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The relationship between body fat and bone mineral density in Korean men and women

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Abstract Previous studies of the effects of body fat on bone mineral density (BMD) have shown conflicting results depending on the age, sex, and menopausal status of the subjects. The purpose of the present study was to investigate the effects of body fat on BMD using data from the Fifth Korea National Health and Nutrition Examination Survey, which was conducted in 2010. Our data were drawn from a relevant population within the survey's range of participants, yielding a total of 4,138 subjects aged 20–93 years (1,133 men <50 years, 946 men ≥50 years, 1,332 premenopausal women, and 727 postmenopausal women). Percent body fat, fat mass (FM), lean mass (LM), and BMD of the total hip, lumbar spine, and arm were measured in the original survey using dual-energy X-ray absorptiometry. Relationships between FM and BMD were evaluated using multiple linear regression analyses. LM was the strongest determinant of BMD. Although FM also showed a significant positive correlation, even after adjusting for LM, with total hip and lumbar spine BMD in men ≥50 years and pre- and postmenopausal women, this positive correlation was not observed in the arm. In an analysis of obese and non-obese subgroups, the positive correlation between FM and BMD disappeared in obese subjects. Furthermore, FM and BMD exhibited a negative correlation in premenopausal obese women. These results suggest that FM contributes to BMD primarily through mechanical loading. FM, then, is not beneficial and may be detrimental to bone health in obese people.

Keywords Bone density · Lean mass · Fat mass · Obesity · Adipose tissue

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Introduction

Osteoporosis is a serious problem in the elderly because it can lead to osteoporotic fractures, which are associated with increased morbidity and mortality [1]. Previous studies have demonstrated that bone mineral density (BMD) is a better long-term predictor of mortality than either blood pressure or serum cholesterol levels [2, 3]. Many genetic and environmental factors influence BMD and the development of osteoporosis, and body weight is one of these [4]. Because of the adaptive response of bone to mechanical loading, a high body weight is widely considered to be a protective factor in bone health [4].

Many researchers have focused on the effects of body composition, rather than simply body weight, on BMD. Measuring body composition involves breaking down body weight into its two main components, lean mass (LM) and

fat mass (FM). In most studies, LM has shown a positive correlation with BMD of the spine, hip, and whole body [5–7]. This positive correlation has been observed regardless of the age, sex, or menopausal status of the subjects. In early studies, FM was also considered to have a beneficial effect on BMD [8]. However, subsequent studies of the effects of FM on BMD have shown conflicting results [7–10]. Some studies have reported that FM is an important determinant of BMD [8]. However, other studies have reported a negative association [7, 9, 10] or no association [11, 12] between FM and BMD.

These discrepancies in the reported effects of FM on BMD can be explained by differences in the study design. In these studies, the populations studied differed in age, sex, and menopausal status [5, 13–17], and most data were drawn from local or regional areas [5, 10, 13] or medical records from healthcare centers [7, 16]. The definition of body fat (percentage or absolute weight) also differed among the studies, and most studies used only a single parameter to measure it [e.g., percent body fat (%BF) or FM] [5, 11, 13, 16]. Moreover, these studies used different adjusted covariables and analytical methods. To resolve the ambiguities created by these variations, our investigation used measures of both %BF and FM at various body sites drawn from data collected in a nationwide survey.

Materials and methods

Data source and study population

The data used in this study were drawn from the Fifth Korea National Health and Nutrition Examination Survey (KNHANES V-1), conducted in 2010 by the Korea Centers for Disease Control and Prevention. KNHANES V-1 was a nationwide, representative survey of 8,958 people in 3,840 households. From this pool of subjects, those aged 20 years or older who had completed surveys on height, body weight, body composition, BMD, serum 25-hydroxyvitamin D levels, menopausal status, smoking, alcohol consumption, and physical activity were selected. Subjects who had a history of stroke, myocardial infarction, angina, rheumatoid arthritis, thyroid disease, renal failure, liver cirrhosis, chronic obstructive pulmonary disease, or bilateral oophorectomy, and subjects who had undergone estrogen treatment for longer than a month, had lost more than 10 kg weight in the preceding year, or had been bedridden for more than 20 days in the preceding month were excluded. We also excluded subjects who had tuberculosis, cancer, or osteoporosis treatment at the time of the survey. Ultimately, data from 4,138 subjects, all of whom provided informed consent, were used. This study

was approved by the institutional review board of Seoul National University Hospital (IRB No. E-1207-001-414).

Measurements

In the original survey, height, body weight, and waist circumference were measured using standard protocols. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared (kg/m^2). Obesity was defined as a BMI greater than 25 kg/m^2.

Body composition and BMD were measured using dual-energy X-ray absorptiometry (DXA; DISCOVERY-W fan-beam densitometer; Hologic, Bedford, MA, USA) and standard procedures. FM was defined as whole-body FM. LM was defined as body mass minus FM. Soft lean mass (SLM) was defined as LM minus bone mineral content; in the extremities, SLM indicated muscle mass. Arm BMD was measured in the course of a whole-body scan for body composition analysis. The left arm was selected for analysis. The lumbar spine (L1–L4) and total hip BMD were measured in individual sessions conducted for detecting osteoporosis. Total hip BMD was measured in the left hip except in subjects who had received a left hip implant. Serum 25-hydroxyvitamin D concentration was measured with a radioimmunoassay kit (DiaSorin, Stillwater, MN, USA).

Smoking status, alcohol consumption, and physical activity were assessed with a self-administered questionnaire. Smoking status was divided into two categories, current smoker and non-smoker. High-risk alcohol consumption was defined as consuming seven or more drinks for men or five or more drinks for women on a single occasion at least once a week. Physical activity was evaluated using the Korean version of the International Physical Activity Questionnaire–Short Form (IPAQ-SF), which contains three domains: vigorous activity, moderate-intensity activity, and walking. Vigorous activity is defined as at least 20 min per day of vigorous activity on 3 or more days per week. Moderate-intensity activity is defined as at least 30 min of moderate-intensity activity on 5 or more days per week. Walking is defined as at least 30 min per day of walking on 5 or more days per week. These categorizations were based on the classification scheme in KNHANES V-1.

Statistical analysis

All subjects were categorized into the following groups: men <50 years, men ≥50 years, premenopausal women, and postmenopausal women. The data are presented as mean ± standard deviation for continuous variables and as a percentage for categorical variables. Differences between different age groups of the same sex were compared using

Student's t test for continuous variables. Pearson's χ^2 test was used to compare differences in distribution between categorical variables. Pearson's correlation analysis was performed between body size or body composition variables and BMD.

Multiple linear regression models were used to evaluate the effects of body fat on BMD. Model 1 included body weight and %BF and model 2 included FM and LM as independent variables for evaluating the effects of pure body fat on BMD. To assess the effects of FM in the presence and absence of obesity, subgroup analyses of obese and non-obese subjects were performed. To evaluate the effects of abdominal obesity on BMD, waist circumference was added to model 2. The effects of the relative distribution of fat and muscle mass on regional BMD were also evaluated. In the arm BMD analysis, arm FM to total FM (AFM/TFM) ratio and arm SLM to total SLM (ASLM/TSLM) ratio were included as independent variables in a multiple linear regression model adjusted by FM and LM. Similarly, leg FM to total FM (LFM/TFM) ratio and leg SLM to total SLM (LSLM/TSLM) ratio were included as

independent variables in the total hip BMD analysis. To adjust for other factors affecting BMD, all the aforementioned regression models accounted for age, height, serum 25-hydroxyvitamin D level, smoking status, alcohol consumption status, and physical activity. All the regression analyses used the enter method to compare the effects of body composition on BMD among the various groups and body sites. PASW Statistics version 18 (SPSS, Chicago, IL, USA) was used to conduct all analyses. $P < 0.05$ was considered statistically significant.

Results

General characteristics

A total of 4,138 subjects, including 1,133 men <50 years, 946 men ≥50 years, 1,332 premenopausal women, and 727 postmenopausal women, were examined in this study. The subjects' general characteristics are shown in Table 1. Men <50 years exhibited a higher BMI and a greater prevalence

Table 1 Subject characteristics

	Men		Women	
	Age <50 ($n = 1,133$)	Age ≥50 ($n = 946$)	Premenopausal ($n = 1,332$)	Postmenopausal ($n = 727$)
Age (years)	36.7 ± 7.5	62.5 ± 8.4[a]	36.4 ± 8.3	62.5 ± 9.2[b]
Height (cm)	172.5 ± 5.8	167.0 ± 5.7[a]	159.7 ± 5.5	152.9 ± 5.8[b]
Body weight (kg)	72.2 ± 10.6	66.3 ± 9.4[a]	57.0 ± 8.9	56.6 ± 8.7
BMI (kg/m^2)	24.2 ± 3.2	23.7 ± 2.8[a]	22.4 ± 3.3	24.2 ± 3.4[b]
Obesity (%)	39.2	32.4[a]	19.1	35.9[b]
Waist circumference (cm)	84.2 ± 23.0	85.3 ± 8.5	74.4 ± 8.9	82.1 ± 9.1[b]
Percent body fat (%)	23.4 ± 5.6	23.3 ± 5.1	33.2 ± 5.2	35.4 ± 5.5[b]
Fat mass (kg)	17.1 ± 5.8	15.6 ± 4.8[a]	19.0 ± 5.2	20.2 ± 5.5[b]
Lean mass (kg)	54.6 ± 6.5	50.3 ± 6.2[a]	37.6 ± 4.8	36.1 ± 4.4[b]
25-Hydroxyvitamin D (ng/ml)	18.1 ± 5.9	21.0 ± 7.4[a]	15.7 ± 5.6	17.8 ± 6.7[b]
Current smoker (%)	52.6	31.8[a]	5.8	5.6
High-risk alcohol consumption (%)	40.6	30.2[a]	11.3	4.3[b]
Vigorous intensity PA (%)	18.3	18.5	13.00	9.40[b]
Moderate-intensity PA (%)	10.7	11.3	9.6	12.8[b]
Walking (%)	38.9	44.3[a]	37.4	41.3
Total hip BMD (g/cm^2)	0.99 ± 0.12	0.92 ± 0.12[a]	0.89 ± 0.1	0.77 ± 0.12[b]
Lumbar spine BMD (g/cm^2)	0.98 ± 0.12	0.95 ± 0.15[a]	0.98 ± 0.12	0.81 ± 0.14[b]
Arm BMD (g/cm^2)	0.82 ± 0.06	0.81 ± 0.08[a]	0.68 ± 0.05	0.63 ± 0.06[b]

Data are expressed as mean ± standard deviation for continuous variables or a percentage (%) for categorical variables

Differential analysis for each continuous variable was performed by the Student's t test

Differential analysis in distribution for each categorical variables was performed by χ^2 test

BMI body mass index, *PA* physical activity, *BMD* bone mineral density

$P < 0.05$ was considered to be statistically significant

[a] A significant difference between men <50 years and men ≥50 years

[b] A significant difference between pre- and postmenopausal women

of obesity than men ≥ 50 years, but waist circumference and %BF did not differ between younger and older men. Postmenopausal women showed a higher BMI, prevalence of obesity, waist circumference, and %BF than premenopausal women.

Effects of body composition on BMD

Body weight, %BF, FM, and LM showed significant positive correlations with all areas of BMD except %BF in men <50 years with all areas of BMD and %BF in men ≥ 50 years with arm BMD (Table 2). Waist circumference also showed significant positive correlations with all areas of BMD except the lumbar spine BMD in men <50 years (Table 2). To evaluate the effects of pure body fat on BMD, %BF was adjusted by body weight (model 1), and FM was adjusted by LM (model 2). In model 1, body weight was positively correlated with BMD in all three sites, and %BF was negatively correlated with BMD in all three sites except the lumbar spine of postmenopausal women (Table 3). In model 2, which included FM and LM instead of body weight and %BF, FM exhibited a positive correlation with total hip and lumbar spine BMD in men ≥ 50 years and pre- and postmenopausal women (Table 3). When controlled for LM, FM showed the strongest correlation with lumbar spine BMD in premenopausal women ($\beta = 0.147$, $P < 0.001$). LM, on the other hand, exhibited a positive correlation with BMD in all three sites, and the β-values for LM were stronger than for FM. Additional data about the correlation of adjusted covariables such as age and height with BMD are given in Supplementary Table 1 (Online Resource 1).

Different effects of FM on BMD depending on the presence of obesity

Subgroup analyses evaluated whether the effects of FM are different in obese and non-obese subjects (Table 4). In non-obese subjects, FM was positively correlated with total hip and lumbar spine BMD in men ≥ 50 years and both pre- and postmenopausal women. However, no significant correlation between FM and total hip or lumbar spine BMD was observed in obese subjects of any age or either sex. For arm BMD, there was no significant correlation between FM

Table 2 Bivariate correlations between BMD and body weight-related parameters

	Men		Women	
	Age <50	Age ≥ 50	Premenopausal	Postmenopausal
Total hip BMD				
Body weight (kg)	0.328***	0.477***	0.463***	0.418***
BMI (kg/m²)	0.303***	0.428***	0.443***	0.285***
Percent body fat (%)	0.002	0.073*	0.177***	0.136***
Fat mass (kg)	0.139***	0.259***	0.361***	0.298***
Lean mass (kg)	0.396***	0.514***	0.455***	0.443***
Waist circumference (cm)	0.088**	0.290***	0.366***	0.184***
Lumbar spine BMD				
Body weight (kg)	0.268***	0.403***	0.404***	0.369***
BMI (kg/m²)	0.211***	0.345***	0.359***	0.241***
Percent body fat (%)	0.020	0.141***	0.165***	0.120**
Fat mass (kg)	0.126***	0.271***	0.317***	0.270***
Lean mass (kg)	0.316***	0.395***	0.389***	0.386***
Waist circumference (cm)	0.051	0.298***	0.352***	0.176***
Arm BMD				
Body weight (kg)	0.340***	0.361***	0.411***	0.406***
BMI (kg/m²)	0.291***	0.285***	0.361***	0.263***
Percent body fat (%)	0.021	−0.037	0.064*	0.092*
Fat mass (kg)	0.160***	0.133***	0.263***	0.273***
Lean mass (kg)	0.390***	0.433***	0.457***	0.449***
Waist circumference (cm)	0.105***	0.224***	0.382***	0.203***

Correlation analyses were performed with Pearson's correlation analyses

BMD bone mineral density, *BMI* body mass index

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Table 3 Multiple linear regressions of BMD on body composition

	Men		Women	
	Age <50 (β)	Age ≥50 (β)	Premenopausal (β)	Postmenopausal (β)
Model 1				
Total hip BMD				
Body weight	0.565***	0.593***	0.583***	0.410***
Percent body fat	−0.302***	−0.201***	−0.149***	−0.111**
Adjusted R^2	0.184	0.300	0.230	0.427
Lumbar spine BMD				
Body weight	0.363***	0.463***	0.429***	0.342***
Percent body fat	−0.170***	−0.088*	−0.070*	−0.079
Adjusted R^2	0.101	0.172	0.169	0.266
Arm BMD				
Body weight	0.502***	0.475***	0.486***	0.427***
Percent body fat	−0.258***	−0.248***	−0.216***	−0.161***
Adjusted R^2	0.187	0.204	0.241	0.388
Model 2				
Total hip BMD				
Fat mass	−0.029	0.072*	0.143***	0.105**
Lean mass	0.481***	0.501***	0.441***	0.302***
Adjusted R^2	0.185	0.305	0.236	0.430
Lumbar spine BMD				
Fat mass	0.005	0.125***	0.147***	0.112**
Lean mass	0.303***	0.372***	0.302***	0.237***
Adjusted R^2	0.103	0.176	0.169	0.267
Arm BMD				
Fat mass	−0.002	−0.032	0.005	0.071*
Lean mass	0.399***	0.426***	0.422***	0.321***
Adjusted R^2	0.177	0.202	0.245	0.388

Model 1 and 2 were adjusted for age, height, serum 25-hydroxyvitamin D, smoking status, alcohol consumption status, and physical activity (vigorous, moderate-intensity, walking)

BMD bone mineral density

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

and BMD, except for the negative correlation in premenopausal obese women ($\beta = -0.186$, $P < 0.01$).

Effects of abdominal obesity on BMD

Waist circumference, a surrogate marker of abdominal obesity, was positively correlated with BMD (Table 2). However, when controlled for FM and LM, the correlation between waist circumference and BMD was not observed, except for a positive correlation with arm BMD in premenopausal women ($\beta = 0.163$, $P < 0.01$) (Table 5). In a subgroup analysis according to the presence of obesity, this positive correlation was maintained only in the non-obese premenopausal women ($\beta = 0.133$, $P < 0.01$); no significant correlation between waist circumference and BMD

was observed in obese premenopausal women (data not shown in table).

Regional effects of fat on BMD

The correlations between regional FM and muscle mass and regional BMD are shown in Table 6. The LSLM/TSLM ratio exhibited a positive correlation with total hip BMD in all men and postmenopausal women. The ASLM/TSLM ratio displayed a positive correlation with arm BMD in all men and premenopausal women. However, neither the LFM/TFM nor the AFM/TFM ratio showed an association with any area of BMD except arm BMD in premenopausal women, which showed a negative correlation with the AFM/TFM ratio ($\beta = -0.064$, $P < 0.01$).

Table 4 Multiple linear regressions of BMD on body composition in obese and non-obese subgroups

	Men				Women			
	Age <50		Age ≥50		Premenopausal		Postmenopausal	
	Non-obese (β) (n = 689)	Obese[a] (β) (n = 444)	Non-obese (β) (n = 640)	Obese[a] (β) (n = 306)	Non-obese (β) (n = 1078)	Obese[a] (β) (n = 254)	Non-obese (β) (n = 466)	Obese[a] (β) (n = 261)
Total hip BMD								
Fat mass	−0.033	−0.043	0.087*	0.000	0.172***	−0.097	0.153***	−0.003
Lean mass	0.463***	0.320***	0.489***	0.324***	0.439***	0.313***	0.244***	0.359***
Adjusted R^2	0.160	0.110	0.272	0.116	0.175	0.082	0.408	0.409
Lumbar spine BMD								
Fat mass	0.011	−0.013	0.154***	0.05	0.176***	−0.06	0.094*	0.099
Lean mass	0.296***	0.203**	0.415***	0.151	0.328***	0.135	0.185***	0.296***
Adjusted R^2	0.087	0.063	0.155	0.098	0.148	0.082	0.286	0.184
Arm BMD								
Fat mass	−0.043	−0.012	−0.015	−0.103	0.041	−0.186**	0.057	0.038
Lean mass	0.307***	0.329***	0.329***	0.352***	0.379***	0.316***	0.277***	0.311***
Adjusted R^2	0.124	0.117	0.150	0.159	0.191	0.177	0.370	0.343

Models were adjusted for age, height, serum 25-hydroxyvitamin D, smoking status, high risk alcohol consumption and physical activity (vigorous, moderate-intensity, walking)

BMD bone mineral density

[a] Obesity was defined as BMI greater than 25 kg/m^2

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Table 5 Multiple linear regressions of BMD on waist circumference

	Men		Women	
	Age <50 (β)	Age ≥50 (β)	Premenopausal (β)	Postmenopausal (β)
Total hip BMD				
Waist circumference	0.005	−0.094	−0.095	−0.009
Adjusted R^2	0.184	0.307	0.237	0.429
Lumbar spine BMD				
Waist circumference	−0.019	−0.019	0.088	−0.01
Adjusted R^2	0.102	0.175	0.170	0.266
Arm BMD				
Waist circumference	0.017	0.035	0.163**	0.101
Adjusted R^2	0.177	0.202	0.250	0.390

Models was adjusted for age, height, fat mass, lean mass, serum 25-hydroxyvitamin D, smoking status, alcohol consumption status, and physical activity (vigorous, moderate-intensity, walking)

BMD bone mineral density

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Discussion

The effects of body composition on BMD were investigated using data from a well-organized, large-scale nationwide survey that included representative groups of different ages and sexes. In this study, LM was the strongest determinant of BMD. Although FM also showed a significant positive association with BMD, even after adjusting for LM, this relationship was not observed in the arm, a non-weight-bearing site, and it was attenuated in obese subjects. The local effects of FM were also not observed when evaluated with the LSFM/TSFM or ASFM/TSFM ratio.

Conflicting results have been reported in the literature on the effects of body fat on BMD [7–10]. These conflicts may have been caused by the different definitions of body

Table 6 Multiple linear regressions of BMD on regional fat mass and soft lean mass distribution

| | Men | | Women | |
	Age <50 (β)	Age ≥50 (β)	Premenopausal (β)	Postmenopausal (β)
Total hip BMD				
LFM/TFM ratio	−0.008	−0.053	−0.024	0.012
LSLM/TSLM ratio	0.078**	0.076**	0.019	0.085**
Adjusted R^2	0.188	0.310	0.235	0.435
Arm BMD				
AFM/TFM ratio	−0.052	−0.040	−0.064**	−0.044
ASLM/TSLM ratio	0.177***	0.144***	0.114***	0.011
Adjusted R^2	0.200	0.216	0.257	0.388

Models were adjusted for age, height, fat mass, lean mass, serum 25-hydroxyvitamin D, smoking status, alcohol consumption status, and physical activity (vigorous, moderate-intensity, walking)

BMD bone mineral density, *LFM* leg fat mass, *TFM* total fat mass, *LSLM* leg soft lean mass, *TSLM* total soft lean mass, *AFM* arm fat mass, *ASLM* arm soft lean mass

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

fat in the studies. In previous studies, %BF showed a negative correlation with BMD [18, 19], whereas FM showed inconsistent correlations with BMD [5, 7, 9, 10]. We evaluated both of two different variables, %BF and FM, in the same subjects. In our two different multiple linear regression models, these variables displayed opposite patterns of correlation; %BF was correlated negatively and FM positively with BMD. This discrepancy may be caused by the stronger relationship of BMD with LM than with FM [20]. For a given body weight, an increase in %BF indicates not only an increase of FM but also a decrease of LM, which can lead to a decrease in BMD. Therefore, a negative association between %BF and BMD does not necessarily mean that body fat exerts a negative effect on BMD. In addition, it suggests that FM, the absolute weight of body fat, may be a more appropriate parameter for evaluating the independent effects of body fat on BMD.

In this study, FM was positively correlated with BMD, and this correlation was maintained in men ≥50 years and pre- and postmenopausal women after adjusting for LM. FM is believed to contribute differently to BMD according to age and sex [5, 13–17]. It appears that FM is a more important determinant of BMD in women than in men [13–15] and in older people than in younger people [5, 16, 17]. These results are consistent with our data. Several hypotheses have been suggested to account for the beneficial effects of FM on BMD. First, FM can contribute to BMD by increasing mechanical loading on the bone. In this study, although FM showed a significant association with BMD in the lumbar spine and total hip, it showed no such association with BMD in the arm. Because the arm is a minimally weight-bearing site, these results support that mechanical loading is a major contributing factor to the effects of FM on BMD. Second, FM can have a role as an important source of estrogen in postmenopausal women.

Adipose tissues can synthesize estrogens from androgen precursors. Increased estrogen production by adipose tissues is believed to have a protective effect on BMD, especially in postmenopausal women [14, 21]. It is also reported that in postmenopausal women, FM was positively correlated with BMD, but hormone replacement therapy attenuated the effect of FM on BMD [22]. Last, insulin and insulin-like growth factor 1 have been proposed as mediators of the effects of FM on bone [23, 24].

In this study, the positive associations between FM and BMD disappeared in obese subjects whereas LM consistently showed a positive association with BMD (Table 3). In contrast, in obese premenopausal women, FM was negatively correlated with arm BMD (Table 4). These results are consistent with recent studies reporting a higher risk of humerus fracture in obese postmenopausal women [25, 26]. This observation suggests that obesity might not be protective against osteoporosis and fracture. One possible explanation for the harmful effects of body fat is that adipose tissues secrete adipokines such as adiponectin and leptin [27]. Negative correlations between serum adiponectin or leptin levels and BMD have been reported [28–30], and it may be speculated that adipokines counterbalance the mechanically beneficial effects of FM on BMD in obese people.

The effects of FM on BMD can differ depending on the type and location of the FM. Although most previous studies have reported a negative association between visceral fat and BMD [31, 32], some studies have reported a positive association [32, 33]. In this study, abdominal obesity was evaluated using waist circumference. Waist circumference cannot distinguish visceral fat from subcutaneous fat. Therefore, when controlled for total FM, waist circumference was not correlated with BMD except arm BMD in premenopausal women. In premenopausal women,

waist circumference was positively correlated with arm BMD. Because visceral fat is relatively low in premenopausal women [34, 35], waist circumference cannot accurately represent it in this group, in contrast to men and postmenopausal women [36].

LM and FM may have systemic or local effects on BMD. To ascertain the local effects of muscle and fat on BMD, a task that few studies have attempted, regional LM and FM ratios were calculated. LSLM/TSLM and ASLM/TSLM ratios were positively correlated with total hip and arm BMD, respectively, but the LFM/TFM and AFM/TFM ratios did not show any significant correlations except in premenopausal women. This result means that muscle may have a local beneficial effect but fat does not. Muscle contraction may provide an explanation for the local effects of muscle on bone. Because larger muscles exert higher tensile forces on the bones to which they are attached, regional muscle can increase regional BMD [37]. This explanation is supported by the positive correlation between muscle strength and BMD in both upper and lower limbs [38–40]. This regional effect of LM explains the stronger correlation of LM and BMD compared to FM and BMD.

There are a few limitations to the present study. Because it is cross-sectional, it cannot establish a causal relationship between FM and BMD. Other factors such as nutrition and occupation, not included in this study, also influence BMD. In addition, waist circumference is a relatively imprecise indicator of visceral fat compared to measurements made by computed tomography (CT) or magnetic resonance imaging (MRI) scans.

In conclusion, this study demonstrated a positive correlation between FM and total hip and lumbar spine BMD in men ≥50 years and pre- and postmenopausal women. However, a positive relationship between FM and BMD was not observed in obese subjects. FM was not associated with arm BMD in men or premenopausal women. Furthermore, FM showed a negative association with arm BMD in obese premenopausal women. These results suggest that FM contributes to BMD mainly by means of mechanical loading, and that FM is not beneficial and might be harmful to bone health in obese individuals.

Conflict of interest All authors have no conflict of interest.

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