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Difference in Bone Mass between Black and White American Children: Attributable to Body Build, Sex Hormone Levels, or Bone Turnover?

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A cross-sectional study of 232 healthy children, with about equal numbers of boys and girls and blacks and whites, aged 4 to 16 yr, was conducted to investigate the racial differences in bone mineral. Bone mineral content (BMC) by dual x-ray absorptiometry was found to be similar between blacks and whites at the spine after controlling for age and Tanner stage. However, total body BMC was higher in blacks, compared with whites of the same age and Tanner stage. Height and weight alone reduced the racial difference in BMC from 152 g to 66 g in girls and from 163 g to 105 g in boys, in whom the difference was further reduced to 66 g after accounting for lean and fat body mass and subscapular skinfold. The only significant sex hormone was androstenedione, which explained another 4–5 g of the racial difference in total body BMC for both boys and girls. Among the biochemical variables, only 25OH vitamin D reduced the residual racial difference in total body BMC to 39 g in girls, whereas serum PTH, urine free deoxypyridinoline ratio, and 1,25(OH)$_2$ vitamin D reduced the residual difference to 25 g in boys. The residual racial differences in bone mass were not statistically significant. (*J Clin Endocrinol Metab* 88: 642–649, 2003)

BLACKS HAVE HIGHER axial and appendicular bone mineral content and density than whites of comparable ages and body weights (1–3). This is associated with a lower incidence of fractures in black adults than in whites (4–6).

Several studies have indicated that the increased bone mineral density (BMD) in blacks dates from infancy (7, 8) and is present through childhood (9, 10), but the etiology of this observable difference remains unclear. Although part of the difference can be attributed to the racial differences in skeletal size (11, 12), recent investigations implicate hormonal differences (13, 14), which could have major effects on bone growth around puberty.

Skeletal maturation, measured by the presence of ossification centers, is more advanced in black infants and children than whites (15). Physical signs of puberty also appear earlier in black children than in whites, although there is no evidence that the subsequent rate of progression through the stages of puberty differs between the races (16). The variability in pubertal and skeletal maturation in determining eventual differences in adult BMD is not yet quantified.

The goal of this study was to investigate whether the average bone mass was higher in black, compared with white, children of the same age and the same stage of sexual maturation, and how much of any difference between the races could be explained by body size and composition. We hypothesized that racial difference in serum levels of sex hormones during growth could contribute to black/white differences in bone mass. Other researchers have reported racial differences in bone metabolism, suggesting that these might contribute to differences in bone mass (17). Hence, this study also investigated whether sex hormone levels and biochemical variables related to bone metabolism could explain some of the observed racial differences in bone mass between black and white children.

Subjects and Methods

Subjects were 232 healthy children, 4–16 yr old, recruited through various means, including advertising on campus, churches, and newspapers. The children had no history of bone disease or growth problems and had not taken medications known to affect bone. Their self-reported race and other demographics were recorded. Approximately equal numbers of white and black boys and girls were recruited. These children were studied on the General Clinical Research Center after informed consent was given by the children's parents or guardians with assent from children over the age of five. The study was approved by the Institutional Review Board at Indiana University.

Bone measurements

Dual-energy x-ray absorptiometry (DXA) measurements of bone mineral content (BMC) were made at the spine and total body using a DPXL machine (Lunar Corp., Madison, WI). In adults, the short-term reproducibility is 1% for total body BMC (TBMC) and 0.8% for spine BMC (SBMC) in our laboratory. Long-term quality control is assured by consistency of daily scans of standard external phantoms.

Abbreviations: 1,25D, 1,25(OH)$_2$ vitamin D; 4-A, androstenedione; 25D, 25OH vitamin D; BAP, bone-specific alkaline phosphatase; BMC, bone mineral content; BMD, bone mineral density; Ca, calcium; Cr, creatinine; CV, coefficient(s) of variation; DHEAS, dehydroepiandrosterone sulfate; DXA, dual-energy x-ray absorptiometry; E1, estrone; E2, estradiol; FdPd; free deoxypyridinoline; OC, osteocalcin; QCT, quantitative computed tomography; SAREA, spine area; SBMC, spine BMC; T, testosterone; TAREA, total body bone area; TBMC, total body BMC.

Body size and composition

Standing height was measured with a wall-mounted stadiometer that was calibrated weekly and weight with an electronic digital scale. Body composition was measured as total lean mass and total fat mass from the DXA total body scan. Anthropometric measurements obtained using steel measuring tapes and calipers included biacromial width, subscapular skinfold, and calf circumference.

Tanner staging

Sexual development of the children was measured by Tanner stage, which ranges from I (prepubertal) to V (fully mature) (18). Using a gender-specific questionnaire, the children reported their Tanner stage by comparing their own physical development to the five stages in standard sets of diagrams. A parent or the research coordinator then reviewed the results with the children to make sure they understood the questionnaire. When an individual reported discordant stages of pubic hair and breast or genital development, the higher of the two stages was used.

Sex hormones

We measured the serum levels of estrone (E1), estrone sulfate, estradiol (E2), testosterone (T), androstenedione (4-A), dehydroepiandrosterone (DHEA), dehydroepiandrosterone sulfate (DHEAS), and SHBG. E1 was measured using kits from Diagnostic Systems Laboratories, Inc. (DSL; Webster, TX). The sensitivity was 1.2 pg/ml and inter- and intraassay coefficients of variation (CV) were 11.1% and 5.6%, respectively. E2 was measured using kits from DSL. The sensitivity was 2.0 pg/ml and the inter- and intraassay CV were 8.9% and 7.5%, respectively. Estrone sulfate was measured by RIA as estrone following extraction of estrone, hydrolysis of the spent plasma, solvent extraction, and Celite chromatography as described (19). The inter- and intraassay CV were 9.7% and 3.5%. T was measured by RIA using a kit supplied by Diagnostic Products (Los Angeles, CA). The inter- and intraassay CV were 10% and 5.1%. The 4-A and DHEA were measured by RIA using kits supplied by Diagnostic Systems Laboratory. The inter- and intraassay CV were 8.8% and 8.7% for 4-A, and 9.6% and 2.8% for DHEA. DHEAS was measured by RIA using a kit supplied by Diagnostic Products. The inter- and intraassay CV were 8.6% and 6.2%. SHBG was measured by immunoradiometric assay using a kit from DSL. The inter- and intraassay CV were 4.9% and 2.0%. All CV refer to the ranges found in children.

Biochemical assays

Random nonfasting blood and urine samples were collected at each visit when subjects arrived at the General Clinical Research Center. Urine samples were collected, aliquoted, and stored at −70 C until analyzed. The serum samples were collected and processed after clotting at room temperature for 30 min. They were then aliquoted and stored at −80 C until analyzed. Calcium (Ca), creatinine (Cr), and free deoxypyridinoline (FdPd) were measured in all urine samples. Serum samples were analyzed for bone-specific alkaline phosphatase (BAP), osteocalcin (OC), intact 1–84 PTH, 25OH vitamin D (25D), and $1,25(OH)_2$ vitamin D (1,25D).

Urine Ca and Cr were analyzed on the Cobas Mira (Roche Diagnostics, Indianapolis, IN). All CV reported for biochemical assays are interassay CV. Urine Ca (CV, 3.7% at 12.2 mg/dl) was analyzed using the Arsenazo III method. Urine Cr (CV, 3.3% at 226.6 mg/dl) was analyzed using the Jaffe Kinetic method. FdPd (CV, 10.9% at 17.5 nmol/liter) was assayed after 1:20 dilution using an ELISA assay supplied by Quidel (formerly Metra Biosystems, Mountain View, CA). Urine Ca and FdPd were divided by the corresponding Cr to yield Ca/Cr ratio and FdPd/Cr ratio.

OC was assayed by RIA (CV, 8.9% at 26.9 ng/ml) using a rabbit polyclonal antiserum raised against bovine OC. Intact PTH was assayed (CV, 9.7% at 17.5 pg/ml) by an immunoradiometric assay (Nichols Institute, San Juan Capistrano, CA). BAP (CV, 7.3% at 12.4 ng/ml) was assayed by an ELISA assay (Quidel).

The 25D (CV, 11.4% at 11.4 ng/ml) was assayed using the vitamin D-binding protein after extraction and purification on HPLC. Serum 1,25 D (CV, 10.6% at 41.6 pg/ml) was assayed using the vitamin D receptor protein purified from calf thymus after extraction and purification on HPLC.

Statistical methods

We chose to measure BMC on each subject using TBMC and at SBMC for two reasons. First, these two sites have well-defined anatomical boundaries, so the analysis of scans does not require the operator to decide on comparable regions of interest, a difficult task when the areas of bone scans vary greatly among children of different ages. Second, we chose BMC over BMD (BMC divided by area) because a change in BMC reflects simply the change in bone mass, whereas a change in BMD is affected by the growth in both bone mass and bone area. If the growth spurt of the bone area is asynchronous with the growth spurt of bone mineral, the change in BMD might be difficult to interpret. Using BMC circumvents the problem of choosing an appropriate method to normalize the bone mass for different sizes (20–22). However, we also investigated the growth in skeletal size by comparing the total body bone area (TAREA) and spine area (SAREA) between black and white children.

Descriptive statistics for different Tanner stages were calculated for the four groups of black and white boys and girls. Tanner stages II and III were combined, as were Tanner stages IV and V, to provide adequate sample sizes for reliable estimates of means and SDs for the various measurements. Multiple regression analysis was used to test for differences in all measurements between races and between sexes while controlling for age and Tanner stage. The primary interest was in estimating and testing the black/white difference separately for TBMC and SBMC while controlling for sex, age, and Tanner stage. If there were significant interactions between any two of the four factors, separate analyses were conducted for subgroups of children. When racial differences were found, height and weight were added to the model to test whether the racial differences could be explained by body size. To explain any residual racial difference in bone mass, three sets of possible factors were added in stepwise fashion. The first set included anthropometric measurements and body composition variables (total lean and fat mass) from DXA. The second set included serum levels of sex hormones, and the third set consisted of biochemical variables. After each set of variables was added to the model, backward elimination was performed to remove the nonsignificant predictors from that set, and the difference in bone mass between black and white children was estimated. Because separate models for boys and girls gave significantly better fit once the anthropometric variables were added, the final results were reported for boys and girls separately.

Results

The numbers of subjects were approximately equal in the four subgroups of black and white boys and girls (Table 1). About 40% of the children were in Tanner stage I, 35% in Tanner stages II or III, and 25% in Tanner stages IV or V. The age distributions by Tanner stage are also displayed within each of the four subgroups. Overall, black children were 0.6 yr younger than white children of the same sex and at the same Tanner stage, and girls were 0.7 yr younger than boys of the same race and the same Tanner stage ($P < 0.01$ for both comparisons).

Table 2 consists of three parts. Parts A and B contain the descriptive statistics for all the measurements for boys and girls, respectively; the means and SDs are presented by race and Tanner stage. The mean TBMC and SBMC are also plotted in Fig. 1. Cross-sectionally, both BMC measures appeared to increase approximately linearly over the five Tanner stages in each group of black and white boys and girls. As expected, the mean bone areas and anthropometric measurements also increased with Tanner stage within each subgroup. Similar trends occurred in sex hormones and biochemical variables, except that serum SHBG and urine

TABLE 1. Sex, race, Tanner stage, and age distributions of the study sample

	Age Distribution (yr)											
	Male						Female					
	Black			White			Black			White		
	n	Mean ± SD	Range	n	Mean ± SD	Range	n	Mean ± SD	Range	n	Mean ± SD[a]	Range
Total	57	9.8 ± 2.7	(4–14)	58	10.0 ± 2.6	(5–14)	58	9.9 ± 2.9	(4–14)	59	9.6 ± 2.6	(5–14)
Tanner stage												
I	20	7.2 ± 2.1	(4–10)	30	8.1 ± 2.0	(5–11)	19	6.6 ± 1.6	(4–10)	26	7.5 ± 2.1	(5–12)
II	16	10.1 ± 1.7	(7–13)	14	11.1 ± 1.3	(8–13)	8	9.8 ± 1.0	(8–11)	9	10.0 ± 1.4	(7–11)
III	11	11.8 ± 1.1	(10–14)	4	12.3 ± 1.0	(11–13)	8	11.1 ± 1.1	(10–13)	10	10.8 ± 1.1	(8–12)
IV	7	12.7 ± 1.1	(11–14)	8	13.0 ± 0.5	(12–14)	8	12.1 ± 1.8	(9–14)	6	12.0 ± 0.6	(11–13)
V	3	12.3 ± 1.5	(11–14)	2	14.0 ± 0.0	(14–14)	15	12.5 ± 1.7	(9–14)	8	12.9 ± 1.1	(11–14)

[a] Mean age is significantly different between races ($P < 0.05$), controlling for Tanner stage and sex, and mean age is significantly different between sexes ($P < 0.01$), controlling for Tanner stage and race.

TABLE 2A. Means and SD values of the bone mass and area measurements, anthropometrics, sex hormones, and biochemical bone turnover markers by race and Tanner stage for boys

	Tanner stage I		Tanner stage II or III		Tanner stage IV or V	
	Black (n = 20)	White (n = 30)	Black (n = 27)	White (n = 18)	Black (n = 10)	White (n = 10)
Bone measurements						
TBMC (g)	1078 ± 373	1033 ± 284	1618 ± 375	1621 ± 333	2261 ± 344	2083 ± 291
TAREA (cm^2)	1217 ± 317	1209 ± 263	1672 ± 295	1686 ± 256	2151 ± 221	2073 ± 219
SBMC (g)	16 ± 6	17 ± 4	25 ± 6	25 ± 5	35 ± 6	36 ± 6
SAREA (cm^2)	22 ± 5	23 ± 4	30 ± 5	30 ± 4	37 ± 5	38 ± 4
Anthropometrics						
Height (cm)	127 ± 13	131 ± 13	148 ± 12	150 ± 8	160 ± 20	166 ± 8
Weight (kg)	32 ± 12	31 ± 8	46 ± 15	48 ± 11	64 ± 13	55 ± 7
Subscapular skinfold (mm)	10 ± 8	8 ± 6	11 ± 8	14 ± 9	19 ± 9	9 ± 3
Calf circumference (cm)	27 ± 4	26 ± 3	31 ± 4	31 ± 3	36 ± 4	33 ± 2
Biacromial width (cm)	30 ± 3	29 ± 3	34 ± 3	34 ± 2	38 ± 2	37 ± 2
Total lean (kg)	23.0 ± 5.8	23.0 ± 5.1	32.7 ± 7.0	32.6 ± 5.2	44.6 ± 6.4	44.5 ± 5.8
Total fat (kg)	6.8 ± 7.0	4.8 ± 3.6	10.0 ± 10.0	12.1 ± 7.8	15.8 ± 9.0	7.2 ± 3.7
Sex hormones						
E1 sulfate (pmol/liter)	406 ± 360	308 ± 196	382 ± 261	574 ± 413	731 ± 348	719 ± 382
E1 (pmol/liter)	27 ± 33	15 ± 14	30 ± 24	31 ± 24	67 ± 34	46 ± 29
E2 (pmol/liter)	15 ± 13	14 ± 10	24 ± 14	29 ± 23	66 ± 35	43 ± 14
Bioavailable E2 (pmol/liter)	9 ± 7	9 ± 7	15 ± 10	20 ± 19	48 ± 25	31 ± 15
Testosterone (nmol/liter)	0.09 ± 0.1	0.14 ± 0.2	1.8 ± 3.4	3.1 ± 4.5	9.5 ± 4.1	8.4 ± 5.3
Bioavailable T (nmol/liter)	0.002	0.004	0.05 ± 0.09	0.09 ± 0.11	0.4 ± 0.2	0.3 ± 0.2
Androstenedione (nmol/liter)	0.8 ± 0.8	0.8 ± 0.8	1.3 ± 1.0	1.5 ± 1.0	2.8 ± 1.3	2.4 ± 0.4
DHEA (nmol/liter)	4.9 ± 5.8	4.4 ± 4.2	5.9 ± 4.5	6.3 ± 4.5	9.4 ± 3.7	7.1 ± 2.3
DHEAS (μmol/liter)	1.7 ± 1.5	1.6 ± 1.5	2.6 ± 2.6	2.7 ± 1.8	4.8 ± 2.2	4.7 ± 1.9
SHBG (nmol/liter)	71 ± 43	76 ± 29	70 ± 33	59 ± 34	37 ± 15	43 ± 18
Biochemical variables						
PTH (pmol/liter)	5.6 ± 2.7	5.8 ± 2.8	6.3 ± 3.5	5.3 ± 1.7	7.1 ± 2.1	10.4 ± 3.6
BAP (U/liter)	115 ± 38	95 ± 22	115 ± 26	114 ± 35	149 ± 49	121 ± 37
OC (μg/liter)	33 ± 21	32 ± 18	35 ± 25	36 ± 21	38 ± 13	50 ± 31
25D (nmol/liter)	63 ± 37	81 ± 41	56 ± 31	74 ± 40	57 ± 31	63 ± 18
1,25D (pmol/liter)	96 ± 28	79 ± 31	97 ± 37	74 ± 40	116 ± 61	93 ± 30
Ca/Cr	0.14 ± 0.11	0.14 ± 0.12	0.06 ± 0.05	0.16 ± 0.09	0.05 ± 0.03	0.10 ± 0.07
FdPd/Cr	1.7 ± 0.6	2.1 ± 0.4	2.0 ± 0.6	2.0 ± 0.7	2.0 ± 0.9	2.3 ± 0.7

Ca/Cr tended to decrease with Tanner stage. All of the differences across Tanner stages were significant except for OC. After further adjustments by age, however, some of the sex hormones and biochemical variables were no longer different across Tanner stages (Table 2C).

Table 2C presents the results of testing for differences between blacks and whites and between boys and girls. The tests for racial differences used the combined data from Parts A and B of Table 2 and controlling for age, Tanner stage (as five categories), and sex. Total BMC and area were significantly higher in blacks than in whites, but no significant racial differences were found in SBMC or area. Blacks also had higher means in anthropometric measurements, except for height and total fat. Most of the sex hormone levels were not significantly different between the races, except that 4-A and DHEA were slightly higher in blacks. Serum 25D, urine Ca/Cr, and urine FdPd/Cr were lower, but serum 1,25D was higher in black children.

Tests for sex differences in Table 2C were based on comparisons of means of boys in Table 2A with corresponding means of girls in Table 2B (with black and white children combined), and controlling for age, Tanner stage, and race.

TABLE 2B. Means and SD values of the bone mass and area measurements, anthropometrics, sex hormones, and biochemical bone turnover markers by race and Tanner stage for girls

	Tanner stage I		Tanner stage II or III		Tanner stage IV or V	
	Black (n = 19)	White (n = 26)	Black (n = 16)	White (n = 19)	Black (n = 23)	White (n = 14)
Bone						
TBMC (g)	877 ± 218	864 ± 243	1559 ± 518	1364 ± 310	2134 ± 409	2010 ± 390
TAREA (cm^2)	1055 ± 206	1045 ± 225	1584 ± 387	1508 ± 237	1978 ± 232	1903 ± 193
SBMC (g)	15 ± 4	15 ± 4	26 ± 10	23 ± 6	39 ± 10	39 ± 11
SAREA (cm^2)	20 ± 4	21 ± 4	29 ± 7	27 ± 4	35 ± 5	36 ± 4
Anthropometrics						
Height (cm)	124 ± 10	125 ± 12	146 ± 11	145 ± 8	159 ± 8	159 ± 5
Weight (kg)	26 ± 6	25 ± 6	43 ± 12	41 ± 8	58 ± 11	54 ± 11
Subscapular skinfold (mm)	8 ± 5	5 ± 1	12 ± 7	12 ± 8	16 ± 8	11 ± 6
Calf circumference (cm)	25 ± 2	25 ± 2	30 ± 4	30 ± 3	33 ± 3	33 ± 3
Biacromial width (cm)	28 ± 2	28 ± 3	34 ± 2	33 ± 2	37 ± 2	36 ± 2
Total lean (kg)	19.6 ± 4.0	19.3 ± 4.0	30.3 ± 6.5	28.6 ± 5.3	38.0 ± 5.1	36.7 ± 4.0
Total fat (kg)	4.4 ± 3.14	3.6 ± 2.3	10.1 ± 6.7	10.0 ± 5.1	16.5 ± 7.9	14.5 ± 8.3
Sex hormones						
E1 sulfate (pmol/liter)	473 ± 386	328 ± 163	1034 ± 861	776 ± 551	1426 ± 1302	1329 ± 775
E1 (pmol/liter)	31 ± 29	19 ± 19	70 ± 65	78 ± 56	99 ± 55	94 ± 51
E2 (pmol/liter)	19 ± 14	12 ± 9	71 ± 89	71 ± 66	133 ± 75	88 ± 46
Bioavailable E2 (pmol/liter)	12 ± 10	7 ± 4	50 ± 66	48 ± 44	91 ± 49	67 ± 40
Testosterone (nmol/liter)	0.12 ± 0.20	0.05 ± 0.10	0.3 ± 0.3	0.3 ± 0.3	0.9 ± 0.6	0.5 ± 0.4
Bioavailable T (nmol/liter)	0.004 ± 0.007	0.001 ± 0.001	0.01 ± 0.01	0.01 ± 0.01	0.03 ± 0.03	0.02 ± 0.02
Androstenedione (nmol/liter)	0.7 ± 0.5	0.8 ± 0.7	2.0 ± 2.2	1.9 ± 1.0	3.6 ± 1.8	2.5 ± 1.2
DHEA (nmol/liter)	3.8 ± 2.5	3.3 ± 2.4	6.5 ± 5.4	7.1 ± 3.9	10.4 ± 4.6	6.9 ± 4.0
DHEAS (μmol/liter)	1.2 ± 0.9	1.0 ± 0.7	2.4 ± 1.4	3.0 ± 2.1	2.7 ± 1.4	3.4 ± 2.0
SHBG (nmol/liter)	60 ± 28	80 ± 28	51 ± 20	50 ± 21	45 ± 24	38 ± 19
Biochemical variables						
PTH (pmol/liter)	6.5 ± 3.0	5.9 ± 2.5	6.8 ± 2.2	6.2 ± 2.5	7.9 ± 4.6	8.5 ± 3.9
BAP (U/liter)	106 ± 46	84 ± 23	113 ± 41	113 ± 43	89 ± 65	79 ± 46
OC (μg/liter)	26 ± 17	34 ± 18	52 ± 40	43 ± 26	32 ± 31	31 ± 23
25D (nmol/liter)	55 ± 24	81 ± 29	40 ± 28	85 ± 42	40 ± 28	51 ± 37
1,25D (pmol/liter)	85 ± 26	86 ± 33	102 ± 34	99 ± 30	106 ± 40	74 ± 28
Ca/Crr	0.10 ± 0.09	0.12 ± 0.10	0.08 ± 0.06	0.17 ± 0.11	0.05 ± 0.03	0.11 ± 0.10
FdPd/Cr	1.9 ± 0.6	2.3 ± 0.9	2.0 ± 0.6	1.8 ± 0.6	1.5 ± 0.6	1.4 ± 0.5

Boys were significantly higher in total body BMC, areas of the total body and spine, and most anthropometrics. The T and E1 levels differed between sexes as expected. DHEAS was slightly higher in boys but 4-A was slightly higher in girls. DHEA and SHBG did not differ between sexes. Of all the biochemical variables, only BAP was higher in boys.

Table 3 presents the models for predicting total body BMC and area, first using sex, age, Tanner stage, and race (model 1). The model shows both BMC and area of the total body are higher in blacks than in white, in boys than in girls and that they increase with age and Tanner stage. Compared with white children of the same sex, age, and Tanner stage, the estimated TBMC of black children was higher by 138 g (10%, $P < 0.0001$), and their total body area was greater by 82 cm^2 (5.3%, $P = 0.0001$). To investigate how much of the racial difference could be explained by body size, height and weight were added to the model (model 2). After adjustments for height and weight, the mean TBMC remained higher in black children, but the difference was reduced to 80 g (5.5%, $P = 0.0004$). The total bone area was still greater in blacks by 40 cm^2 (2.6%, $P = 0.004$). These six demographic and developmental characteristics accounted for 92% of the variation in total body BMC and 95% of the variation in total body area, with no significant interactions between any two variables. These findings on both TBMC and area were very consistent across boys and girls when separate models were fitted to the two groups (results not shown).

Table 4 shows similar models for predicting SBMC and area with (model 4) and without (model 3) adjusting for height and weight. Both SBMC and area increase with age and Tanner stage. After adjusting for age, sex, and Tanner stage in model 3, racial differences (1.2 g of SBMC and 0.5 cm^2 of total SAREA higher in black children) were not statistically significant. Height and weight accounted for most of the small differences in model 4, with over 85% of the total variance explained by the six predictors. Findings for SBMC and area were also consistent across boys and girls when separate models were fitted to the two groups (results not shown).

To investigate whether the residual racial difference in TBMC could be explained by other biological differences between black and white children, we extended model 2 for predicting TBMC in Table 3 by sequentially adding three sets of predictor variables: anthropometrics, sex hormones, and biochemical measurements related to bone metabolism. Once the anthropometric variables were entered, the age-by-sex interaction became significant. Separate models for boys and girls resulted in significantly better fits for both groups, so all subsequently models were fitted separately for boys and girls. Table 5 shows the model fit and the residual racial difference in TBMC with the addition of each set of explanatory variables.

For boys, the addition of subscapular skinfold, together with lean and fat body mass, improved the model fit sub-

TABLE 2C. Test results of mean differences between blacks and whites (boys and girls combined) and mean differences between boys and girls (blacks and whites combined)

	Tests of effects of Tanner stage[a]	Tests of race differences[b]	Tests of sex differences[c]
Bone			
TBMC	***	***B	**M
TAREA	***	***B	***M
SBMC	***	ns	ns
SAREA	***	ns	**M
Anthropometrics			
Height	***	ns	ns
Weight	***	**B	**M
Subscapular skinfold	*	*B	ns
Calf circumference	***	*B	**M
Biacromial width	***	***B	***M
Total lean	***	**B	***M
Total fat	***	ns	ns
Sex hormones			
E1 sulfate	*	ns	***F
E1	ns	ns	***F
E2	ns	ns	*F
Bioavailable E2	ns	ns	*F
Testosterone	***	ns	***M
Bioavailable T	***	ns	***M
Androstenedione	***	*B	**F
DHEA	ns	*B	ns
DHEAS	ns	ns	*M
SHBG	ns	ns	ns
Biochemical variables			
PTH	*	ns	ns
BAP	**	ns	**M
OC	ns	ns	ns
25D	ns	***W	ns
1,25D	*	**B	ns
Ca/Cr	ns	***W	ns
FdPd/Cr	**	**W	ns

Only significant results ($P < 0.05$) are shown in the table. B, Higher mean in blacks; W, higher mean in whites; F, higher mean in girls; M, higher mean in boys; ns, not significant.

[a] Tests of overall means across Tanner stages with boys and girls (Tables 2A and 2B) combined, controlling for age, race, and sex.

[b] Tests of overall means between blacks and whites with boys and girls (Tables 2A and 2B) combined, controlling for age, Tanner stage, and sex.

[c] Tests of overall means between boys (Table 2A) and girls (Table 2B) with blacks and whites combined, controlling for age, Tanner stage, and race.

* Significantly different at $P < 0.05$.

** Significantly different at $P < 0.01$.

*** Significantly different at $P < 0.001$.

stantially, decreasing the racial difference in TBMC from 105 g to 65 g, which was still significant ($P < 0.01$). Although these variables improved the fit of the model in girls, they did not explain any of the residual racial difference in TBMC, which remained at 66 g ($P < 0.01$).

To investigate whether sex hormone levels could explain the residual racial difference, the sex hormones were added to the separate models for boys and girls. Among the boys, only 4-A showed a significant positive correlation with TBMC. Despite minimal improvement in model fit, the addition of 4-A reduced the estimated racial difference from 65 g to 61 g. In girls, both 4-A and E2 were positive predictors of TBMC ($P < 0.05$), reducing the estimated racial difference from 66 g to 61 g. With the subsequent addition of biochemical variables, however, 4-A remained the only significant predictor in both boys and girls.

When the biochemical variables were added to the model in boys, PTH, free FdPd/Cr, and 1,25D together reduced the boys' racial difference in mean TBMC from 61 g to 25 g (still higher in blacks), which was not statistically significant ($P > 0.32$). Among the girls, 25D was the only biochemical variable that marginally improved the fit of the model. Its inclusion reduced the estimated racial difference from 61 g to 39 g, again no longer statistically significant ($P > 0.14$).

Discussion

In this study, we examined the difference in bone mass between black and white children. For children at the same age and Tanner stage, we found no difference in BMC or area at the lumbar spine between blacks and whites. The lack of black/white difference in BMC agrees with Wang *et al.* (23), although they found BMD to be higher in blacks than a combined group of whites, Asians, and Hispanics in subsequent follow-up (24), but differs from at least two other studies on children. Bell *et al.* (10) found that black children between the ages of 7 and 12 yr have higher spine BMD after adjusting for sex, age, and weight. Because black children are usually more sexually advanced than white children of the same age (as reflected by the lower ages for black children, compared with whites in the same Tanner stage in Table 1), not controlling for Tanner stage in our data also resulted in

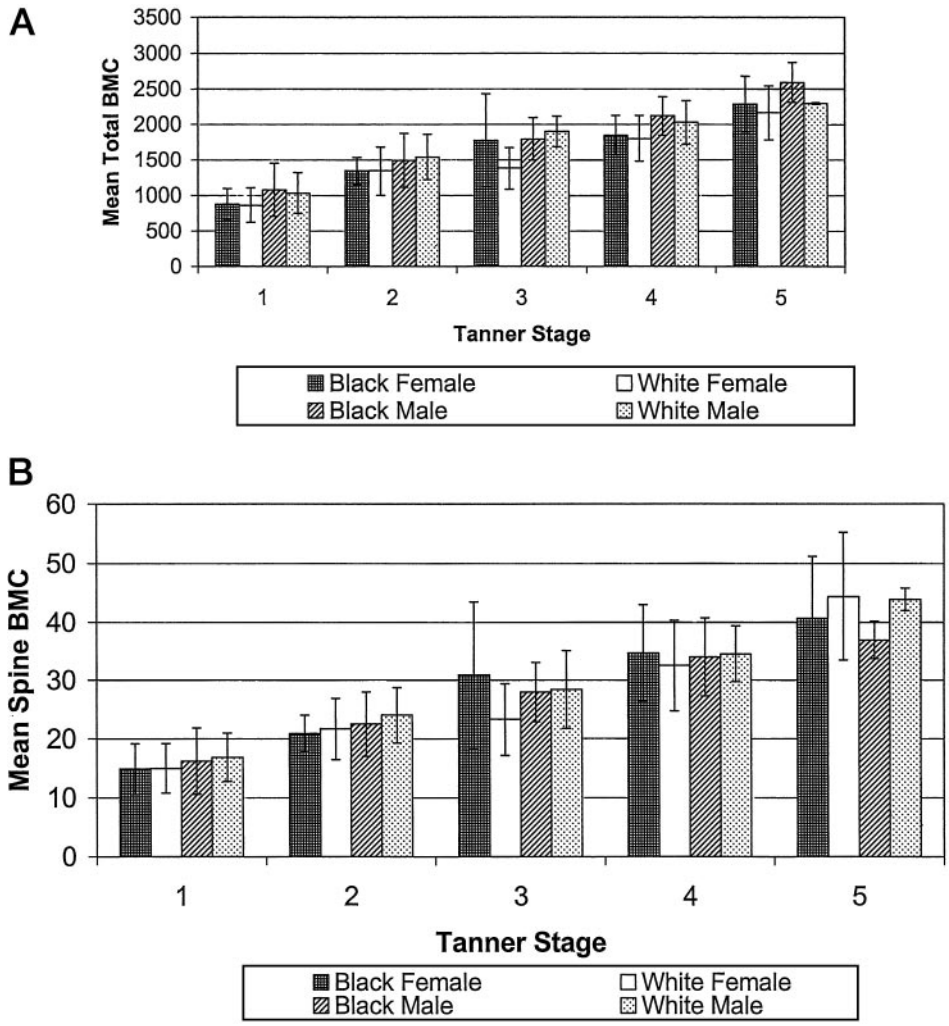

FIG. 1. Mean TBMC (A) and mean SBMC (B) plotted against Tanner stages for black and white boys and girls.

TABLE 3. Parameter estimates for the prediction of total BMC and area by demographics and Tanner stage, with and without adjusting for body size

	Model 1 Unadjusted for height and weight		Model 2 Adjusted for height and weight	
	Total BMC (g)	Total area (cm^2)	Total BMC (g)	Total area (cm^2)
Intercept	−122.2	268.7	−1049.9	−884.6
Black *vs.* white	138.2[c]	82.1[c]	80.3[c]	39.9[b]
Male *vs.* female	111.2[c]	108.1[c]	34.7	50.3[c]
Age (yr)	130.8[c]	104.4[c]	36.0[c]	15.9[c]
Tanner stage (*vs.* stage I)				
II	88.2	98.8[a]	−22.6	7.0
III	180.4[b]	157.2[b]	23.7	28.5
IV	315.2[c]	273.1[c]	103.6[a]	91.1[b]
V	641.4[c]	408.8[c]	240.3[c]	96.5[b]
Height (cm)			9.7[c]	12.4[c]
Weight (kg)			16.1[c]	9.9[c]
R^2	82.7	83.6	92.3	95.0

[a] $P < 0.05$; [b] $P < 0.01$; [c] $P < 0.001$.

TABLE 4. Parameter estimates for the prediction of spine BMC and area by demographics and Tanner stage, with and without adjusting for body size

	Model 3 Unadjusted for height and weight		Model 4 Adjusted for height and weight	
	Spine BMC (g)	Spine area (cm^2)	Spine BMC (g)	Spine area (cm^2)
Intercept	−1.4	8.3	−17.3	−12.1
Black *vs.* white	1.2	0.5	0.3	−0.1
Male *vs.* female	−0.4	1.4[b]	−1.5[a]	0.6
Age (yr)	2.3[c]	1.7[c]	0.8[b]	0.3[a]
Tanner stage (*vs.* stage I)				
II	0.1	0.7	−1.6	−0.6
III	2.3	2.4[b]	−0.1	0.6
IV	6.6[c]	4.5[c]	3.3[a]	1.9[a]
V	13.4[c]	6.6[c]	7.3[c]	2.4[b]
Height (cm)			0.2[c]	0.2[c]
Weight (kg)			0.2[c]	0.1[c]
R^2	78.6	79.7	85.3	89.3

[a] $P < 0.05$; [b] $P < 0.01$; [c] $P < 0.001$.

an apparently higher spine BMD in blacks. In another study, Gilsanz *et al.* (9, 25) showed a sizable divergence in trabecular bone density by quantitative computed tomography (QCT) as black and white children reached Tanner stages IV and V. QCT measures only trabecular bone, but anteroposterior DXA scans in our study included the cortical envelope and posterior processes of the spine. Because we did not show a

TABLE 5. Estimated mean difference in TBMC between black and white children while controlling for various sets of factors[a]

Controlling for:	R^2	Estimated difference in TBMC (g) (black *vs.* white)
Boys		
Age, sex, Tanner stage	85.2	162.9**
Height, weight	92.9	105.3**
Lean body mass, fat body mass, subscapular skinfold	95.5	64.7*
Androstenedione	95.7	60.7*
PTH, FdPd/Cr, 1,25D	96.4	24.5
Girls		
Age, sex, Tanner stage	81.7	151.8**
Height, weight	93.1	66.0*
Lean body mass, fat body mass, subscapular skinfold	96.6	66.2**
Androstenedione, estradiol	96.9	60.8*
25D	97.0	38.7

[a] Based on only those subjects with complete data in the final model.

* $P < 0.05$.

** $P < 0.01$.

racial difference in spine BMC, the racial difference may be primarily in trabecular rather than cortical bone. This speculation is consistent with data from adult studies. In normal women aged 55–75 yr, the percent difference between blacks and whites is much larger in QCT than in BMD measurements of the spine (26). The racial difference in adult spine BMD, also reported by others (27), could be due to a longer period of postpubertal growth in blacks because they reach Tanner stage V at an earlier age.

The higher TBMC in our black children appears to be in all Tanner stages, which means that it exists already in prepubertal children as previously reported (7–10). Nevertheless, despite the lack of power to detect a significant interaction between race and Tanner stage, the raw data in Fig. 1 suggest that the racial difference might become more pronounced when girls reach Tanner stage III and boys reach Tanner stage IV. This pattern would be similar to that observed in trabecular density of the spine (9, 25).

The racial difference in TBMC could be partially explained by the larger body size (weight more than height) of black children. Age, sex, Tanner stage, and body size together explain over 92% of the variation of total body BMC and area (>85% for spine) in children between the ages of 4 and 16 yr. Each factor tends to have similar effects on BMC and its corresponding area. Thus, our findings agree with most studies that conclude that racial/ethnic difference may be largely accounted for by differences in bone size (14, 28).

The addition of other anthropometric measurements besides height and weight did not further explain the racial difference in TBMC in girls. In contrast, inclusion of height and weight alone explained less of the racial difference in boys. The further inclusion of total lean and fat body mass and sc fat was necessary to reduce the boys' racial difference in TBMC to a level similar to that observed in girls.

Although we had hypothesized that differences in sex hormone levels might have led to higher bone mass in blacks, the data in Table 2 did not show any systematic differences in hormone levels between blacks and whites in the same Tanner stages. Furthermore, only 4-A appeared to have a consistent, albeit small, effect on TBMC after adjusting for age, Tanner stage, and body size and composition, explaining a few grams of the residual racial difference in TBMC in both sexes. However, this does not mean that sex hormone levels are unimportant in determining bone mass. Most of the effects of sex hormones on TBMC could have been mediated through their effects on sexual maturation (Tanner stage) and body size (height, weight, lean mass), which explain the majority of the variation in TBMC. It has been hypothesized that some of the racial difference in BMD is related to differences in serum E1 (13). Estrogens may mediate their effect on BMD by increasing GH secretion, leading to GH-induced increases in bone mass (14). However, we did not find significant differences in E1 or E2 levels between whites and blacks at the same Tanner stage. We did not examine direct or indirect measures of GH secretion.

We (29) previously reported that lower bone turnover in black children might explain their higher bone mass. This more carefully designed study shows that there might be a differential effect between boys and girls. Consistent with previous studies (17), we found racial differences in 25D, 1,25D, and Ca/Cr. Additionally, we found FdPd/Cr to be higher in whites. In boys, adding 1,25D, PTH, and FdPd/Cr to the model reduced the residual racial difference in TBMC by 60%, making it statistically nonsignificant. In girls, however, only 25D entered the model, reducing the residual racial difference by 36%. Therefore biochemical variables related to bone metabolism appear to account for a nontrivial part of the racial difference in TBMC despite the large variations in their measurements caused by both biological fluctuations and assay result variability.

In summary, black children on average have higher total body BMC than white children. Over half of this difference can be explained by differences in the body size and composition of the two races. A substantial portion of the residual differences can be explained by bone metabolism and, to a much smaller extent, by sex hormone levels, leaving only 2% of the difference between the races unexplained.

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