Dietary patterns associated with bone mineral density in premenopausal Japanese farmwomen[1–3]

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ABSTRACT

Background: Because several nutrients are known to affect bone mineral density (BMD), the analysis of dietary patterns or combinations of foods may provide insights into the influence of diet on bone health.

Objective: We evaluated associations between dietary patterns and BMD in Japanese farmwomen.

Design: The study included 291 premenopausal farmwomen (aged 40–55 y) who participated in the Japanese Multi-centered Environmental Toxicant Study (JMETS; $n = 1407$). Forearm BMD was measured by using dual-energy X-ray absorptiometry. Diet was assessed by using a validated self-administered diet history questionnaire comprising 147 food items, from which 30 food groups were created and entered into a factor analysis.

Results: Four dietary patterns were identified. The "Healthy" pattern, characterized by high intakes of green and dark yellow vegetables, mushrooms, fish and shellfish, fruit, and processed fish, was positively correlated with BMD after adjustment for several confounding factors ($P = 0.048$). In contrast, the "Western" pattern, characterized by high intakes of fats and oils, meat, and processed meat, tended to be inversely associated with BMD; however, the association was not significant ($P = 0.08$).

Conclusion: A dietary pattern with high intakes of fish, fruit, and vegetables and low intakes of meat and processed meat may have a beneficial effect on BMD in premenopausal women. *Am J Clin Nutr* 2006;83:1185–92.

KEY WORDS Bone mineral density, dietary pattern, diets, fruit and vegetables, Japanese farmwomen

INTRODUCTION

Osteoporosis and related fractures among senior citizens are well recognized as a major public health problem in developed nations. They are the second-leading cause in Japan for patients to become bedridden, preceded only by cerebrovascular diseases in Japan. The prevalence of osteoporosis and related fractures appears to be increasing (1). In addition, osteoporosis and related fractures impose high health care costs in long-term nursing home care. The prevention of bone loss is thus desirable for both medical and economic reasons.

With regard to nutritional approaches to bone metabolism, a great deal of attention has been focused on the benefits of calcium and vitamin D. Other nutrients and dietary components, such as potassium, magnesium, vitamin K, and fruit and vegetables, have also shown beneficial effects (2–6), although a clear relation with bone metabolism has not been established. Moreover, beneficial effects have been hypothesized for protein, saturated fat, phosphorus, vitamin C, sodium, and dietary isoflavone (7–12). With regard to diet, however, the most common approach, that of examining single nutrients or foods, may not adequately account for complicated interactions and cumulative effects. Because people consume diets consisting of a variety of foods with complex combinations of nutrients, rather than isolated nutrients, the examination of only single nutrients or foods could result in the identification of erroneous associations between dietary factors and disease.

To overcome these limitations, the dietary pattern approach—namely, the measurement of overall diet—has been widely used to elucidate the relations between diet and disease (13, 14). This approach allows the development of appropriate recommendations for overall dietary habits to prevent undesirable conditions and diseases. Tucker et al (15) used the dietary pattern approach with cluster analysis to show that a diet rich in fruit and vegetables is associated with a greater bone mineral density (BMD) in elderly men. In Japan, only one study (16) examined the relation between diet and the results of an ultrasound bone density meter (USBDM) among elderly men and women. The results showed that the factor 2 score (ie, that for a diet with a high intake of breads instead of rice and a frequent intake of dairy products, called a bread-style diet) was significantly lower among elderly women in the USBDM-measured low bone density group (16). In the current study, we attempted to identify dietary patterns by using factor analysis. In addition, we examined the relations between dietary patterns and BMD in Japanese farmwomen aged

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40–55 y who live in rural communities and have maintained more traditional dietary habits than do typical residents of large cities.

SUBJECTS AND METHODS

Study population

The Japanese Multi-centered Environmental Toxicant Study (JMETS) was a nationwide, community-based study of farm-women sampled between 2000 and 2003. The study was conducted in 5 districts—1 district is on the north end of Kyushu Island (the southernmost Japanese island), and the other 4 districts are located at the north end of Honshu Island (the largest Japanese island)—where the rice produced and consumed by the farmers has a low-to-moderate cadmium contamination. Study recruitment and enrollment were described in detail elsewhere (17, 18). Before the study, orientation sessions were held to explain the purposes and protocol of the study to the participants. At the same time, participants were instructed in completing 2 kinds of questionnaires and were asked to bring the questionnaires to the examination. A total of 1407 women aged 20–78 y who agreed to participate in the study completed the questionnaires, and their BMD was measured.

All subjects provided written informed consent. The study protocol was approved by the Committee on Medical Ethics of the Jichi Medical School.

Dietary assessment and food grouping

We used a previously validated 16-page self-administered diet history questionnaire (DHQ) to assess dietary habits in the previous month (19, 20). The DHQ consists of 7 sections: general dietary behaviors; most frequent cooking methods; frequency and amount of consumption of 6 alcoholic beverages; consumption frequency and semiquantitative portion size of 121 selected food and nonalcoholic beverages; dietary supplements; frequency and amount of consumption of 19 staple foods (ie, rice, bread, noodles, and other wheat foods) and miso soup (fermented soybean paste soup); and open-ended items for foods consumed regularly (≥1 time/wk) but not appearing in the DHQ. The food and beverage items and portion sizes in the DHQ were derived primarily from data in the National Nutrition Survey of Japan and several cookbooks for Japanese dishes (19). Measures of dietary intakes of 147 food and beverage items and energy were calculated by using an ad hoc computer algorithm for the DHQ, which was based on the Standard Tables of Food Composition in Japan (21). Information on dietary supplements and data from the open-ended questionnaire items were not used in the calculation of dietary intakes. More detailed descriptions of the questionnaire, the methods of calculating nutrients, and the validity of the questionnaire are given elsewhere (19, 20).

To reduce the complexity of the data, food items were categorized into groups (**Table 1**). In general, the food grouping was based on the principles of similarity of nutrient profiles or culinary usage of the foods, mainly according to the Standard Tables of Food Composition in Japan (21), and the classification of food groups used by the National Nutrition Survey of Japan (22). Finally, 30 separate food groups were established and used in our analyses to identify dietary patterns.

Measurement of bone mineral density

BMD (g/cm^2) and bone mineral mass [(BMM) g] were measured by using dual-energy X-ray absorptiometry (DXA) of each participant's nondominant forearm by using an osteometer (DTX-200; Osteometer MediTech Inc, Hawthorne, CA). DXA scanned at the distal sites of the radius and ulna. Subjects' BMD and bone mineral content [(BMC) g] were calculated in the area of the bones between the distal site of an 8-mm gap between the 2 bones and the proximal site 24 mm from the gap. The CVs of forearm BMD measurements were all within 1.0%.

Measurement of confounding factors

In addition to diet, we measured the following factors that may be related to BMD: body weight, body height, physical activity level, smoking habit, history of bone fracture, supplement use, menopausal status, current use of hormone replacement therapy, parity, and age at menarche. Body weight and height were measured to the nearest 0.1 kg and 0.1 cm, respectively, while subjects were wearing light clothing but no shoes. Body mass index (BMI) was calculated as body weight (kg) divided by body height squared (m^2). The maximum grasping power value of a participant's nondominant hand was measured 3 times by using a hand dynamometer. Grasping power was used in our analyses as an indicator of physical activity.

Age (in y, continuous), current smoking (yes or no), frequency of bone fracture (times, continuous), current use of hormone replacement therapy (yes or no), parity (times, continuous), and age at menarche (in y, continuous) were obtained from an 8-page questionnaire. Alcohol consumption (g/d) and use of calcium or multivitamin supplements (yes or no) were assessed from the DHQ.

Statistical analysis

In the statistical analysis, the dietary environmental cadmium exposure of the subjects did not show any significant effects on renal tubular functions (17) or BMD (18) after adjustment for possible confounders. However, to avoid unknown long-term effects of cadmium exposure, we restricted the cohort of the current study to the 339 women aged 40–55 y who were still menstruating at the time of entry. Of these 339 women, 48 were excluded for collagen disease ($n = 1$), hyperthyroidism ($n = 1$), a reported daily energy intake < 2.7 or > 14.4 MJ (650–3450 kcal) ($n = 9$; 23), and a reported change in dietary habits within the previous 3 y ($n = 38$). The remaining subjects had no history of taking medications that may affect bone or calcium metabolism and no history of any condition that affects bone metabolism. Thus, data from 291 women were included in the final analysis.

We calculated the ratio of energy intake (EI) to basal metabolic rate (BMR) to evaluate the relative accuracy of the reported energy intake. To compare the relative degree of underreporting and overreporting, we temporarily used EI:BMR as defined by FAO/WHO/UNU: ratios of 1.27 for the minimum survival level, 1.56 for the sedentary level for women and 2.0–2.4 for the maximum sustainable lifestyle level (24).

Analyses were conducted by using FACTOR PROCEDURE software (version 8.2; SAS Inc, Cary, NC; 25). Factor analysis was used to derive the dietary patterns on the basis of the 30 food groups from the DHQ. Intake of these food groups was adjusted for total energy intake by using the residual method (26). To

TABLE 1
The 30 food groupings used in the dietary pattern analysis[1]

Food group	Foods in the group
Rice	Well-milled rice, rice with barley (70% rice and 30% barley), rice with embryo, half-milled rice, 70%-milled rice, brown rice
Noodles	Japanese noodles (buckwheat or Japanese wheat noodles), instant noodles, Chinese noodles, pasta, spaghetti
Breads	White bread, butter roll, croissant, pizza, okonomiyaki (Japanese pancake fried with various ingredients), takoyaki (small ball of wheat flour with bits of octopus)
Miso soup	Miso (fermented soybean paste) soup
Dairy products	Whole milk, low-fat milk, skim milk, yogurt, cheese, cottage cheese, lactic acid bacteria beverages, ice cream, coffee cream
Meats	Beef, pork, ground beef or pork, chicken, liver (beef, pork, or chicken)
Processed meats	Ham, sausage, bacon, salami
Fish and shellfish	Eel, white-meat fish (sea bream, flatfish, codfish, and others), blue-back fish (mackerel, sardine, herring, and others), red-meat fish (tuna, salmon, and skipjack), shrimp, squid, octopus, oysters, other shellfish
Processed fish	Dried fish, small fish with bones, canned tuna, fish eggs, boiled fish in soy sauce, salted gut (fish, squid, or shellfish), surimi (ground fish meat) products
Eggs	Eggs
Nuts	Peanuts, other types of nuts
Soy products	Tofu (soybean curd), tofu products such as atsuage (deep-fried tofu cutlet), ganmodoki (deep-fried tofu burger), aburaage (deep-fried tofu pouch), natto (fermented soybeans), cooked beans, miso as seasoning
Green and dark yellow vegetables	Carrots, pumpkins, tomatoes, green pepper, broccoli, lettuce, green leafy vegetables such as spinach
White vegetables	Cabbage, cucumber, Chinese cabbage, bean sprouts, Japanese radish, onion, cauliflower, eggplant, burdock, lotus root
Pickled vegetables	Salted pickles, umeboshi (pickled and dried plum), kimchi (Korean pickles)
Fruit and vegetable juices	Vegetable juice, tomato juice, 100% fruit juice, sweetened fruit drinks (50% fruit)
Fruit	Oranges, grapefruits, bananas, apples, strawberries, grapes, peaches, pears, kiwi fruit, persimmons, melons, watermelon, raisins, canned fruit
Sugary foods	Sugar for coffee and tea, sugar for cooking, jam, marmalade
Mushrooms	Shiitake, shimeji, enoki
Seaweeds	Wakame seaweed, purple laver, brown algae
Potatoes	White potatoes, French fries, sweet potatoes, taros, konnyaku (devil's tongue jelly)
Sweets	Japanese sweetened bun, pancake, potato chips, senbei and arare (rice snacks), crackers, salted snacks, Japanese sweets with or without azuki beans, cakes, soft cookies, hard cookies, chocolates, candies, caramels, chewing gums, jellies, doughnut
Butter	Butter
Fats and oils	Margarine, vegetable oil, salad dressing with oil
Alcohol	Beer, sake (rice wine), shochu (distilled spirits), chuhai (shochu highball), whiskey, wine
Tea	Green tea, oolong tea, black tea
Coffee	Coffee, cocoa
Soft drinks	Cola, nonfruit juices, soft drinks without sugar, such as sports beverages
Seasonings	All condiments (eg, ketchup), mayonnaise, table salt, salt and salt-rich seasonings used during cooking, soy sauce, oil-free dressings, curry or stew roux, spices
Soup	Corn soup, Chinese soup

[1] Foods listed in the table were from the self-administered diet history questionnaire.

identify the number of factors to be retained, we used the criterion of eigenvalues > 1.0, the most widely used criterion in factor analysis, as a first step. However, this procedure created 12 independent factors, a number too large for further analyses. The screen plots dropped substantially (from 1.81 to 1.59) after the third factor and remained closer (1.54 for the fifth factor and 1.50 for the sixth factor) after the fifth factor, which suggested that the retention of 3 or 4 factors would be optimal. Finally, we decided to retain 4 factors for further analyses. The factors were rotated by orthogonal transformation (VARIMAX rotation function in SAS) to achieve a simpler structure with greater interpretability. After Varimax rotation, factor scores for each subject were saved from the principal component analysis. Factor loadings represent correlation coefficients between individual food groups and dietary patterns. The proportion of variance explained by each factor was calculated by dividing the sum of the squares of the respective factor loadings by the number of variables. The factor scores for each pattern and for each individual were determined by summing the intakes of each food group weighted by the factor loading (27). All data presented here are from the Varimax rotation. The scores were used for comparison with nutrient intake and other lifestyle factors and to estimate associations with BMD.

Factors were divided into quintiles, and sample means and frequencies were calculated. Partial correlation coefficients (adjusted for age) were calculated between each factor and forearm BMD and between each factor and energy-adjusted nutrient intake. We compared the adjusted mean (± SE) for each quintile of each dietary pattern using 3 models. In model 1, we adjusted for age and lifestyle variables, such as BMI, grasping power, and current smoking, as confounding factors. In model 2, we further adjusted for a history of bone fracture and female hormone-related factors, such as the use of hormone replacement therapy, age at menarche, and parity. In model 3, we also adjusted for

TABLE 2
Characteristics of study subjects[1]

	Premenopausal women
Age (y)	46.4 ± 3.7[2]
Body height (cm)	156.1 ± 5.2
Body weight (kg)	57.8 ± 8.4
BMI (kg/m^2)	23.7 ± 3.3
Grasping power (kg)	29.1 ± 4.5
Forearm bone mineral density (g/cm^2)	0.489 ± 0.053
Forearm bone mineral mass (g)	3.20 ± 0.45
Smoking status [*n* (%)]	
Current	11 (4)
Former	4 (1)
Never	276 (95)
History of fracture [*n* (%)]	26 (9)
Hormone replacement therapy [*n* (%)]	2 (1)
Age at menarche (y)	13.0 ± 1.2
Parity (*n*)	2.5 ± 0.9
Calcium supplement use [*n* (%)]	13 (4)
Multivitamin supplement use [*n* (%)]	14 (5)
EI:BMR[3]	1.41 ± 0.32
< 1.27	100 (34)
> 2.4	1 (1)
Nutrient intakes	
Total energy (MJ/d)	7.9 ± 1.7
Protein (% of energy)	13.6 ± 2.1
Fat (% of energy)	26.5 ± 5.6
Carbohydrate (% of energy)	57.8 ± 7.0
Potassium (mg/d)	2322 ± 713
Magnesium (mg/d)	251 ± 73
Calcium (mg/d)	498 ± 185
Phosphorus (mg/d)	969 ± 282
Vitamin C (mg/d)	109 ± 55
Vitamin D (μg/d)	7.8 ± 4.4
Vitamin K (μg/d)	322 ± 181
Isoflavon (mg/d)	36.4 ± 21.8
Alcohol (g/d)	2.6 ± 6.1

[1] $n = 291$. EI:BMR, the ratio of energy intake to basal metabolic rate.
[2] $\bar{x}$ ± SD (all such values).
[3] Subjects who had an EI:BMR < 1.27 were defined as severe underreporters and those with an EI:BMR > 2.4 were defined as overreporters according to the FAO/WHO/UNU (24).

dietary variables, such as the use of calcium or multivitamin supplements. *P* values to test for linear trends were calculated by using dietary pattern scores as a continuous variable after control for possible confounding factors.

All statistical analyses were performed by using SAS software (version 8.2). A *P* value of < 0.05 was considered significant, except during the analysis of correlations between dietary patterns and nutrient intake, because those correlations were not necessarily independent of each other. In those instances, a partial correlation coefficient of > 0.2 or < −0.2 was considered significant.

RESULTS

Mean (±SD) values for forearm BMD, nutrient intake, and continuous potential confounders used in the present analysis are shown in **Table 2**. Proportional distributions are presented for categorical variables. The following activities were rare among participants in the current study: current smoking (4%) and the use of calcium supplement (4%), multivitamin supplement (5%), and hormone replacement therapy (1%). The mean value of EI: BMR as an indicator of reporting accuracy was 1.41 ± 0.32. Thirty-four percent of the subjects had an EI:BMR below the minimum survival value of 1.27, and 1% had an EI:BMR higher than the maximum value of 2.4 for a sustainable lifestyle.

The factor-loading matrices are shown in **Table 3**. The high positive loadings indicate strong associations between given food groups and patterns, whereas negative loadings indicate negative associations with the patterns. The patterns were labeled according to the food groups with high loadings. Factor 1, which loaded heavily on green and white vegetables, mushrooms, fish and shellfish, fruit, processed fish, seaweed, and soy products, was labeled the "Healthy" pattern. Factor 2, with high loadings for rice, miso soup and soy products, was labeled the "Japanese traditional" pattern. Factor 3 with high loadings for fats and oils, meat, processed meats, and seasoning was labeled the "Western" pattern. Factor 4, with high loadings for coffee, soft drinks, dairy products, sugary foods, and meats, was labeled the "beverage and meats" pattern. Overall, the 4 dietary patterns accounted for 29.7% of the variance in food intakes.

The subjects were divided into quintiles by the factor score of each dietary pattern. Samples means and frequencies were calculated across quintiles. Sample characteristics of premenopausal women in the lowest and highest quintiles of each food pattern (Q1 and Q5, respectively) are shown in **Table 4**. Participants in the highest quintile of the Healthy pattern were older (47.3 ± 3.7 y), whereas those in the highest quintile of the Western pattern were younger (45.6 ± 3.3 y). The greatest incidence of calcium supplement use (10.3%) was observed in the highest quintile of the Western pattern, whereas the smallest incidence of multivitamin supplement use (3.5%) was observed in the highest quintile of the Japanese traditional pattern.

Partial correlation coefficients between each of the 4 dietary patterns and forearm BMD and energy-adjusted nutrient intakes are shown in **Table 5**. BMD was not correlated with any dietary pattern after adjustment for age only. For energy-adjusted nutrient intakes, the Healthy pattern was correlated with protein ($r = 0.65$), potassium ($r = 0.82$), magnesium ($r = 0.69$), calcium ($r = 0.51$), phosphorus ($r = 0.70$), vitamin C ($r = 0.51$), vitamin D ($r = 0.53$), vitamin K ($r = 0.48$), and alcohol ($r = 0.22$). The Western pattern was positively correlated with fat ($r = 0.54$) and negatively correlated with carbohydrate ($r = -0.55$). In contrast, the Japanese traditional pattern showed a strong positive correlation with isoflavone ($r = 0.49$) and a negative correlation with fat ($r = -0.22$).

The multivariate-adjusted mean BMD across quintiles of all 4 dietary patterns is shown in **Table 6**. The highest quintile of the Healthy pattern had a significantly higher BMD than did the lowest quintile after adjustment for nondietary factors and dietary supplements (0.498 ± 0.006 and 0.476 ± 0.006 g/cm^2 for Q5 and Q1, respectively; $P = 0.014$). The highest quintile of the Western pattern had a significantly lower BMD than did the lowest quintile (0.480 ± 0.006 and 0.500 ± 0.006 g/cm^2 for Q5 and 1, respectively; $P = 0.043$). To test for linear trend, modeling of factor scores as continuous variables showed a positive and significant association in the Healthy pattern ($P = 0.048$), whereas a negative, but nonsignificant, association was observed in the Western pattern for premenopausal women ($P = 0.08$). No association with BMD was seen for any other dietary pattern.

TABLE 3
Factor-loading matrix for the 4 dietary patterns identified among 291 premenopausal Japanese farmwomen who participated in the Japanese Multi-centered Environmental Toxicant Study[1]

	Factor 1: Healthy	Factor 2: Japanese traditional	Factor 3: Western	Factor 4: Beverage and meats
Green and dark yellow vegetables	0.61	—	—	—
Mushrooms	0.57	—	—	—
Fish and shellfish	0.57	—	—	—
Fruit	0.49	—	—	—
Processed fish	0.44	—	—	−0.35
White vegetables	0.40	0.35	0.33	—
Eggs	—	—	—	—
Alcohol	—	—	—	—
Rice	−0.50	0.64	−0.28	—
Miso soup	—	0.61	—	—
Soy products	0.26	0.54	—	—
Seaweeds	0.36	0.39	—	—
Nuts	—	—	—	—
Noodles	—	−0.33	—	−0.25
Sweets	—	−0.53	−0.42	—
Breads	—	−0.63	—	—
Fats and oils	—	—	0.62	—
Meats	—	—	0.59	0.30
Processed meats	—	—	0.54	—
Butter	—	—	0.41	—
Seasonings	—	—	0.37	—
Soup	—	—	0.30	—
Salted vegetables	0.30	—	−0.37	—
Coffee	—	—	—	0.65
Sugary foods	—	—	—	0.50
Soft drinks	—	—	—	0.35
Dairy products	—	—	—	0.35
Fruit and vegetable juices	—	—	—	—
Potatoes	—	0.30	—	−0.37
Tea	—	—	—	−0.45
Percentage of variance (%)	8.3	8.1	7.0	6.3

[1] Data for 291 subjects from the self-administered diet history questionnaire. Absolute values < 0.25 were excluded from the table for simplicity.

DISCUSSION

Using factor analysis, an approach that considers overall eating patterns, we identified 4 dietary patterns in premenopausal women aged 40–55 y and found associations between dietary patterns and BMD. The Healthy pattern showed a positive correlation with BMD, whereas the Western pattern showed a negative association.

To our knowledge, no previous study examined the relation between dietary patterns by using factor analysis and BMD as measured by DXA. Although only one cross-sectional study has examined the relation between dietary patterns and BMD in Japanese elderly men and women, BMD in that study was measured by using USBDM (16). Uchida et al (16) reported that the factor 2 score (ie, a bread-style diet) was significantly lower in the low USBDM-measured group than in the mean and high USBDM-measured groups of elderly women. A second study, by Tucker et al (15), examined the association between BMD and dietary patterns derived from cluster analysis. That study, a case-control study from the Framingham Osteoporosis Study, found that the cluster for a diet high in fruit, vegetables, and cereals had significantly greater BMD at all 3 hip sites and in the radius in elderly men but not in elderly women, whereas a cluster high in candy had significantly lower BMD in both men and women. Direct comparison between the results of our study and these other studies is difficult because they are derived by using different analytic methods (ie, factor or cluster analysis) and in populations with different age ranges and genetic and cultural make-ups, who may have the specific (customary) dietary and lifestyle patterns of Western and Asian countries. Therefore, the results should be interpreted with caution.

Diets high in animal meat intakes and low in fruit and vegetable intakes—typical diets in industrialized countries—have a negative effect on bone health by increasing calcium excretion and bone resorption (28). In addition, acidosis may inhibit osteoblast function and increase osteoclast activity, which limits bone formation and increasing bone loss (29). However, high intakes of dietary potassium and magnesium, along with other nutrients associated with intakes of fruit and vegetables, have been suggested to promote an alkaline environment by reducing the potential renal acid load and net endogenous acid production (30, 31). In a previous study, New et al (4) and Macdonald et al (7) found that the intakes of several nutrients related to fruit and vegetables were positively correlated with BMD and negatively correlated with bone loss in premenopausal women (4, 7). In addition, a previous cross-sectional study showed a correlation between high intakes of magnesium, potassium, and fruit and vegetables (per serving) and BMD in both elderly men and

TABLE 4

Sample characteristics for the lowest and highest quintiles (Q) of 4 dietary patterns identified for 219 premenopausal women participating in the Japanese Multi-centered Environmental Toxicant Study[1]

	Healthy		Japanese traditional		Western		Beverage and meats	
	Q1	Q5	Q1	Q5	Q1	Q5	Q1	Q5
Age (y)	45.3 ± 3.7[2]	47.3 ± 3.7[3]	45.8 ± 4.2	46.2 ± 3.6	47.2 ± 4.0	45.6 ± 3.3[4]	47.2 ± 3.8	45.8 ± 3.7
Grasping power (kg)	29.5 ± 4.0	27.5 ± 4.0[4]	30.0 ± 5.0	28.8 ± 5.0	28.5 ± 4.4	28.9 ± 4.1	29.4 ± 5.0	28.8 ± 4.5
Forearm bone mineral density (g/cm^2)	0.482 ± 0.054	0.495 ± 0.052	0.496 ± 0.058	0.495 ± 0.048	0.499 ± 0.055	0.482 ± 0.059	0.479 ± 0.061	0.496 ± 0.051
Forearm bone mineral mass (g)	3.19 ± 0.51	3.28 ± 0.44	3.29 ± 0.48	3.18 ± 0.50	3.34 ± 0.48	3.17 ± 0.46	3.13 ± 0.48	3.29 ± 0.45
Age at menarche (y)	12.9 ± 1.3	13.1 ± 1.2	13.0 ± 1.2	13.2 ± 1.3	12.8 ± 1.1	13.0 ± 1.2	13.2 ± 1.3	12.9 ± 1.2
Parity (*n*)	2.5 ± 1.0	2.4 ± 0.8	2.4 ± 0.7	2.7 ± 0.9	2.4 ± 0.9	2.5 ± 0.8	2.5 ± 1.1	2.5 ± 0.9
BMI (kg/m^2)	24.6 ± 3.6	24.0 ± 3.3	24.3 ± 3.4	23.7 ± 3.1	23.8 ± 4.1	24.0 ± 3.5	23.9 ± 3.6	24.5 ± 3.0
< 18.5 [*n* (%)]	2 (3.5)	2 (3.5)	1 (1.7)	2 (3.5)	1 (1.7)	2 (3.5)	3 (5.2)	0 (0)
18.5–24.9 [*n* (%)]	33 (56.9)	34 (58.6)	37 (63.8)	39 (67.2)	37 (63.8)	36 (62.1)	36 (62.1)	33 (56.9)
≥ 25.0 [*n* (%)]	23 (39.7)	22 (37.9)	20 (34.5)	17 (29.3)	20 (34.5)	20 (34.5)	19 (32.8)	25 (43.1)
Smoking status [*n* (%)]								
Current	1 (1.7)	3 (5.2)	2 (3.5)	2 (3.5)	3 (5.2)	2 (3.5)	1 (1.7)	4 (6.9)
Former	2 (3.5)	0 (0)	1 (1.7)	0 (0)	1 (1.7)	1 (1.7)	1 (1.7)	2 (3.5)
Never	55 (94.8)	55 (94.8)	55 (94.8)	56 (96.7)	54 (93.1)	55 (94.8)	56 (96.6)	52 (89.7)
Calcium supplement use [*n* (%)]	2 (3.5)	4 (6.9)	2 (3.5)	4 (6.9)	1 (1.7)	6 (10.3)[5]	3 (5.2)	3 (5.2)
Multivitamin supplement use [*n* (%)]	3 (5.2)	4 (6.9)	5 (8.6)	2 (3.5)[5]	3 (5.2)	4 (6.9)	2 (3.5)	2 (3.5)
History of fracture [*n* (%)]	8 (13.8)	3 (5.3)	8 (14.0)	4 (6.9)	3 (5.2)	7 (12.3)	7 (12.1)	4 (6.9)
Hormone replacement therapy [*n* (%)]	0 (0)	1 (1.7)	0 (0)	0 (0)	1 (1.7)	0 (0)	1 (1.7)	0 (0)

[1] The factors were standardized continuous variables, and each subject had a score for each factor. $n = 58$ in Q1, Q2, Q4, and Q5 and 59 in Q3.
[2] $\bar{x}$ ± SD (all such values).
[3,4] Test for linearity across quintiles of factors: [3]$P < 0.001$, [4]$P < 0.05$.
[5] Significant difference between quintiles in all categories, $P < 0.01$ (chi-square test).

women (3). In accordance with these previous findings, the Western pattern identified in the current study is negatively associated with BMD; however, the association was not significant ($\beta = -0.005$, $P = 0.08$). In contrast, the Healthy pattern, which was highly and positively correlated with potassium, magnesium, calcium, vitamin C, vitamin D, and vitamin K, also was positively correlated with BMD ($\beta = 0.006$, $P = 0.048$).

The current study has several limitations. First, the DHQ assessed dietary habits only in the previous month, which was too short a time for the examination of a nutrient–bone mass association. Therefore, as in our previous report, we included only those subjects who had maintained stable dietary habits for ≥3 y (6). Second, the classification of menopausal status was self-reported according to 3 categories (regular, irregular, or no menstrual cycle). We did not ask the irregularly menstruating or nonmenstruating women about the length of time since their last menses. Therefore, given its clear effect on bone metabolism, we also considered age in the definition of menstrual status. Moreover, because the BMD of the perimenopausal women showed no decrease and did not differ significantly from that of the premenopausal women (0.492 and 0.486 g/cm^2, respectively; $P = 0.14$), we evaluated women with regular and irregular cycles together as premenopausal women. Third, 4 of the 5 selected districts were cadmium-polluted areas, in which low-to-moderate cadmium contamination of rice has been detected.

TABLE 5

Partial Pearson correlation coefficients between each of 4 dietary patterns and bone mineral density and daily nutrient intakes for 291 premenopausal Japanese farmwomen who participated in the Japanese Multi-centered Environmental Toxicant Study[1]

	Factor 1: Healthy	Factor 2: Japanese traditional	Factor 3: Western	Factor 4: Beverage and meats
Forearm bone mineral density (g/cm^2)	0.05	0.01	−0.08	0.08
Nutrient intakes				
Carbohydrate (% of energy)	−0.39	0.20	−0.55	0.06
Protein (% of energy)	0.65	−0.01	0.18	−0.10
Fat (% of energy)	0.25	−0.22	0.54	−0.03
Potassium (mg/d)	0.82	0.14	0.05	0.19
Magnesium (mg/d)	0.69	0.22	0.00	0.02
Calcium (mg/d)	0.51	0.07	−0.07	0.12
Phosphorus (mg/d)	0.70	0.09	0.10	0.06
Vitamin C (mg/d)	0.51	0.11	−0.07	−0.03
Vitamin D (μg/d)	0.53	−0.01	−0.02	−0.26
Vitamin K (μg/d)	0.48	0.31	−0.03	−0.04
Isoflavone (mg/d)	0.28	0.49	−0.08	−0.21
Alcohol (g/d)	0.22	−0.15	0.19	−0.01

[1] All nutrients were energy-adjusted by using the residual method. All partial correlation coefficients were adjusted for age. A partial correlation coefficient of >0.2 or <−0.2 was considered significant.

TABLE 6
Multivariate-adjusted bone mineral density by quintile (Q) of 4 dietary patterns among 291 premenopausal women participating in the Japanese Multicentered Environmental Toxicant Study[1]

Dietary pattern	Q1 ($n = 58$)	Q2 ($n = 58$)	Q3 ($n = 59$)	Q4 ($n = 58$)	Q5 ($n = 58$)	*P* for trend
Factor 1: Healthy						
Model 1	0.476 ± 0.006[2]	0.480 ± 0.006	0.504 ± 0.006	0.491 ± 0.006	0.497 ± 0.006	0.11
Model 2	0.476 ± 0.006	0.479 ± 0.006	0.503 ± 0.006[3]	0.492 ± 0.006	0.498 ± 0.006[4]	<0.05
Model 3	0.476 ± 0.006	0.479 ± 0.006	0.504 ± 0.006[3]	0.492 ± 0.006	0.498 ± 0.006[4]	<0.05
Factor 2: Japanese traditional						
Model 1	0.491 ± 0.006	0.490 ± 0.006	0.483 ± 0.006	0.488 ± 0.006	0.495 ± 0.006	0.58
Model 2	0.493 ± 0.007	0.490 ± 0.006	0.485 ± 0.006	0.486 ± 0.006	0.495 ± 0.006	0.95
Model 3	0.493 ± 0.007	0.490 ± 0.006	0.485 ± 0.006	0.486 ± 0.007	0.495 ± 0.007	0.92
Factor 3: Western						
Model 1	0.500 ± 0.006	0.484 ± 0.006	0.492 ± 0.006	0.490 ± 0.006	0.480 ± 0.006	0.06
Model 2	0.501 ± 0.006	0.484 ± 0.006	0.492 ± 0.006	0.491 ± 0.006	0.482 ± 0.006	0.08
Model 3	0.501 ± 0.006	0.484 ± 0.006	0.492 ± 0.006	0.491 ± 0.006	0.482 ± 0.007	0.08
Factor 4: Beverage and meats						
Model 1	0.477 ± 0.006	0.494 ± 0.006	0.483 ± 0.006	0.501 ± 0.006	0.492 ± 0.006	0.31
Model 2	0.478 ± 0.006	0.495 ± 0.006	0.484 ± 0.006	0.501 ± 0.006	0.492 ± 0.006	0.35
Model 3	0.478 ± 0.006	0.495 ± 0.006	0.484 ± 0.006	0.501 ± 0.006	0.492 ± 0.006	0.34

[1] Model 1: multivariate models were adjusted for age, BMI (kg/m^2), grasping power, and current smoking. Model 2: further adjusted for fracture history, the use of hormone replacement therapy, age at menarche, and parity. Model 3: further adjusted for the use of calcium and multivitamin supplements.
[2] $\bar{x}$ ± SE (all such values).
[3,4] Significantly different from Q1: $^3P < 0.01$, $^4P < 0.05$.

However, BMD was not related to urinary cadmium excretion in these subjects ($r = 0.02$, $P = 0.72$), and we previously reported that dietary cadmium exposure did not affect BMD in the premenopausal (41–48 y), perimenopausal (49–55 y), and even postmenopausal (56–75 y) women after adjustment for possible confounders (18). Fourth, the validity and reproducibility of the dietary patterns identified in the current study are unknown. Methodologic studies that examine the validity and reproducibility of the dietary factor analysis used in the current study and that establish the appropriate statistical procedures may have improved the current results. Undoubtedly, such studies may be conducted in the future to find more appropriate dietary factors to represent the current diversity of Japanese diets. In fact, the identified dietary factors in the current study accounted for only 29.7% of the variance in food intake in Japan. Finally, our sample size was comparatively small, which may have attenuated our ability to detect significant differences in BMD.

The principal components method itself also has limitations that stem from several subjective or arbitrary decisions that investigators must make. These decisions may have some effect on both the results and their interpretation (32). Therefore, the current study attempted to replicate dietary patterns reported in other epidemiologic studies by using similar steps in the subjective decision-making process. Moreover, we repeated the same analyses with varied numbers of factors and randomly divided the sample into 2 groups to examine whether these subjective choices affected the reproducibility of our findings. The results showed closely similar dietary patterns (data not shown). Our decision to retain 4 factors was based on eigenvalues, scree plots, and interpretability; however, it should be noted that >2 meaningful dietary patterns must exist in nature, as proposed by Newby (33). In addition, the dietary patterns defined in the current study were not established a priori but were based on actual data. The Western pattern in our study was similar to patterns labeled "Western" among Japanese (34), US (11, 35) and Swedish (36) populations. The Healthy pattern was also somewhat similar to the Healthy and Prudent (13, 35) patterns observed across different populations. Even though we observed similar patterns, it should be noted that the results of dietary pattern analysis depend on the population and may differ according to the geographic area, race, and culture of the population. In the current study, we identified a Japanese traditional pattern, characterized by high consumption of rice, miso soup, and soy products, that was quite different from the Western pattern. This pattern was comparable to the rice/snack and traditional pattern seen in a previous Japanese study (34, 37).

In conclusion, among Japanese premenopausal women, dietary patterns were associated with BMD. A diet with high intakes of green vegetables, fruits, fish and shellfish and low intakes of meat and processed meat may contribute to the maintenance of BMD. Our data suggest dietary recommendations for preventing bone loss in premenopausal women; however, further studies in various populations following different dietary patterns are required to confirm these results.

HO carried out the data analysis and wrote the manuscript. SS was involved in the design of the dietary study and assisted in manuscript preparation. HH and EO were responsible for the study design, data collection, and data management. KM and YH were involved in data collection. KMK provided statistical programming support. FK was responsible for the study design, data collection, and the overall management. All the authors provided suggestions during the preparation of the manuscript and approved the final version submitted for publication. None of the authors had any personal or financial conflict of interest.

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