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Research Article

Relationship between Body Mass Index and Bone Mineral Density in People with Osteoporosis: A Cross-Sectional Analytical Study

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Abstract

Background: Obesity and osteoporosis are prevalent global health problems. This study aims to investigate the relationship between bone density and body mass index (BMI) in patients with osteoporosis and osteopenia.
Methods: Demographic data, BMI, bone mineral density (BMD), and T-scores of the lumbar spine (L1-L4) and neck of the left femur were collected using the files of individuals who were referred to the Bone Density Measurement Center, Nuclear Medicine Center, Abadan, Iran, from February 2022 to September 2023. The relationship between BMD of the lumbar spine and neck of the left femur and BMI in individuals with osteoporosis, osteopenia, and normal BMD, with varying weight categories ranging from underweight to obese or overweight, was investigated.
Results: In this study, 475 people were included in three groups. The mean BMI was higher than normal. In the group with osteoporosis, the BMD of the lumbar spine of the overweight and obese group was higher than the underweight and normal weight groups ($P < 0.001$). There was a direct significant correlation between BMD of the spine and BMI in the group with osteoporosis ($r = 0.389$, $P < 0.001$). A direct and significant correlation was observed between BMI and BMD of the femur ($r = 0.296$) and between BMI and BMD of the lumbar spine ($r = 0.233$).
Conclusion: BMI and BMD of the neck of the femur and lumbar spine were directly correlated.

Keywords: Bone Density; Femur; Lumbar Spine; Obesity

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Background

Osteoporosis is a bone disorder characterized by low bone mass and bone tissue destruction. Common fractures include the proximal femur, vertebrae, and distal radius, which can severely impact the quality of life (QOL) (1). The prevalence of osteoporosis in Iranian individuals aged 50 and older is high and increasing, with the femoral neck region showing the lowest rates (2). Fractures and pain are the most obvious and direct symptoms of patients with osteoporosis, greatly reducing their QOL and medical treatment (3).

Obesity and osteoporosis have common genetic and environmental factors. Menopause is the most common pathological condition that leads to the simultaneous increase in fat and decrease in bone mass. Some studies suggest that excess fat mass from obesity may not protect against osteoporosis and may even harm bones (4, 5). There is no clear consensus yet, as conflicting studies exist. However, adipocytes and osteoblasts share a common mesenchymal stem cell (MSC) progenitor. Thus, molecules that promote osteoblastogenesis inhibit adipogenesis and vice versa (5). Increased adipogenesis leads to fatty marrow and inhibits osteoblastogenesis, resulting in reduced bone formation, insufficient bone mass, and osteoporosis (6).

Studies have shown that women who are postmenopausal and have obesity exhibit decreased markers for bone formation and increased markers for bone resorption (4). Obesity and osteoporosis are major global health problems due to their increasing prevalence. The complex interaction between obesity and bone metabolism is not fully understood. Obese individuals have a higher risk of certain fractures due to increased bone marrow adipogenesis, which causes decreased bone mass (7). As we age, the bone marrow shifts towards more fat cells, causing an increase in osteoclast activity and a decrease in osteoblast function, which ultimately leads to osteoporosis (8). Age, sex, weight, body mass index (BMI), high-density lipoprotein (HDL) cholesterol, and diabetes are significant predictors of osteoporosis (9). The reduction of bone density and osteoporosis in postmenopausal women affect many risk factors, whose identification aims to create a more effective prevention of this disease in the elderly (10). According to factors such as BMI, triglyceride (TG), and other related indicators, such as the patient's age and the number of births, osteoporosis fractures can be predicted in time (11).

Due to the high prevalence of obesity and osteoporosis in Iran (2) and the lack of studies on their relationship in Abadan City, Iran, this study aims to investigate the link between bone density and BMI in patients referred to the bone density department of Abadan Nuclear Medicine Center.

Methods

Demographic data and measurements related to BMI, bone mineral density (BMD), and T-scores of the lumbar

Table 1. Demographic characteristics of participants

Variable	Total (n = 475)	Neck of femur group			P-value
		Normal (n = 205)	Osteopenia (n = 223)	Osteoporosis (n = 47)	
Age (year)	58.19 ± 10.24	55.54 ± 10.24[b,c]	58.90 ± 9.59[a,c]	66.36 ± 8.36[a,b]	< 0.001[¥]
Sex					0.316[*]
Women	426 (89.7)	180 (42.3)	205 (48.1)	41 (9.6)	
Men	49 (10.3)	25 (51.0)	18 (36.7)	6 (12.2)	< 0.001[¥]
BMI (kg/m²)	28.76 ± 5.50	30.37 ± 5.71[b,c]	27.96 ± 4.96[a,c]	25.53 ± 4.86[a,b]	< 0.001[†]
Underweight	8 (1.7)	1 (12.5)	6 (75.0)	1 (12.5)	
Normal	105 (22.1)	26 (24.8)	54 (51.4)	25 (23.8)	
Obese and overweight	362 (76.2)	178 (49.2)	163 (45.0)	21 (5.8)	< 0.001[¥]
BMD of the neck of femur	0.81 ± 0.15	0.94 ± 0.11[b,c]	0.75 ± 0.05[a,c]	0.57 ± 0.06[a,b]	< 0.001[¥]

The results are presented as mean ± standard deviation (SD) for quantitative variables and frequency (%) for categorical variables.
[¥]P calculated from one-way analysis of variance (ANOVA) with Tukey post-hoc; [*]P calculated from chi-square test; [†]P calculated from Fisher's exact test; a, b, and c represent the results of the Tukey post-hoc test, indicating a significant difference with the normal, osteopenia, and osteoporosis groups, respectively.
BMI: Body mass index; BMD: Bone mineral density

spine (L1-L4) and neck of the left femur were collected using the files of individuals who were referred to the Bone Density Measurement Center of the Nuclear Medicine Center, Abadan City, between February 1, 2022, and September 22, 2023. It was conducted using the convenience sampling method. This study was approved by the Ethics Committee of Abadan University of Medical Sciences (Ethical Approval ID: IR.ABADANUMS.REC.1402.056).

The individuals in this research study were classified according to their T-score. Those with T-scores between -1.5 and -2.5 were diagnosed with osteopenia. If their T-score was less than -2.5, they were diagnosed with osteoporosis (1). The T-score of those diagnosed with normal BMD was above zero or 0-1.

The BMI was calculated by dividing weight by the square of height. A BMI of under 18.5 kg/m^2 was considered underweight, a BMI between 18.5 and 24.9 kg/m^2 was considered normal weight, a BMI between 25 and 29.9 kg/m^2 was considered overweight, and a BMI of 30 kg/m^2 or more was considered obese (12).

The study investigated the relationship between BMD of the lumbar spine and neck of the left femur and BMI in individuals with osteoporosis, osteopenia, and normal BMD with varying weight categories ranging from underweight to obese or overweight.

Dual-energy X-ray absorptiometry (DEXA) is widely used to measure BMD. It uses X-rays to determine bone density and firmness (1).

Statistical Analysis Method: The data were analyzed and presented using several statistical measures, including the mean, standard deviation (SD), and frequency distribution. In addition to the statistical measures mentioned above, we also conducted normality tests using the Kolmogorov-Smirnov (K-S) test.

The K-S test was used to determine whether the data followed a normal distribution. To compare differences between groups, we used analysis of variance (ANOVA) with the post-hoc Tukey test.

We also performed nonparametric tests such as the Kruskal-Wallis and Mann-Whitney U tests to compare variables that did not meet the normality and equal variance assumptions.

The chi-square (Fisher's exact) test was used to examine the association between categorical variables, while Pearson's correlation coefficient was utilized to evaluate the relationship between two continuous variables.

All statistical analyses were conducted using SPSS software (version 16.0, SPSS Inc., Chicago, IL, USA), with a significance level of 0.05.

Results

475 people were examined. The mean age of these people was 58.19 ± 10.24 years, including 426 (89.7%) women and 49 (10.3%) men. The mean BMD in the osteoporosis group was lower than the osteopenia and normal groups, and this difference was significant. In this study, 362 (76.2%) people referred to the bone density measurement center were overweight and obese. The mean BMI in the study subjects was 28.76 ± 5.50 kg/m^2, higher than normal. In all three groups, the mean BMI was higher than normal. The mean BMI in the osteoporosis group was lower than in the osteopenia and normal groups, and this significant relationship was observed (P < 0.001), that is, with a decrease in BMD, a decrease in BMI was observed (Tables 1 and 2).

The results of table 3 show the mean BMD in osteoporosis, osteopenia, and normal groups based on BMI groups (obese and overweight, normal, and underweight), which do not show a significant relationship between femoral neck BMD in three different BMI groups. In normal weight group, there was a significant relationship between femoral neck BMD between individuals with osteoporosis, osteopenia, and normal BMD (P < 0.001).

In the overweight and obese group, there was a significant relationship between BMD of the neck of the femur in the individuals with osteoporosis, osteopenia, and normal BMD (P < 0.001).

Table 2. Demographic characteristics of participants

Variable	Total (n = 475)	Neck of femur group			P-value
		Normal BMD (n = 218)	Osteopenia (n = 159)	Osteoporosis (n = 98)	
Age (year)	58.19 ± 10.24	56.80 ± 10.24[c]	58.13 ± 10.67[c]	61.38 ± 8.83[a,b]	0.001[¥]
Sex					
Women	426 (89.7)	190 (44.6)	141 (33.1)	95 (22.3)	0.027[*]
Men	49 (10.3)	28 (57.1)	18 (36.7)	3 (6.1)	
BMI (kg/m²)	28.76 ± 5.50	30.06 ± 5.86[b,c]	28.52 ± 4.88[a,c]	26.25 ± 4.71[a,b]	< 0.001[¥]
Underweight	8 (1.7)	3 (37.5)	3 (37.5)	2 (25.0)	< 0.001[†]
Normal	105 (22.1)	38 (36.2)	28 (26.7)	39 (37.1)	
Obese and overweight	362 (76.2)	177 (48.9)	128 (35.4)	57 (15.7)	
BMD of the lumbar spine	0.95 ± 0.22	1.12 ± 0.19[b,c]	0.87 ± 0.05[a,c]	0.69 ± 0.08[a,b]	< 0.001[¥]

The results are presented as mean ± standard deviation (SD) for quantitative variables and frequency (%) for categorical variables.
[¥]P calculated from one-way analysis of variance (ANOVA) with Tukey post-hoc; [*]P calculated from chi-square test; [†]P calculated from Fisher's exact test; a, b, and c represent the results of the Tukey post-hoc test, indicating a significant difference with the normal, osteopenia, and osteoporosis groups, respectively.
BMI: Body mass index; BMD: Bone mineral density

Table 3. Bone mineral density (BMD) and association with body mass index (BMI) in the femur and lumbar spine groups with normal BMD, osteopenia, and osteoporosis

Variable (BMD of the neck of femur)	Femur group			P-value
	Normal BMD (n = 205)	Osteopenia (n = 223)	Osteoporosis (n = 47)	
BMI				
Underweight	0.83 ± 0.00	0.73 ± 0.05	0.64 ± 0.00	0.131[£]
Normal weight	0.91 ± 0.07[b,c]	0.74 ± 0.05[a,c]	0.56 ± 0.06[a,b]	< 0.001[£]
Obese and overweight	0.94 ± 0.11[b,c]	0.74 ± 0.04[a,c]	0.57 ± 0.04[a,b]	< 0.001[£]
P-value	0.242[£]	0.738[£]	0.318[£]	
Variable (BMD of the lumbar spine)	Lumbar Spine group			P-value
	Normal BMD (n = 218)	Osteopenia (n = 159)	Osteoporosis (n = 98)	
BMI				
Underweight	1.04 ± 0.09	0.87 ± 0.06	0.67 ± 0.09	0.787[£]
Normal weight	1.14 ± 0.27[b,c]	0.85 ± 0.04[c]	0.65 ± 0.10[a,b]	< 0.001[£]
Obese and overweight	1.12 ± 0.16[b,c]	0.87 ± 0.05[c]	0.71 ± 0.05[a,b]	< 0.001[£]
P-value	0.547[£]	0.298[£]	0.001[£]	

The results are presented as mean ± standard deviation (SD) for quantitative variables.
[£]P calculated from Kruskal-Wallis test with Mann-Whitney-U post-hoc; a, b, and c represent the results of the post-hoc test, indicating a significant difference with the normal, osteopenia, and osteoporosis groups, respectively.
BMI: Body mass index; BMD: Bone mineral density

There was a significant relationship between BMD of the lumbar spine in individuals with osteoporosis, osteopenia, and normal BMD (P < 0.001). In the overweight and obese group, there was a significant relationship between BMD of the lumbar spine in individuals with osteoporosis, osteopenia, and normal BMD (P < 0.001) (Table 3).

In the group with osteoporosis, the BMD of the lumbar spine of the overweight and obese group was higher than the underweight and normal weight groups, and this relationship was significant (P = 0.001) (Table 3). However, no significant difference was observed between BMD in the femur (P = 0.131) and lumbar spine (P = 0.787) in the underweight group in individuals with osteoporosis, osteopenia, and normal BMD (Table 3).

Table 4 shows the correlation between BMI and BMD in three groups of osteoporosis, osteopenia, and normal BMD, and there was a direct and significant correlation between BMD of the spine and BMI in the group with osteoporosis (r = 0.389, P < 0.001).

Table 4. Pearson correlation coefficient between body mass index (BMI) and bone mineral density (BMD) of the femur and lumbar spine, by groups

Factor	Femur group		
	Normal BMD (n = 205)	Osteopenia (n = 223)	Osteoporosis (n = 47)
	BMD of the neck of femur		
BMI (kg/m²)	0.100 (0.155)	0.145 (0.031)	0.161 (0.280)
	Lumbar spine group		
	Normal BMD (n = 218)	**Osteopenia (n = 159)**	**Osteoporosis (n = 98)**
	BMD of the lumbar spine		
BMI (kg/m²)	-0.002 (0.972)	0.092 (0.249)	0.389 (< 0.001)

The results of the Pearson correlation coefficient test arte reported as r (P).
BMI: Body mass index; BMD: Bone mineral density

In table 5, the correlation between BMI and BMD of the neck of the femur and lumbar spine was examined in general. A direct and significant correlation was observed between BMI and BMD of the femur (r = 0.296) and between BMI and BMD of the lumbar spine (r = 0.233).

Table 5. Pearson correlation coefficient between body mass index (BMI) and bone mineral density (BMD) of the femur and lumbar spine

	BMI	Femur BMD	Lumbar spine BMD
BMI	1	-	-
Femur BMD	0.296*	1	-
Lumbar spine BMD	0.233*	0.522*	1

Correlation is significant at the 0.01 level (two-tailed)
BMI: Body mass index; BMD: Bone mineral density

Discussion

In this study, 475 people were examined. The mean BMI was higher than normal in all three groups (individuals with osteoporosis, osteopenia, and normal BMD). The mean BMI in the osteoporosis group was lower than in the osteopenia and normal BMD groups, and this significant relationship was observed, that is, with a decrease in BMD, a decrease in BMI was observed. In the group with osteoporosis, the BMD of the spine of the overweight and obese group was higher than the underweight and normal weight groups, and this relationship was significant. There was a direct and significant correlation between BMD of the spine and BMI in the group with osteoporosis. The correlation between BMI and BMD of the neck of the femur and spine was examined in general, and a direct and significant correlation was observed between BMI and BMD.

The research conducted by Bijelic et al. found no statistically significant association between BMI values and osteoporosis (10). Jia and Cheng study showed that the smaller the BMI value, the greater the loss of BMD, and the lower the BMI and TGs, the greater the decrease in bone mass (11).

Alfahal et al.'s study showed that postmenopausal women with osteoporosis had a significant increase in serum lipid profile and BMI. BMI was not significantly different between case and control groups. There was a positive Pearson correlation between BMD and serum total cholesterol, low-density lipoprotein (LDL), and TG (13). A study by Wu et al. showed that BMI was more of a protective factor for osteoporosis (14).

A study by Wu et al. showed that obese subjects had lower osteoporosis than normal-weight subjects. As BMI increases, the risk of osteoporosis decreases in the Chinese adult population, and the lipid profile may be a potential mediator that reduces the risk of osteoporosis (15). According to Lloyd et al.'s study, there is a positive correlation between BMI and BMD, which remains consistent regardless of age, sex, or race. An increase of 10 points in BMI can elevate a person's BMD level from osteoporotic to normal. The study identifies a conservative and cross-sectional connection between obesity and osteoporosis amongst a group of elderly Americans (16). In the study of Cui et al., it was observed that BMD in women was significantly lower than in men. There was also a significant difference in BMD with BMI in men and women. Moreover, Individuals with a BMI less than 18.5 had a higher prevalence of osteoporosis than those with a BMI ≥18.5 in both sexes (9). Multivariate linear regression analysis showed a non-linear positive correlation between BMI and femur and lumbar spine BMD in the population aged over 50. Maintaining BMI within the slightly overweight range of around 26 kg/m^2 could optimize BMD while reducing other harmful effects (17). In a study by Zhang and Pu, it was found that the relationship between BMI and BMD was not linear and had a saturation point at a BMI of 24.3 kg/m^2 for femoral neck BMD. Individuals over 50 showed a positive relationship between obesity and

bone density, and a saturation value was also observed between BMI and BMD. The study suggests that maintaining a moderate BMI of around 24.3 kg/m^2 leads to an optimal balance between BMI and BMD in adults over 50 (18). In the population-based study by Ouyang et al., 6143 adolescents aged 8 to 19 years were analyzed using multivariate linear regression. The results showed a positive correlation between BMI and total BMD, consistent across all gender and age subgroups. The relationship between BMI and BMD was found to be nonlinear, with a saturation point. The study suggests that maintaining BMI at saturation levels may optimize BMD while reducing side effects (19).

In 2016, Wu et al. observed significant body weight and BMI differences between underweight, normal weight, and overweight groups. There was a positive correlation between body weight, BMI, and height with BMDs of all anatomical points examined (20). The study by Doğan et al. aimed to determine the effect of BMI and age on BMD in elderly men and women. Results showed a significant relationship between femur BMD and BMI in men and between waist and femur BMD and BMI in women. Additionally, a significant relationship between femur BMD and BMI/age was found in women, confirming the effect of high BMI on femoral neck and L2-L4 BMD in elderly individuals (21). A study by Li found that lumbar BMD had a positive correlation with BMI after controlling for other factors. An inverted U-shaped association between BMI and lumbar BMD was discovered, particularly in women and blacks. The study suggests that a reasonable increase in BMI may be beneficial for improving BMD, but an excessive increase in BMI may negatively affect bone health in women and blacks (22).

One of the limitations of this study is the small sample size of patients with osteoporosis, which is due to the low number of patients referred to the bone density measurement center in Abadan City.

Because the mean BMI was higher than normal in the patients in this study for the diagnosis of bone problems, this study can suggest that individuals prevent or improve osteoporosis through a healthy lifestyle and weight management. It may also be useful for specialists treating osteoporosis.

Conflicting studies investigate the relationship between BMD and BMI. The discrepancies can be due to differences in the type and method of studies, sample size, different communities and races, differences in individuals' genetics, or other unknown causes. More studies are suggested, preferably multicenter studies with a large sample size.

Conclusion

The mean BMI in the osteoporosis group was lower than in the osteopenia and normal groups; with a decrease in BMD, a decrease in BMI was observed. In the group with osteoporosis, the BMD of the spine of the overweight and obese group was higher than the underweight and normal weight groups. There is a direct and significant correlation between BMD of the spine and BMI in the group with osteoporosis. The correlation between BMI and BMD of the neck of the femur and spine was examined in general, and a direct and significant correlation was observed between BMI and BMD.

Conflict of Interest

The authors declare no conflict of interest in this study.

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