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Differences in age-related bone mass of proximal femur between Chinese women and different ethnic women in the United States

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Abstract Substantial racial differences in bone mass and bone loss rate have been reported, but the extent of the difference between native Chinese women and women of different races in the United States is not clear. We used a DXA bone densitometer to measure bone mineral density (BMD), bone mineral content (BMC), bone area (BA), and volumetric BMD (vBMD) in different regions of the proximal femur in 3614 Chinese women aged 20 years and older. Regression models were chosen to best fit the changes of these parameters with increasing age. The values in their fitted curves were determined by the Cartesian coordinate numeration system. Subsequently, we compared these fitted curves to full-matched data of non-Hispanic black, non-Hispanic white, and Mexican American women reported by the third National Health and Nutrition Examination Survey (NHANES III). We found that all fitted curves of bone mass of non-Hispanic black women were significantly higher than those of Chinese, non-Hispanic white, and Mexican American women (P = 0.000). The BMD and BMC fitted curves in various regions of the hip for non-Hispanic blacks were 22%–28% and 26%–43% higher than those for Chinese women, 8.3%–13% and 7.9%–9.5% higher than those for non-Hispanic whites, and 8.8%–10% and 13%–19% higher than those for Mexican Americans, respectively. However, when the expression of difference was transformed from BMD to vBMD at the femoral neck, the difference between Chinese and non-Hispanic black women was reduced from 22% to 18% and that between Chinese and non-Hispanic white women from 7.4% to 0.8%, but the difference increased from 3.2% to 9.6% between non-Hispanic white and Mexican American women and from 13% to 17% between non-Hispanic white and non-Hispanic black women. By the age of 80 years, the accumulated bone loss rate in various regions of the proximal femur for Chinese, Mexican Americans, non-Hispanic whites, and non-Hispanic blacks were –38.9% ± 1.8%, –34.4% ± 3.1%, –27.8% ± 5.9%, and –28.4% ± 4.8%, respectively. In conclusion, bone mass in the proximal femur of native Chinese women is significantly lower, and the bone loss rate greater, than those of non-Asian women in the United States. At the femoral neck, the vBMD of Chinese women is similar to that of non-Hispanic white women.

Key words bone mineral content · bone mineral density · bone loss rate · difference · race · women

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Introduction

Hip fragility fracture is the most serious complication caused by osteoporosis and has become a major public health problem [1–8]. Low bone mineral density (BMD) and/or osteoporosis is a common disease in middle-aged and aged women, and is the most direct risk factor that results in hip fragility fracture. BMD measurement is an effective method to predict the risk of fragility fracture [9,10]. BMD is related to many factors, such as heredity, race, region, environment, nutrition, and lifestyle [11–14]. There is a significant difference in BMD in sex- and age-matched reference populations from different races or from different regions [15–21]. For example, BMD values in white women are exceeded by those in black women, values in Asian women by those in white women, and values in women from middle and southern Mexico by those from northern Mexico [16–19]. The likelihood of developing osteoporosis in an individual woman is determined by the peak bone mass and bone loss rate as the result of menopause and aging. In general, bone mineral content (BMC) decreases about 15% every decade in postmenopausal women [1]. Over a lifetime, bone loss could be as much as 30%–40% of peak bone mass [22]. In aged women without hip fracture, BMD decreases about 0.51% each year [23–28]. To understand the differences in age-related BMD, volumetric BMD (vBMD), BMC, bone

area (BA), and bone loss rate of the proximal femur between native Chinese women and women of different races in the United States, we measured these factors at different regions of the proximal femur in 3614 Chinese women, aged 20 years and older, using dual-energy X-ray absorptiometry (DXA) bone densitometer. We analyzed and compared them with the data of non-Hispanic black, non-Hispanic white, and Mexican American women available from the third National Health and Nutrition Examination Survey (NHANES III) [29].

Subjects and methods

Subjects

A total of 3614 women, aged 20 years and older, who were residents of Changsha, capital city of Hunan Province in Central South China and its surrounding area, were randomly selected between October 1996 and April 2006. All these women were recruited by public health organizations (health stations/clinics) responsible for the health of local residents. All subjects were screened with a detailed questionnaire and history and physical examinations. According to the study protocol of QDR reference database [30], subjects were excluded from the study if they had conditions affecting bone metabolism, such as diseases of kidney, liver, parathyroid and thyroid, diabetes mellitus, oligomenorrhea or menopause before age 40, hyperprolactinemia, oophectomy, rheumatoid arthritis, ankylosing sondylitis, malabsorption syndromes, malignant tumors, hematological diseases, and previous pathological fractures. Also excluded were subjects who had been receiving glucocorticoids, estrogens, thyroid hormone, fluoride, bisphosphonate, calcitonin, thiazide diuretics, barbiturates, antiseizure medications, vitamin D, or calcium-containing drugs. Informed consent was obtained from all participating volunteers.

Parametric measurements

The parameters, including bone area (BA, in cm^2), bone mineral content (BMC, in g), and bone mineral density (BMD, in g/cm^2), were measured by DXA (QDR-4500 A or Delphi A; Hologic, Bedford, MA, USA), using a fan-beam bone densitometer, according to the manufacturer's recommended standard analysis procedures for the left proximal femur, including the femoral neck, trochanter, intertrochanter, and total femur. The in vivo precision errors for DXA (Delphi A) on two repeated BA, BMC, and BMD measurements for 33 subjects (mean age, 54.2 ± 11.7 years; range, 36–74 years), by the root-mean-square coefficient of variation (RMSCV) [31] were, for the femoral neck, 1.37% for BA, 2.11% for BMC, and 1.88% for BMD; for the trochanter, 3.69% for BA, 3.79% for BMC, and 0.82% for BMD; for the intertrochanter, 3.33% for BA, 3.55% for BMC, and 1.27% for BMD; and for total femur, 1.76% for BA, 2.30% for BMC, and 0.88% for BMD. The BA, BMC, and BMD data for non-Hispanic black, non-Hispanic white, and Mexican American women were obtained from a previous report [29] in which the BA, BMC, and BMD at the proximal femur were measured with the Hologic QDR 1000 bone densitometer. We also estimated volumetric BMD (vBMD, in g/cm^3) from these data as previously described [32], using the following formula: femoral neck vBMD = BMC/A^2, where A is the projected BA.

Statistical analysis

All calculations were performed using SPSS V11.0 for Windows software (SPSS, Chicago, IL, USA). The mean values of BMD, vBMD, BMC, and BA in 10-year groups in each race were fitted by various regression models. The best fit models [with the largest coefficients of determination (R^2)] were considered as the best fitting curves to describe BMD, vBMD, BMC, and BA changes with age. The Cartesian coordinate numeration method that we previously established [33] was used to determine the values of BMD, vBMD, BMC, and BA in the fitted curves. The differences in fitted curves of BMD, vBMD, BMC, and BA, and age-related loss rates of BMD, vBMD, and BMC, among various races were assessed by paired-sample t test. The different ratios (DR) [DR (%) = (the former/the latter of paired races –1) × 100] of BMD, vBMD, and BMC, and accumulated bone mass loss rate (ABLR) [ABLR (%) = (the bone mass of age point – the peak bone mass)/the peak bone mass × 100] [34] between different races were also calculated using the values in fitted curves.

Results

Basic data of Chinese subjects

For convenience in comparison with the data from NHANES III [29], Chinese subjects were stratified in 10-year age groups. The age distribution and cross-sectional anthropometrical features of the subjects, and age-related BMD, vBMD, BMC, and BA in various regions of the proximal femur in each age group, were calculated. The results are displayed as mean ± SD in Tables 1 and 2.

Comparisons of fitted curves

Figures 1–3 show the comparisons of fitted curves of age-associated BMD, vBMD, BMC, and BA in various regions in the proximal femur among different races. The cubic regression model was the best to analyze BMD, vBMD, and BMC change with age in various regions of the femur for the four races. R^2 of the fitted curves were 0.961–1.000 (P = 0.007–0.000). The cubic regression model was also the best fit curve (R^2 = 0.932–0.997, P = 0.029–0.000) to describe age-related BA in most regions for different races, except for the S model (R^2 = 0.942, P = 0.000) at the femoral neck and quadratic regression (R^2 = 0.981, P = 0.000) at the

Table 1. Age distribution and anthropometrical features of 3614 women in China

Age group (years)	*n*	Age (years)	Weight (kg)	Height (cm)	BMI (kg/m^2)
20–29	488	23.9 ± 2.73	50.8 ± 6.16	157.9 ± 5.22	20.4 ± 2.18
30–39	534	35.3 ± 3.04	54.6 ± 7.82	157.1 ± 5.20	22.1 ± 2.81
40–49	1148	44.2 ± 2.85	56.9 ± 7.84	156.0 ± 5.26	23.3 ± 2.99
50–59	627	54.1 ± 2.97	57.5 ± 8.27	154.9 ± 4.89	24.0 ± 3.24
60–69	535	64.1 ± 2.74	56.5 ± 8.93	152.9 ± 5.52	24.1 ± 3.25
70–79	225	73.7 ± 2.51	53.8 ± 9.65	150.7 ± 5.57	23.6 ± 3.87
≥80	57	82.7 ± 3.42	47.5 ± 9.65	148.1 ± 6.08	21.6 ± 3.62

Values are mean ± standard deviation
BMI, body mass index

Table 2. Age-related BMD (g/cm^2), vBMD (g/cm^3), BMC (g), and BA (cm^2) at regions of the femur in Chinese women

Age (years)	*n*	Femoral neck	Trochanter	Intertrochanter	Total femur	Femoral neck (vBMD)
BMD						
20–29	488	0.785 ± 0.092	0.637 ± 0.083	0.990 ± 0.120	0.858 ± 0.097	0.173 ± 0.024
30–39	534	0.794 ± 0.104	0.633 ± 0.088	1.002 ± 0.135	0.862 ± 0.108	0.171 ± 0.025
40–49	1148	0.779 ± 0.104	0.623 ± 0.090	0.993 ± 0.130	0.851 ± 0.108	0.167 ± 0.026
50–59	627	0.705 ± 0.103	0.561 ± 0.093	0.915 ± 0.132	0.779 ± 0.109	0.153 ± 0.025
60–69	535	0.622 ± 0.090	0.489 ± 0.083	0.807 ± 0.125	0.688 ± 0.101	0.136 ± 0.023
70–79	225	0.576 ± 0.106	0.440 ± 0.101	0.744 ± 0.151	0.629 ± 0.124	0.127 ± 0.026
≥80	57	0.494 ± 0.118	0.362 ± 0.105	0.619 ± 0.155	0.524 ± 0.131	0.108 ± 0.028
BMC						
20–29	488	3.59 ± 0.47	5.65 ± 1.08	17.23 ± 2.85	26.49 ± 3.88	
30–39	534	3.71 ± 0.55	5.86 ± 1.20	17.81 ± 3.46	27.33 ± 4.47	
40–49	1148	3.64 ± 0.53	5.85 ± 1.13	17.69 ± 3.20	27.19 ± 4.37	
50–59	627	3.27 ± 0.51	5.30 ± 1.14	16.41 ± 3.02	24.97 ± 4.19	
60–69	535	2.85 ± 0.44	4.57 ± 1.00	14.68 ± 2.90	22.10 ± 3.91	
70–79	225	2.62 ± 0.47	4.19 ± 1.13	13.33 ± 3.18	20.14 ± 4.45	
≥80	57	2.27 ± 0.56	3.48 ± 1.12	11.08 ± 3.27	16.83 ± 4.68	
BA						
20–29	488	4.57 ± 0.32	8.88 ± 1.20	17.43 ± 2.35	30.90 ± 2.91	
30–39	534	4.67 ± 0.31	9.24 ± 1.13	17.75 ± 2.55	31.66 ± 3.09	
40–49	1148	4.68 ± 0.31	9.39 ± 1.11	17.84 ± 2.47	31.89 ± 2.99	
50–59	627	4.64 ± 0.31	9.42 ± 1.17	17.99 ± 2.42	32.03 ± 2.93	
60–69	535	4.59 ± 0.32	9.33 ± 1.18	18.18 ± 2.36	32.09 ± 2.93	
70–79	225	4.56 ± 0.30	9.51 ± 1.22	17.97 ± 2.31	32.00 ± 2.86	
≥80	57	4.62 ± 0.40	9.59 ± 1.31	17.90 ± 2.36	32.11 ± 2.93	

Values are mean ± standard deviation (SD)
BMD, bone mineral density; vBMD, volumetric BMD; BMC, bone mineral content; BA, bone area

intertrochanter for non-Hispanic white (NHW) women (Fig. 3). The BMD, vBMD (Fig. 1), and BMC (Fig. 2) fitted curves for non-Hispanic black (NHB) women were always highest whereas BMD and BMC fitted curves for Chinese women were always lowest. In some regions, The BMD curves for NHW and Mexican American (MA) women were similar. The vBMD reference curves at the femoral neck for Chinese and NHW women were similar. Figure 3 demonstrates that the BAs in various regions in the femur increased with age for NHB and NHW women and were greater than those for MA and Chinese women.

Comparisons of different ratios of bone mass

The mean ± SD (with 95% confidence interval) of different ratios (DR) of age-specific BMD, vBMD, and BMC among different races are shown in Table 3. The mean values of DR between NHB and Chinese women of BMD and BMC in various regions of hip were 22%–28% and 26%–43% respectively, and those between NHW and MA women were smaller. The DR of BMD was 7.4% ± 4.3% at the femoral neck between Chinese women and NHW women. In other words, the age-specific BMD at the femoral neck of Chinese women was about 7.4% ± 4.3% lower than NHW women, but that of vBMD between the two races decreased to 0.8% ± 3.7%. The DR between MA and NHW women of BMD was 3.2% ± 2.7% at the femoral neck, while when transforming BMD into vBMD, the DR increased to 9.6 ± 1.8%. The values of the peak bone mass (PBM) obtained from fitted curves are presented in Table 4. The PBMs of Chinese women were 16.0% ± 2.14%, 8.67% ± 2.87%, and 8.96% ± 1.97% lower than NHB, NHW, and MA women, respectively. The PBM of NHW women were about 8.75% ± 1.70% lower than NHB women. The peak BMD of NHW women was about 3.25% ± 2.39% lower than MA women, but the peak BMC of NHW women were about 3.22% ± 2.52% higher than MA women.

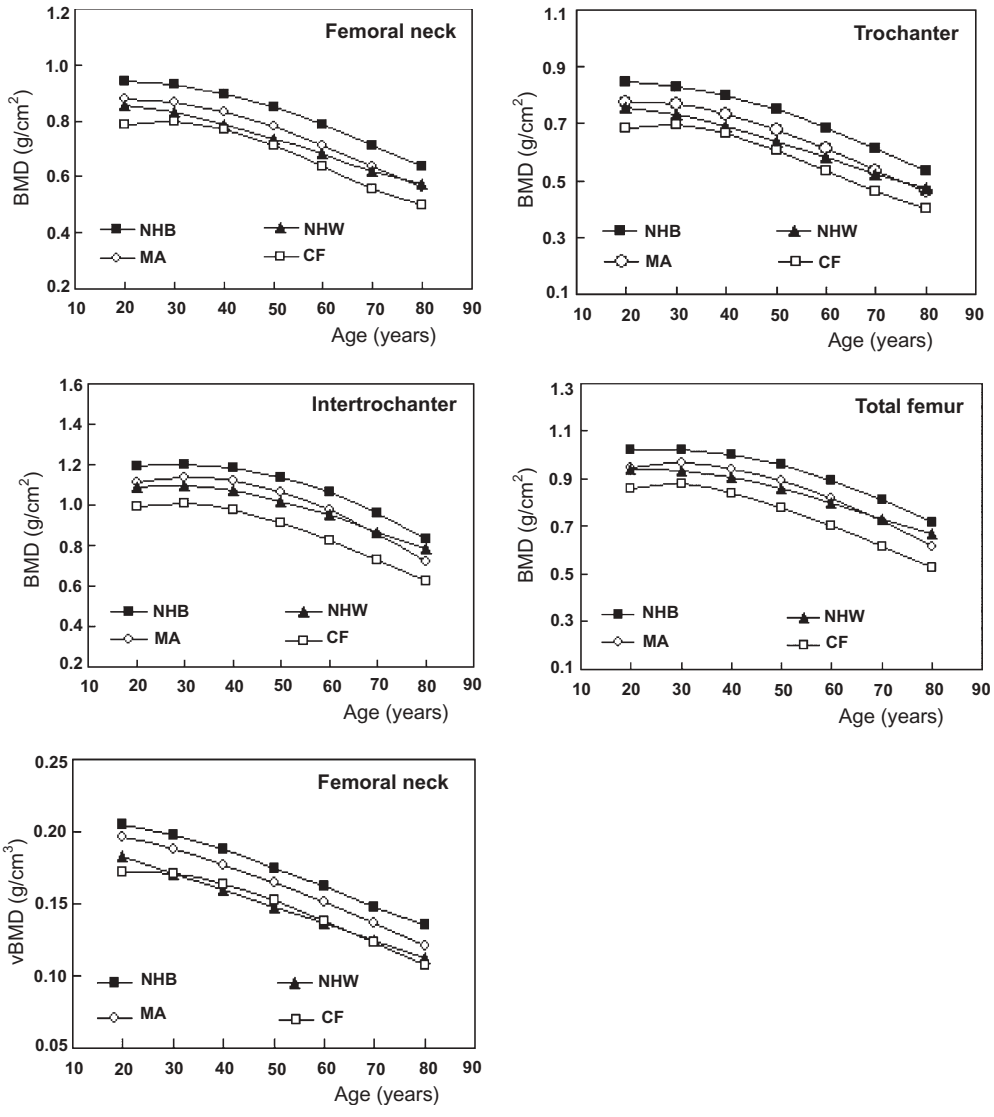

Fig. 1. Comparison of fitted curves for bone density at femoral neck, trochanter, intertrochanter and total femur in different racial women. BMD, bone mineral density; vBMD, volumetric BMD; NHB, non-Hispanic blacks; NHW, non-Hispanic whites; MA, Mexican Americans; CF, Chinese females. The fitted curves were compared with paired-samples *t* test among various races, and *P* values are provided in Table 5

Table 3. The mean value of the different ratios (DR, %) of BMD, BMC, or vBMD at the regions of hip (±SD) of the women from various races

Paired races	Femoral neck	Trochanter	Intertrochanter	Total femur	Femoral neck (vBMD-DR, %)
BMD-DR (%)					
NHB–CF	22 ± 4.4 (17–26)	28 ± 12 (17–39)	27 ± 5.8 (20–31)	25 ± 7.2 (18–31)	18 ± 4.1 (14–22)
NHB–NHW	13 ± 2.1 (11–15)	8.3 ± 2.0 (6.5–10)	10 ± 1.8 (8.4–12)	10 ± 1.9 (8.3–12)	17 ± 2.8 (15–20)
NHB–MA	9.7 ± 2.4 (7.5–12)	10 ± 4.9 (5.6–15)	8.8 ± 3.5 (5.6–12)	9.1 ± 3.8 (5.6–13)	7.0 ± 2.6 (4.6–9.4)
MA–CF	11 ± 1.8 (9.1–12)	16 ± 6.0 (11–22)	15 ± 2.5 (13–18)	12 ± 2.4 (10–14)	10 ± 2.2 (8.4–12)
MA–NHW	3.2 ± 2.7 (0.7–5.7)	–1.5 ± 4.7(–5.8–2.8)	1.2 ± 4.3(–2.7–5.2)	0.9 ± 4.3(–3.0–4.9)	9.6 ± 1.8 (7.9–11)
NHW–CF	7.4 ± 4.3 (3.4–11)	19 ± 11 (8.3–29)	14 ± 6.2 (8.5–20)	13 ± 7.0 (6.7–20)	0.8 ± 3.7(–2.6–4.2)
BMC-DR(%)					
NHB–CF	26 ± 6.0 (20–31)	43 ± 17 (28–59)	28 ± 10 (18–37)	31 ± 11 (21–41)	
NHB–NHW	9.5 ± 3.3 (6.5–13)	7.9 ± 1.7 (6.3–9.5)	8.5 ± 1.7 (7.0–10)	8.5 ± 1.9 (6.8–10)	
NHB–MA	13 ± 2.0 (11–14)	19 ± 5.0 (14–23)	15 ± 5.2 (11–20)	16 ± 4.7 (11–20)	
MA–CF	11 ± 3.4 (8.3–15)	21 ± 9.5 (12–29)	11 ± 4.0 (7.0–14)	13 ± 4.9 (8.3–17)	
MA–NHW	–2.7 ± 3.4(–5.9–0.4)	–8.9 ± 4.3(–13 to –4.9)	–5.8 ± 4.4(–9.9 to –1.7)	–6.2 ± 4.3(–10 to –2.1)	
NHW–CF	15 ± 6.9 (8.5–21)	33 ± 16 (18–48)	18 ± 9.7 (8.9–27)	21 ± 11 (11–30)	

Values are 95% confidence interval of the mean in parentheses
DR (%) = (the former of paired races / the latter of paired races –1)× 100
NHB, non-Hispanic blacks; CF, Chinese females; NHW, non-Hispanic whites; MA, Mexican Americans; BMD, bone mineral density; BMC, bone mineral content; vBMD, volumetric BMD

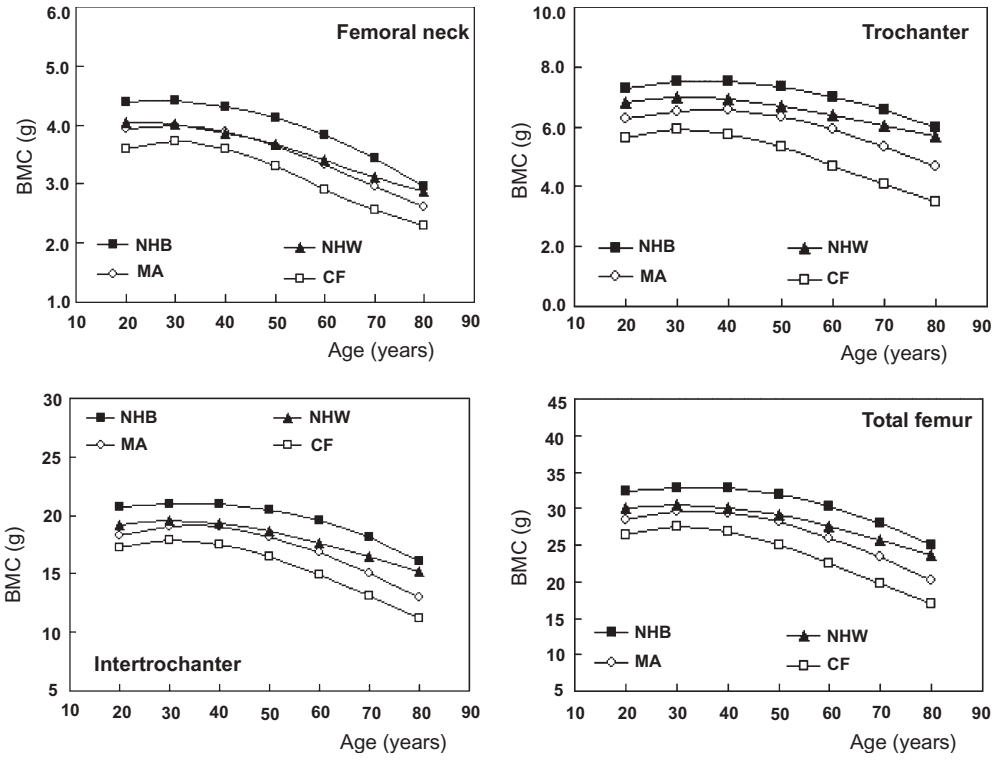

Fig. 2. Comparison of fitted curves for bone mineral content (BMC) varying with age at femoral neck, trochanter, intertrochanter and total femur in various racial women. NHB, non-Hispanic blacks; NHW, non-Hispanic whites; MA, Mexican Americans; CF, Chinese females. The fitted curves were compared with paired-samples *t* test among various races, and *P* values are provided in Table 5

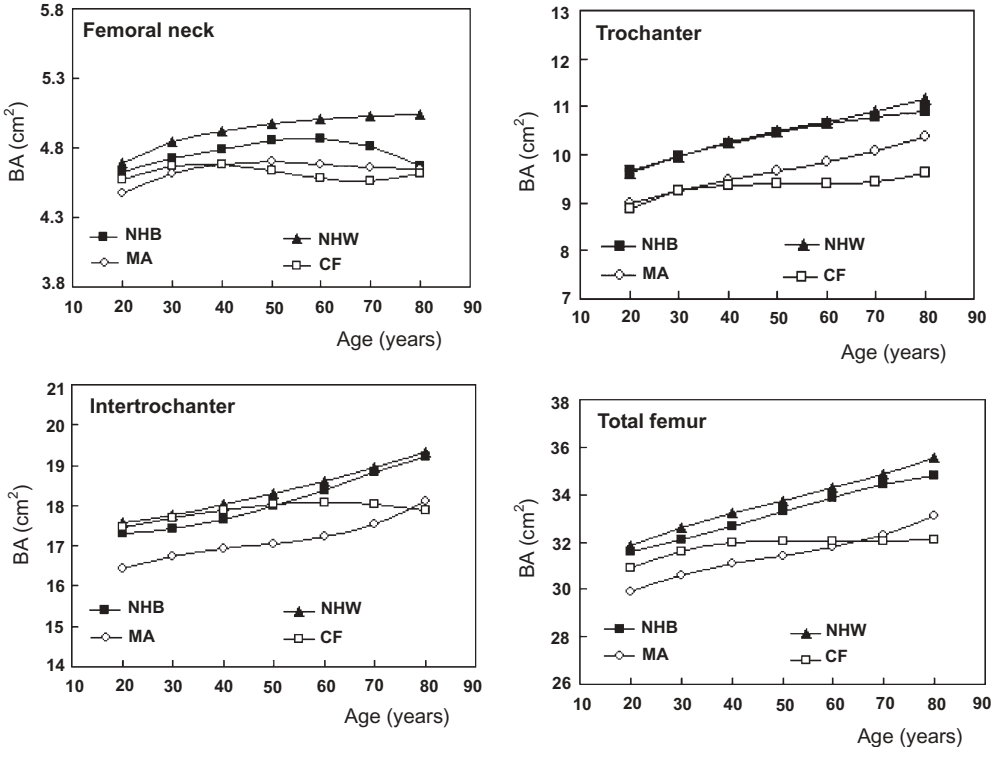

Fig. 3. Comparison of fitted curves for bone area (BA) varying with age at femoral neck, trochanter, intertrochanter and total femur in women from various races. NHB, non-Hispanic blacks; NHW, non-Hispanic whites; MA, Mexican Americans; CF, Chinese females. The fitted curves were compared with paired-samples *t* test among various races, and *P* values are provided in Table 5

Comparisons of accumulated bone loss rate

Figure 4 shows the comparison of fitted curves for accumulated bone loss rate (ABLR) among different races. The *P* values of paired-sample *t* tests for these curves among different races are presented in Table 5. The ABLR by the age of 80 years at various regions are shown in Table 4. The mean of ABLR of Chinese women was significantly higher than that of NHB, NHW, and MA women. The ABLR of MA women was significantly higher than NHB and NHW women. The average decreases in bone mass in each 10-year interval from 50 to 80 years were 11.8% ± 0.59% for

Table 4. PBM and ABLR by the age of 80 years at different regions of hip in women from various races

	Chinese women		NHB women		NHW women		MA women	
	PBM	ABLR (%)	PBM	ABLR (%)	PBM	ABLR (%)	PBM	ABLR (%)
BMD								
Femoral neck	0.798	–37.5	0.944	–32.8	0.857	–33.4	0.876	–36.1
Trochanter	0.640	–42.8	0.749	–27.8	0.700	–28.1	0.705	–35.7
Intertrochanter	1.010	–38.1	1.204	–30.7	1.099	–28.7	1.138	–36.4
Total femur	0.878	–39.8	1.021	–30.1	0.940	–29.0	0.965	–36.3
vBMD								
Femoral neck	0.172	–37.5	0.205	–34.0	0.183	–38.4	0.196	–38.4
BMC								
Femoral neck	3.72	–38.2	4.40	–32.7	4.02	–28.4	4.00	–34.8
Trochanter	5.91	–40.4	7.51	–20.2	7.00	–18.9	6.54	–28.6
Intertrochanter	17.9	–37.4	21.0	–23.6	19.6	–22.6	19.1	–31.9
Total femur	27.5	–38.2	32.9	–24.0	30.6	–22.4	29.6	–31.6
Total		–38.9 ± 1.8[a]		–28.4 ± 4.8		–27.8 ± 5.9		–34.4 ± 3.1[b]

ABLR (%) = (the bone mass of age point – PBM) / PBM × 100 [34]
PBM, peak bone mass; ABLR, accumulated bone loss rate; BMD, bone mineral density (g/cm^2); vBMD, volumetric BMD (g/cm^3); BMC, bone mineral content (g); NHB, non-Hispanic blacks; NHW, non-Hispanic whites; MA, Mexican Americans
[a] P = 0.008–0.001 paired comparison with NHB, NHW, and MA women
[b] P = 0.000 paired comparison with NHB and NHW women

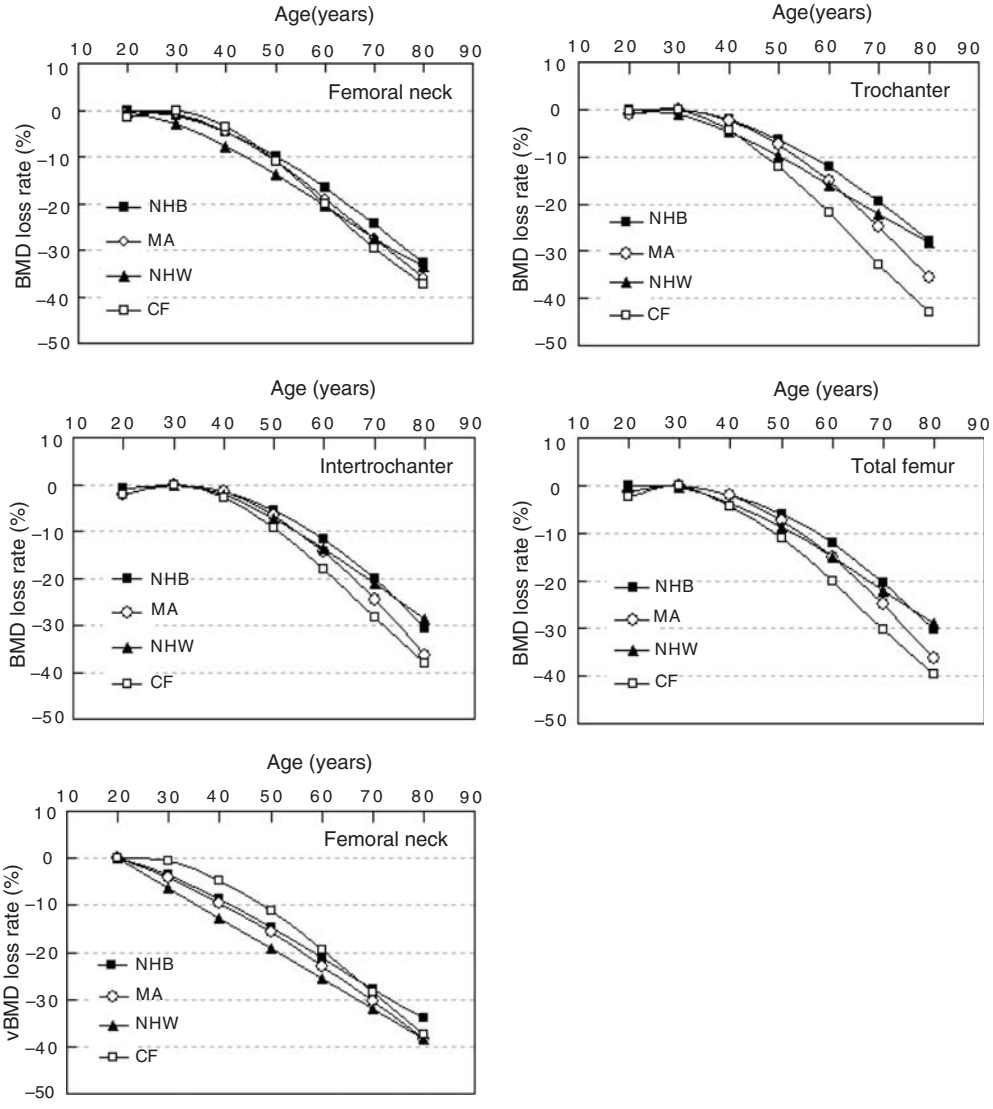

Fig. 4. The comparison of fitted curves for accumulated bone loss rate at the femoral neck, trochanter, intertrochanter and total femur in women from different races. BMD, bone mineral density; vBMD, volumetric BMD; NHB, non-Hispanic blacks; MA, Mexican Americans; NHW, non-Hispanic whites; CF, Chinese females. The fitted curves were compared with paired-samples t test among various races, and P values are indicated in Table 5

Table 5. *P* values of paired-samples *t* tests for the fitted reference curves of age-related BMD, vBMD, BMC, BA, and ABLR at regions of the hip in women between different races

	Paired races					
	NHB–CF	NHB–NHW	NHB–MA	MA–CF	MA–NHW	NHW–CF
Femoral neck						
BMD	0.000	0.000	0.000	0.000	0.015	0.001
BMC	0.000	0.000	0.000	0.000	0.057	0.000
BA	0.008	0.005	0.000	0.532	0.000	0.001
vBMD	0.000	0.000	0.000	0.000	0.000	0.641
BMD-ABLR	0.091	0.004	0.065	0.276	0.248	0.892
vBMD-ABLR	0.355	0.000	0.018	0.004	0.007	0.005
Trochanter						
BMD	0.000	0.000	0.000	0.000	0.477	0.000
BMC	0.000	0.000	0.000	0.000	0.000	0.000
BA	0.000	0.161	0.000	0.025	0.000	0.000
BMD-ABLR	0.018	0.014	0.066	0.006	0.665	0.074
Intertrochanter						
BMD	0.000	0.000	0.000	0.000	0.313	0.000
BMC	0.000	0.000	0.000	0.000	0.007	0.000
BA	0.327	0.001	0.000	0.005	0.000	0.044
BMD-ABLR	0.011	0.406	0.061	0.006	0.274	0.041
Total femur						
BMD	0.000	0.000	0.000	0.000	0.409	0.000
BMC	0.000	0.000	0.000	0.000	0.004	0.000
BA	0.005	0.000	0.000	0.262	0.000	0.002
BMD-ABLR	0.009	0.088	0.053	0.002	0.431	0.042

NHB, non-Hispanic blacks; CF, Chinese females; NHW, non-Hispanic whites; MA, Mexican Americans; BMD, bone mineral density; BMC, bone mineral content; BA, bone area; vBMD, volumetric BMD; ABLR, accumulated bone loss rate

Chinese women, 10.6% ± 0.72% for MA women, and 8.67% ± 1.09% and 7.83% ± 0.92%, respectively, for NHB and NHW women.

Discussion

In our previous study [35], we compared the BMD reference curves of Chinese women, Japanese women, and American Caucasian women, in which the BMD values in the reference curves of Chinese women and Japanese women were calculated using their fitted curve equations and those of American Caucasian women were directly available from the reference database of Hologic bone densitometer. Our recent study [33] found that the BMD reference curve that was calculated using the fitted curve equation appeared distorted. The distortion gradually enlarged with increasing age. There was significant difference between the BMD reference curve for white women (NHANES III dataset) obtained from the reference database of the Hologic bone densitometer and the BMD fitted curve for non-Hispanic whites women based on data of NHANES III [29] (results not shown). In this study, the reference curves of changes in BMD, vBMD, BMC, and BA with age for different races, which were established by the Cartesian coordinate numeration system [33], can maintain authenticity of their own fitted curves and avoid the effect of sampling error on the cross-sectional results of age. For instance, the connecting curve of the average values of the age groups is rough and uneven, but the fitted curve is smooth. Thus, it makes the results more reliable and representative. Based on the fitted curves, we calculated and compared the differences in age-related BMD, vBMD, BMC, BA, and bone loss rate among women of different races. To get information about the basic characteristics of Chinese women, and fully matched and comparable data with reported data [29], we stratified the subjects in 10-year groups, and calculated the age cross-sectional anthropometrical features (see Table 1), and BMD, vBMD, BMC, and BA data (see Table 2).

Our results show that the fitted curves of age-related BMD and BMC in the proximal femur for Chinese women always had the lowest levels among the four races, whereas those for non-Hispanic black women always had the highest levels, and those for non-Hispanic white and Mexican American women had intermediate levels (see Figs. 1, 2). The vBMD reference curves at the femoral neck for Chinese and non-Hispanic white women were similar, and both were significantly lower than those for both non-Hispanic black and Mexican American women. The vBMD reference curve for Mexican Americans was lower than that of non-Hispanic black women (see Fig. 1, Table 5). It is observed from Figs. 1 and 2 that the peak BMD and peak BMC at the hip of Chinese women occurred later than those of women in the United States. The main reason is probably dietary composition. The nutrition status of Chinese women is different from that of American women. In addition, Chinese women develop later than American women. In various skeletal regions, the order of peak BMD for different races was Chinese < non-Hispanic whites < Mexican Americans < non-Hispanic blacks, but the order of peak BMC was Chinese < Mexican Americans < non-Hispanic whites < non-Hispanic blacks (see Table 4). Our results are identical to those of previous reports that the BMD value

in black women is higher than that in white women at every age point, the value in white women is higher than that in Asian women, whereas the vBMDs of Asian women and white women are similar [15,16,20,36]. However, no study has considered the differences between native Chinese women and non-Hispanic black and Mexican American women in the United States.

The BAs of various skeletal regions for non-Hispanic whites women increased with advancing age, and for non-Hispanic black and Mexican American women, apart from the femoral neck, the BAs in other regions also increased with age, suggesting that hip volume for non-Hispanic whites, non-Hispanic blacks, and Mexican Americans increased with advancing age. The change in the trend of BA in Chinese women differed from those in non-Hispanic whites, non-Hispanic blacks, and Mexican Americans, which may be associated with the different figure of Chinese women. At the femoral neck, the vBMD fitted curves of Chinese females and non-Hispanic white women sometimes crossed and overlapped, and the difference between the two curves was only 0.8% (see Table 3), without significant difference (see Table 5).

Compared with differences in BMD, the differences in vBMD between non-Hispanic blacks and Chinese women, and between non-Hispanic black and Mexican American women, were reduced (see Table 3), because the BA of the femoral neck was smaller in Chinese women or Mexican American women than that in non-Hispanic blacks (see Fig. 3). However, the differences in vBMD between non-Hispanic white and Mexican American and non-Hispanic white and black women increased (see Table 3). The major reason for this phenomenon was that the BA of the femoral neck in non-Hispanic white women was significantly larger than those in Mexican American and non-Hispanic black women. The difference in BMD was close to that in vBMD between Chinese and Mexican American women (11% ± 1.8% vs. 10% ± 2.2%) (see Table 3), because the BA was the single factor when BMD was transformed to vBMD and the BAs were similar between the two races, so there was no marked change when expression of bone density varied. This phenomenon suggested that using the equation provided by Katzman et al. [32] to calculate vBMD in an attempt to reduce or avoid the effect of bone size on area BMD may lead to different results. However, it seems an effective method to eliminate the difference between Asians and American/European whites [15,16,20,37].

It is well known that, strictly speaking, investigation in age-related bone loss rate should adopt a longitudinal tracking study, but this is too time consuming and difficult to carry out. Therefore, an age cross-sectional study is widely accepted to investigate bone mass and bone loss changes with age in a wide age range and large sample of the reference population [17,18,21,23,29,32,34,38–41]. Our results confirmed that there exist significant racial differences in age-related bone loss rate (see Fig. 4). Moreover, the differences varied with age, skeletal region, and/or different expression of bone mass (see Table 5). For example, at the femoral neck, there was no significant difference in ABLR of BMD when those of Chinese, non-Hispanic white, and Mexican American women were compared to each other, but significant difference appeared in ABLR of vBMD among the three curves ($P = 0.007$–0.004). Although there was no significant difference in ABLR of vBMD between Chinese and non-Hispanic black women, from curves we can see that the ABLR in Chinese women was markedly larger than that in non-Hispanic black women (see Fig. 4). At the total femur, ABLR of BMD was significantly larger than those in non-Hispanic black and Mexican American women ($P = 0.009$–0.002). By the age of 80 years, the total ABLR of Chinese women was significantly larger than those of non-Hispanic black, white, and Mexican American women, and ABLR of Mexican American women was significantly larger than those of non-Hispanic black and white women, and ABLR of non-Hispanic whites was close to that of non-Hispanic blacks.

Although women in the Chinese mainland have lower bone mass and higher ABLR, the incidence of hip fracture is far lower than many other races in developed countries and regions (including Hong Kong and Taiwan) [3,7,42,43]. Slemenda [44] thought that decrease of physical activities, especially weight-loading activities, may be associated with the higher incidence of hip fractures in populations from developed countries and regions. A fall is the most direct reason for hip fracture in aged people. Because of the impaired functions of nerves and skeletal muscle, vision, gait, activity ability, balance, etc., the relative risk of fall increases in aged people [45,46]. Most elderly Chinese people live with their offspring, so they are often accompanied by their offspring when they go out, and are well taken care of while participating in activities. This situation may reduce or avoid the risk of slip-related hip fractures of elderly women. An earlier study found that the relative risk of hip fracture in women increased with height [47]. The stature of Chinese mainland women is relatively smaller, which perhaps is one of the factors that decrease risk of hip fracture. The prevalence of age-related hip fracture in American white women was two times as high as that in black women because of the higher peak BMD [48] and lower age-related bone loss rate [49] in black women. Our study further confirms that in various skeletal regions, not only peak BMD, but also BMD, vBMD, and BMC over the entire age range from 20 to 80 years of black women are significantly higher than those of white women. The ABLRs of BMD and vBMD at the femoral neck of black women are significant lower than those of white women.

In summary, there are significant differences in bone mass, bone size, and accumulated bone loss rate in the proximal femur among native Chinese women and non-Hispanic black, white, and Mexican women in the United States. After adjusting for bone size, the vBMD at the femoral neck in Chinese women is similar to that in non-Hispanic whites, but significantly lower than non-Hispanic blacks and Mexican Americans.

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