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Dietary Pattern-Based Differences in the Associations Between Weight Control, Bone Mineral Density, and the Risk of Fracture Among Iranian Postmenopausal Women With Osteoporosis: An Application of Theory of Planned Behavior

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Abstract

Objectives: The aim of the present study was to investigate the relationships between cognitive factors, weight control behavior, bone mineral density (BMD), and the risk of bone fracture by the dietary pattern among Iranian postmenopausal women with osteoporosis.

Materials and Methods: In this cross-sectional study (2017), 240 postmenopausal women with osteoporosis referring to two densitometry clinics in Tabriz (Iran) were recruited to participate in the study using a convenience sampling technique. Then, nutrition survey, BMD, the risk of bone fracture, weight control behavior, and a framework-based weight control behavior questionnaire (Weight-CuRB) were applied to collect data.

Results: Using factor analysis, three distinct dietary patterns were identified, including healthy, mixed, and western patterns, which accounted for 24.24% of the total variance in food intake. After adjustment for cognitive and socio-demographic variables, patients with a western dietary pattern and no control on weight showed the increased risk of major osteoporotic (odds ratio [OR]: 4.82, CI: 2.02-11.45, $P = 0.000$) and hip (OR: 3.13, CI: 1.36-7.19, $P = 0.007$) fractures ($P<0.001$). In addition, in the subjects with western dietary pattern and no control over their weight, results showed an increased risk of low BMD (OR: 0.451, CI: 0.199-1.042, $P = 0.044$).

Conclusions: In general, the increased intake of fruits, nuts, the vegetable oil in a healthy dietary pattern, and adoption of appropriate weight control behaviors may reduce the risk of bone fracture in postmenopausal women with osteoporosis. Accordingly, health practitioners and healthcare providers should consider weight control in their risk assessment of bone fracture in postmenopausal women with osteoporosis.

Keywords: Weight control, Osteoporosis, Theory of planned behavior, Dietary patterns, Risk of fracture, Bone mineral density

Introduction

Osteoporosis is a bone-thinning disease characterized by low bone mass, high bone fragility, and incident bone fractures (1). Currently, 200 million people suffer from osteoporosis worldwide (2). In Iran, the fracture incidence rate in the lumbar vertebrae and femur of women is reported to be 41.7% and 3.6%, respectively (3). According to the Iranian multicenter osteoporosis study, 70% of women and half of older than 50 men suffer from osteoporosis and osteopenia (4). In their study, Saei Ghare et al showed that the prevalence of osteoporosis among 45 and older-than-45-year-old women was 14.3% and 50.7%, respectively (3).

The relationship between body weight and the risk of bone fractures seems to be complicated (5-7). In the subjects with low body mass index (BMI) <18.5 kg/m^2, a supportive function for tissues surrounding the bones, especially the hip, is imagined to act against physical pressures and strains. In addition, the accumulation of estradiol in fat tissues and their reduced availability to the bone tissue are reported to lead to bone fracture in patients with high BMI >25 kg/m^2 (8, 9).

Additional factors might be involved in the determination of bone fracture (10). According to (11), nutrition plays an important role in maintaining a healthy weight and an appropriate bone mineral density (BMD). In

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recent years, various dietary patterns have been examined to uncover the relationship between diet and health-related factors (12,13). As with many perceived behavioral controls, the weight control behavior of individuals could arise from their intention and the so-called antecedent of the intention, including personal attitude, subjective norms, and the ultimate perceived behavioral control. This is called the theory of planned behavior (TPB), which is based on the assumption that human behavior results from the human intention to undertake the behavior and his/her ability to do it consciously (14).

Considering the significance of a dietary pattern and a weight control plan in relation to the prevalence of osteoporotic fractures, the current study was conducted to determine the relationship between BMD, the risk of bone fracture, and weight control by dietary patterns among postmenopausal women with osteoporosis.

Materials and Methods

The samples were selected to participate in the study from July to December 2017. Applying a convenience sampling method, 240 postmenopausal women with osteoporosis were recruited from two bone densitometry centers in Tabriz, Iran. The inclusion criteria were postmenopausal women with primary osteoporosis (with T-score ≤ -2.5 for the mean lumbar spine (L1-4), femoral neck, or total) diagnosed by a rheumatologist. On the other hand, the exclusion criteria included treatment with antidepressants and psychotropic drugs, treatment with immunosuppressive agents (i.e., kidney transplantation, liver, autoimmune, and cancers), corticosteroids (i.e., betamethasone, prednisone, hydrocortisone, and dexamethasone), type 2 diabetes mellitus, rheumatoid arthritis, history of rheumatism and/or lupus, ankylosing spondylitis, spondylitis arthritis, and the patients on special (therapeutic) diet regimens.

Demographic Characteristics

Demographic data and the data related to the indicators of osteoporosis were collected by an expert healthcare professional. Data included age, marital status, education status, income, taken dietary supplements, the age of menopause, and family history of osteoporosis plus T-score (The difference in bone mass from the average of bone mass in healthy 30-year-old individuals), Z-score (patient's BMD differs from the average BMD of their age, gender, and racially), and BMD at either spine (L1-4), femoral neck, or total body.

Weight Control Behavior Questionnaire (Weight-Curb)

The weight control behavior of women was classified on the basis of TPB using a previously validated questionnaire (Weight-Curb). Five subscales were analyzed, including attitude, intention, subjective norms, perceived behavior control, and weight control behavior. Accordingly, women fell into two categories. Those with the score of weight control behavior lower than the median were considered to have no control over weight (the first group) and those with the score above the median were considered to have control of weight (the second group). The validity and reliability of Weight-Curb were confirmed in a previous study (15).

Nutrition Intake

A validated food frequency questionnaire (FFQ) was applied to determine dietary patterns (16). In addition, food items consumed by participants were classified into twenty-two food groups for dietary pattern analysis. To identify dietary patterns, the principal component analysis was conducted using VARIMAX rotation, entering food groups into the exploratory factor analysis. Further, the score of the patterns was estimated with a weighted method applying the weight of factor loadings related to each item. Furthermore, the pattern with a high score was considered as the dominant dietary pattern.

Bone Fracture Risk and Bone Mineral Density

The possibility of a 10-year bone fracture was investigated in women aged 40 to 90 using the fracture risk assessment tool (FRAX® algorithm) developed by the World Health Organization. Major osteoporotic fractures (MOF) were diagnosed in bone densitometry centers, including the spine, forearm, hip (i.e., femoral neck, intertrochanteric, and sub-trochanteric fractures), and shoulder fractures. The cut-off point of MOF ≥20% and of <20% was considered as "high risk" and "low risk", respectively. For the hip fracture, the cut-off point of ≥3% and of <3% was considered as "high risk" and "low risk", respectively (17).

The BMD of the femoral neck and lumbar spine was measured with a dual-energy X-ray absorptiometry (18). BMDs below median "0: low BMD" and higher than median "1: high BMD" were considered to be in the first and second groups, respectively.

Statistical Analysis

Statistical data analysis was performed using IBM SPSS Statistics software package (version 22). Additionally, exploratory factor analysis was conducted to determine dietary patterns, in which factor loading values greater than 0.1 were considered as acceptable to allocate an item to a pattern. Moreover, a logistic regression analysis was conducted to calculate the odds ratio (OR) between the dietary patterns, weight control, BMD, and the risk of fracture. Further, three adjusting models were used in this regard. Model 1 was adjusted for "attitude", "intention", "subjective norms", and "perceived behavioral control". In addition, Model 2 was adjusted as model 1 + "age", "the age of menopause onset", "income", and "BMI". Finally, Model 3 was adjusted as model 1 and model 2 + "T-score", "Z-score", and "dietary supplements". Furthermore, the logistic regression analysis was used for the OR within a 95% confidence interval (CI) and the significant difference between the dietary patterns, the fracture risk of the hip, and MOF based on BMD.

Results

Participants

The mean (standard deviation) of age, T-score, Z-score, age of menopause onset, and BMD at the spine (L1-4), femoral neck, or the total were 60.13 (6.57), -2.96 (0.50), -1.22 (0.77), 46.76 (5.73), and 0.56 (16), respectively. Two hundred and eight participants were married, and 178 of them were with a moderate level of income and lower. Further, 120 participants had a BMI of ≥25. As regards education status, 146 of them had <diploma literacy. In addition, 99 participants had a family history of osteoporosis, and finally, 140 of them were under supplement therapy with calcium and vitamin D.

Dietary Patterns

Table 1 presents factor loading scores, which reflect correlation coefficients between food groups and dietary patterns. Using factor analysis, three dietary patterns were identified (Table 1) according to food groups with the highest positive loadings. The first pattern (the healthy pattern) included liquid vegetable oils, fruits, nuts, low-fat and high-fat dairy products, olive oil, and unrefined grains. The second pattern (the mixed pattern) encompassed red meat, legumes, refined grains, fish and poultry, solid fats, and vegetables. In addition, the third pattern (the western pattern) included sweets and desserts, processed meat, tea and coffee, canned foods, potato side dishes, and soft drinks. These three patterns explained 24.44% of the total variance among which, 8.92%, 7.73%, and 7.59% were associated with western, healthy, and mixed patterns, respectively.

Table 1. The Result of Exploratory Factor Analysis for Dietary Patterns in Postmenopausal Women With Osteoporosis (n = 240)

Items	Dietary Patterns		
	Mixed	Healthy	Western
Egg	**0.577**	0.210	-0.328
Red meat	**0.519**	-0.384	0.151
Processed grains	**0.494**	-0.265	0.202
Vegetables	**0.399**		
Mayonnaise	**-0.383**		0.302
Legumes	**0.377**	0.169	
Fish and hen meat	**0.377**		-0.210
Fast-foods	**-0.257**	-0.108	
Solid oils	**0.236**	-0.219	-0.172
Unprocessed grains	-0.281	**0.660**	-0.107
Nuts		**0.527**	
Liquid vegetable oil	0.258	**0.374**	
Fruits		**0.306**	
Olive and olives oil		**0.285**	-0.107
High-fat and low-fat dairy	0.260	**0.265**	
Pickles and salt		**-0.162**	
Soda			**0.670**
Potato	0.379	-0.113	**0.606**
Cans	-0.219	-0.166	**0.408**
Organ meats	-0.107	-0.219	**0.382**
Tea and coffee			**0.170**
Sweets and desserts		-0.124	**0.155**
Number and percent	**78 (32.7)**	**71 (29.5)**	**91 (37.8)**
Variance in food intake	**7.594%**	**7.735%**	**8.917%**
Total variance		24.24%	

Note. (1) We considered factor-item loading values greater than 0.1 as acceptable to allocate an item to a pattern.
(2) We found 3 dietary patterns in FFQ thorough analysis of them. Therefore, we highlighted in bold these patterns in order to discriminate them from others.

The Risk of MOF in Relation to the Dietary Patterns and Weight Control Behavior

Based on the results (Table 2), the risk of MOF reduced in a woman following the healthy dietary pattern when the parameters of attitude, intention, subjective norms, perceived behavioral control, age, age at menopause, income, BMI, T-score, Z-score, and the supplement intake were adjusted in the analysis (OR: 2.55, 95% CI:1.47-4.41, $P < 0.001$). Moreover, the odds of MOF was 3.42 in women with a Western dietary pattern and no control on weight behaviors when age, age at menopause, income, and BMI were adjusted in the analysis ($P < 0.001$). The OR for those with a mixed dietary pattern was 4.64, 3.51, and 2.58 in models 1, 2, and 3, respectively ($P < 0.01$).

The Risk of Hip Fracture in Relation to Dietary Patterns and Weight Control Behavior

The multivariate-adjusted OR of the hip bone fracture across three dietary patterns based on weight control behavior is presented in Table 2. In comparison with women exhibiting weight control behavior, those with the western dietary pattern without behavioral control over their weights were at the increased risk of hip bone fracture when attitude, intention, subjective norms, and perceived behavioral control were adjusted in the analysis (OR: 3.13, 95% CI: 1.36-7.19, $P < 0.007$). Additionally, the OR of the incident hip bone fracture was 2.12 in women with no weight control compared to those following this healthy dietary pattern and showing weight control behavior ($P < 0.000$). The OR for those with a mixed dietary pattern was 2.98, 2.14, and 2.10 in models 1, 2, and 3, respectively ($P < 0.01$).

The Odds Ratio of Low BMD Across Dietary Patterns Based on the Weight Control Behavior

The OR of low BMD across three dietary patterns is provided in Table 3. In subjects with the Western dietary pattern and no weight control behavior, the likelihood of low BMD increased when attitude, intention, subjective norms, and perceived behavioral control were adjusted in the analysis (OR: 0.451, 95% CI: 0.199-1.042, $P = 0.044$).

Table 2. Logistic Regression Results for the Risk of MOF and Hip Fracture Across the Dietary Pattern Based on Weight Control Behavior in Iranian Postmenopausal Women With Osteoporosis (n = 240)

	Site of Fracture	Healthy Pattern		Mixed Pattern		Western Pattern	
		OR (95% CI)	*P* Value	OR (95% CI)	*P* Value	OR (95% CI)	*P* Value
Model 1	MOF	4.58 (1.90-11.01)	0.001	4.64 (1.94-11.05)	0.001	4.82 (2.02-11.45)	0.000
	Hip	2.96 (1.31-6.71)	0.009	2.98 (1.31-6.76)	0.000	3.13 (1.36-7.19)	0.007
Model 2	MOF	3.25 (1.49-7.07)	0.003	3.51 (1.59-7.76)	0.002	3.63 (1.65-8.00)	0.001
	Hip	2.12 (1.01-4.47)	0.047	2.14 (1.01-4.50)	0.045	2.19 (1.03-4.64)	0.040
Model 3	MOF	2.55 (1.47-4.41)	0.001	2.58 (1.49-4.48)	0.001	2.72 (1.55-4. 76)	0.000
	Hip	2.09 (1.09-4.01)	0.025	2.10 (1.09-4. 03)	0.026	2.16 (1.12-4.17)	0.022

Note. MOF: Major osteoporosis fracture; OR: Odds ratio; CI: Confidence interval; BMI: Body mass index; Model 1: Adjusted for attitude, intention, subjective norms, and perceived behavioral control; Model 2: Adjusted as model 1 + age, the age of menopause, income, and BMI; Model 3: Adjusted as model 1 and mode l 2+ T-score, Z-score, and supplements.

Table 3. Logistic Regression Results for the Risk of Low BMD Across the Dietary Pattern Based on Weight control in Postmenopausal Women With Osteoporosis (n = 240)

Dietary Patterns	Model 1		Model 2		Model 3	
	OR (95% CI)	*P* Value	OR (95% CI)	*P* Value	OR (95% CI)	*P*-value
Healthy pattern	0.408 (0.176-0.945)	0.033	0.311 (0.154-0.630)	0.001	0.306 (0.146-0.643)	0.002
Mixed pattern	0.411 (0.178-0.952)	0.038	0.321 (0.159-0.647)	0.001	0.353 (0.177-0.707)	0.003
Western pattern	0.306 (0.146-0.643)	0.002	0.307 (0.146-0.643)	0.002	0.347 (0.170-0.727)	0.004

Note. OR: Odds ratio; CI: Confidence interval; Model 1: Adjusted for F1 = attitude; F2 = Intention; F3 = Subjective norms; and F4 = Perceived behavioral control; Model 2: Adjusted as model 1 + age, the age of menopause, income, and BMI; Model 3: Adjusted as model 1 and model 2+ T-score, Z-score, and supplements; BMD: Bone mineral density at the spine (L1-4), femoral neck, or the total.

Furthermore, the OR of the low BMD within the healthy dietary pattern was 0.311 when age, age at menopause, income, and BMI confounding factors were adjusted in the analysis ($P < 0.001$). The OR for those with the mixed dietary pattern were 0.411, 0.321, and 0.307 in models 1, 2, and 3, respectively ($P < 0.05$).

Risk of Hip Fracture and MOF Across Dietary Patterns Based on BMD

Table 4 presents the risk of MOF and hip bone fracture across the dietary pattern based on BMD. As shown, the healthy dietary pattern tended to decrease the risk of MOF (OR: 2.35, 95% CI: 1.05-5.26, $P < 0.036$) and hip bone fracture (OR: 4.03, 95% CI: 1.65-9.84, $P < 0.0001$) after identifying confounding variables from age, age at menopause, income, BMI, education status, marital status, family history of osteoporosis, T-score, Z-score, and supplements intake. Finally, the OR of MOF and the hip bone fracture were 3.42 and 9.32 times higher in women with the western dietary pattern compared to those in model 1, respectively ($P < 0.01$).

Discussion

It is believed that a collection of sociocultural perspectives, including dietary patterns, physical activity, and quality of life in combination with biological factors could be

Table 4. Logistic Regression Results for the Risk of MOF and Hip Fracture Across the Dietary Pattern Based on BMD Status in Postmenopausal Women With Osteoporosis (n = 240)

	Site of Fracture	Healthy Pattern		Mixed Pattern		Western Pattern	
		OR (95% CI)	*P* Value	OR (95% CI)	*P* Value	OR (95% CI)	*P* Value
Model 1	MOF	3.23 (1.54-6.75)	0.002	3.25 (1.55-6.83)	0.002	3.42 (1.62-7.20)	0.001
	Hip	7.58 (3.12-17.35)	0.000	7.73 (3.37-17.71)	0.000	9.32 (3.69-23.54)	0.000
Model 2	MOF	3.10 (1.46-6.60)	0.003	3.16 (1.48-6.74)	0.003	3.24 (1.52-6.90)	0.002
	Hip	6.47 (2.74-15.24)	0.000	6.49 (2.76-15.24)	0.000	6.65 (2.40-18.38)	0.000
Model 3	MOF	2.35 (1.05-5.26)	0.036	2.46 (1.10-5.48)	0.027	2.50 (1.11-5.59)	0.026
	Hip	4.03 (1.65-9.84)	0.000	4.07 (1.66-9.64)	0.000	6.60 (2.80-15.53)	0.036

Note. BMI: Body mass index; OR: Odds ratio; CI: Confidence interval; Model 1: Adjusted for age, age of menopause, income, and BMI; Model 2: Adjusted as model 1 + education status, married status, and family history of osteoporosis; Model 3: Adjusted as model 1 and model 2+ T-score, Z-score, and supplements; BMD: Bone mass density at the spine (L1-4), femoral neck, or total; MOF: Major osteoporosis fracture.

associated with the prevalence of MOF and hip bone fractures (19). Our data showed that almost two-thirds of Iranian women follow western and mixed dietary patterns. Further, women with a western diet and no control over their weight were more prone to MOF and hip fracture compared to those with a healthy diet and control over their weight. As another main finding in our study, subjects with the western diet and low BMD were more prone to MOF and hip fracture in comparison with those with healthy and mixed dietary patterns. The risk factors for bone fracture included inadequate nutrition, low BMD, advancing age, being female, and the lack of physical activity (20-22). Bone fracture is more common in women because sex steroid hormones is less produced during post menopause in women, which, in turn, decreases the ability of the body to maintain calcium in the bones (23). Some studies have also reported the relationship between dietary patterns and bone metabolism disorders (24, 25). The risk of nutritional disturbances, particularly trace element deficiency is high during menopause. Some of these nutrients such as Zn and Cu are necessary cofactors for enzymes that are involved in bone metabolism (26, 27). According to a previous research, women who follow a healthy diet, including the high amount of fruits, vegetables, and grain, are less prone to incident bone fractures (28).

In our study, weight control behavior decreased the likelihood of MOF and hip fractures. This is in line with the report of Crandall et al showing that weight loss is associated with a 65% higher incidence of bone fracture in the hip, upper limp, and the central body. Similarly, the results of their study demonstrated that weight gain is associated with a higher incidence of bone fracture in the upper and lower limbs. Another study reported an increased risk of bone fracture with both weight loss and weight gain practices (6). Likewise, Armstrong et al observed that the relative risk for bone fracture in the overweight (25.0-29.9 kg/m^2) women and those with BMI =20.0-24.9 kg/m^2 was 1.71% and 2.55%, respectively (29). Singh et al also showed that subjects with high-fat mass and the lack of physical activity were more prone to bone fracture compared to others (30). On the other hand, Lv et al suggested that weight gain could be linked to the reduced incidence of bone fracture when weight loss was a significant risk factor for bone fracture (31). In a study conducted on 827 women, it was found that women with dramatic weight loss practice are subjects to experience bone fractures more often than women with stable weight (32).

Based on the results of our study, adopting a suitable healthy diet and weight control behavior are associated with a reduction in the risk of MOF in osteoporosis women. In addition to weight control behavior and dietary patterns, there are numerous investigations on today's dietary supplements with preventive and therapeutic prospects for osteoporosis (33,34). For instance, Riedt et al showed that the administration of calcium supplements improved the BMD in overweight postmenopausal women who followed weight loss programs (35). The increased risk of fracture in the present study could be related to the high renal excretion of calcium that is linked to the western dietary pattern, characterized by the high intake of processed meat, soda, sweet, organs meat, and desert. This may also be related to the increased risk of low BMD and MOF. In contrast, healthy and mixed diets are found to provide a high content of calcium. Vitamins K and A, which are linked to high BMD, are also found to be rich in mixed and healthy diets (36).

In the present study, both healthy and mixed dietary patterns were rich in calcium and the above-mentioned vitamins while the western dietary pattern was poor in these nutrients. Healthy and mixed dietary patterns in the present study were positively related to minerals such as Fe, Ca, phosphor, magnesium, and vitamins including A, D, K, C, and B groups, which lead to bone health (37). Thus, healthy and mixed dietary patterns may have reduced the risk of fractures. These findings are in accordance with those of Tucker et al who reported six dietary patterns in the elderly and showed that the high consumption of fruits and vegetables is associated with high BMD (38).

In conclusion, our findings indicated a reduced likelihood of MOF and hip bone fracture in women with a healthy dietary pattern (including liquid vegetable oil, fruits, nuts, low-fat and high-fat dairy products, olive oils, and unrefined grains) and consistent weight control behavior. In contrast, a western dietary pattern (containing sweets and desserts, processed meat, tea and coffee, pre-packaged foods, potato cans, and soft drinks) may be associated with low BMD and the incidence of bone fracture. Therefore, physicians should consider weight control in the assessment for the risk of bone fracture among postmenopausal women with osteoporosis. Accordingly, physicians, health practitioners, and health-care providers should consider the dietary patterns of their patients while designing any osteoporosis prevention and/or treatment programs aiming at reducing the risk of fractures among postmenopausal women with osteoporosis.

Limitations and Strengths

The current study was based on a validated TPB-based questionnaire to explore the cognitive factors of weight control behavior and dietary patterns incidental to osteoporotic fractures. Given the lack of similar studies in the literature, the current report is considered to present unique information regarding the relationships between weight control behavior, dietary pattern, and bone fractures. However, the study suffers from a few limitations. The FFQ is error-prone to under-report or over-report. In addition, various socio-economical, personal, and environmental confounding factors have to be adjusted to investigate the relations of dietary patterns with osteoporosis and the risk of osteoporotic fractures.

Thus, we suggest the replication of similar studies in other gender and age groups within different communities. Eventually, due to the high between-groups-variance of 24.4%, there may be other additional dietary patterns in the studied population, which merits more-detailed investigations..

Conflict of Interests

The authors remark that they have no conflict of interests.

Ethical Issues

The present study was conducted in conformity with the regulations of the Ethics Committee of Tabriz University of Medical Sciences (Ethical approval code: IR.TBZMED.REC.920). Additionally, written informed consent was taken from all participants before study initiation.

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