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Contribution of fat free mass and fat mass to bone mineral density among reproductive-aged women of white, black, and Hispanic race/ethnicity

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Abstract

Purpose—To evaluate the contribution of fat-free mass (FFM) and fat mass (FM) to bone mineral density (BMD) and bone mineral apparent density (BMAD) among reproductive-aged women.

Methods—Dual-energy X-ray absorptiometry scans were performed on 708 healthy black, white, and Hispanic women, 16-33 years old. The independent effect of FFM and FM on BMD and BMAD and the interaction of body composition measurements with race/ethnicity and age, were evaluated.

Results—FFM correlated more strongly than FM with BMD at the lumbar spine (r=0.52 vs. r=0.39, P<.01) and the femoral neck (r=0.54 vs. r=0.41, P<.01). There was a significant positive association between bone density measures [ln(BMD) and ln(BMAD)] and both ln(FFM) and ln(FM). The association of FFM with spinal BMD was stronger in 16-24-year-old women than in 25-33-year-old women (P=.006). The effect of FFM on femoral neck BMD was greater in blacks (P=.043) than Hispanics, while the effect of FM on spinal BMD was less (P=.047).

Conclusions—Both FM and FFM are important contributors to bone density although the balance of importance is slightly different between BMD and BMAD.

Keywords

bone mineral density; body composition; fat free mass; fat mass

Introduction

Prior studies have demonstrated that weight has a positive effect on bone mineral density (BMD) during the reproductive years. Whether this relationship is affected by the amount of fat free mass (FFM) versus fat mass (FM) present is less clear. Khosla et al. found that FM was the most important determinant of BMD (1) while several other studies have observed that the most important determinant of BMD was FFM. For example, Witzke and Snow observed that FFM was the only predictor of BMD in a study of 54 adolescent girls,(2) and in a study of 921 women between 20 and 25 years of age, Wang et al. noted that both FFM and FM

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predicted BMD at all sites, but that FFM was more important.(3) Similarly, a longitudinal study of 241 women who were followed from the age of 27 to 36 years of age demonstrated that FFM was the best predictor of BMD.(4)

Differences in the results of these studies could be due to differences in the age range of the populations under investigation. To determine this, a study is needed that includes both adolescent and adult women. Another factor that is important to evaluate is the effect of race/ethnicity on the relationship between body composition and BMD. Determining the effect of race is difficult because most studies on premenopausal women have included only non-Hispanic whites(4-6) or not specified the racial composition of their sample at all.(1,7-10) Two studies have included Asian women, but not women of other races or ethnic groups(11,12) and one included only women from Mexico.(13) In fact, only one study published to date on premenopausal women has investigated the impact of race/ethnicity by including women from white, black, and Hispanic backgrounds in the same study.(3) This important investigation, however, was limited to women between the ages of 20 and 25 years and thus data are lacking on minority women of other ages.

The purpose of this investigation was to fill these gaps in the literature by examining the contribution of FM and FFM to the BMD and bone mineral apparent density (BMAD) of women 16-33 years of age. Our sample included non-Hispanic black, non-Hispanic white, and Hispanic women, and differences by both age and race were examined.

Methods

We conducted secondary data analysis of a sample of healthy, non-Hispanic black, non-Hispanic white, and Hispanic women (self-identified), 16-33 years of age, who participated in a larger, prospective study of the effect of hormonal contraception on BMD between October 9, 2001, and September 14, 2004. The methods for the larger study are reported in detail elsewhere.(14) Briefly, recruitment was planned to achieve a sample that was balanced by race/ethnicity, age group (16-24 years and 25-33 years), and contraceptive method for analytic purposes. Women were excluded from participation in the larger study if they weighed >300 pounds (due to safety limitations of the DXA machine), were not eligible to receive hormonal contraceptive containing estrogen, wished to become pregnant in ≤3 years, had received depot medroxyprogesterone acetate or oral contraceptive pills in the last 6 or 3 months, respectively, had used medications or had a medical condition known to affect BMD, or had a dietary intake known or suspected to be high in isoflavones. In addition, women with abnormal serum levels of vitamin D, thyroid stimulating hormone, or liver function tests were excluded to avoid including those with a possible medical condition that could affect their BMD. A total of 805 women agreed to participate and provided written informed consent. Child assent and parental permission was obtained for participants under 18 years of age. Of the 805 women, 92 failed additional screening tests and 5 were removed from the study following the baseline bone scan due to results indicative of osteoporosis (T-score ≤-2.5). Removal of these women from further study was carried out for safety reasons related to the larger study. Thus, a total of 708 women were included in the current analysis performed on baseline data. Those excluded (n=97) did not differ from women included in the analyses (n=708) on age, but they were more likely to be black (22% vs. 10% Hispanic and 2% white, $P<.001$) and have a higher body mass index (28.4 kg/m^2 vs. 24.4 kg/m^2, $P<.001$). All participants received free well-woman care during participation in the study and were compensated for their time and travel to the clinic. The study received approval from the Institutional Review Board at the University of Texas Medical Branch at Galveston.

In the present analyses we included data collected for height, weight, age, and body composition measurements using information collected in the clinic on the day of the baseline

study visit. Height was measured in centimeters using a wall-mounted stadiometer (Heightronic, Snoqualmie, WA); weight was measured with a digital scale accurate to the nearest 0.1 kg. Body mass index (BMI) was calculated using the formula: BMI = weight (kg)/height (m^2). All women had fully developed secondary sex characteristics, were Tanner Stage 5, and were menstruating.

Body composition and bone density measures were obtained using dual-energy X-ray absorptiometry (DXA) (Hologic QDR 4500W densitometer). Body composition and bone density data included percent body fat, fat free mass (FFM) (kg), fat mass (FM) (kg), and bone mineral density (BMD) (g/cm^2) measured at the lumbar spine (L1-L4), total hip (femoral neck, trochanter, intertrochanteric regions), and whole body. We report data for the lumbar spine and the left femoral neck due to its high predictability of hip fracture relative to other hip sites.(15) Fat free mass is a measure of non-bone FFM not including bone mineral content (BMC). The BMD calculations (BMD=BMC[g]/projected area of the bone [cm^2]) have been shown to be influenced by bone size as they are based on two of three dimensions of bone (length and width without depth). To address this issue, we also calculated spine bone mineral apparent density (BMAD; g/cm^3), which is an approximation of the volumetric density of bone estimated from the BMC and the projected area of the bone (A). For the lumbar spine we used the formula described by Carter et al. (spine BMAD=$BMC/A^{3/2}$).(16) In this formula the volume of the measured spine is approximated by $A^{3/2}$. For the femoral neck, BMAD was calculated as femoral neck BMAD=BMC/A^2.(17) Long-term accuracy of the DXA machine was assessed through the use of a phantom spine calibrated daily prior to the scanning of participants. The in vitro percent coefficient of variation (%CV) of this machine was 0.27%. Scanning of subjects and analyses of the scans by the operator were conducted using a standardized protocol recommended by the International Society for Clinical Densitometry. Seventy-eight percent of subjects were scanned by the same certified radiologic technologist. Two additional certified technologists performed bone scans on the remaining 19% and 3% of subjects. The in vivo %CV was obtained by scanning 30 healthy women twice in the same day by the same technologist as has been recommended in the literature.(18,19) The site-specific percent coefficient of variation was 0.55% for the lumbar spine, 0.78% for the hip, 1.95% for the femoral neck, 4.83% for the spine BMAD, and 5.63% for the femoral neck BMAD.

Data were analyzed using SPSS statistical software (v. 15.0, Chicago, Illinois) and STATA 10 (Stata Corporation, College Station, TX). Subsequent to inspection of the data, descriptive analyses, and tests of normality, logarithmic transformations were performed to correct departures from normality on body composition and bone density measures. Bivariate associations were analyzed using analysis of variance (ANOVA) with Bonferroni-adjusted pairwise comparisons or independent-group t-tests on log transformed data, as appropriate. Fisher's *r*-to-*z*-transformation was used to compare the difference between two correlations. Multiple linear regression analyses were performed to evaluate the effect of FFM and FM on BMD and BMAD of the lumbar spine and left femoral neck. Specifically, interaction terms were assessed to evaluate possible differences in the relationship between FM and FFM and bone density by race/ethnicity and by age group while adjusting for age, race/ethnicity, and height (for BMD only). The regression models were designed to investigate the relationship between FFM and FM and bone mineral measures in separate models as well as using the same regression model while adjusting for covariates. Descriptive statistics, results of univariate and multivariable analyses, and significance levels are reported. An alpha level of .05 was considered statistically significant.

Results

Women were 16 to 33 years old (mean=24, SD=5.0), with 53% (n=373) being 16-24 years of age and the remainder (n=335) 25-33 years of age. Twenty-nine percent of the sample (n=204)

were black, 36% (n=257) were Hispanic, and 35% (n=247) self-identified as white. Hispanic women were predominately of Mexican origin.

Overall differences in body composition and BMD measures were observed by race/ethnicity (Table 1). With regard to body composition, on average, Hispanic women were shorter while black women weighed more. White women had lower BMI relative to black and Hispanic women, who did not differ. Blacks had greater FFM relative to whites and Hispanics (both $P<.0001$), although fat mass did not significantly differ between the latter two groups. With regard to bone density measures, blacks had higher mean BMD and BMAD values at the lumbar spine and left femoral neck relative to whites and Hispanics (all pairwise comparisons $P<.01$).

Examination of body composition measures by age group (16-24,25-33) revealed significant between-group differences in weight and BMI (but not height), with these values being greater in the older age group (Table 1). Similarly, FFM and FM were greater among those 25-33 years of age as compared to those 16-24 years of age (both $P<.0001$). With regard to bone density measures, women in the 16-24-year-old age group demonstrated lower BMD and BMAD values at the lumbar spine relative to women 25-33 years of age, both $P<.0001$. At the femoral neck, age group differences were trivial (Table 1).

FFM and FM were correlated with BMD and BMAD at the lumbar spine and left femoral neck, all $P<.01$ (Table 2). A stronger correlation was observed for FFM compared to FM with BMD at the lumbar spine ($z=3.01$, $P<.01$) and the left femoral neck ($z=3.05$, $P<.01$). Further examination of these correlations by race/ethnicity revealed that the positive relationship between FM and lumbar spine BMD differed between Hispanic and black women. Specifically, the relationship was stronger among Hispanic women ($r=.48$) relative to black women ($r=.33$) ($z=1.97$, $P<.05$). Similarly, the correlation between FFM and BMD at the left femoral neck differed between Hispanic and black women; however, this relationship was stronger among black women ($r=.60$) relative to Hispanic ($r=.47$) women ($z=2.02$, $P<.05$).

The relationships between body composition (FM and FFM) and bone density (BMD and BMAD) at two anatomical sites (lumbar spine and left femoral neck) were examined in separate and same multiple linear regression models.. Table 3 presents the results of the main effects multiple linear regression models for the relationship of ln(FFM) and ln(FM) with bone density measures [ln(BMD) and ln(BMAD)] after adjusting for age, race/ethnicity, and height for BMD models, and age and race/ethnicity for BMAD models. Both ln(FFM) and ln(FM) showed significant positive associations with ln(BMD) and ln(BMAD) at the lumbar spine and femoral neck when FFM and FM were analyzed in separate models.. When included in the same model, FFM continue to show similar strong associations for all BMD measures but not for BMAD measures while the opposite was true for FM.

The interaction terms between age group (16-24 y vs. 25-33 y) and ln(FFM and FM), and race/ethnicity and ln(FFM and FM) were examined in separate models. There was an age interaction effect on the relationship between ln(FFM) and ln(spine BMD) (Figure 1a), and ln(FM) and ln(spine BMD) (Figure 1b). The effect of FFM on spinal BMD was significantly stronger ($P=.006$) in younger women (16-24 y) than older women (25-33 y). The same effect was found for FM, but statistical significance was not achieved ($P=.06$). No such interaction existed between ln(FFM and FM) and age group for ln(femoral neck BMD) (Figure 1c,d). Similarly, there were race/ethnicity interaction effects on the relationship between ln(FFM) or ln(FM) and BMD measures [ln(spine BMD) or ln(femoral neck BMD)]. The regression coefficient for FM was smaller among blacks ($P=.047$) and whites ($P=.066$) compared to Hispanics (Figure 2b). The opposite scenario was observed for the relationship between ln(FFM) and ln(femoral neck BMD); blacks had greater regression coefficients than Hispanics ($P=.043$) (Figure 2c).

Discussion

This study confirms the findings of previous investigators that FFM positively correlates with BMD in premenopausal women. For example, Douchi observed in a sample of 296 premenopausal women that FFM, but not FM, was a determinant of spinal BMD.(12) Similarly, Witzke and Snow found in a population of adolescent women that FFM correlated with BMD at the lumbar spine, femoral neck, greater trochanter, and mid-femoral shaft.(2) These results were supported by Wang et al. who noted among women 20-25 years of age that both FM and FFM were associated with BMD at the spine and hip, but that FFM had a stronger effect.(3) Together, these studies suggest that the development of muscle mass may be an important factor in achieving peak bone density.

In contrast to our findings, Reid and colleagues observed in their study of 68 premenopausal women that FM was the most important factor related to bone density. Furthermore, they stated that the importance of FFM observed by others was due to a failure to consider height.(8) To correct this omission, they recommended that the measurement BMD/height be used. Based on this recommendation, we conducted similar analyses and measured the association between BMAD as well as BMD with FM and FFM. In contrast to Reid, we observed a correlation between FFM and both BMD and BMAD when these analyses were performed. This agrees with the findings of Kerr et al. who noted that the relationship between BMD and lean body mass persists even after controlling BMD for height.(20) Thus, other factors, such as differences in populations, most likely contributed to the discrepancy in findings between these studies and the one conducted by Reid.

Published studies on the mechanism through which lean mass increases BMD are abundant (21-26). Lean mass is considered the surrogate of muscle force, which drives the accrual of bone mass and strength during childhood and adolescence through osteogenesis, and maintains BMD during adulthood. In addition, increased body lean mass is associated with increased physical activity and a healthy diet (27,28) which enhance bone formation. Fat mass also contributes to bone formation through skeletal loading. However, the resultant effect of fat mass on bone formation is not as great as excessive body fat it is often associated with a less healthy diet and physical inactivity.

We also observed that blacks had greater FFM, on average, than white and Hispanic women. Furthermore, blacks had a higher mean BMD at the lumbar spine and femoral neck relative to Hispanics and a higher BMD at the spine and femoral neck relative to whites. Our observation that FFM contributes more to BMD than FM may explain, in part, the higher bone density observed among young blacks as compared with whites. Genetics may play a significant role in this relationship as well because heavier bones have been observed among blacks as compared with other racial/ethnic groups at a very young age.(29,30)

In addition, we observed that the relationship between BMD and FFM and FM may differ by race/ethnicity and age. Overall, the effect per unit of FFM on femoral neck BMD was greater in blacks than Hispanics, which may also contribute to the higher BMD observed among blacks. In addition, the effect of FFM on spinal BMD was stronger among younger women compared to older women. Similar to our findings, FFM was noted in a longitudinal study of 8-26-year-old women to have a stronger effect on bone gains achieved during the years immediately following menarche as compared to later adolescence.(31)

This study has several limitations. First, we were not able to include women over 300 pounds, due to manufacturer's instructions regarding the DXA table. In addition, women were not included if they were unable to receive hormonal contraceptives containing estrogen, or wished to become pregnant in $\leq$3 years because the primary specific aims of the larger study addressed contraceptive use. Together, these limitations could impact the overall generalizability of our

findings and selection bias cannot be ruled out. Finally, DXA measurement of FFM may be influenced by a number of factors, such as the presence of food in the stomach or stool in the colon. Protocol for the larger study included an overnight fast for all patients prior to their clinic visit, therefore food in the stomach should not have been a factor but stool in the colon could have affected our measurements.

In conclusion, we observed that FFM is a critical factor in the determination of BMD. This may help explain differences in BMD previously observed between women of different races.

Acknowledgments

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References

1. Khosla S, Atkinson EJ, Riggs BL, et al. Relationship between body composition and bone mass in women. J Bone Miner Res 1996;11:857–63. [PubMed: 8725184]
2. Witzke KA, Snow CM. Lean body mass and leg power best predict bone mineral density in adolescent girls. Med Sci Sports Exerc 1999;31:1558–63. [PubMed: 10589857]
3. Wang MC, Bachrach LK, Van Loan M, et al. The relative contributions of lean tissue mass and fat mass to bone density in young women. Bone 2005;37:474–81. [PubMed: 16040285]
4. Bakker I, Twisk JW, Van Mechelen W, et al. Fat-free body mass is the most important body composition determinant of 10-yr longitudinal development of lumbar bone in adult men and women. J Clin Endocrinol Metab 2003;88:2607–13. [PubMed: 12788863]
5. Sowers MF, Kshirsagar A, Crutchfield MM, et al. Joint influence of fat and lean body composition compartments on femoral bone mineral density in premenopausal women. Am J Epidemiol 1992;136:257–65. [PubMed: 1415147]
6. Blum M, Harris SS, Must A, et al. Leptin, body composition and bone mineral density in premenopausal women. Calcif Tissue Int 2003;73:27–32. [PubMed: 14506951]
7. Lindsay R, Cosman F, Herrington BS, et al. Bone mass and body composition in normal women. J Bone Miner Res 1992;7:55–63. [PubMed: 1549959]
8. Reid IR, Plank LD, Evans MC. Fat mass is an important determinant of whole body bone density in premenopausal women but not in men. J Clin Endocrinol Metab 1992;75:779–82. [PubMed: 1517366]
9. Reid IR, Legge M, Stapleton JP, et al. Regular exercise dissociates fat mass and bone density in premenopausal women. J Clin Endocrinol Metab 1995;80:1764–8. [PubMed: 7775619]
10. Winters KM, Snow CM. Body composition predicts bone mineral density and balance in premenopausal women. J Womens Health Gend Based Med 2000;9:865–72. [PubMed: 11074952]
11. Liu JM, Zhao HY, Ning G, et al. Relationship between body composition and bone mineral density in healthy young and premenopausal Chinese women. Osteoporos Int 2004;15:238–42. [PubMed: 14727013]
12. Douchi T, Yamamoto S, Oki T, et al. Difference in the effect of adiposity on bone density between pre- and postmenopausal women. Maturitas 2000;34:261–6. [PubMed: 10717492]
13. Lazcano-Ponce E, Tamayo J, Cruz-Valdez A, et al. Peak bone mineral area density and determinants among females aged 9 to 24 years in Mexico. Osteoporos Int 2003;14:539–47. [PubMed: 12844213]
14. Berenson AB, Odom SD, Radecki Breitkopf C, et al. Physiologic and psychologic symptoms associated with use of injectable contraception and 20 microgram oral contraceptive pills. Am J Obstet Gynecol. 2008in press
15. Marshall D, Johnell O, Wedel H. Meta-analysis of how well measures of bone mineral density predict occurrence of osteoporotic fractures. BMJ 1996;312:1254–9. [PubMed: 8634613]
16. Carter DR, Bouxsein ML, Marcus R. New approaches for interpreting projected bone densitometry data. J Bone Miner Res 1992;7:137–45. [PubMed: 1570758]

17. Katzman DK, Bachrach LK, Carter DR, et al. Clinical and anthropometric correlates of bone mineral acquisition in healthy adolescent girls. J Clin Endocrinol Metab 1991;73:1332–9. [PubMed: 1955516]

18. Baim S, Wilson CR, Lewiecki EM, Luckey MM, Downs RW Jr, Lentle BC. Precision assessment and radiation safety for dual-energy X-ray absorptiometry: position paper of the International Society for Clinical Densitometry. J Clin Densitom 2005;8:371–8. [PubMed: 16311420]

19. Ravaud P, Reny JL, Giraudeau B, et al. Individual smallest detectable difference in bone mineral density measurements. J Bone Miner Res 1999;14:1449–56. [PubMed: 10457279]

20. Kerr DA, Papalia S, Morton A, et al. Bone mass in young women is dependent on lean body mass. J Clin Densitom 2007;10:319–26. [PubMed: 17574465]

21. Schoenau E, Neu CM, Beck B, Manz F, Rauch F. Bone mineral content per muscle cross-sectional area as an index of the functional muscle-bone unit. J Bone Miner Res 2002;17:1095–1101. [PubMed: 12054165]

22. Tudor-Locke C, McColl RS. Factors related to variation in premenopausal bone mineral status: a health promotion approach. Osteoporos Int 2000;11:1–24. [PubMed: 10663354]

23. Ilich-Ernst J, Brownbill RA, Ludemann MA, Fu R. Critical factors for bone health in women across the age span: how important is muscle mass? Medscape Womens Health 2002;7:2. [PubMed: 12142855]

24. Frost HM. Muscle, bone, and the Utah paradigm: a 1999 overview. Med Sci Sports Exerc 2000;32:911–917. [PubMed: 10795780]

25. Ferretti JL, Capozza RF, Cointry GR, et al. Gender-related differences in the relationship between densitometric values of whole-body bone mineral content and lean body mass in humans between 2 and 87 years of age. Bone 1998;22:683–690. [PubMed: 9626409]

26. Rittweger J, Beller G, Ehrig J, et al. Bone-muscle strength indices for the human lower leg. Bone 2000;27:319–326. [PubMed: 10913929]

27. Barbeau P, Gutin B, Litaker M, Owens S, Riggs S, Okuyama T. Correlates of individual differences in body-composition changes resulting from physical training in obese children. Am J Clin Nutr 1999;69:705–11. [PubMed: 10197572]

28. Kyle UG, Morabia A, Schutz Y, Pichard C. Sedentarism affects body fat mass index and fat-free mass index in adults aged 18 to 98 years. Nutrition 2004;20:255–60. [PubMed: 14990265]

29. Kalkwarf HJ, Zemel BS, Gilsanz V, et al. The bone mineral density in childhood study: bone mineral content and density according to age, sex, and race. J Clin Endocrinol Metab 2007;92:2087–99. [PubMed: 17311856]

30. Ettinger B, Sidney S, Cummings SR, et al. Racial differences in bone density between young adult black and white subjects persist after adjustment for anthropometric, lifestyle, and biochemical differences. J Clin Endocrinol Metab 1997;82:429–34. [PubMed: 9024231]

31. Young D, Hopper JL, Macinnis RJ, et al. Changes in body composition as determinants of longitudinal changes in bone mineral measures in 8 to 26-year-old female twins. Osteoporos Int 2001;12:506–15. [PubMed: 11446568]

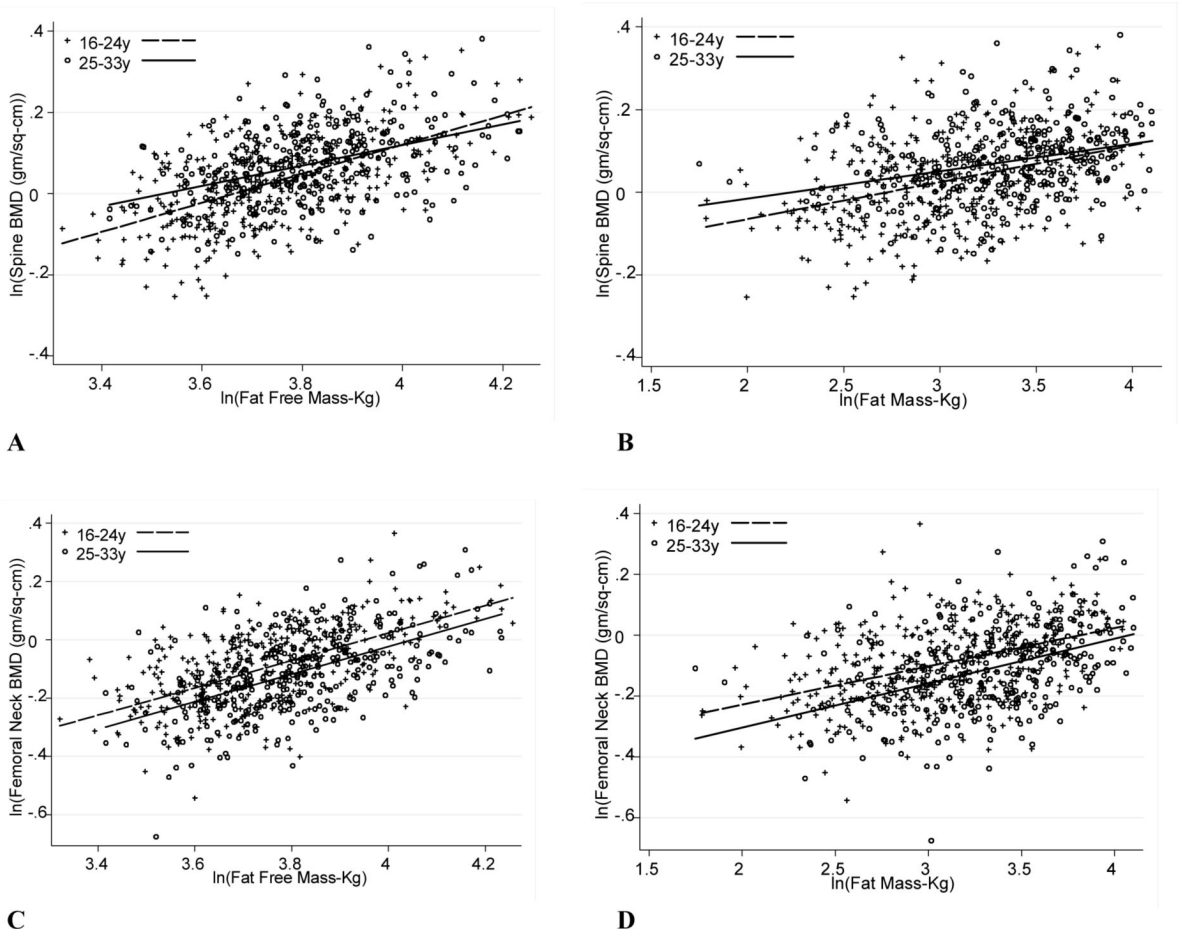

Figure 1.

Influence of age on the relationships between FFM/FM and spine/femoral neck BMD. (A) Between FFM and spine BMD. (B) Between FM and spine BMD. (C) Between FFM and femoral neck BMD. (D) Between FM and femoral neck BMD.

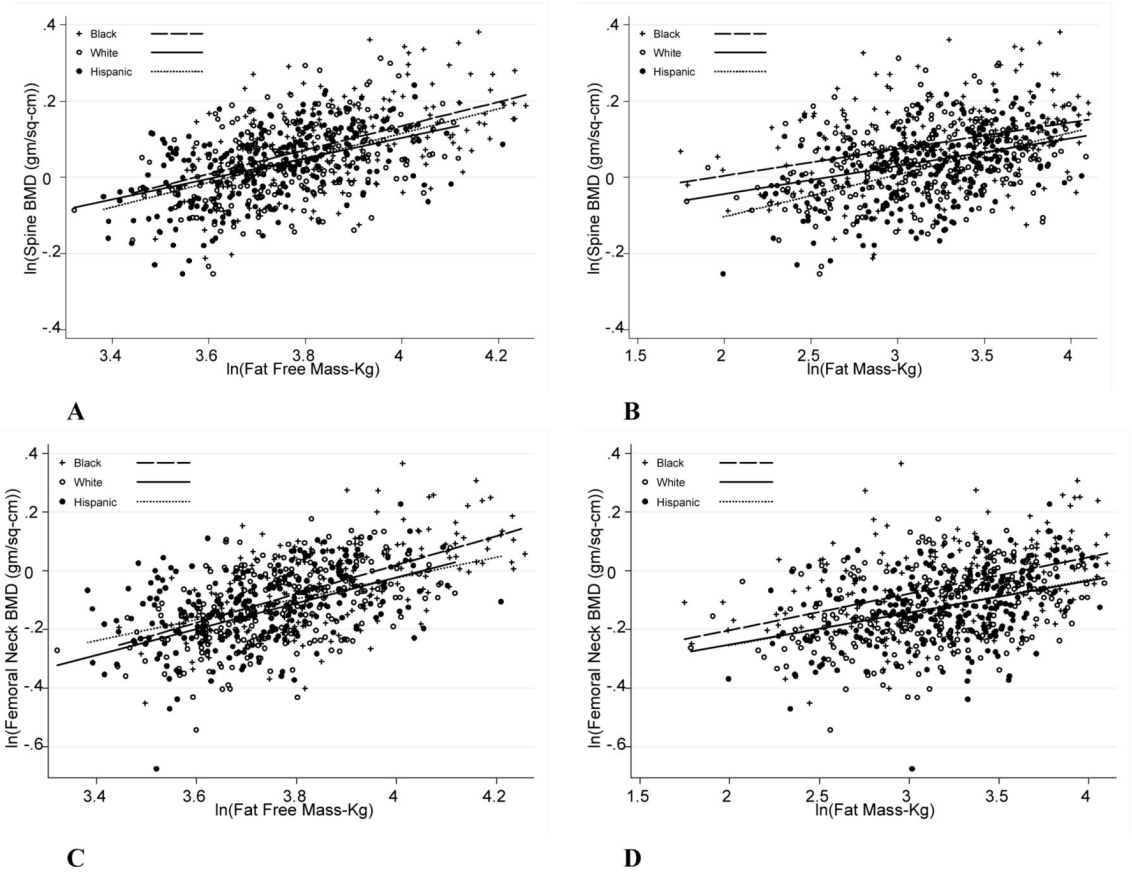

Figure 2.

Racial influence on the relationship between FFM/FM and spine/femoral neck BMD. (A) Between FFM and spine BMD. (B) Between FM and spine BMD. (C) Between FFM and femoral neck BMD. (D) Between FM and femoral neck BMD.

Table 1

Body Composition and Bone Density Characteristics for the Total Sample, by Race/Ethnicity, and by Age Group (M ±SD)

		Race/Ethnicity				Age Group (y)		
	Total Sample	**Black**	**White**	**Hispanic**	***P*†**	**16-24**	**25-33**	***P*‡**
Height (m)	1.62 ± .07	1.63 ± .07[a]	1.64 ± .06[a]	1.58 ± .06[b]	<.0001	1.62 ± .07	1.62 ± .06	0.80
Weight (kg)	72.6 ± 18.5	78.5 ± 21.5[a]	70.5 ± 16.6[b]	70.0 ± 16.5[b]	<.0001	68.7 ± 17.6	77.0 ± 18.4	<.0001
Body Mass Index (kg/m^2)	27.7 ± 6.7	29.6 ± 7.7[a]	26.2 ± 6.2[b]	27.8 ± 6.1[a]	<.0001	26.2 ± 6.3	29.4 ± 6.8	<.0001
Fat free mass (kg)	44.3 ± 7.7	48.1 ± 8.7[a]	43.4 ± 6.4[b]	42.0 ± 6.7[c]	<.0001	43.0 ± 7.6	45.7 ± 7.5	<.0001
Fat mass (kg)	26.5 ± 11.6	28.4 ± 13.5	25.4 ± 11.2	26.1 ± 10.3	0.126	23.8 ± 11.0	29.6 ± 11.6	<.0001
Lumbar spine BMD (g/cm^2)	1.05 ± .11	1.10 ± .12[a]	1.04 ± .10[b]	1.03 ± .09[b]	<.0001	1.04 ± 0.11	1.08 ± 0.1	<.0001
Lumbar spine BMAD (g/cm^3)	.142 ± .01	.149 ± .01[a]	.138 ± .01[b]	.141 ± .01[c]	<.0001	.140 ± .01	.145 ± .01	<.0001
Femoral neck BMD (g/cm^2)	.91 ± .12	.96 ± .14[a]	.89 ± .11[b]	.89 ± .11[b]	<.0001	.92 ± .12	.90 ± .12	0.054
Femoral neck BMAD (g/cm^3)	.202 ± .03	.217 ± .04[a]	.191 ± .03[b]	.200 ± .03[c]	<.0001	.20 ± .03	.20 ± .03	0.021

†Overall significance determined by analysis of variance performed on log transformed values, with Bonferroni-adjusted pairwise comparisons. Values that share same superscripts do not significantly differ from each other.

‡Pairwise comparisons performed using independent group t-tests.

Table 2

Zero-Order Spearman Rank Order Correlation Coefficients between Bone Density Measurements and Body Composition for the Total Sample and by Race/Ethnicity

	Lumbar Spine BMD (g/cm^2)	Lumbar Spine BMAD (g/cm^3)	Left Femoral Neck BMD (g/cm^2)	Left Femoral Neck BMAD (g/cm^3)
	Total sample **Black (B)** **White (W)** **Hispanic (H)**	**Total sample** **Black (B)** **White (W)** **Hispanic (H)**	**Total sample** **Black (B)** **White (W)** **Hispanic (H)**	**Total sample** **Black (B)** **White (W)** **Hispanic (H)**
BMI (g/cm^2)	**.42****	**.49****	**.47****	**.32****
	.34**	.42**	.50**	.28**
	.40**	.47**	.45**	.35**
	.51**	.52**	.42**	.22**
FFM (kg)	**.52****	**.40****	**.54****	**.27****
	.50**	.37**	.60**	.27**
	.41**	.30**	.49**	.30**
	.55**	.43**	.47**	.16**
FM (kg)	**.39****	**.42****	**.41****	**.24****
	.33**	.37**	.47**	.25**
	.36**	.41**	.39**	.27**
	.48**	.47**	.36**	.17**
Weight (kg)	**.47****	**.44****	**.49****	**.27****
	.41**	.39**	.54**	.27**
	.41**	.40**	.47**	.31**
	.53**	.47**	.42**	.17**

Note. BMD = bone mineral density; BMAD = bone mineral apparent density, BMI = body mass index, FFM = fat free mass, FM = fat mass.

The first correlation coefficient shown in boldface is for the total sample followed by the correlation for blacks, whites, and Hispanics.

* $P<.05$

** $P<.01$, two-tailed.

Table 3

Regression Coefficient ± SE and R-Squared Value for the Association of ln(FFM) or ln(FM) or both with ln(BMD) or ln(BMAD) Based on Multiple Regression Models

Model	ln(Spine BMD)[a]	ln(Femoral neck BMD)[a]	ln(Spine BMAD)[b]	ln(Femoral neck BMAD)[b]
Model with FFM				
R^2	0.30	0.37	0.21	0.14
ln(FFM)	0.302 ± 0.024[a]	0.532 ± 0.030[a]	0.206 ± 0.022[b]	0.265 ± 0.040[b]
Model with FM				
R^2	0.23	0.26	0.24	0.15
ln(FM)	0.070 ± 0.008[a]	0.131 ± 0.010[a]	0.082 ± 0.008[b]	0.102 ± 0.014[b]
Model with FFM and FM				
R^2	0.30	0.37	0.25	0.16
ln(FFM)	0.309 ± 0.037[a]	0.503 ± 0.046[a]	0.075 ± 0.032[b†]	0.111 ± 0.058[b*]
ln(FM)	-0.003 ± 0.012[a*]	0.011 ± 0.014[a*]	0.063 ± 0.011[b]	0.074 ± 0.021[b]

Regression coefficients were significant at $P<.001$ otherwise indicated

SE = Standard error; ln(FFM) = natural logarithm of FFM in kg; ln(FM) = natural logarithm of FM in kg.

[*] Not significant at P<.05

[†] P=0.021

[a] Adjusted by age (continuous, yrs), race/ethnicity (black, white, and Hispanic), and height (m).

[b] Adjusted by age and race/ethnicity.