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Race and Sex Differences in Bone Mineral Density and Geometry at the Femur

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Abstract

Introduction—Differences in osteoporotic hip fracture incidence between American whites and blacks and between women and men are considered to result, in part, from differences in bone mineral density and geometry at the femur. The aim of this study was to quantify differences in femoral bone density and geometry between a large sample of healthy American white and black women and men.

Subjects and Methods—Healthy American white (n=612) and black (n=164) premenopausal women, aged 23 to 57 years, and healthy American white (n=492) and black (n=169) men, aged 20 to 63 years, had volumetric bone mineral density (vBMD) and geometry variables measured at the femur by computerized tomography (CT), and areal bone mineral density (aBMD) at femoral neck measured by dual x-ray absorptiometry (DXA).

Results—American blacks had higher vBMD at the femoral neck and femoral shaft cortex than American whites whereas femoral axis length and femoral neck area were not different. Men had lower vBMD at the femoral neck and femoral cortex than women but had greater femoral axis length and femoral neck area than women. The higher aBMD in American blacks than whites persisted after correction for measured area whereas the higher aBMD in men than women disappeared.

Conclusions—At the femoral neck, American whites have lower bone density than American blacks but similar geometry. Women have higher bone density than men in both races but have smaller geometry variables. The differences in bone density may account in part for the differences in hip fracture incidence between American blacks and whites, whereas the differences in femur size may account for the differences in hip fracture rates between men and women.

Keywords

sex; race; femur; bone mineral density; geometry

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Introduction

Osteoporotic age-related hip fracture occurs at both femoral neck and greater trochanter sites at the proximal femur [1,2]. The fracture has a higher incidence in women than men and in American whites than American blacks[3] [4]. It is generally considered that these differences in fracture incidence reflect, in part, higher bone strength in men than women, and in blacks than whites. The two major components of bone strength at the hip are bone mineral density and bone geometry. Both femoral bone density [5,6] and hip geometry [7-10] predict hip fracture. However, it is not well established how much of the sex and race differences in bone strength in American whites and blacks resides in bone density and how much in bone geometry.

Bone density is measured noninvasively by two main imaging techniques: dual x-ray absorptiometry (DXA) and computed tomography (CT). Most published femoral bone density values comparing American men and women and comparing American blacks and whites have been acquired using bone density measured by DXA [11]. DXA measures bone mineral content in an area of the femoral neck that is fixed in length but whose width varies with skeletal size. To correct for size, bone mineral content (g) is usually divided by the measured area (cm²) and expressed in g/cm² as areal bone mineral density (aBMD) which is a composite measure of cortical and cancellous bone. DXA also provides an image of the hip and upper femur from which simple geometric variables can be measured [7]. However, the resolution of the image and variation in projection size make most measures of hip geometry from DXA problematic.

In contrast, CT measures volumetric bone mineral density (vBMD) in g/cm³ and is capable of measuring cortical and cancellous components separately. However, to make accurate measures of cortical bone density, the sampled volume has to be large enough to be representative but be distant enough from the periosteum and endosteum to avoid averaging with surrounding tissues, usually referred to as partial-volume effect[12]. The rim of cortical bone at the femoral neck varies around its circumference and even at its widest is only about 1mm thick. Thus, measurement of femoral neck cortical vBMD by CT which has a pixel size of about 0.5 mm is compromised because of influence from cancellous bone at the endosteal surface and soft tissue at the periosteum. However, a true measure of cortical vBMD at the femur can be made at a femoral shaft which has sufficient thickness that influence from cancellous bone and soft tissue can be avoided. In addition to having the capability of measuring density in g/cm³, the CT image provides geometric measures that are independent of patient positioning.

The primary aim of this study was to compare, in healthy adult American white and black men and women, vBMD and geometry at the hip in order to examine how these variables might account for the differences in hip fracture incidence that occur at a later age in these populations. Secondary aims were to examine the interrelationships among cortical and cancellous vBMD measures, their relationship with femoral neck aBMD and with anthropometric measures that are known to affect bone mineral density and geometry, including age, height, weight, fat and lean tissue.

Materials and Methods

Subjects

The subjects comprised healthy American white (n=612, families=301) and black (n=164, families= 77) premenopausal women, aged 23 to 57 years and healthy white (n=492, families=245) and black (n=169, families=79) men, aged 20 to 63 years, from Indiana. These subjects were participants in a larger study on the genetics of peak bone mineral density measured by DXA involving sister pairs and brother pairs, the results of which have, in part,

been published[13-15]. The CT protocol was added in July 2000 in subjects having an aBMD measured as part of the genetic study. The majority of the CT scans were performed on the same day as the aBMD. The studies were performed at the Indiana Clinical Research Center at Indiana University. Informed written consent, approved by Indiana University-Purdue University Indianapolis and Clarian IRB, was obtained from all subjects.

Height and Weight

Height and weight were measured using a Harpenden Stadiometer and a Scale-Tronix weighing scale, which were regularly calibrated throughout the study. Chronological age was recorded at the time of the DXA and CT measurement.

Quantitative Computed Tomography (CT)

CT of the lower pelvis and right proximal femur was performed on a multi-slice helical CT scanner (MX 8000, QUAD Philips Medical Systems, Andover, MA), with a CT solid 4 bar (0, 50, 100 and 200 mg/cm³) calcium hydroxyapatite standard (Image Analysis, KY) placed behind the proximal thigh. Each day the CT scanner was 'air calibrated' (air = 0 Hounsfield units) to reset Hounsfield Units as part of the quality assurance. The CT scan parameters were 120kVp, 200mAs 512×512 matrix, 1.0mm slice width with a 50% overlap and 0.58 mm pixel size. Subjects were placed in the supine position with both feet taped together in 15 degrees of internal rotation. 'Scout' images were obtained to ensure that the proximal end of the calcium hydroxyapatite standard was positioned just above the acetabulum and that the inner edge of the standard was lateral to the mid-line at the upper half of the femur. Images of the proximal femur were displayed on an image analysis work station (Philips Medical Systems, Andover, MA). The vertical distance from the lesser trochanter to the medial femoral condyle was measured and the midpoint of this distance calculated to position an image for the midfemur shaft measurements.

Volumetric BMD—Mid-coronal multiplanar reformatted images were created through the femoral neck and shaft just proximal to the midfemur slice, and the images were saved to an Agfa IMPAX image archive (Agfa Corp., Ridgefield Park, NJ) and to local disk. Fixed anatomical areas of interest, clearly separated from the periosteum and endosteum, were delineated in the medial and lateral cortices of the femoral shaft and vBMD was taken as the average) (Figure 1B). At the femoral neck because the cortex is too narrow to define an area of interest untainted by adjacent tissues [12], vBMD at the narrowest width of the neck, containing both cortical and cancellous bone, was measured (Figure 1C). An area containing only cancellous bone was also measured after delineating a region visualized by the workstation resizing tool with the adjustable markers within the endosteal surface to clearly separate its edge from the cortical rim (Figure 1C). Volumetric BMD of the total and cancellous bone at the femoral neck and cortical bone at the femoral shaft were calculated from their respective Hounsfield Units using the linear relationship between Hounsfield Units and known densities of the four bar calcium hydroxyapatite standard. The linear relationship was extrapolated for measuring vBMD.

Geometric variables—Geometric variables were measured on the image analysis work station and included femoral axis length, total bone area and cortical bone area at the mid thigh, and neck area at the minimal neck width (Figure 1).

Midthigh fat and muscle—Total, muscle, and bone cross-sectional areas at the femoral midshaft were visually identified, outlined manually, and measured by the CT software (Figure 1A). Fat area was calculated by subtracting the muscle plus bone area from the total area and muscle area was calculated by subtracting bone area from muscle-plus-bone area

Dual X-ray Absorptiometry (DXA)

Areal BMD (aBMD) was measured by DXA on a DPXL instrument in men and a Prodigy in women (GE Lunar, Madison, WI) at the right femoral neck. The instruments were cross calibrated on the same day at least weekly throughout the study using a phantom step wedge (BMIL QA/QC Phantom) [16] and no significant differences were detected between instruments over a wide range of densities. Image analysis was performed using software versions 4.6/4.7. The femoral neck area was measured by the DXA software. Coefficient of variation of aBMD measured in 115 pairs of sisters, who had duplicate DXA measurements after they were repositioned on the instrument, was 1.1% for femoral neck and 1.54 % for measured area. At the same time, total body fat and lean tissue were also measured. Coefficient of variation in 22 postmenopausal women, who had duplicate DXA measurements performed after they were repositioned on the instrument, was 1.7% for total body fat and 1.4% for total body lean.

Statistics

The mean, standard deviation, and range of all measurements were calculated for each sex-by-race group, as were Pearson correlations between measurements. To account for within-family correlations, generalized estimating equations were used to calculate all p-values for the correlations and between-group statistical comparisons in generalized linear models. Each model fitted the bone density or geometry as a linear function of other variables, such as race and sex. When significant overall differences were found, differences between sexes were then tested within each race and differences between races were tested within each sex. The subgroup analyses produced more readily interpretable results compared with two-way analysis-of-variance when there were significant race-by-sex interactions in some of the outcome measures. If any bone density measurement was related to age, age was added as a covariate in the generalized linear model so the between group comparisons were based on age-adjusted means to correct for unequal ages between groups. Since measures of aBMD were only partially corrected for bone size, they were further corrected for the area measured as an additional covariate for additional between-group comparisons. Finally, each bone density or geometry measurement, further corrected for the anthropometric measurements as additional covariates in the model, was also compared between groups to investigate whether any between-group differences could be explained by differences in overall body size. The estimated effects (regression coefficients and statistical significance) of race, age, height, weight, thigh fat tissue, and thigh lean tissue were calculated separately for men and women. They can be used in equations of the form: predicted bone density/geometry = $b_0 + b_1(\text{black versus white}) + b_2(\text{age}) + b_3(\text{height}) + b_4(\text{weight}) + b_5(\text{thigh fat}) + b_6(\text{thigh lean})$, to calculate the expected bone density/geometry of any individual, where b_0 is the intercept, and black is coded 1 and white is coded 0. Similar equations were used to estimate the sex effect within each race, with “black versus white” replaced “male versus female” (male coded 1, female coded 0) as a predictor variable in the separate equations for blacks and whites.

Results

Age and Anthropometrics (Table 1)

Race—Black women were heavier, had greater thigh fat and thigh lean tissue than white women. Black men were older and shorter, and had higher thigh lean tissue than white men.

Sex—Men were younger, taller, and had higher thigh lean tissue and lower fat tissue than women. White men were heavier than white women.

Femoral vBMD and aBMD (Table 2)

Cortical midshaft vBMD was higher at the medial than the lateral site in both women and men in both races ($p < 0.001$, data not shown).

Race—Cortical midshaft vBMD, total neck (cortical plus cancellous bone) vBMD, cancellous neck vBMD, and neck aBMD were higher in blacks than whites in both sexes.

Sex—Total neck vBMD was higher in women than men in both races. Cortical midshaft vBMD was higher in white women than men but not different between black men and women. Cancellous vBMD was higher in black women than men but was not different between white women and men. In contrast, neck aBMD was higher in men than women.

Age-Corrected BMD (Figure 2)

Race—After correcting for unequal distributions of age across groups, all mean bone-density values remained significantly higher in blacks than in whites.

Sex—Age-corrected vBMD was consistently lower, although not always significantly, in men than women whereas aBMD was higher. However, when further corrected for femoral neck area, aBMD was no longer different between men and women of either race ($p > 0.4$).

Femoral Geometry (Table 3)

Race—Total midshaft bone area was higher in blacks than whites in both sexes. Midshaft cortical bone area was not different between black and white women but was somewhat higher ($p < 0.05$) in white men than black men. Total neck area and femoral axis length were not different between whites and blacks in either sex.

Sex—Total midshaft bone area, cortical midshaft bone area, total neck area and femoral neck axis were all higher in men than women.

Age-Corrected Femoral Geometry (Figure 3)

Race—After correcting for unequal distributions of age across groups there was no difference in shaft cortical bone area, neck total bone area or femoral axis length between blacks and whites although the shaft total bone area was higher in blacks than whites.

Sex—All age-corrected mean geometric measures remained significantly higher in men than in women.

BMD Interrelationships (Table 4)

Cancellous neck vBMD, total neck vBMD and neck aBMD were relatively highly correlated in both races and both sexes with r values > 0.62 . In contrast the midshaft cortical vBMD correlations with cancellous neck vBMD and total neck vBMD had values < 0.28 . The correlation between cortical vBMD and aBMD (< 0.11) was always weak.

Femoral Geometry Interrelationships (Table 5)

The correlations among the measures of geometry were about equally high across races and across sexes (range 0.31-0.80)

Fat and Lean Tissue Interrelationships. (data not shown)

Midthigh fat area was relatively highly related to total body fat mass ($r=0.87$) and weight ($r=0.81$); and midthigh lean area was relatively highly related to total body lean tissue mass ($r=0.78$), weight ($r=0.68$) and midthigh fat area ($r=0.53$).

Race and Sex Differences in vBMD and aBMD Corrected for Age, Fat, Lean, Weight, and Height (Table 6a, 6b)

Age (negative), height (negative) and lean tissue (positive) were variables most consistently related to bone density.

Race—Blacks, both women and men, had higher bone density, corrected for age and anthropometrics, than whites.

Sex—Men, both white and black, had lower bone density, corrected for age and anthropometrics, than women except at the midshaft cortical bone where the difference between black men and women was not statistically significant.

Race and Sex Differences in Geometry Corrected for Age, Fat, Lean, Weight, and Height (Table 7a, 7b)

Age (positive), height (positive), weight (positive), fat tissue (negative) and lean tissue (positive) were generally related to geometry but not consistently. Only the correlation of height was consistently significant with all geometry measures. The correlations with age and weight were least consistent across geometry measures

Race—Blacks, both women and men, had smaller geometry variables, corrected for age and anthropometrics, than whites except at the midshaft bone area where blacks were larger than whites.

Sex—Men, both white and black, had higher bone geometry corrected for age and anthropometrics, than women.

Discussion

The higher hip fracture rates in American whites as compared to American blacks and in women compared to men continue to be an important field for researching factors underlying osteoporotic hip fracture. In this study using CT to separately measure vBMD and geometry at the hip in healthy black and white Americans, the results suggest that differences in bone density may explain in part the race differences in fracture incidence, whereas differences in bone geometry may explain the sex differences.

Femoral vBMD measured by CT at both cortical and cancellous sites was higher in healthy American blacks than American whites in this study. The racial difference in vBMD persisted, as it did for aBMD, after correction for age and anthropometric measures including lean mass, fat mass, weight and height. A higher vBMD has also been reported in American black men over 65 years of age as compared to white men [17]. The racial difference in vBMD corroborates observations using DXA, that femoral aBMD is higher in American blacks than American whites [11], occurs in both women [13] and men [15], appears in childhood [18] associated with higher skeletal mineral retention [19], and persists into old age [20]. The factors responsible for the racial difference in bone density between American blacks and whites are unknown but are likely to involve both environmental and genetic factors. Heritability of aBMD is equally high in blacks and whites [15] although the genes underlying these racial differences in BMD remain to be identified.

Women had higher cancellous and total vBMD at the femoral neck than men. Similar findings have been reported by others [21]. The effect of sex was less marked in cortical vBMD. These differences in vBMD persisted after correction for age and anthropometrics. The cause of the higher BMD in women than men cannot be addressed in this study. However, it could lie both in intrinsic mechanisms, including sex-specific genes regulating bone density [15], or extrinsic mechanisms, including an adaptation of a smaller skeleton to equivalent mechanical forces. The higher vBMD in women contrasts markedly with the lower aBMD found in women than men [11]. Since aBMD has been shown to predict the risk of hip fracture [5,6], it is generally considered that the lower bone density in women is one of the main factors for the higher incidence of hip fracture in women than men. However, when aBMD was corrected for the larger area of femoral neck measured by DXA in men, the sex differences in aBMD disappeared. Thus the estimation of risk of hip fracture from aBMD is probably as much dependent on area measured, i.e. skeletal size, as it is on true mineral density.

Mean cortical vBMD at the femur across sexes and races in this study ranged from 1,371 to 1,402 mg/cm³ which is similar to that previously reported in a number of studies [12,22-24]. These values are about two to three times as high as those reported for the cortical bone at the femoral neck [21,24]. However, the latter are similar in value to our vBMD for femoral neck suggesting that measures of cortical bone at the femoral neck reported by others do not represent true cortical bone but a composite of cortical and cancellous bone. Cortical bone in this study showed a small but consistently positive increase in vBMD from the lateral to medial side of the femur shaft in both sexes and both races. This difference may reflect higher mechanical forces transmitted down the medial aspect of the shaft because of the shape of the femur. On the other hand in animal models, increases in mechanical loads on cortical bone leads to changes in shape and increases in bone mass rather than an increase in vBMD [25] [26]. Thus the mechanisms underlying regional variation in vBMD remain unclear.

Mean cancellous vBMD at the femoral neck ranged from 212 to 276 mg/cm³ which is in agreement with those reported for a smaller sample of healthy men and women aged 20 to 29 [21], but is much higher than the range reported in a large sample of older men aged 65 to 69 years [24]. The variance in cancellous vBMD relative to its mean was much higher than it was for cortical vBMD. One SD in cancellous bone vBMD in our sample ranged from 34% to 40% of the mean whereas in cortical bone it ranged from 4 to 6%. Cortical vBMD, untainted by partial-volume effects, reflects tissue density of bone in the cortex and is, thus, defined mostly by the ratio of collagen to mineral and the extent of the Haversian system. The lack of an effect of age on cortical vBMD in this sample (except for a weak decline in white women), which ranged from aged 20 to 59 years, indicates that cortical porosity causing bone loss is not present in this age group. The relatively low variance of cortical vBMD perhaps reflects the longer half-life of cortical bone as a tissue, its predominant structural function and the fact that age and lean-tissue mass do not greatly influence it in this age group. Conversely, the relatively high variance of cancellous vBMD probably reflects cancellous bone tissue's predominant metabolic function and its variation with age and lean-tissue mass.

Although a measure of cortical vBMD in the femoral neck is likely to be informative in terms of the neck's propensity to fracture, the rim of cortical bone at this site is too thin to delineate a volume that is free from interference from soft tissue at the periosteum and cancellous bone at the endosteum. In this study we found that vBMD and its variance at the total femoral neck (cancellous plus cortical bone) was about halfway between the value of cancellous bone at the femoral neck and cortical bone at the mid-shaft. However, the variance of the measure and the relationships with age, fat and lean tissue were similar to those found with cancellous bone suggesting that total femoral neck bone density is strongly influenced by metabolic factors and reflects the cancellous bone in the medulla more than the cortical bone in the rim.

There are a number of strengths of the study. Published comparisons of CT measures of cortical and cancellous bone at the femur in healthy young American white and black men and women are very limited. Measures of cortical and cancellous vBMD in men and women and blacks and whites allow the examination of whether genes regulating the normal variation in vBMD are the same or different for cortical and cancellous bone and whether any of these genes are sex-or race-specific. CT simultaneously measures muscle mass which is an important predictor of cancellous vBMD. Finally CT and DXA measurements in the same subjects allow the comparison of aBMD and vBMD and the exploration of the limitations in aBMD variables.

This study has several limitations. For a population study our sample reflects those who volunteered rather than an unbiased selection. The sample size is not extensive and the groups of men and women and blacks and whites do not have equal numbers. Cortical shaft vBMD and total neck vBMD are derived from the extrapolated relationship between Hounsfield units and BMD on the assumption that this curve remains linear. However, this is intrinsic to the use of an external calcium standard for quantitative CT that is limited in its highest value because of interference with the acquisition of CT data.

In summary we have demonstrated that American blacks have higher cortical and cancellous vBMD than whites but geometry is similar whereas women have higher density than men but smaller femur size. The results suggest that differences in bone density explain in part the race differences in fracture incidence, whereas differences in bone geometry explain in part the sex differences. CT measures of cortical and cancellous bone separately and bone geometry are likely to lead to a better understanding of the higher rates of hip fractures in whites and in women and may facilitate the search for genes that underlie the high heritability of the normal variation in bone density and geometry at the hip.

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Figure1.

Illustration of CT images from which femoral measurements are made (AR =area, AV= Hounsfield units).

A. Midthigh fat = total area- muscle/bone area: Midthigh lean =muscle/bone area — bone area

B. Shaft cortical density calculated as the mean density of a medial (right) and lateral (left) selected area (black) in relation to the calcium hydroxyapatite standard (bottom)

C. Femoral neck total vBMD, calculated from the total area (697.8), and cancellous vBMD, calculated from the defined area (144.3), are calculated in relation to the calcium hydroxyapatite standard (bottom)

D. Femoral geometry: femoral axis and minimum width of femoral neck measured directly from CT image by work station soft ware.

Figure 2.

Age-corrected: A. femoral shaft cortical vBMD; B. femoral total neck vBMD; C. femoral neck cancellous vBMD; D. femoral neck aBMD; E. femoral neck aBMD also corrected for area measured, in white $\square$ and black $\blacksquare$ women and men. Data are expressed as mean (standard error, se); a, $p < 0.001$ difference between races; x, $p < 0.001$ difference between sexes)

Figure 3.

Age-corrected: A. femoral shaft area; B. femoral shaft cortical area; C. femoral neck area; and D. femoral axis length in white □ and black ■ women and men.

Data are expressed as mean (standard error, se); a, p<0.001 difference between races; x, p<0.001 difference between sexes)

Table 1Mean (standard deviation, range) age and anthropometrics in white and black women and men^a.

	White	Black	p-value ^b
Women			
n	612	164	
Age (years)	42.0 (6.4, 25.5-57.1)	41.6 (6.1, 23.2-56.0)	n.s.
Height (cm)	165.3 (6.0, 145.6-180.6)	165.1 (6.2, 147.3-183.5)	n.s.
Weight (kg)	74.2 (16.9, 40.9-128.3)	85.8 (20.6, 43.4-146.9)	<0.001
Midthigh Fat (mm ²)	10874 (4804, 3266-34752)	13684 (5650, 1025-31992)	<0.001
Midthigh Lean (mm ²)	10758 (1830, 6386-18869)	12813 (2293, 8268-18868)	<0.001
Men			
n	492	169	
Age (years)	33.0 (10.5, 20.0-63.9) ***	36.4 (10.4, 20.1-59.8) ***	<0.01
Height (cm)	178.4 (6.1, 161-197) ***	175.8 (6.6, 161-200) ***	<0.001
Weight (kg)	86.6 (16.7, 55.7-153.4) ***	82.9 (16.0, 50.6-134.3)	n.s.
Midthigh Fat (mm ²)	6272 (3073, 1147-21813) ***	5654 (3457, 733-22280) ***	n.s.
Midthigh Lean (mm ²)	15097 (2588, 9002-23089) ***	15973 (2603, 10708-25304) ***	<0.001

n.s. non significant

^a All statistical tests for between-group comparisons of means have accounted for within-sibship correlations.^b Difference between black and white within each sex.

*** significantly different from women within race, p<0.001.

Table 2Mean (standard deviation, range) of femoral BMD in white and black women and men ^a.

	White	Black	p-value ^b
Women			
n	612	164	
Cortical Midshaft vBMD (mg/cm ³)	1298 (48, 1158- 1515)	1321 (54, 1074- 1463)	<0.001
Total Neck vBMD (mg/cm ³)	435 (73, 249- 701)	491 (84, 301- 710)	<0.001
Cancellous Neck vBMD (mg/cm ³)	210 (78, 23-489)	273 (99, 94-608)	<0.001
Neck aBMD (mg/cm ²)	1.02 (0.12, 0.69- 1.39)	1.11 (0.14, 0.77- 1.58)	<0.001
Men^c			
n	492	169	
Cortical Midshaft vBMD (mg/cm ³)	1272 (53, 1107- 1544) **	1321 (48, 1210- 1564)	<0.001
Total Neck vBMD (mg/cm ³)	394 (79, 188-639) ***	431 (82, 244-651) ***	<0.001
Cancellous Neck vBMD (mg/cm ³)	216 (87,19-451)	235 (90, 47-488) *	<0.05
Neck aBMD (mg/cm ²)	1.09 (0.16, 0.58-1.56) ***	1.17 (0.16, 0.81-1.65) ***	<0.001

^a All statistical tests for between-group comparisons of unadjusted means have accounted for within-sibship correlations.^b For testing the difference between black and white within each sex.^c Means of men that are significantly different from women within each race are indicated by*
p<0.05**
p<0.01***
p<0.001.

Table 3
Mean (standard deviation, range) of femoral geometry in white and black women and men.^a

	White	Black	p-value ^b
Women			
n	612	164	
Midshaft Bone Area (mm ²)	518.4 (65.7, 359.6-800.0)	543.8 (69.2, 363.9- 780.4)	<0.001
Midshaft Cortical Bone Area (mm ²)	361.7 (49.4, 235.1-529.1)	366.7 (53.0, 256.7-511.5)	n.s.
Neck Bone Area (mm ²)	692.7 (107.9, 426.8-1168.1)	684.5 (123.0, 432.7-1210.9)	n.s.
Femoral Axis Length (mm)	91.6 (5.0, 76.7-110.7)	92.0 (4.9, 81.1-106.5)	n.s.
Men ^c			
n	492	169	
Midshaft Bone Area (mm ²)	639.1 (79.1, 425.9-880.9)	668.0 (82.5, 458.7, 919.0)	<0.05
Midshaft Cortical Bone Area (mm ²)	445.8 (63.7, 237.4-648.5)	438.4 (61.4, 281.4-586.9)	<0.05
Neck Bone Area (mm ²)	941.3 (149.3, 520.3-1416.8)	926.9 (168.8, 623.4-1440.9)	n.s.
Femoral Axis Length (mm)	102.2 (5.6, 89.0-119.9)	101.4 (5.5, 83.6-117.3)	n.s.

^a All statistical tests for between-group comparisons of means have accounted for within-sibship correlations.

^b For testing the difference between black and white within each sex.

^c All means are different between men and women (p<0.001) within each sex n.s. non significant

Table 4

Correlations among bone density measurements for white women, black women, white men, black men, in order within each cell^a.

	Cancellous Neck vBMD	Total Neck vBMD	Femoral Neck aBMD
Midshaft cortical vBMD	0.14 [*] , 0.10, 0.20 [*] , 0.15	0.22 [*] , 0.19 [#] , 0.28 [*] , 0.17	0.10 [#] , 0.03, 0.11 [#] , 0.11
Cancellous neck vBMD	–	0.62 [*] , 0.67 [*] , 0.80 [*] , 0.76 [*]	0.64 [*] , 0.65 [*] , 0.72 [*] , 0.65 [*]
Total Neck vBMD	–	–	0.71 [*] , 0.62 [*] , 0.79 [*] , 0.75 [*]

after accounting for within-sib correlations

^a Correlations between bone density measures significant at

[#] p<0.05

^{*} p<0.001

Table 5

Correlations among bone geometry measurements for white women, black women, white men, black men, in order within each cell ^a

	Midshaft Cortical Bone Area	Total Neck Area	Femoral Axis Length
Total Midshaft Bone Area	0.80 [*] , 0.66 [*] 0.79 [*] , 0.64 [*]	0.56 [*] , 0.49 [*] 0.54 [*] , .48 [*]	0.50 [*] , 0.58 [*] 0.53 [*] , 0.53 [*]
Midshaft Cortical Bone Area		0.42 [*] , 0.45 [*] 0.43 [*] , 0.34 [*]	0.35 [*] , 0.32 [*] 0.42 [*] , 0.42 [*]
Total Neck Area			0.36 [*] , 0.50 [*] 0.41 [*] , 0.31 [*]

after accounting for within-sib correlations.

^aCorrelations between bone geometry measures significant at

*
p<0.001

Table 6a

Differences in bone densities between black and white (bold) within each sex controlling for age and anthropometrics as covariates in a generalized linear model. The estimated effects (regression coefficients) of race, age, height, weight, thigh fat tissue, and thigh lean tissue are presented with their statistical significance

	Women				Men			
	Midshaft cortical vBMD (mg/cm ³)	Total Neck vBMD (mg/cm ³)	Cancellous neck vBMD (mg/cm ³)	Femoral Neck aBMD (g/cm ²)	Midshaft cortical vBMD (mg/cm ³)	Total Neck vBMD (mg/cm ³)	Cancellous neck vBMD (mg/cm ³)	Femoral Neck aBMD (g/cm ²)
Black vs. White {b1}	20.2 ***	39.0 ***	43.4 ***	0.037 ***	50.4 ***	37.2 ***	21.7 **	0.087 **
Age {b2} (year)	-1.12***	-2.99***	-3.70***	-0.0036***	0.033	-3.33***	-4.28***	-0.0052***
Height {b3} (cm)	-0.131	-1.33**	-0.886	0.0032***	0.071	-1.53*	-1.49**	0.0017
Weight {b4} (Kg)	-0.430	0.418	1.159**	0.0018*	-0.272	0.202	-0.121	0.0011
Thigh Fat {b5} (mm ²)	0.0017*	0.0008	0.0001	-0.0000	0.0038*	-0.0005	0.002	-0.0000
Thigh Lean {b6} (mm ²)	0.0016	0.0087***	0.0083***	0.00002***	-0.0006	0.0081***	0.0089***	0.00002***
Intercept {b0}	1383	649.0	334.0	0.313	1318	642.9	490.0	0.520

Regression coefficients b0-b6 as described in statistical analysis

* <.05

** <.01

*** <.001

Differences in bone densities between men and women (bold) within each race controlling for age and anthropometrics as covariates in a generalized linear model. The estimated effects (regression coefficients) of race, age, height, weight, thigh fat tissue, and thigh lean tissue are presented with their statistical significance

	White				Black			
	Midshaft cortical vBMD (mg/cm ³)	Total Neck vBMD (mg/cm ³)	Cancellous neck vBMD (mg/cm ³)	Femoral Neck aBMD (g/cm ²)	Midshaft cortical vBMD (mg/cm ³)	Total Neck vBMD (mg/cm ³)	Cancellous neck vBMD (mg/cm ³)	Femoral Neck aBMD (g/cm ²)
Male vs. female {b1}	-15.2*	-85.9***	-49.6***	-0.126***	16.1	-82.4***	-59.6***	-0.077**
Age {b2} (year)	-0.183	-3.29***	-4.13***	-0.0045***	-0.417	-2.97***	-4.50***	-0.0051***
Height {b3} (cm)	0.109	-1.06**	-0.875*	0.0030***	-0.739	-2.43**	-2.05**	0.0009
Weight {b4} (Kg)	-0.398	0.275	0.479	0.0009	0.546	0.421	0.935	0.0025*
Thigh Fat {b5} (mm ²)	0.0019*	0.001	0.0014	-0.0000	0.0009	-0.0002	0.0008	-0.0000
Thigh Lean {b6} (mm ²)	0.0001	0.0076***	0.0082***	0.00002***	-0.0008	0.0087***	0.0064*	0.00002***
Intercept {b0}	1281	635.3	388.7	0.393	1428	881.1	638.3	0.793

Regression coefficients b0-b6 as described in statistical analysis

* <.05
** <.01
*** <.001

Differences in bone geometries between black and white (bold) within each sex controlling for age and anthropometrics as covariates in a generalized linear model. The estimated effects (regression coefficients) of race, age, height, weight, thigh fat tissue, and thigh lean tissue are presented with their statistical significance

	Women				Men			
	Total Midshaft Bone Area (mm ²)	Midshaft Cortical Bone Area (mm ²)	Total Femoral Neck Area (mm ²)	Femoral Axis Length mm	Total Midshaft Bone Area (mm ²)	Midshaft Cortical Bone Area (mm ²)	Total Femoral Neck Area (mm ²)	Femoral Axis Length mm
Black vs. White {b1}	0.45	-21.1	-40.9	0.246	36.5	-9.5	-4.1	0.166
Age {b2} (year)	0.878	0.536	2.31	-0.007	1.17	0.558	2.66	0.026
Height {b3} (cm)	4.90	1.99	5.77	0.459	5.16	2.36	7.82	0.438
Weight {b4} (Kg)	1.02	0.579	1.51	0.035	1.49	0.922	2.99	0.101
Thigh Fat {b5} (mm ²)	-0.0016	-0.0004	-0.0007	-0.0030	-0.0030	-0.0034	-0.0089	-0.0004
Thigh Lean {b6} (mm ²)	0.0094	0.0103	0.0071	0.0054	0.0054	0.0088	0.0040	0.0000
Intercept {b0}	-486.6	-138.5	-539.3	13.25	-512.9	-185.5	-805.0	16.51

Regression coefficients b0-b6 as described in statistical analysis

* <.05
** <.01
*** <.001

Differences in bone geometries between men and women (bold) within each race controlling for age and anthropometrics as covariates in a generalized linear model. The estimated effects (regression coefficients) of race, age, height, weight, thigh fat tissue, and thigh lean tissue are presented with their statistical significance

Table 7b

	White				Black			
	Total Midshaft Bone Area (mm ²)	Midshaft Cortical Bone Area (mm ²)	Total Femoral Neck Area (mm ²)	Femoral Axis Length mm	Total Midshaft Bone Area (mm ²)	Midshaft Cortical Bone Area (mm ²)	Total Femoral Neck Area (mm ²)	Femoral Axis Length mm
Men vs. Women{b1}	4.6	0.56	115	2.44	46.6	26.3	136	3.69
Age{b2} (year)	1.11	0.771	3.25	0.029	1.16	0.222	1.50	0.028
Height{b3} (cm)	4.90	2.39	7.28	0.476	5.22	1.92	6.74	0.395
Weight{b4} (Kg)	1.17	0.507	1.45	0.063	1.49	0.917	3.16	0.047
Thigh Fat{b5} (mm ²)	-0.0017	-0.0008	-0.0018	-0.0003	-0.0028	-0.0011	-0.0064	-0.0002
Thigh Lean{b6} (mm ²)	0.0087	0.0111	0.0096	0.0001	0.0027	0.0061	-0.0001	0.0001
Intercept{b0}	-499.2	-213.9	-838.0	8.64	-490.6	-100.1	-677.7	21.91

Regression coefficients b0-b6 as described in statistical analysis

* <.05
** <.01
*** <.001