.3	12	36.4	
Former	14	31.8	15	34.1	15	34.1	
Menopause status:							
No	38	40.4	27	28.7	29	30.8	0.87
Yes	58	37.9	43	28.1	52	34.0	
Education							
Other	110	38.9	92	32.5	81	28.6	0.36
BS or higher	64	32.5	71	36.0	63	31.5	
Sun exposure (h/week) ^a							
Hot season	20.7 (12.0)		22.6 (13.7)		12.9 (12.9)		0.43
Cold season	14.6(11.5)		16.7(13.5)		15.6 (11.3)		0.34
Age ^a	57.7 (13.8)		62.9 (13.2)		59.4 (12.9)		0.001

	Serum 25(OH)D (ng/ml)			
Total vitamin D intake (mg/day) ^a	6.0 (7.4)	7.9 (6.2)	9.8 (8.1)	<0.0001
Total calcium (mg/day) ^a	733 (346)	943 (414)	1100 (492)	<0.0001
BUA (dB/MHz)	82.3 (20.2)	84.3 (19.9)	81.1 (20.5)	0.36

^aMean (SD)

Table 2

Participants' serum vitamin D levels and bone ultrasound attenuation (BUA) values

Group	Number ^a	Serum vitamin D ng/ml mean (SD)		<i>t</i> test vitamin D (<i>p</i> [*])	BUA mean (SD)		<i>t</i> test BUA (<i>p</i> [*])
White females	123	30.5	(10.8)		76.7	(19.2)	
Black females	124	20.6	(12.0)	<0.0001	82.4	(21.5)	0.03
White males	136	28.9	(9.2)		84.8	(19.6)	
Black males	101	18.2	(7.1)	<0.0001	86.2	(18.7)	0.56

^aMissing one participant^{*}Age-adjusted comparisons between races

Table 3

Linear regression models of BUA for all subjects and comparisons models for men and women

	All subjects $B^{\dagger}$ (se) $R^{2\dagger} = 0.19$	Women $B^{\dagger}$ (se) $R^{2\dagger} = 0.27$	Men $B^{\dagger}$ (se) $R^{2\dagger} = 0.16$
Intercept	102.89 (5.91) ***	114.04 (8.44) ***	89.81 (7.67) *
Age	-0.38 (0.08) ***	-0.61 (0.14) ***	-0.28 (0.09) *
Serum D			
>30 ng/ml	4.10 (2.53)	2.42 (3.53)	5.35 (3.64)
20–30 ng/ml	5.00 (2.27)	6.32 (3.47)	4.09 (3.04) δ
<20 ng/ml	0	0	0
Race			
Black	4.26 (2.07) *	2.90 (2.89)	6.95 (3.00) *
White	0	0	0
BMI			
30	7.04 (2.39)	5.77 (3.48)	6.65 (3.35)
25–29	3.53 (2.16) $\delta\delta\delta$	3.45 (3.26) $\delta\delta$	2.81 (2.84) δ
20–24	0	0	0
<20	-8.14 (3.53)	-12.94 (5.19)	-3.64 (4.84)
History of fracture			
Yes	-4.65 (2.40) *	-8.95 (3.30) **	1.82 (3.52)
No	0	0	0
Physical activity			
180 min/week	1.91 (2.70)	-1.59 (4.23)	5.09 (3.48)
120–179 min/week	3.90 (2.52)	1.99 (3.32)	6.66 (3.77)
0–120 min/week	0	0	0
Smoking			
Ever	-3.68 (2.35)	1.17 (3.58)	-7.51 (3.13) *
Never	0	0	0
Calcium intake	-0.0006 (0.002)	-0.005 (0.003)	0.005 (0.003)
Menopausal status			
Postmenopausal	-3.83 (3.37)	1.09 (4.00)	
Pre- or perimenopausal	0	0	
Estrogen use			
Ever	0.53 (3.07)	1.37 (3.15)	
Never	0	0	
Sex			
Females	-5.19 (2.59) *		
Males	0		

 $\dagger$ Regression coefficient, se standard error

[†]Coefficient of determination R^2

*
 $p < 0.05$

**
 $p < 0.001$

 $p < 0.0001$

\$
 $p < 0.05$

\$\$
 $p < 0.001$

\$\$\$
 $p < 0.0001$ for trend

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Table 4

Linear regression models of BUA for Whites and Blacks

	Blacks	Whites
	$B^{\dagger}$ (se)	$B^{\dagger}$ (se)
	$R^{2\dagger} = 0.19$	$R^{2\dagger} = 0.19$
Intercept	119.37 (8.15) ***	91.62 (8.07) ***
Age	-0.52 (0.12) ***	-0.28 (0.10) *
Serum D		
>30 ng/ml	6.10 (4.67)	4.92 (3.53)
20–30 ng/ml	6.44 (3.24) [§]	5.24 (3.55)
<20 ng/ml	0	0
Sex		
Females	-2.76 (3.69)	-7.53 (3.74) *
Males	0	0
BMI		
30	3.86 (3.81)	9.09 (3.15)
25–29	2.63 (3.52) [§]	3.66 (2.78) ^{§§§}
20–24	0	0
<20	-9.37 (6.26)	-7.25 (4.33)
History of fracture		
Yes	-0.33 (4.03)	-7.29 (2.99) *
No	0	0
Physical activity		
180 min/week	1.18(4.71)	2.51 (3.31)
120–179 min/week	2.84 (4.15)	4.97 (3.19)
0–120 min/week	0	0
Smoking		
Ever	-6.12 (3.62)	-1.84 (3.16)
Never	0	0
Calcium intake	-0.007 (0.004)	0.003 (0.003)
Menopausal status		
Postmenopausal	-4.29 (4.89)	-2.41 (4.99)
Pre- or perimenopausal	0	0
Estrogen use		
Ever	-0.74 (4.58)	1.89 (4.36)
Never	0	0

[†]Regression coefficient, se standard error[‡]Coefficient of determination R^2 * $p < 0.05$

^{**}
 $p < 0.001$

^{***}
 $p < 0.0001$

^{\$}
 $p < 0.05$

^{\$\$}
 $p < 0.001$

^{\$\$\$}
 $p < 0.0001$ for trend

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