

Associations of fat mass and fat distribution with bone mineral density in pre- and postmenopausal Chinese women

X. Fu · X. Ma · H. Lu · W. He · Z. Wang · S. Zhu

Received: 17 December 2009 / Accepted: 27 January 2010 / Published online: 20 March 2010
© International Osteoporosis Foundation and National Osteoporosis Foundation 2010

Abstract

Summary Fat mass (FM) is closely related to bone mineral density (BMD). However, the associations of FM and fat distribution with BMD in pre- and postmenopausal women are still poorly understood. The present study showed android fat mass accumulation after menopause had a negative association with BMD.

Introduction FM is closely related to BMD. However, it is unknown whether FM and central fat distribution have different associations with BMD in pre- and postmenopausal women. The study aims to investigate the associations of FM and fat distribution with BMD in pre- and postmenopausal Chinese women.

Methods Two hundred sixty premenopausal and 267 postmenopausal women aged 18 to 79 years were analyzed. Lean mass (LM), FM, percent body fat (%BF), android FM, gynoid FM, and total and regional BMD were measured using dual-energy X-ray absorptiometry. Fat distribution was assessed by android to gynoid FM ratio (AOI). Multiple

regression analysis was performed to examine the associations of BMD with FM, LM, and AOI.

Results FM, %BF, android FM, and AOI were significantly higher, whereas total and regional BMD were significantly lower in postmenopausal women (all $p < 0.01$). In premenopausal women, FM was positively associated with total and regional BMD (all $p < 0.05$). AOI had no significant association with BMD. In postmenopausal women, FM was significantly associated with total and regional BMD even additionally adjusting for LM (all $p < 0.01$). AOI had significantly negative association with total, head, arm, and leg BMD (all $p < 0.05$). The results remained unchanged when replacing FM with %BF.

Conclusions There were different associations of FM and fat distribution with BMD in pre- and postmenopausal Chinese women. Increased central body fat had a negative association with BMD. Our findings may have significant implications in the prevention of menopause-related osteoporosis through reducing centralized fat deposition.

Keywords Bone mineral density · Fat distribution · Fat mass · Menopausal status

X. Fu · H. Lu · W. He · Z. Wang · S. Zhu (✉)
Obesity and Body Composition Research Center,
School of Public Health, Zhejiang University,
388 Yu-hang-tang Road,
Hangzhou, Zhejiang 310058, China
e-mail: zsk@zju.edu.cn

X. Ma
Injury Research Center, Medical College of Wisconsin,
Milwaukee, WI, USA

Z. Wang
Obesity Research Center, St. Luke's-Roosevelt Hospital,
College of Physicians and Surgeons, Columbia University,
New York, NY, USA

Introduction

Osteoporosis is an important public health problem worldwide due to its high morbidity in aging populations especially for women. Bone mineral density (BMD) has been widely accepted as a surrogate measure for the diagnosis of osteopenia and osteoporosis [1, 2]. A number of genetic and environmental factors have been demonstrated to affect BMD [3, 4]. Body weight is one of the important determinants [5–7]. However, the relative effect

of lean mass (LM) and fat mass (FM), the components of body weight, on BMD remains controversial. In addition, the associations between FM and BMD in different ethnicities are inconsistent. Several studies have reported that FM is positively related to BMD in whites and Japanese women [8–11], whereas other research groups have suggested that excessive FM may not protect against decreases in bone mass [12–15]. In a large-scale sample of Chinese and white subjects, FM of both ethnicities was negatively correlated with bone mass when body weight was adjusted [12]. Although previous studies showed either a positive or negative effect of whole body FM on bone mass, regional fat distribution may also influence bone mass independently of total body FM [16–21]. Yet, the results on BMD and central obesity are inconsistent. These conflicting clinical and epidemiologic studies suggest a complex influence of FM and fat distribution on BMD.

FM is a more important determinant of BMD in women than in men, and the effect of FM on BMD in women may differ according to different menopausal status [9, 22]. Menopause is accompanied by dramatic body composition changes, including an increase in total body and central adiposity (android region), decrease in gynoid fat proportion, and a significant decrease in total and regional BMD [23, 24]. Postmenopausal women with a low body weight, low percent body fat (%BF), or low body mass index are at an increased risk of low bone mass and rapid bone loss, both of which are independent contributing factors to postmenopausal osteoporosis [25]. However, a contrary finding also exists [13]. The roles of FM and fat distribution on BMD in different estrogenic status, i.e., pre- and postmenopause, are still unclear. In addition, studies on the association between postmenopausal fat distribution and BMD based on Asian populations, whose body composition and lifestyle are possibly different from western populations [26], are limited. The aim of the present study was to explore the different associations of FM and central fat distribution with BMD in pre- and postmenopausal Chinese women.

Subjects and methods

Subjects

A total of 547 healthy women aged from 18 to 79 years old were included from the participants in a community-based chronic disease prevention study conducted by the Obesity and Body Composition Research Center of Zhejiang University School of Public Health from 2008 to 2009. Women with known metabolic bone diseases or those under any medications likely to influence BMD were excluded from the study. Twenty women were excluded because of

hysterectomy. In the end, 260 premenopausal women and 267 postmenopausal women were included in the analysis. Written informed consent was obtained and the study was approved by the Ethics Committee of the Second Affiliated Hospital of Zhejiang University.

Variable definition

Subjects completed a questionnaire on demographic, lifestyle, and menopausal information. Smoking was categorized as nonsmokers and smokers. Drinking was coded as yes or no. Drinkers were those who drank an alcoholic beverage less than one time per day during the past month. Nondrinkers were those who drank no beer, wine, or hard liquor during the past month. None of the subjects were heavy drinkers. Regular menstruation was defined as the 25–35-day interval between menstrual on-set. Menopause was designated if there was a complete natural cessation of menses for more than 12 months. Years since menopause (YSM) for postmenopausal women were recorded.

Anthropometry and body composition measurement

Physical measurements were obtained based on standardized protocol. Height was measured without shoes to the nearest 0.1 cm, weight with only light clothing to the nearest 0.1 kg (Detecto, USA). All values were recorded as the mean of three measures. Body mass index (BMI) was calculated as body weight (in kilograms) divided by height (in meters) squared.

Dual-energy X-ray absorptiometry (DXA; software version 11.40.004; GE-lunar Prodigy, WI, USA) was used to measure LM, FM, percent body fat (%BF), android FM, gynoid FM, and total and regional BMD through whole-body scans. For the android region, the lower boundary is at pelvis cut. The upper boundary is above pelvis cut by 20% of the distance between pelvis and femoral neck cuts. Lateral boundaries are the arm cuts. The gynoid region is defined by the upper boundary below the pelvis cut line by 1.5 times the height of the android region. The height of the gynoid region is equal to two times the height of the android region. Lateral boundaries are the outer leg cuts. Body fat distribution was assessed by android to gynoid fat ratio (AOI). Regional BMD refers to the mean bone density in the regions of head, rib, arm, spine, trunk, hip, and leg. DXA was calibrated daily using a standard phantom provided by the manufacturer. Measurements were maintained within the manufacturer's precision standards of $\leq 0.8\%$.

Statistical analysis

Basic characteristics of subjects were compared by Student's *t* test for continuous variables and by χ^2 test for categorical

variables. Because a significant interaction between AOI and menopausal status was found for the total and regional BMD, pre- and postmenopausal women were analyzed separately to evaluate the associations of BMD with AOI, FM, and LM in multiple regression models. In model 1, we first explored the associations of FM and AOI with total body and regional BMD. We then added LM into model 1 to investigate the associations of LM with total body and regional BMD with the presence of FM and AOI in the model (model 2). In addition, the regression was rerun replacing FM with %BF. Covariates such as age, height, smoking, drinking, and YSM in postmenopausal women were included in the regression models. SPSS (version 16.0 for Windows, SPSS Inc., Chicago, IL, USA) was used for analysis. All statistical tests were two-tailed, and $p < 0.05$ was considered significant.

Results

Descriptive statistics

The basic characteristics of the subjects are shown in Table 1. Compared to premenopausal women, postmenopausal women were older, shorter, weighed more, and had a higher BMI (all $p < 0.01$). There was no significant difference in drinking and smoking habits between the two groups (both $p > 0.05$). FM, %BF, android FM, and AOI were significantly higher in postmenopausal women than in premenopausal women (all $p < 0.01$). LM and gynoid FM had no significant difference (both $p > 0.05$). Total body and regional BMD were significantly lower in postmenopausal women than in premenopausal women (all $p < 0.01$).

Multiple regression analysis

The results of multiple linear regression analysis are shown in Table 2. In model 1, both in pre- and postmenopausal women, FM was significantly positive association with total body and regional BMD (all $p < 0.05$), whereas AOI had no significant relationships with total body and regional BMD except for head BMD in postmenopausal women ($p < 0.05$). When additionally adjusted for LM (model 2), in premenopausal women, the significant association between FM and BMD was eliminated except for the regional BMD of rib, spine, and trunk. While AOI did not have any significant associations with total body and regional BMD, LM had a significantly positive association with BMD in all body regions (all $p < 0.01$). In postmenopausal women, FM was significantly associated with total body and regional BMD, even after additionally adjusting for LM

Table 1 Characteristics of the subjects by menopausal status

	Premenopausal (<i>n</i> =260)	Postmenopausal (<i>n</i> =267)	<i>p</i> value
Age (years)	38.0±8.6	61.0±7.2	<0.01
Height (cm)	157.5±5.5	155.4±5.4	<0.01
Weight (kg)	55.8±8.3	58.1±8.0	<0.01
BMI (kg/m ²)	22.5±3.1	24.1±3.0	<0.01
Body composition measures			
FM(kg)	16.9±5.4	19.5±5.4	<0.01
Android FM (kg)	1.6±0.6	2.0±0.6	<0.01
Gynoid FM (kg)	3.2±0.8	3.2±0.8	0.96
LM (kg)	36.3±3.8	36.3±3.6	0.80
%BF (%)	29.7±5.8	33.0±5.5	<0.01
AOI	0.5±0.1	0.6±0.2	<0.01
Body mineral density measures (g/cm ²)			
Total body	1.12±0.08	1.03±0.10	<0.01
Head	2.25±0.28	2.02±0.32	<0.01
Rib	0.64±0.05	0.60±0.06	<0.01
Arm	0.82±0.06	0.75±0.08	<0.01
Spine	1.04±0.11	0.92±0.12	<0.01
Trunk	0.89±0.07	0.82±0.08	<0.01
Hip	1.08±0.09	0.99±0.10	<0.01
Leg	1.18±0.10	1.09±0.12	<0.01
Drinkers (%)	27	28	0.51
Smokers (%)	4	3	0.39

Student's *t* test for continuous variables and χ^2 test for categorical variables

(all $p < 0.01$). LM was also significantly associated with total body and regional BMD (all $p < 0.05$). AOI had a significantly negative association with total body, head, arm, and leg BMD in postmenopausal women (all $p < 0.05$), while such an association was not found in premenopausal women. We further replaced FM with %BF and reran the regression models (Table 3). The results were almost identical. %BF was significantly associated with BMD in post- but not in premenopausal women. When additionally adjusting for LM, the associations between %BF and BMD had no changes in pre- and postmenopausal women. LM was significantly associated with BMD both in pre- and in postmenopausal women. AOI was negatively associated with total body, head, arm, and leg BMD in postmenopausal women. Covariates such as smoking, drinking, and YSM had no significant associations with BMD in regression models. Height had a positive association with BMD, but such an association was eliminated when there was additionally adjusted for LM. Age showed a positive association in premenopausal women with BMD and a negative association in postmenopausal women with BMD (data not shown).

Table 2 β coefficients of FM, AOI, and LM for total body and regional BMD from multiple regression analysis in pre- and postmenopausal women

	Total	Head	Rib	Arm	Spine	Trunk	Hip	Leg
Model 1								
Premenopausal								
FM	0.209**	0.151*	0.421***	0.166*	0.318***	0.304***	0.219**	0.228**
AOI	0.017	−0.002	0.029	0.021	−0.081	0.019	0.007	0.051
Postmenopausal								
FM	0.377***	0.308***	0.553***	0.310***	0.470***	0.461***	0.378***	0.338***
AOI	−0.077	−0.118*	0.075	−0.057	0.002	0.051	0.026	−0.082
Model 2 (additional adjusted for LM)								
Premenopausal								
FM	0.082	0.073	0.272***	0.021	0.226**	0.186*	0.127	0.103
AOI	−0.037	−0.035	−0.033	−0.04	−0.120	−0.031	−0.031	0.000
LM	0.397***	0.244**	0.462***	0.450***	0.286**	0.367***	0.284**	0.388***
Postmenopausal								
FM	0.296***	0.264***	0.482***	0.199**	0.418***	0.376***	0.299***	0.268***
AOI	−0.134*	−0.149*	0.025	−0.136*	−0.034	−0.008	−0.029	−0.131*
LM	0.290***	0.158*	0.255***	0.400***	0.184**	0.303***	0.284***	0.249**

Covariates included in the regression model were age, height, smoking status, drinking status, and years since menopause in postmenopausal women

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table 3 β coefficients of %BF, AOI, and LM for total body and regional BMD from multiple regression analysis in pre- and postmenopausal women

	Total	Head	Rib	Arm	Spine	Trunk	Hip	Leg
Model 1								
Premenopausal								
%BF	0.076	0.063	0.245**	0.032	0.204**	0.167*	0.099	0.099
AOI	0.087	0.045	0.123	0.092	−0.020	0.091	0.059	0.120
Postmenopausal								
%BF	0.275***	0.245***	0.442***	0.189**	0.379***	0.345***	0.287***	0.250***
AOI	−0.035	−0.089	0.128*	−0.013	0.046	0.101	0.066	−0.045
Model 2 (additional adjusted for LM)								
Premenopausal								
%BF	0.063	0.055	0.228***	0.018	0.193**	0.154*	0.111	0.086
AOI	−0.035	−0.033	−0.037	−0.040	−0.125	−0.033	−0.035	−0.002
LM	0.424***	0.268**	0.552***	0.457***	0.360***	0.429***	0.326***	0.422***
Postmenopausal								
%BF	0.261***	0.236***	0.427***	0.172**	0.367***	0.329***	0.273***	0.238***
AOI	−0.141*	−0.156*	0.013	−0.139*	−0.043	−0.017	−0.038	−0.138*
LM	0.396***	0.252**	0.426***	0.471***	0.333***	0.437***	0.390***	0.345**

Covariates included in the regression model were age, height, smoking status, drinking status, and years since menopause in postmenopausal women

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Discussion

It has been known for some time that body weight is a significant predictor of hip fracture risk in women [27]. However, the influence of its major components, FM and LM, on BMD remains unclear. The present study explored the associations of total body FM and fat distribution with BMD in pre- and postmenopausal Chinese women. Our study found that FM and android fat distribution have different associations with BMD in post- but not in premenopausal women. The negative association between android fat distribution and BMD in postmenopausal women yields valuable information that positive control central adiposity deposition during menopause transition has important significance not only to metabolic diseases but also to postmenopausal osteoporosis.

The observed positive association between FM and BMD in postmenopausal women was in accordance with previous studies [8, 22]. Although the precise mechanism of the relationship between FM and BMD in postmenopausal women is not clear, several potential theories have been proposed. One straightforward explanation is that greater FM imposes a greater mechanical stress on bones, and in response, bone mass increases to accommodate the greater load. However, FM accounts for only 25% of body weight in normal-weight women. Therefore, weight-associated gravitational forces may be insufficient to explain the impact of FM on bone [12]. Recent evidence has shown that adipose tissue can release more than 20 adipocytokines into circulation, which led some to suggest that adiposity influences BMD through alternative mechanisms such as adipocyte-dependent hormonal factors [28, 29]. In postmenopausal women, adipocytes are important sources of estrogen production, and estrogen is known to inhibit bone resorption by inducing osteoclasts apoptosis [30]. Adipocyte-derived hormones such as adiponectin and leptin may also play roles in regulating BMD. Vitro studies showed that adiponectin inhibited osteoclasts bone-resorption activity [31]. Leptin, produced by adipocytes, is also positively correlated with BMD in women [32, 33].

Although bone mass increased with total body FM in our study, BMD was negatively associated with central adiposity accumulation, indicated as AOI, in postmenopausal women. A prospective study showed the significant association between increased intra-abdominal fat and change of C-reactive protein, tissue plasminogen activator antigen, leptin, and adiponectin in women going through the menopausal transition [34]. These visceral adiposity-associated inflammatory markers and adipokines may exert detrimental influence on bone metabolism [33, 35–38]. A recent study using computerized tomography to measure abdominal fat found a negative effect of visceral fat on femoral bone phenotypes [20]. In the present study,

adipocyte-derived hormonal factors were not measured. The associations between FM and fat distribution with BMD in postmenopausal women could not be explained in terms of either biomechanical or biochemical function of FM. Further studies should be conducted to address the underlying mechanism.

The findings of this study confirmed previous studies that LM has a strong positive effect on bone mass [39, 40]. The positive effect of FM on BMD in premenopausal women was eliminated when additionally adjusting for LM. This implies that bone strength is primarily determined by the dynamic loads from muscle force, but not by the static loads, such as FM [41]. Furthermore, the effect of ovarian estrogen may override the effect of aromatized estrogen derived from FM on BMD in premenopausal women [42]. After menopause, some changes, including a decrease in LM and increase in FM, occur in body composition, and the biochemical functions of FM may become prominent.

The major strength of the present study is that fat distribution was examined using a regional analysis of whole-body DXA scan. Android to gynoid fat ratio, which is closely related to metabolic disturbance in a previous study, is significantly greater in postmenopausal women than in premenopausal women [43]. We used AOI as the central adiposity indicator to investigate the association with BMD rather than waist–hip circumference ratio and trunk–leg fat ratio [16, 17] and found that an android type of fat distribution in postmenopausal women was negatively associated with the BMD of total body and major body regions. This is the first study to explore the association between AOI and BMD. The significant association between AOI and BMD suggests that central adipose tissue is not only correlated with metabolic diseases but also with bone health.

Limitations to the present study should be noted. First, although this is the first study using AOI to show the associations with BMD in women, the subjects are all Chinese and the results may not be generalized to other ethnicities. Second, our data are cross-sectional, so that we are not able to draw the cause and effect relationship between FM and fat distribution with BMD. Third, in the present study, we did not measure the femoral neck or lumbar spine sites to define the diagnosis of osteoporosis. Several studies have used mean BMD to explore the association between body composition and osteoporosis [13, 19, 44, 45]. In addition, as identified in the studies, the diagnostic differentiation of the total body BMD is similar to that of the lumbar spine and femoral neck sites BMD in women [46–48]. Finally, body weight was not included as a controlling variable due to its collinearity with FM and LM. The correlation coefficients between FM and body weight and between LM and body weight are 0.91 and 0.85, respectively, in our data. Including body weight in the

regression model with the presence of LM and FM caused a high multicollinearity in the regression models. In addition, a newly published study on osteoporosis in specific body composition phenotypes indicated that controlling for weight may not be an appropriate adjustment when investigating the influence of FM on BMD [49].

In conclusion, our study showed that there were different associations of FM and fat distribution with BMD in pre- and postmenopausal women. Android fat mass accumulation after menopause had a negative association with BMD. From the public health point of view, rational control weight gain and the prevention of centralized fat deposition during menopause may have significant implications in decreasing menopause-related osteoporosis.

Conflicts of interest None.

References

- Bates DW, Black DM, Cummings SR (2002) Clinical use of bone densitometry: clinical applications. *JAMA* 288:1898–1900
- NIH Consensus Development Panel on Osteoporosis Prevention, Diagnosis, and Therapy (2001) Osteoporosis prevention, diagnosis, and therapy. *JAMA* 285:785–795
- Krall EA, Dawson-Hughes B (1993) Heritable and life-style determinants of bone mineral density. *J Bone Miner Res* 8:1–9
- Ho SC, Chan SG, Yip YB, Chan CS, Woo JL, Sham A (2008) Change in bone mineral density and its determinants in pre- and perimenopausal Chinese women: the Hong Kong Perimenopausal Women Osteoporosis Study. *Osteoporos Int* 19:1785–1796
- Felson DT, Zhang Y, Hannan MT, Anderson JJ (1993) Effects of weight and body mass index on bone mineral density in men and women: the Framingham study. *J Bone Miner Res* 8:567–573
- De Laet C, Kanis JA, Odén A et al (2005) Body mass index as a predictor of fracture risk: a meta-analysis. *Osteoporos Int* 16:1330–1338
- Wardlaw GM (1996) Putting body weight and osteoporosis into perspective. *Am J Clin Nutr* 63:433S–436S
- Reid IR, Ames R, Evans MC, Sharpe S, Gamble G, France JT, Lim TM, Cundy TF (1992) Determinants of total body and regional bone mineral density in normal postmenopausal women—a key role for fat mass. *J Clin Endocrinol Metab* 75:45–51
- Reid IR, Plank LD, Evans MC (1992) Fat mass is an important determinant of whole body bone density in premenopausal women but not in men. *J Clin Endocrinol Metab* 75:779–782
- Khosla S, Atkinson EJ, Riggs BL, Melton LJ 3rd (1996) Relationship between body composition and bone mass in women. *J Bone Miner Res* 11:857–863
- Douchi T, Oki T, Nakamura S, Ijuin H, Yamamoto S, Nagata Y (1997) The effect of body composition on bone density in pre- and postmenopausal women. *Maturitas* 27:55–60
- Zhao LJ, Liu YJ, Liu PY, Hamilton J, Recker RR, Deng HW (2007) Relationship of obesity with osteoporosis. *J Clin Endocrinol Metab* 92:1640–1646
- Yu Z, Zhu Z, Tang T, Dai K, Qiu S (2009) Effect of body fat stores on total and regional bone mineral density in perimenopausal Chinese women. *J Bone Miner Metab* 27:341–346
- Hsu YH, Venners SA, Terwedow HA et al (2006) Relation of body composition, fat mass, and serum lipids to osteoporotic fractures and bone mineral density in Chinese men and women. *Am J Clin Nutr* 83:146–154
- Janicka A, Wren TA, Sanchez MM, Dorey F, Kim PS, Mittelman SD, Gilsanz VF (2007) Fat mass is not beneficial to bone in adolescents and young adults. *J Clin Endocrinol Metab* 92:143–147
- Tarquini B, Navari N, Perfetto F, Piluso A, Romano S, Tarquini R (1997) Evidence for bone mass and body fat distribution relationship in postmenopausal obese women. *Arch Gerontol Geriatr* 24:15–21
- Douchi T, Yamamoto S, Oki T, Maruta K, Kuwahata R, Nagata Y (2000) Relationship between body fat distribution and bone mineral density in premenopausal Japanese women. *Obstet Gynecol* 95:722–725
- Stewart KJ, Deregis JR, Turner KL, Bacher AC, Sung J, Hees PS, Tayback M, Ouyang P (2002) Fitness, fatness and activity as predictors of bone mineral density in older persons. *J Intern Med* 252:381–388
- Shen W, Chen J, Punyanitya M, Shapses S, Heshka S, Heymsfield SB (2007) MRI-measured bone marrow adipose tissue is inversely related to DXA-measured bone mineral in Caucasian women. *Osteoporos Int* 18:641–647
- Gilsanz V, Chalfant J, Mo AO, Lee DC, Dorey FJ, Mittelman SD (2009) Reciprocal relations of subcutaneous and visceral fat to bone structure and strength. *J Clin Endocrinol Metab* 94:3387–3393
- Kim CJ, Oh KW, Rhee EJ, Kim KH, Jo SK, Jung CH, Won JC, Park CY, Lee WY, Park SW, Kim SW (2009) Relationship between body composition and bone mineral density (BMD) in perimenopausal Korean women. *Clin Endocrinol (Oxf)* 71:18–26
- Cui LH, Shin MH, Kweon SS, Park KS, Lee YH, Chung EK, Nam HS, Choi JS (2007) Relative contribution of body composition to bone mineral density at different sites in men and women of South Korea. *J Bone Miner Metab* 25:165–171
- Ley CJ, Lees B, Stevenson JC (1992) Sex- and menopause-associated changes in body-fat distribution. *Am J Clin Nutr* 55:950–954
- Gambacciani M, Spinetti A, de Simone L, Cappagli B, Maffei S, Taponeco F, Fioretti P (1993) The relative contributions of menopause and aging to postmenopausal vertebral osteopenia. *J Clin Endocrinol Metab* 77:1148–1151
- Ravn P, Cizza G, Bjarnason NH, Thompson D, Daley M, Wasnich RD, McClung M, Hosking D, Yates AJ, Christiansen C (1999) Low body mass index is an important risk factor for low bone mass and increased bone loss in early postmenopausal women. Early Postmenopausal Intervention Cohort (EPIC) study group. *J Bone Miner Res* 14:1622–1627
- Park YW, Allison DB, Heymsfield SB, Gallagher D (2001) Larger amounts of visceral adipose tissue in Asian Americans. *Obes Res* 9:381–387
- Ensrud KE, Lipschutz RC, Cauley JA, Seeley D, Nevitt MC, Scott J, Orwoll ES, Genant HK, Cummings SR (1997) Body size and hip fracture risk in older women: a prospective study. Study of Osteoporotic Fractures Research Group. *Am J Med* 103:274–280
- Schwartz AV (2003) Diabetes mellitus: does it affect bone? *Calcif Tissue Int* 73:515–519
- Kontogianni MD, Dafni UG, Routsias JG, Skopouli FN (2004) Blood leptin and adiponectin as possible mediators of the relation between fat mass and BMD in perimenopausal women. *J Bone Miner Res* 19:546–551
- Kameda T, Mano H, Yuasa T et al (1997) Estrogen inhibits bone resorption by directly inducing apoptosis of the bone-resorbing osteoclasts. *J Exp Med* 186:489–495

31. Oshima K, Nampei A, Matsuda M, Iwaki M, Fukuhara A, Hashimoto J, Yoshikawa H, Shimomura I (2005) Adiponectin increases bone mass by suppressing osteoclast and activating osteoblast. *Biochem Biophys Res Commun* 331:520–526
32. Ritland LM, Alekel DL, Matvienko OA, Hanson KB, Stewart JW, Hanson LN, Reddy MB, Van Loan MD, Genschel U (2008) Centrally located body fat is related to appetitive hormones in healthy postmenopausal women. *Eur J Endocrinol* 158:889–897
33. Ağbaht K, Gürlek A, Karakaya J, Bayraktar M (2009) Circulating adiponectin represents a biomarker of the association between adiposity and bone mineral density. *Endocr* 35:371–379
34. Lee CG, Carr MC, Murdoch SJ, Mitchell E, Woods NF, Wener MH, Chandler WL, Boyko EJ, Brunzell JD (2009) Adipokines, inflammation, and visceral adiposity across the menopausal transition: a prospective study. *J Clin Endocrinol Metab* 94:1104–1110
35. Ozkurt B, Ozkurt ZN, Altay M, Aktekin CN, Çağlayan O, Tabak Y (2009) The relationship between serum adiponectin level and anthropometry, bone mass, osteoporotic fracture risk in postmenopausal women. *Ekleml Hastalıkları Cerrahisi* 20:78–84
36. Lenchik L, Register TC, Hsu FC, Lohman K, Nicklas BJ, Freedman BI, Langefeld CD, Carr JJ, Bowden DW (2003) Adiponectin as a novel determinant of bone mineral density and visceral fat. *Bone* 33:646–651
37. Ganesan K, Teklehaimanot S, Tran TH, Asuncion M, Norris K (2005) Relationship of C-reactive protein and bone mineral density in community-dwelling elderly females. *J Natl Med Assoc* 97:329–333
38. Oelzner P, Franke S, Müller A, Hein G, Stein G (1999) Relationship between soluble markers of immune activation and bone turnover in post-menopausal women with rheumatoid arthritis. *Rheumatology (Oxford)* 38:841–847
39. Gjesdal CG, Halse JI, Eide GE, Brun JG, Tell GS (2008) Impact of lean mass and fat mass on bone mineral density: the Hordaland Health Study. *Maturitas* 59:191–200
40. Li S, Wagner R, Holm K, Lehotsky J, Zinaman MJ (2004) Relationship between soft tissue body composition and bone mass in perimenopausal women. *Maturitas* 47:99–105
41. Petit MA, Beck TJ, Shults J, Zemel BS, Foster BJ, Leonard MB (2005) Proximal femur bone geometry is appropriately adapted to lean mass in overweight children and adolescents. *Bone* 36:568–576
42. Kuwahata A, Kawamura Y, Yonehara Y, Matsuo T, Iwamoto I, Douchi T (2008) Non-weight-bearing effect of trunk and peripheral fat mass on bone mineral density in pre- and post-menopausal women. *Maturitas* 60:244–247
43. Lee K, Lee S, Kim YJ, Kim YJ (2008) Waist circumference, dual-energy X-ray absorptiometrically measured abdominal adiposity, and computed tomographically derived intra-abdominal fat area on detecting metabolic risk factors in obese women. *Nutrition* 24:625–631
44. Matsuo T, Douchi T, Nakae M, Uto H, Oki T, Nagata Y (2003) Relationship of upper body fat distribution to higher regional lean mass and bone mineral density. *J Bone Miner Metab* 21:179–183
45. Douchi T, Iemura A, Matsuo T, Kuwahata T, Oki T, Yoshimitsu N, Nagata Y (2003) Relationship of head lean mass to regional bone mineral density in elderly postmenopausal women. *Maturitas* 46:225–230
46. Bagur A, Vega E, Mautalen CD (1995) Discrimination of total body bone mineral density measured by dxa in vertebral osteoporosis. *Calcif Tissue Int* 56:263–267
47. Revilla RM, Hernández ER, Villa LF, Seco C, Sanchez-Atrio A, Rico H (1997) Total body bone measurements in spinal osteoporosis by dual-energy X-ray absorptiometry. *Calcif Tissue Int* 61:44–47
48. Nordin BE, Chatterton BE, Schultz CG, Need AG, Horowitz M (1996) Regional bone mineral density interrelationships in normal and osteoporotic postmenopausal women. *J Bone Miner Res* 11:849–856
49. Waters DL, Hale L, Grant AM, Herbison P, Goulding A (2009) Osteoporosis and gait and balance disturbances in older sarcopenic obese New Zealanders. *Osteoporos Int* 21:351–357