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Body Mass Index May Positively Correlate with Bone Mineral Density of Lumbar Vertebra and Femoral Neck in Postmenopausal Females

Authors' Contribution:
Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
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Background: Our study aimed to explore the relationship between body mass index (BMI) and bone mineral density (BMD) of lumbar vertebra and femoral neck in postmenopausal females.

Material/Methods: From September 2012 to September 2014, 236 healthy postmenopausal females who underwent physical examinations at the Women & Children's Health Care Hospital of Linyi were enrolled into our study. These subjects were divided into 3 groups: underweight group, normal weight group, and overweight group. In addition, there were 2 age stratifications: <60 years old and ≥60 years old. DPX-L type dual-energy X-ray bone densitometry (American Lunar Company) was used to measure the BMD of lumbar vertebra and femoral neck in the recruited subjects. Pearson test was used for correlation analysis.

Results: BMDs and T-scores of lumbar vertebra (L_1–L_4), femoral neck, proximal femur, and Ward's triangle region among the groups were ranked as follows: underweight group < normal weight group < overweight group. There were significant differences in body weight and BMI among the underweight, normal weight, and overweight groups ($P<0.05$). The T-scores of all examined anatomic locations showed significant differences between the underweight group and normal weight group, as well as between the underweight group and overweight group (both $P<0.05$). Only the T-scores of lumbar vertebra L_2–L_4 had significant differences between the normal weight group and overweight group ($P<0.05$). The BMDs of all anatomic components under study showed statistical differences in both age stratifications between the overweight group and underweight group, as well as between the overweight group and normal weight group (both $P<0.05$). When stratified above 60 years old, the BMDs of lumbar vertebra (L_1, L_2 and L_4) showed statistical differences between the normal weight group and underweight group ($P<0.05$). Various factors could be ranked according to the absolute values of correlation coefficients as below: body weight, BMI, height, and age. Body weight, BMI, and height were positively correlated with the BMDs of all examined anatomic locations ($P<0.05$). However, age was negatively correlated with the various components of the body (lumbar vertebra L_1, L_2 and L_4, femoral neck, proximal femur, Ward's triangle region: $P<0.05$; lumbar vertebra L_3: $P>0.05$).

Conclusions: Our study provides evidence that body weight and BMI are important factors affecting BMD. Postmenopausal females with low BMI are more likely to have osteopenia, and are likely to develop osteoporosis. BMI can be used as an important index to prevent osteoporosis.

MeSH Keywords: Body Mass Index • Femoral Neck Fractures • Lumbar Vertebrae • Osteoporosis

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Background

Osteoporosis is a common and complex health problem that inflicts postmenopausal females, especial in the elderly [1]. It is a progressive skeletal disease manifested by decreased bone mineral density (BMD) and collateral damage to the bone microarchitecture, which can subsequently lead to impaired skeletal strength and elevated susceptibility to fractures [2]. It has been statistically observed that over 50% of the adults at age 50 years or older suffer from osteoporosis, among which approximately 70% are postmenopausal females [3]. Additionally, osteoporosis affected more than 900 million females aged over 50 years in 2010. Given the paucity of effective disease-preventing strategies, it is estimated that by 2020 over 10 million females will be adversely impacted [4]. BMD has been widely accepted as a surrogate parameter for the diagnosis of osteopenia and osteoporosis [5]. Clinically, an individual with BMD greater than 2.5 standard deviation (SD) below the adult mean value are considered to have developed osteoporosis, further supporting the utility of BMD as a diagnostic avenue for abnormal bone mass and osteoporosis [6]. Generally, there are multiple distinct factors that are connected with BMD, including certain nutrients such as calcium and vitamin D, caffeine, alcohol, body weight, physical activity, and exercise [7,8]. A previous study has shown that among these factors, body weight and body mass index (BMI) exert a prominent impact on the BMD of postmenopausal females [9].

Body weight primarily consists of fat mass (FM) and lean mass (LM), with FM accounting for about 16–25% of the total body weight in individuals with normal weight and LM constituting the remaining [10]. The correlation between LM and BMD is more significant in males than in females, and the impact of FM on BMD is more prominent in postmenopausal females than in their premenopausal counterparts [11]. Some previous studies have implicated body FM as the most significant predictor of the BMD in postmenopausal women [12,13]. In contrast, other studies presented evidence that LM and FM are related to bone mass [14,15]. BMI is a defined value derived from the weight and height of an individual to quantify the amount of tissue mass (muscle, fat, and bone), which serves to categorize the person as underweight, normal weight, overweight, or obese [16]. A previous study has established that increased BMI has a protective impact on bone density, and individuals with moderate overweight were found to have augmented BMD values, indicating that BMI and weight gain may be connected with BMD [17]. More importantly, increased body weight has been demonstrated to correlate with endocrine alterations, which can positively influence bone metabolism in a direct or indirect manner [18]. Notably, low body weight or BMI likely predispose postmenopausal females to rapid bone loss and low bone mass, which are considered to play crucial roles in the pathogenesis of postmenopausal females' osteoporosis [5]. However, a specific BMI value chart to accurately predict osteoporosis and related fracture risk remains to be fully established. Preliminary results suggested that a BMI of 26~28 may confer some protection, whereas a BMI of 22~24 likely indicates an increased risk [19]. Therefore, we carried out the current analysis and sought to clarify whether body weight and BMI have an important impact on the BMD of lumbar vertebra and femoral neck in postmenopausal females.

Material and Methods

Ethics statement

The study was performed with approved protocols by the Institutional Review Board of Women & Children's Health Care Hospital of Linyi. The informed written consent was obtained from each eligible patient and all procedures were conducted according to the Declaration of Helsinki [20].

Subjects and grouping

From September 2012 to September 2014, 236 healthy postmenopausal females who underwent physical examinations at Women & Children's Health Care Hospital of Linyi were enrolled into our study. Their age ranged from 50 to 75 years old (mean age, 63.8±5.2 years old) with menopausal age at 50 ~ 56 years old (mean menopausal age, 50.1±4.2 years old), menopause duration of 1~27 years (mean menopause duration, 14.1±5.5 years), body weight of 38~96 kg (mean body weight, 59.1±9.5 kg), height of 142.3~172.3 cm (mean height, 153.8±5.5), and body mass index (BMI) of 16.2~34.9 kg/m^2 (mean BMI, 24.9±3.1 kg/m^2). Inclusion criteria: all subjects completed a health questionnaire as confirmed by physical and laboratory examinations; and all patients had never taken any drugs known to affect bone metabolism. Exclusion criteria: (1) postmenopausal females with kidney disease, liver disease, diabetes, malnutrition, hyperparathyroidism, hyperthyroidism, high lactation hyperprolactinemia, ovariectomy, rheumatism arthritis, rigidity spondylitis, Paget's' bone disease, cancer, non-traumatic fractures and bone deformities; (2) postmenopausal females with a long-term medication history of steroids, antiepileptic drugs, diuretics, fluoride, and estrogen; (3) postmenopausal females with artificial artifact, middle position change, and apparent deformity of spine or other technical problems during the measurement. The menopausal age, height, and body weight of the subjects were recorded, and BMI was computed as a ratio of weight to height squared (kg/m^2). According to the normal value [19 to 25 (kg/m^2)] of BMI defined by World Health Organization (WHO), the 236 healthy postmenopausal females were divided into 3 groups: underweight group (BMI ≤20 kg/m^2), overweight group (BMI >25 kg/m^2), and normal weight group [21]. In addition, there were 2 age stratifications: <60 years old and ≥60 years old.

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Table 1. Basic data among underweight, normal weight, and overweight groups.

Category	Underweight (n=24)	Normal weight (n=124)	Overweight (n=88)
Age (years old)	63.4±6.8	63.5±4.7	64.4±5.3
Body weight (kg)	45.3±5.2	56.2±6.2[a]	66.9±7.4[b,c]
Height (cm)	155.2±6.5	153.2±6.2	154.2±3.9
BMI(kg/m^2)	18.7±0.6	23.8±0.8a	28.1±1.7[b,c]
Menopause age (years old)	51.0±3.7	49.7±4.5	50.2±4.1
Menopause duration (years)	15.4±5.5	14.4±5.5	13.3±5.4
BMD (g/cm^2)			
Lumbar vertebra L_1	0.665±0.231	0.821±0.221[a]	0.934±0.190[b,c]
Lumbar vertebra L_2	0.746±0.243	0.867±0.201[a]	0.952±0.203[b,c]
Lumbar vertebra L_3	0.678±0.279	0.854±0.151[a]	0.945±0.321[b,c]
Lumbar vertebra L_4	0.758±0.273	0.878±0.223[a]	0.987±0.187[b,c]
Femoral neck	0.638±0.189	0.721±0.145[a]	0.774±0.156[b,c]
Proximal femur	0.689±0.134	0.794±0.222[a]	0.865±0.193[b,c]
Ward's triangle region	0.547±0.130	0.657±0.212[a]	0.773±0.140[b,c]

[a] Represents $P<0.05$ when normal weight group is compared with underweight group; [b] represents $P<0.05$ when overweight group is compared with underweight group; [c] represents $P<0.05$ when overweight group is compared with normal weight group. BMI – body mass index; BMD – bone mineral density.

Bone mineral density (BMD) measurement

DPX-L type dual-energy X-ray bone densitometry (American Lunar Company) with instrument precision of 1% and repeated measurement error <1% was used to measure BMD of lumbar vertebra and femoral neck in the subjects. The measurements were carried out by a trained specialist, and the instrument was regularly checked for functionality with standard modules.

BMD T-score

According to the WHO definition, normal T-scores were calculated with the installed software of the apparatus, in which the mean ± standard deviation (SD) of BMD was established from postmenopausal females. T-scores ≥–1.0 SD indicated normal health, while –2.5 SD < T-scores <–1.0 SD and T-scores ≤–2.5 SD indicated osteopenia and osteoporosis, respectively.

Statistical analysis

SPSS 19.0 statistical software (SPSS Inc, Chicago, IL, USA) was used for statistical analysis. The measurement data were presented as mean ±SD, and the homogeneity of variance tested before comparisons. The *t* test was used to compare 2 groups and single-factor analysis of variance (ANOVA) was used to compare 3 or more groups, which was tested by LSD-t test. Pearson test was used for correlation analysis. $P<0.05$ means a significant difference.

Results

Basic data

Age, height, menopause age, and menopause duration in the underweight group, normal weight group, and overweight group showed no significant differences ($P>0.05$). However, the body weight and BMI were significantly different among all groups ($P<0.05$). The BMDs of lumbar vertebra (L_1–L_4), femoral neck, proximal femur, and Ward's triangle region increased with elevating BMI, and showed significant differences among the 3 groups ($P<0.05$) (Table 1).

T-scores in different positions

T-scores of lumbar vertebra (L_1–L_4), femoral neck, proximal femur, and Ward's triangle region among the groups were

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Table 2. T-scores in different parts among underweight, normal weight and overweight groups.

Position	Underweight (n=24)	Normal weight (n=124)	Overweight (n=88)
Lumbar vertebra L_1	−3.567±1.322	−2.578±1.345[a]	−2.276±1.781[a,b]
Lumbar vertebra L_2	−3.789±1.561	−2.903±1.476[a]	−2.370±1.761[a]
Lumbar vertebra L_3	−3.590±1.604	−2.532±1.341[a]	−1.712±1.734[a]
Lumbar vertebra L_4	−3.455±1.701	−2.340±1.476[a]	−1.121±1.562[a]
Femoral neck	−2.432±1.023	−1.670±1.231[a]	−1.332±1.198[a,b]
Proximal femur	−2.211±1.165	−1.543±1.289[a]	−1.179±1.228[a,b]
Ward's triangle region	−3.511±0.921	−2.712±1.119[a]	−2.612±0.602[a,b]

[a] Represents $P<0.05$ between underweight group *vs.* normal weight group and underweight group *vs.* overweight groups; [b] represents $P>0.05$ between normal weight group *vs.* overweight groups.

ranked as follows: underweight group < normal weight group < overweight group. There were significant differences for the T-scores of lumbar vertebra (L_1–L_4), femoral neck, proximal femur, and Ward's triangle region between the underweight group and normal weight group, as well as between the underweight group and overweight groups (both $P<0.05$). Only the T-scores of lumbar vertebra L_2–L_4 had significant differences between the normal weight group and overweight group ($P<0.05$) (Table 2).

BMD values in different age stratifications

The BMDs of lumbar vertebra (L_1–L_4), femoral neck, proximal femur, and Ward's triangle region showed statistical differences within each age stratification between the overweight group and underweight group, as well as between the overweight group and normal weight group (both $P<0.05$). When stratified under 60 years old, all BMDs showed no significant difference between the normal weight group and underweight group ($P>0.05$). In sharp contrast, when stratified above 60 years old, the BMDs of lumbar vertebra (L_1, L_2 and L_4) showed statistically significant differences between the normal weight group and underweight group ($P<0.05$) (Table 3).

Correlation analysis

The results of correlation analysis concerning how different factors influenced postmenopausal females' BMDs are shown in Table 4. The absolute values of correlation coefficient were obtained and utilized to rank each factor as follows: body weight, BMI, height, and age. Specifically, body weight, BMI, and height were positively correlated with the BMDs of lumbar vertebra (L_1–L_4), femoral neck, proximal femur, and Ward's triangle region ($P<0.05$). However, age was negatively correlated with different components of the body with varying statistical significance (lumbar vertebra L_1, L_2 and L_4, femoral neck, proximal femur, and Ward's triangle region: $P<0.05$; lumbar vertebra L_3: $P>0.05$). The correlation between body weight and various anatomical locations of the body was the most significant, especially for lumbar vertebra L_1 and lumbar vertebra L_2 (lumbar vertebra L_1: r=0.460; lumbar vertebra L_2: r=0.459, $P<0.05$).

Discussion

There are several main findings of our study, with important implications. We showed that the BMD in lumbar vertebra (L_1–L_4), femoral neck, proximal femur, and Ward's triangle region of postmenopausal females were significantly lower in the underweight group than in the normal weight group or overweight group. Intriguingly, BMD increased with increased BMI. Combined together, these results suggested that both body weight and BMI serve as important factors affecting BMD. We speculate that the underlying mechanisms are primarily multifaceted, involving mechanical load, hormones, and nutritional status. A previous study has shown that, as a mechanical load factor, larger body weight and BMI endow individuals with the capacity to withstand larger mechanical load, which reduces bone resorption and stimulates bone formation, thereby increasing bone strength and bone mineral content, delaying the occurrence of osteoporosis and reducing its severity [22]. In addition, postmenopausal females with higher BMI exhibit decreased production of sex hormone-binding globulins, which leads to increased levels of free sex hormones. Estrogens engage the estrogen receptors on osteoblasts, thus boosting their osteoprotegerin expression and resulting in reduced osteoclast activity and bone resorption. Estrogens also function to prevent bone absorption of parathyroid hormones and promote bone

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Table 3. Bone mineral density values in different age stratifications.

Group	Underweight (n=24)	Normal weight (n=124)	Overweight (n=88)
<60 (years old)			
Lumbar vertebra L_1	0.757±0.251[a]	0.787±0.267[a,b]	0.938±0.192
Lumbar vertebra L_2	0.783±0.250[a]	0.819±0.259[a,b]	0.965±0.188
Lumbar vertebra L_3	0.714±0.367[a]	0.786±0.328[a,b]	0.947±0.229
Lumbar vertebra L_4	0.809±0.254[a]	0.908±0.278[a,b]	0.997±0.174
Femoral neck	0.650±0.188[a]	0.697±0.192[a,b]	0.791±0.131
Proximal femur	0.725±0.216[a]	0.766±0.265[a,b]	0.895±0.178
Ward's triangle region	0.612±0.173[a]	0.642±0.203[a,b]	0.838±0.160
≥60 (years old)			
Lumbar vertebra L_1	0.669±0.292[a]	0.821±0.194[a]	0.931±0.215
Lumbar vertebra L_2	0.729±0.266[a]	0.861±0.184[a]	0.968±0.208
Lumbar vertebra L_3	0.739±0.231[a]	0.836±0.218[a,b]	0.970±0.256
Lumbar vertebra L_4	0.738±0.286[a]	0.868±0.205[a]	0.995±0.205
Femoral neck	0.652±0.199[a]	0.707±0.144[a,b]	0.793±0.148
Proximal femur	0.673±0.285[a]	0.778±0.178[a,b]	0.889±0.202
Ward's triangle region	0.585±0.242[a]	0.638±0.163[a,b]	0.709±0.183

[a] Represents $P<0.05$ between overweight group *vs.* underweight group and overweight group *vs.* normal weight groups; [b] represents $P>0.05$ between underweight group *vs.* normal weight groups.

Table 4. The results of correlation analysis between postmenopausal females' bone mineral density and difference factors.

Group	Body weight	Height	BMI	Age
BMD (g/cm^2)				
Lumbar vertebra L_1	0.460*	0.314*	0.427*	–0.157*
Lumbar vertebra L_2	0.459*	0.316*	0.424*	–0.142*
Lumbar vertebra L_3	0.423*	0.288*	0.389*	–0.126
Lumbar vertebra L_4	0.436*	0.284*	0.407*	–0.201*
Femoral neck	0.387*	0.267*	0.354*	–0.151*
Proximal femur	0.417*	0.283*	0.384*	–0.163*
Ward's triangle region	0.387*	0.285*	0.344*	–0.234*

The figures in table represent correlation coefficient, * represents $P<0.05$. BMI – body mass index; BMD – bone mineral density.

formation [23]. It has been shown that individuals with higher BMI are more likely to suffer hyperinsulinemia, as impaired production of insulin-like growth factor-1 (IGF-1)-binding globulins results in increased expression of IGF-1, which stimulates the differentiation of osteoblasts and promotes bone formation [24]. It should be noted that body weight and BMI also reflect the nutritional status of humans, and malnutrition directly affects bone reconstruction [25].

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Our results indicate that postmenopausal females with low BMI exhibit osteopenia with predisposition for osteoporosis. As one of the components of body weight, FM assumes a determining role in predicting lumbar vertebra and femoral neck BMD of postmenopausal females. This affects hormonal responses, as well as expression and release of molecules such as leptin, resistin, and adiponectin in adipose tissues, which synergistically results in downregulation of bone turnover and bone resorption, and upregulation of osteoclast activities, which contribute to bone formation [10]. One risk factor for osteoporosis was identified as low bone mass in femoral neck of postmenopausal females, leading to bone fragility and fracture susceptibility. The bone loss could be largely explained by weight loss and infrequent physical activities that are essential for nourishing bone remodeling and bone density increment [26]. It is widely believed that a decrease in body weight could result in bone loss, which may promote the initiation and development of osteoporotic diseases [27]. Moreover, the rate of bone loss is highly connected with various contributing factors, including age, muscular strength, body weight, and menopausal duration. A previous study evaluated the BMD of femoral neck and spinal BMD among postmenopausal females and found that BMD is up-regulated along with an increase in body weight, accompanied by activated expression of hormones, which facilitates bone mass storage against bone resorption [28]. In line with our results, Mendez and colleagues presented evidence that overweight in postmenopausal females is mainly responsible for triggering adipocytes to release bone mass-enhancing hormonal cytokines. These results suggested that the probability of osteoporosis developing in postmenopausal females with a higher BMD of lumbar vertebra and femoral neck is largely determined by the extent of obesity [9]. It is also well-known that obese postmenopausal females tend to have high estrogenicity with fat tissues. Particularly, androstenedione and testosterone are converted to estrone and estradiol, resulting in high BMD and low bone turnover and conferring increased protection against fracture [19]. Additionally, obesity can lead to chronic inflammatory processes and generation of reactive oxygen species (ROS), which mainly deteriorates the proliferation and survival of osteoblasts, osteoclast, and osteocytes [29].

Conclusions

In summary, our study identifies body weight and BMI as important factors affecting BMD. Postmenopausal females with low BMI show osteopenia, and are more likely to develop osteoporosis. BMI can thus be utilized as an important index to prevent osteoporosis. Therefore, routine BMD monitoring in postmenopausal females with low weight may be necessary to determine when to introduce early clinical interventions for osteoporosis.

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Competing interests

No competing interests exist.

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