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Age and sex effects on the association between body composition and bone mineral density in healthy Chinese men and women

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Abstract

Objective: Many studies have examined the relationships between body composition and bone mineral density (BMD), but little attention has been given to how these relationships vary by age and sex. The aim of this study was to investigate the distributions of lean mass (LM), fat mass (FM), and BMD and the correlation between body composition and BMD in Chinese men and women of different ages.

Methods: In total, the body compositions of 1,475 men and 1,534 women aged 20 to 96 years were analyzed. Using dual-energy x-ray absorptiometry, we measured the BMD of the spine, femur, and total body and the LM, FM, and percentage of body fat (Fat %). The population was divided into groups based on age and sex: young, premenopausal, and postmenopausal women and young, middle-aged, and older men. The correlations between BMD and variables of body composition were investigated using the Pearson correlation test and multiple regression analysis.

Results: The peak BMD values of the spine, femur, and total body are observed in women aged 30 to 39, 20 to 29, and 30 to 39 years, respectively, and in men aged 20 to 29 years at all sites. The peak LM, FM, and Fat % values were observed at age 40 to 49, 60 to 69, and 70 to 79 years in women, respectively, and at 40 to 49, 70 to 79, and 70 to 79 years in men, respectively. A statistically significant correlation was observed between LM and BMD of all sites (r = 0.253-0.591, $P < 0.01$) in all groups. However, FM was significantly correlated to BMD only in postmenopausal women and older men (r = 0.089-0.336, $P < 0.01$). Fat % negatively correlated to BMD in young people (r = −0.169 to −0.366, $P < 0.05$). When stepwise regression models were analyzed, LM remained the strongest predictor of total body, spine, and femur BMD (standardized coefficients = 0.264-0.637, $P < 0.001$) in Chinese men and women of different ages.

Conclusions: We believe that LM is the strongest predictor of BMD at all ages for Chinese men and women, even though positive correlations between FM and BMD existed in old people.

Key Words: Body composition – Bone mineral density – Lean mass – Fat mass – Age – Sex.

Bone development is influenced by many variables, including genetic and environmental factors and the potential interactions between them. Body weight, which is regulated by diet intake, physical activity, and lifestyle, is strongly associated with bone mass and bone loss. Although extensive epidemiological studies have shown that high body weights or high body mass indices (BMIs) are related to high bone mass and that decreases in body weight may cause bone loss,[1,2] the basic mechanisms underlying this association remain unclear. Specifically, the relationship between the individual components of body weight (fat mass [FM] and lean mass [LM]) and bone mass are undefined. There is also a controversy as to whether LM or FM is a better predictor of bone mineral density (BMD). Several studies have indicated a positive association between lean tissue and bone mass,[3,4] but a number of others demonstrated that both FM and LM contribute equally to bone mass, especially in women.[5,6] However, Reid[7] reported a significant relationship between FM and BMD in women, but not in men, which suggested that the relationship is sex-dependent. In another study, FM seemed to contribute inversely to BMD at all sites in young men but was positively related to BMD at the forearm and calcaneum in older men.[8] Therefore, the relationship also seems to be age-dependent.

Nevertheless, most of those studies were carried out in white populations,[9-12] and data from Asian countries, especially from eastern China, are limited.[13,14] In addition, most studies were primarily focused on postmenopausal women. Although different associations were expected in men who have a different lifestyle, such as different levels of activity, different eating habits, and so on, there are few complex analyses or comparisons on the similarities or differences between the body compositions of men and women of different ages.

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To investigate the relationship between LM, FM, and BMD in a group of healthy Chinese women (n = 1,534) and men (n = 1,475) aged 20 to 96 years, we measured body LM, FM, and BMD using dual-energy x-ray absorptiometry (DXA) technology. We compared the relationships between the variables and determined the strongest predictor of BMD at different ages for both sexes.

The aim of the present study was to determine (1) the characteristics of the distribution of body composition (LM, FM, and BMD) at different ages and sexes in eastern Chinese people, (2) whether age affects the relationship between body composition and BMD, and (3) the sex-related differences in this relationship. To examine the effect of age, the participants were divided into groups based on age and sex: young, premenopausal, and postmenopausal women and young, middle-aged, and older men. Our study was unique because groups of men and women of different ages were compared in the same study.

METHODS

Participants

The current study included 1,534 women aged 20 to 96 years and 1,475 men aged 20 to 94 years. All of the participants were from Shanghai, China, and were recruited at Shanghai Huadong Hospital, affiliated with Fudan University, when undergoing physical examinations between January 2004 and December 2007. All participants were in good health according to clinical medical evaluations. None of the participants had chronic diseases, such as hyperthyroidism, hyperparathyroidism, renal failure, malabsorption syndrome, alcoholism, chronic colitis, multiple myeloma, leukemia, or chronic arthritis. Likewise, none of the participants were taking any medications that were likely to affect bone or soft tissue metabolism, such as antiosteoporotic (eg, glucocorticoids, heparin, warfarin, thyroxine, sex hormone, bisphosphonate, selective estrogen receptor modulators, calcitonin, parathyroid hormone analogue, or calcitriol) or weight-controlling drugs. Candidates on diets for weight loss or weight gain were excluded from the study. All of the postmenopausal women had experienced natural menopause. Menopause was defined clinically as the absence of menstrual cycles for at least 1 year. The study protocol and procedures were approved by the ethics committee of the hospital and Fudan University of Medicine. All of the participants provided written informed consent before any measurements were obtained.

Anthropometric parameters and BMD measurement

Anthropometric parameters including age, weight, and standing height were obtained. The women were divided into three age groups: young (age, 20-30 y), premenopausal (age, 30 y to menopause), and postmenopausal (mean menopause age, 49.21 ± 4.14 y; mean age of postmenopausal women, 66.5 ± 11.2 y). The men were also divided into three age groups: young (age, 20-30 y), middle-aged (age, 30-50 y), and older (age, >50 y). We established the age of 50 years as the boundary for stratification in men for ease of comparison

TABLE 1. *Basic characteristics, anthropometric measurements, and regional and total body BMD in various age groups of women and men*

	n	Height, cm	Weight, kg	BMI, kg/m^2	LSBMD, g/cm^2	FNBMD, g/cm^2	TBMC, g	TBMD, g/cm^2	LM, kg	FM, kg	Fat %
Women age, y											
20-29	189	162.2 ± 5.7	54.8 ± 7.1	21.1 ± 2.60	0.96 ± 0.10	0.79 ± 0.12	1976 ± 247	1.068 ± 0.095	38.43 ± 4.12	15.11 ± 4.18	26.98 ± 4.75
30-39	227	160.5 ± 5.22	56.4 ± 6.89	21.8 ± 2.45	0.99 ± 0.12	0.78 ± 0.10	1980 ± 232	1.072 ± 0.077	38.18 ± 3.93	16.33 ± 3.84	28.77 ± 4.1
40-49	269	160.6 ± 5.88	59.2 ± 8.1	23.3 ± 3.03	0.95 ± 0.12	0.76 ± 0.09	1965 ± 220	1.059 ± 0.082	39.77 ± 4.27	18.47 ± 4.85	30.28 ± 4.58
50-59	256	158.7 ± 5.78	60.9 ± 9.25	24.1 ± 3.28	0.88 ± 0.14	0.70 ± 0.11	1805 ± 308	1.013 ± 0.099	38.84 ± 4.93	20.29 ± 6.29	32.36 ± 4.26
60-69	248	153.8 ± 4.60	57.5 ± 7.70	24.0 ± 4.79	0.76 ± 0.12	0.62 ± 0.09	1597 ± 277	0.944 ± 0.077	38.01 ± 4.35	20.87 ± 5.01	34.11 ± 4.33
70-79	208	153.0 ± 5.51	58.5 ± 9.67	25.0 ± 3.37	0.78 ± 0.19	0.57 ± 0.09	1444 ± 274	0.909 ± 0.114	36.61 ± 5.29	20.46 ± 5.55	34.27 ± 5.12
>80	137	151.4 ± 5.34	56.5 ± 9.82	24.7 ± 4.14	0.86 ± 0.18	0.58 ± 0.09	1397 ± 294	0.937 ± 0.107	35.50 ± 5.10	20.01 ± 5.96	34.18 ± 5.27
Men age, y											
20-29	192	172.9 ± 6.72	68.9 ± 9.77	23.1 ± 2.79	0.99 ± 0.13	0.89 ± 0.14	2422 ± 446	1.144 ± 0.107	53.7 ± 6.85	12.9 ± 4.66	18.39 ± 4.88
30-39	225	172.9 ± 6.20	71.8 ± 10.46	24.0 ± 2.99	0.98 ± 0.12	0.87 ± 0.10	2342 ± 316	1.109 ± 0.080	54.6 ± 8.59	16.75 ± 5.03	21.48 ± 3.76
40-49	251	171.9 ± 5.60	73.8 ± 7.99	25.0 ± 2.65	0.96 ± 0.14	0.85 ± 0.11	2380 ± 318	1.105 ± 0.090	55.86 ± 6.75	17.02 ± 4.12	22.42 ± 3.64
50-59	247	171.5 ± 6.13	74.9 ± 10.23	25.5 ± 2.78	0.95 ± 0.13	0.77 ± 0.11	2362 ± 381	1.11 ± 0.097	55.59 ± 6.20	18.15 ± 4.46	23.34 ± 3.95
60-69	231	168.2 ± 5.23	73.1 ± 9.18	26.1 ± 2.94	0.97 ± 0.16	0.77 ± 0.12	2389 ± 208	1.094 ± 0.103	53.08 ± 6.23	18.22 ± 4.36	24.46 ± 3.50
70-79	205	166.3 ± 5.44	71.5 ± 10.97	25.7 ± 3.03	1.03 ± 0.21	0.72 ± 0.12	2122 ± 351	1.074 ± 0.109	49.78 ± 6.55	18.99 ± 5.11	26.2 ± 4.22
>80	124	164.3 ± 5.83	66.3 ± 10.08	24.5 ± 3.39	0.97 ± 0.22	0.68 ± 0.12	2059 ± 364	1.048 ± 0.116	46.57 ± 6.10	17.71 ± 5.59	26.01 ± 5.00

Data are expressed as mean ± SD.
BMI, body mass index; BMD, bone mineral density; LSBMD, lumbar spine bone mineral density; FNBMD, femoral neck bone mineral density; TBMD, total body bone mineral density; TBMC, total body bone mineral content; FM, fat mass; LM, lean mass; Fat %, percentage of body fat.

between men and women, since the mean menopause age of women was 49.21 ± 4.14 years.

Body weight and body height were recorded, and both measurements were made without wearing shoes. BMI was calculated as weight (kilograms) divided by height squared (square meters).

Total and regional BMD, including lumbar spine (L2-4); left femoral neck; and FM, LM, and body fat percentage (Fat %) were measured using DXA. The measurement was taken using a DXA densitometer (Hologic Delphi A; Hologic Inc.). The precision error in our laboratory was 0.86% in the lumbar spine BMD, 1.86% in the femoral neck BMD, 0.95% in the total body BMD, 0.74% in LM, and 1.5% in FM. The densitometer was standardized by a standard phantom before each measurement.

Data analysis

SPSS version 14.0 was used for the statistical analyses. The means and SDs were calculated for all anthropometric data. The correlations between BMD and body composition variables were investigated using the Pearson correlation test for normally distributed variables or Spearman correlation for non–normally distributed variables. When multiple linear regression analysis was used, BMDs in the lumbar spine, femoral neck, and total body were dependent variables, whereas age, LM, and FM were independent variables. Weight, height, and BMI were adjusted in the analysis, and standardized coefficients were reported. The two-sample *U* test was used for the comparison of BMD between men and women. All statistical tests were two-tailed, and $P < 0.05$ was considered significant.

RESULTS

Age distributions and characteristics of anthropometry and densitometer measurements in healthy Chinese men and women

Table 1 shows the basic characteristics, anthropometric measurements, and regional and total body BMD of the studied population, which was stratified into subgroups by age and sex. According to these results, in women, the peak BMD values of the spine, femoral neck, and total body were observed at 30 to 39, 20 to 29, and 30 to 39 years, respectively, and the peak values of LM, FM, and Fat % were observed at 40 to 49, 60 to 69, and 70 to 79 years, respectively. In men, the peak BMD values of the spine, femoral neck, and total body were all observed at 20 to 29 years, and the peak values of LM, FM, and Fat % were observed at 40 to 49, 70 to 79, and 70 to 79 years, respectively. The peak BMD values of the lumbar spine and femoral neck were 0.99 (SD, 0.12) and 0.79 (SD, 0.12) g/cm^2, respectively, for women and 0.99 (SD, 0.13) and 0.89 (SD, 0.14) g/cm^2, respectively, for men. In this study, the values of peak bone mass of the lumbar spine of women and men were the same. In addition, BMD of the spine increased after the age of 70 years in women and 50 years in men owing to hyperostosis of the spine.

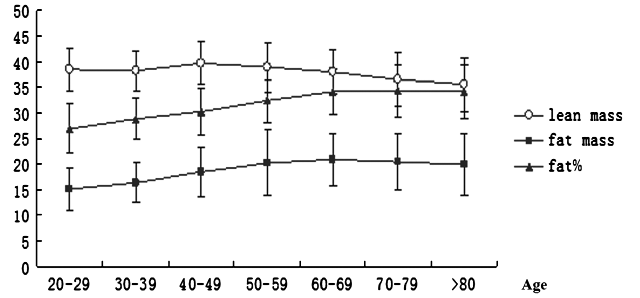

FIG. 2. Lean mass (in kilograms), fat mass (in kilograms), and fat percentage measurements and changes associated with age in Chinese women.

As expected, men were taller and heavier and had higher BMI than women. BMDs of the spine, femur, and total body and LM were almost significantly higher in men than in women in each age group ($P < 0.01$, two-sample *U* test). FM and Fat % were significantly higher in women than in men in each age group ($P < 0.01$). In both sexes, aging was accompanied by an increase in FM and Fat % and a decrease in LM and BMD, but FM and Fat % also decreased after age 80 years.

Figures 1 to 4 show body composition characteristics and changes associated with age in Chinese women and men.

Correlation between bone mass and body composition variables in men and women

Tables 2 and 3 present the outcomes of the correlation tests in men and women. The relationship between body composition and BMD is similar in young men and young women. LM was positively correlated to BMD of all sites ($r = 0.332$, 0.348, and 0.293 for the spine, femur, and total body, respectively, in women; $r = 0.344$, 0.561, and 0.476 for the spine,

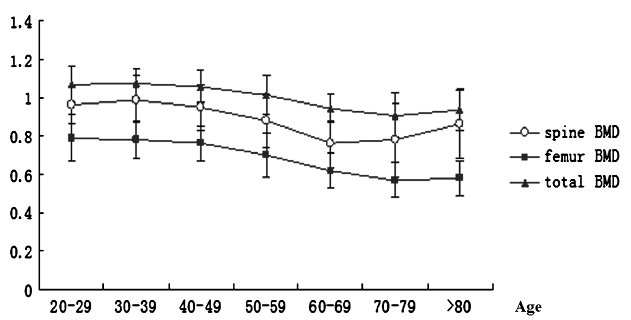

FIG. 1. Bone mass (in grams per square centimeter) characteristics and changes associated with age in Chinese women. BMD, bone mineral density.

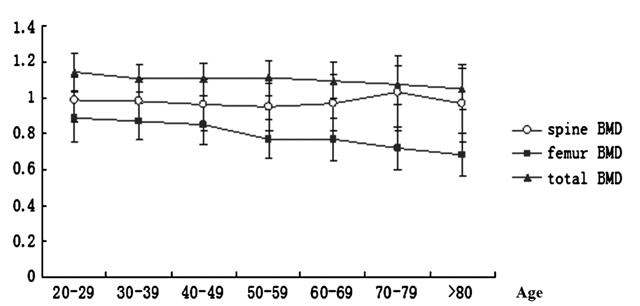

FIG. 3. Bone mass (in grams per square centimeter) measurements and changes associated with age in Chinese men. BMD, bone mineral density.

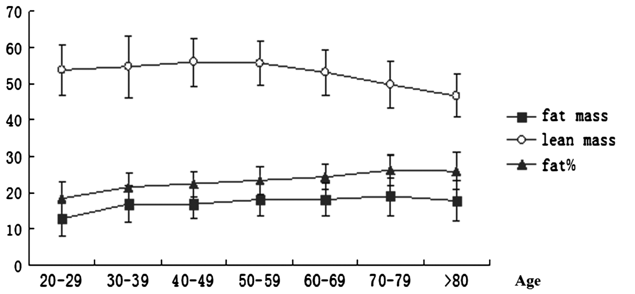

FIG. 4. Lean mass (in kilograms), fat mass (in kilograms) and fat percentage measurements and changes associated with age in Chinese men.

femur, and total body, respectively, in men; all $P < 0.01$). Fat % was negatively correlated to BMD of all sites ($r = -0.249$, -0.169, and -0.366 for the spine, femur, and total body, respectively, in women; $r = -0.322$, -0.219, and -0.364 for the spine, femur, and total body, respectively, in men; $P < 0.01$ in spine and total body BMD and $P < 0.05$ in femoral neck BMD for both sexes). The correlations between FM and BMD were weak but negatively correlated to total body BMD in women ($r = -0.212$, $P < 0.05$) and to spine BMD in men ($r = -0.186$, $P < 0.01$).

In both premenopausal and postmenopausal women, LM was positively correlated to BMD of all sites ($r = 0.329$, 0.362, and 0.301 for the spine, femur, and total body, respectively, in premenopausal women; $r = 0.347$, 0.445, and 0.318 for the spine, femur, and total body, respectively, in postmenopausal women; all $P < 0.01$), and weight and BMI were positively correlated to BMD of all sites. FM was positively correlated to femoral neck BMD ($r = 0.241$, $P < 0.01$) in premenopausal women, but, in postmenopausal women, FM was correlated to BMD of all sites ($r = 0.261$, 0.303, and 0.122 for the spine, femur, and total body, respectively; $P < 0.01$). In postmenopausal women, years since menopause were inversely correlated to BMD of all sites.

In men, there was a significant association between LM and BMD of all sites in middle-aged and older groups ($r = 0.268$, 0.325, and 0.336 for the spine, femur, and total body, respectively, in the former; $r = 0.253$, 0.469, and 0.380 for the spine, femur, and total body, respectively, in the latter; all

TABLE 2. *Pearson correlation of BMD with age, BMI, LM, and FM and Spearman correlation of BMD with Fat % in women*

	LSBMD	FNBMD	TBMC	TBMD
Young (n = 189)				
Age	0.208[a]	−0.041	0.139	0.138
Height	0.117	0.067	0.402[b]	0.079
Weight	0.165[a]	0.213[b]	0.373[b]	0.065
BMI	0.117	0.194[a]	0.195[a]	0.023
LM	0.332[b]	0.348[b]	0.591[b]	0.293[b]
FM	−0.088	−0.003	−0.014	−0.212[a]
Fat %	−0.249[b]	−0.169[a]	−0.281[b]	−0.366[b]
Premenopause (n = 529)				
Age	−0.185[b]	−0.110	−0.072	−0.113
Height	0.198[b]	0.090	0.473[b]	0.153[a]
Weight	0.266[b]	0.351[b]	0.478[b]	0.194[b]
BMI	0.198[b]	0.338[b]	0.303[b]	0.142[a]
LM	0.329[b]	0.362[b]	0.575[b]	0.301[b]
FM	0.115	0.241[b]	0.263[b]	0.041
Fat %	−0.050	0.090	0.006	−0.122[a]
Postmenopause (n = 816)				
Age	−0.063	−0.462[b]	−0.468[b]	−0.354[b]
YSM	−0.083[a]	−0.459[b]	−0.471[b]	−0.360[b]
Height	0.171[b]	0.415[b]	0.561[b]	0.318[b]
Weight	0.307[b]	0.414[b]	0.498[b]	0.255[b]
BMI	0.241[b]	0.218[b]	0.226[b]	0.097[b]
LM	0.347[b]	0.445[b]	0.562[b]	0.318[b]
FM	0.261[b]	0.303[b]	0.336[b]	0.122[b]
Fat %	0.105[a]	0.104[b]	0.072[a]	−0.069[a]

BMI, body mass index; BMD, bone mineral density; LSBMD, lumbar spine bone mineral density; FNBMD, femoral neck bone mineral density; TBMD, total body bone mineral density; TBMC, total body bone mineral content; FM, fat mass; LM, lean mass; Fat %, percentage of body fat.
[a]$P < 0.05$.
[b]$P < 0.01$.

TABLE 3. *Pearson correlation of BMD with age, BMI, LM, and FM and Spearman correlation of BMD with Fat % in men*

	LSBMD	FNBMD	TBMC	TBMD
Young (n = 192)				
Age	−0.043	−0.097	0.007	0.057
Height	0.226[a]	0.257[b]	0.458[b]	0.251[b]
Weight	0.176	0.439[b]	0.494[b]	0.291[b]
BMI	0.113	0.372[b]	0.344[b]	0.216[a]
LM	0.344[b]	0.561[b]	0.649[b]	0.476[b]
FM	−0.186[b]	−0.014	0.006	−0.167
Fat %	−0.322[b]	−0.219[a]	−0.249[b]	−0.364[b]
Middle-aged (n = 476)				
Age	−0.029	0.024	0.038	0.009
Height	0.153[a]	0.146	0.542[b]	0.227[b]
Weight	0.261[b]	0.332[b]	0.528[b]	0.255[b]
BMI	0.221[b]	0.305[b]	0.286[b]	0.161[a]
LM	0.268[b]	0.325[b]	0.585[b]	0.336[b]
FM	0.084	0.128	0.129	−0.011
Fat %	−0.021	−0.015	−0.106	−0.180[a]
Older (n = 807)				
Age	0.126[b]	−0.226[b]	−0.142[b]	−0.157[b]
Height	0.093[b]	0.267[b]	0.224[b]	0.212[b]
Weight	0.304[b]	0.460[b]	0.270[b]	0.283[b]
BMI	0.302[b]	0.393[b]	0.192[b]	0.250[b]
LM	0.253[b]	0.469[b]	0.297[b]	0.380[b]
FM	0.227[b]	0.274[b]	0.125[b]	0.089[b]
Fat %	0.157	0.108[b]	0.019	−0.040[a]

BMI, body mass index; BMD, bone mineral density; LSBMD, lumbar spine bone mineral density; FNBMD, femoral neck bone mineral density; TBMD, total body bone mineral density; TBMC, total body bone mineral content; FM, fat mass; LM, lean mass; Fat %, percentage of body fat.
[a]$P < 0.05$.
[b]$P < 0.01$.

TABLE 4. *Correlation of LM and FM with weight, BMI, age, and YSM in women*

	FM	Weight	Age	YSM
Young (n = 189)				
LM	0.373[a]	0.851[a]	0.007	
FM		0.826[a]	0.021	
Premenopause (n = 529)				
LM	0.582[a]	0.882[a]	0.087	
FM		0.879[a]	0.167	
Postmenopause (n = 816)				
LM	0.651[a]	0.890[a]	−0.248[a]	−0.256[a]
FM		0.909[a]	−0.012	−0.034

Data are presented as Pearson correlation coefficient.
BMI, body mass index; FM, fat mass; LM, lean mass; YSM, years since menopause.
[a]$P < 0.01$.

TABLE 5. *Correlation of LM and FM with weight, BMI, and age in men*

	FM	Weight	Age
Young (n = 192)			
LM	0.356[a]	0.901[a]	−0.025
FM		0.720[a]	0.013
Middle-aged (n = 476)			
LM	0.207[a]	0.832[a]	0.068
FM		0.690[a]	0.053
Older (n = 807)			
LM	0.427[a]	0.855[a]	−0.408[a]
FM		0.712[a]	−0.048

Data are presented as Pearson correlation coefficient.
BMI, body mass index; FM, fat mass; LM, lean mass.
[a] $P < 0.01$.

$P < 0.01$). However, the association between FM and BMD was significant in the older group ($r = 0.227$, 0.274, and 0.089 for the spine, femur, and total body, respectively; all $P < 0.01$) but was not associated in the middle-aged group ($r = 0.084$, 0.128, and −0.011 for the spine, femur, and total body, respectively; all $P > 0.05$). Weight and BMI were also positively correlated to BMD of all sites in men, as in women.

LM and FM were found to be moderately correlated in different age groups of both sexes ($r = 0.373$, 0.582, and 0.651 for the spine, femur, and total body, respectively, in women; $r = 0.356$, 0.207, and 0.427 for the spine, femur, and total body, respectively, in men; all $P < 0.01$), and both were also highly correlated to weight, as shown in Tables 4 and 5.

Multiple regression analysis of body composition and BMD adjusted for weight, height, and BMI

Tables 6 and 7 present the outcomes of multiple regression analysis. To assess the relative importance of LM versus FM on BMD, stepwise multivariate analysis was performed, with age, LM, and FM as independent variables and BMD as the dependent variable, adjusted for weight, height, and BMI. The results indicated that both LM and FM were significant in the multivariate analysis. LM was the principal determinant of BMD of all sites in this study. Although FM was also important in predicting BMD of postmenopausal women and older men, it was negatively associated with BMD in young groups and did not predict spine and femur BMD in premenopausal women or all-sites BMD in middle-aged men.

To summarize, our findings showed that, among the body composition parameters, LM was the best predictor of BMD because it was significantly correlated to BMD of all sites in all groups, whereas FM only partially related to BMD in this study. Fat % was negatively associated with bone density in the young. Therefore, the effect of LM on bone density was greater than that of FM.

DISCUSSION

Previous studies do not agree on whether LM or FM is the major determinant of bone mass. Several authors have suggested that LM is the best predictor of BMD, whereas FM is negatively related to bone mass when adjusted for body weight.[15,16] Other cross-sectional studies suggested that bone density is related to FM,[17] and even others showed that both LM and FM are related to bone mass.[6,18] However, most of these studies were conducted with postmenopausal women, and only limited data are available in men, among whom some reported that LM determines bone mass, whereas FM was not related to bone mineral measures in men.[19] Others have shown a positive association between FM and hip BMD in men.[20] However, the relationships between body composition and BMD in premenopausal women and young men are different. Some studies indicate that increased FM is associated with smaller bone mass in healthy young men, challenging the view of a high BMI as a protective factor for osteoporosis, and this negative association between total FM and bone density is independent from sex steroid concentrations.[21] Other authors suggest that, in young premenopausal women, LM tends to be positively associated with bone mass; FM and Fat %, however, are positively associated with bone measures, but adjustment for bone size removes or reverses this association.[22] Despite this, others showed that, in premenopausal women, fat mass has a significant negative effect on bone mass and suggested the importance of reducing fat mass to achieve peak bone mass in young adult women.[23] However,

TABLE 6. *Regression analysis of age, LM, and FM with LSBMD, FNBMD, and TBMD adjusted for weight, height, and BMI in women*

	LSBMD			FNBMD			TBMD		
	β	t	P	β	t	P	β	t	P
Young									
LM	0.411	5.075	0.000	0.348	4.466	0.000	0.432	5.398	0.000
FM	−0.246	−3.033	0.003	−0.154	−1.850	0.066	−0.373	−4.658	0.000
Age	0.209	2.783	0.006	−0.044	−0.557	0.578	0.143	1.947	0.054
Premenopause									
LM	0.348	6.056	0.000	0.375	6.605	0.000	0.417	5.921	0.000
FM	−0.065	−0.926	0.355	0.072	1.022	0.308	0.182	2.552	0.011
Age	−0.219	−3.818	0.000	−0.142	−2.504	0.013	−1.180	−2.037	0.043
Postmenopause									
LM	0.320	10.407	0.000	0.264	7.315	0.000	0.299	7.617	0.000
FM	0.025	0.606	0.531	0.127	3.635	0.001	0.082	2.166	0.031
Age	0.017	0.550	0.583	−0.394	−14.414	0.000	−0.109	−1.363	0.173
YSM	−0.002	−0.068	0.946	−0.142	−1.938	0.053	−0.286	−9.601	0.000

BMI, body mass index; LSBMD, lumbar spine bone mineral density; FNBMD, femoral neck bone mineral density; TBMD, total body bone mineral density; FM, fat mass; LM, lean mass; YSM, years since menopause.

TABLE 7. *Regression analysis of LM, FM, and age with LSBMD, FNBMD, and TBMD adjusted for weight, height, and BMI in men*

	LSBMD			FNBMD			TBMD		
	β	*t*	*P*	β	*t*	*P*	β	*t*	*P*
Young									
LM	0.448	5.074	0.000	0.637	7.974	0.000	0.606	7.539	0.000
FM	−0.345	−3.908	0.000	−0.213	−2.666	0.009	−0.378	−4.712	0.000
Age	−0.028	−0.335	0.738	−0.079	−1.056	0.293	0.076	1.018	0.311
Middle-aged									
LM	0.268	3.693	0.000	0.325	4.567	0.000	0.336	4.738	0.000
FM	0.049	0.663	0.508	0.087	1.199	0.232	−0.067	−0.920	0.359
Age	−0.048	−0.653	0.515	0.001	0.020	0.984	−0.014	−0.197	0.844
Older									
LM	0.313	13.500	0.000	0.403	18.411	0.000	0.374	17.840	0.000
FM	0.106	5.016	0.000	0.101	5.055	0.000	−0.071	−3.397	0.001
Age	0.258	12.299	0.000	−0.058	−2.906	0.004	−0.009	−0.425	0.671

BMI, body mass index; LSBMD, lumbar spine bone mineral density; FNBMD, femoral neck bone mineral density; TBMD, total body bone mineral density; FM, fat mass; LM, lean mass.

some studies reported that lean body mass is an important determinant of BMD in young men, but both LM and FM are important for BMD in young women.[24]

In our study, we evaluated 1,534 women and 1,475 men aged 20 to 96 years with wide variations in body composition and found that LM and FM both showed associations with BMD. However, there were sex- and age-related differences in the associations between these body composition variables and bone density.

In young people whose bone mass is at its peak value, LM predicted all-sites BMD, but FM and Fat % are negatively associated with bone mineral measures. In middle-aged people whose bone mass remains stable, LM has a stronger effect on BMD than FM. In older people, among whom bone loss is prevalent, LM and FM are both consistent predictors of bone density. LM was the best predictor of bone mass because the increase in LM seemed to have a strong association with incremental bone mass in all groups and because FM also related to BMD, especially in old people. In addition, we found that increasing FM may protect the femur from bone deterioration in the older population. However, Fat % was always significantly negatively related to total BMD, and a positive correlation between FM and bone mass disappeared when adjusted for the mechanical loading effects of body weight. These findings suggest that the effects of LM and FM on BMD of young people and old people are different, and that LM is the primary determinant of BMD, whereas FM is a complementary factor. In this study, the associations between body mass and BMD also indicated sex differences. FM showed more positive effect on BMD in women than in men.

Several explanations have been proposed for this relationship. Both LM and FM may affect bone mass by mechanical loading of the skeleton.[7]

In addition, FM has a protective effect on BMD because of the conversion of androgens to estrogens,[25] which improves bone mass in both men and women[26,27] and maintains healthy plasma levels of insulin and regulating factors including insulinlike growth factor–1, leptin, and adiponectin.[28] Furthermore, obesity has been associated with insulin resistance, characterized by high plasma levels of insulin. High plasma insulin levels may contribute to androgen and estrogen overproduction in the ovary and reduce production of sex hormone–binding globulin by the liver. These changes result in elevated sex hormone levels, leading to increased bone mass due to reduced osteoclast activity and, possibly, increased osteoblast activity.[7] Recently, some detrimental effects of FM on bone have been reported, including that adipocytes and osteoblasts originate from a common progenitor, pluripotential mesenchymal stromal cells, and that their differentiation is regulated through the peroxisome proliferator–activated receptor-γ pathway.[29] The activation of peroxisome proliferator–activated receptor-γ drives the differentiation of mesenchymal stromal cells toward adipocytes over osteoblasts. Obesity, however, may be associated with Vitamin D insufficiency and secondary hyperparathyroidism due to reduced availability of Vitamin D_3 because of its deposition in body fat compartments, which also affects bone health.[30]

The association between LM and BMD is complicated, and physical activity seems to be the most plausible link between these measures. Weight-bearing activities are associated with increased LM and BMD.[31] However, positive correlations between LM and bone mass remained significant after adjustments for body weight, suggesting that the effects of LM on bone mass are not entirely attributable to mechanical loading. Recent investigation indicated putative cross-talk between muscle and osteocyte cells because sarcopenia and osteoporosis frequently manifest together and are closely interdependent.[32] Several studies demonstrated the activation of osteocytes after the addition of conditioned media collected from in vitro muscle cells and vice versa,[33,34] indicating promotion of myoblast-to-myotube formation. In fact, bone is sensitive to applied strain rate, which may modulate the production of mediators by osteocytes, such as prostaglandins and nitric oxide, and stimulate the production of other cytokines and growth factors such as insulinlike growth factor.[35]

The relationship between BMD and LM is stronger in men than women, in young people than in old people, in premenopausal women than in postmenopausal women, and in trained persons than in nontrained persons.[36,37] Possible reasons for this may be related to physical activity because it is the underlying mechanism between LM and BMD. Physical activity is significantly greater in men than in women and in young than in the old. Physical activity increases LM and BMD but decreases FM. Therefore, physical activity is a potential confounder of the association between LM and BMD. Therefore, greater physical activity may contribute to the lack of a relationship between FM and BMD. The association between LM and BMD could be expected to be more prominent among active people. Less physical activity in old age may disrupt this association, allowing the FM to be an important predictor of BMD in older people. It seems that the effect of LM on BMD might be attenuated by a sedentary lifestyle. As shown by the present study, LM decreased, and FM increased with age, so the effect of FM on BMD increased, but the effect of LM decreased, in older people.

In our study, significant sex and age differences were observed in BMI, LM, FM, Fat %, and bone mass. During early adulthood, the maturation of bone occurred later in the spine than in the femur in women but occurred concurrently in men. The reason for this phenomenon may be the fact that most Chinese women conceive and deliver babies at approximately 25 to 30 years of age and that women experience a transient loss of bone density of approximately 3% to 7% during lactation; this loss is rapidly regained after weaning.[38] The rate and extent of recovery are influenced by the duration of lactation and postpartum amenorrhea and differ by skeletal site. The recovery of bone mass was observed at the lumbar spine, in contrast with that at the femoral neck, which showed only a partial recovery.[39] Therefore, the bone mass in the spine recovered significantly after age 30 years, when weaning was complete. Bone mass did not recover as much in the femur, demonstrated by the fact that peak bone mass was reached later in the spine than in the femur.

Our study has some limitations. First, it is not population-based. Second, it is limited to the evaluation of fat and lean mass by DXA. Therefore, we could not detect the fat and lean mass of different body segments and could not differentiate subcutaneous fat from visceral fat. Third, our study does not account for other possible determinants of BMD, including lifestyle habits, vitamin D status, or sex hormone levels, and it does not evaluate possible mechanisms of action of body composition variables on bone density.

Overall, examination of our data suggests that both fat and lean body mass can influence bone mass, and three main findings emerge. First, LM is a better determinant of BMD than FM in Chinese people, although FM is positively correlated to BMD in older people. Second, FM is negatively related to BMD in healthy Chinese men and women with peak bone mass. Third, FM influences bone mass more in older women than in older men.

CONCLUSIONS

Our study highlights the possibility that different physiological conditions influencing body mass components can modulate their effects on bone density, as shown in the varied associations between LM or FM and BMD among different age groups and different sexes. Based on these findings, we conclude that, in young and middle-aged persons, greater LM and less FM contribute to high BMD, whereas in older persons, greater LM and greater FM contribute to high BMD.

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