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NUTRITION EPIDEMIOLOGY HIGHLIGHTS ORIGINAL ARTICLE

A fruit, milk and whole grain dietary pattern is positively associated with bone mineral density in Korean healthy adults

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BACKGROUND/OBJECTIVES: Osteoporosis is a major health problem that will grow in burden with ageing of the global population. Modifiable risk factors for osteoporosis, including diet, have significant implications for disease prevention. We examined associations between dietary patterns and bone mineral density (BMD) in a Korean adult population.
SUBJECTS/METHODS: In total, 1828 individuals from the Healthy Twin Cohort were included as subjects. Information on general characteristics, lifestyles and health status was obtained through a health examination, and BMD was assessed using DEXA. Dietary intake was assessed using a 3-day food record, and dietary patterns were examined by factor analysis. Associations between dietary patterns and BMD were examined using mixed linear regression, adjusting for family and twin structure as well as other potential risk factors for bone health.
RESULTS: Four dietary patterns were identified (Rice and kimchi; eggs, meat and flour; Fruit, milk and whole grains; and Fast food and soda). The 'Fruit, milk and whole grains' pattern was associated with a reduced risk of having low BMD in men (odds ratio (OR) = 0.38; 95% confidence interval (CI) = 0.22–0.67) and women (OR = 0.45; 95% CI = 0.28–0.72) and was positively associated with BMD at multiple sites. The 'rice and kimchi' pattern had a positive association with only whole-arm BMD in men and women.
CONCLUSIONS: Our results suggest that a dietary pattern with high intake of dairy products, fruits and whole grains may contribute positively to bone health in a Korean adult population, and dietary pattern-based strategies could have potential in promoting bone health.

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INTRODUCTION

Osteoporosis is a systemic skeletal disease characterised by reduced bone mass and disrupted bone architecture, resulting in increased bone fragility and fracture risk.[1] Osteoporosis is commonly referred to as a 'silent disease' because there are no symptoms until a fracture occurs. Such osteoporotic fractures are a major cause of morbidity and disability in older people.[2] As the population grows older, the prevalence of osteoporosis and the incidence of osteoporosis-related fractures are becoming major social and medical concerns in both developed and developing countries.[3] Low bone mineral density (BMD) is considered a hallmark of osteoporosis as well as a valuable predictor of low-trauma fractures.[4]

The accumulation and loss of bone mass are influenced by various factors, such as age, gender, ethnicity, heredity, lifestyles (physical activity, smoking and alcohol intake) and nutritional status (calcium, protein and vitamin D intake).[5–7] Many previous studies support the idea that diet has a key role in modulating BMD in the acquisition of peak bone mass in early adults[8] and in changing the rate of bone loss in elderly men and women.[9]

Regarding diet, however, most studies have focused on a single nutrient or food/food group to examine its association with bone health.[10–13] These common approaches have methodological and conceptual limitations,[14,15] in that they can detect the effects of only a single nutrient or food on bone health and thus cannot explain the interactions among nutrients and foods.[16] In addition, such studies do not provide tangible practical dietary advice, because of course, nobody normally consumes just a single food or nutrient.[14,15,17]

Recently, dietary pattern analysis has been widely used to assess relationships between overall diet and health outcomes.[18] For exploring dietary patterns, two approaches, namely a priori and a posteriori, have been used.[19] A priori methods use a pre-defined diet quality index, such as the Healthy Eating Index or the Mediterranean Diet Score, which are based generally on existing knowledge about what constitutes a healthy diet.[20] A posteriori methods involve statistical exploratory *post hoc* techniques, such as factor and cluster analyses, that use information from actual dietary intake data to aggregate variables or subjects into factors or groups representing common underlying patterns of food consumption within a population.[15] Thus, a posteriori dietary pattern analyses have often been used to identify relationships between overall diet quality and health status in a specified population in nutritional epidemiological studies,[21,22] as such an approach can describe the actual eating patterns of the population and provide useful insights into existing eating behaviours.

Several studies have identified positive associations between bone health and dietary patterns: a 'nutrient-dense' dietary pattern in Canadian young men,[22] a 'nuts and meat' dietary pattern in Northern Irish young adults[19] and a 'healthy' dietary pattern in Canadian[21] and Scottish adults.[23] On the other hand, inverse associations between bone health and an 'energy-dense, nutrient-poor' dietary pattern in Australian women,[24] a 'refined' dietary pattern in Northern Irish young adults[19] and a

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'traditional English' dietary pattern in UK post-menopausal women[25] have been reported.

Most previous studies on the association between bone health and dietary patterns were conducted in Western countries and not in Asian populations, including Korea. Because dietary patterns in Western countries differ from those in Asian countries, the results based on Western population diets are of limited value in developing dietary guidelines to improve bone health in Asian populations.

The traditional Korean diet is composed mainly of grains and vegetables but recently has been changing to a more Western dietary pattern, characterised by higher intakes of meat and dairy products. Thus, the aim of this study was to examine the association between dietary patterns and BMD in Koreans.

SUBJECTS AND METHODS

Subjects and study design

The participants in this study were from the Healthy Twin Cohort, part of the Korean Genomic Epidemiologic Study since 2005.[26] The 1909 adult twins, aged ⩾30 years, and their first-degree adult family members from the Healthy Twin Cohort, who visited study centres located in Seoul or Pusan, Korea from 1 July 2009 to 31 January 2012 and completed a questionnaire, health examinations and a nutrition survey, were included as participants. We excluded subjects who reported implausibly low or high daily energy intakes ($<$ 500 or 5000 kcal per day) and those without BMD measurements. Thus, 1818 subjects (716 men, 1102 women) were ultimately eligible for analysis. Details about the design and methodology of the Healthy Twin Cohort have been published previously.[27]

All participants provided written informed consent. This study was conducted according to the declaration of Helsinki guidelines, and the procedures involving human subjects were approved by the institutional review boards of the Korean Centre for Disease Control and the three participating centres (Samsung Medical Centre, Pusan Paik Hospital and Dankook University Hospital).

Dietary patterns

Dietary intake data were obtained from a 3-day food record (2 weekdays and 1 weekend day). When subjects visited the centre for the first time, trained staff provided detailed instructions on keeping a food diary. When the subject submitted the completed 3-day food record at the second visit, a trained dietician reviewed and confirmed the records with them using three-dimensional food models and supplemental instruments, such as measuring cups, spoons and a ruler, during a face-to-face interview to increase accuracy. Daily nutrient intakes were calculated using the food composition database of the Korean Nutrition Society (Canpro 3.0; Korean Nutrition Society, Korea, 2002).

Dietary patterns were identified by factor analysis using the principal component analysis method. For factor analysis, the food items consumed by the subjects were grouped into 22 foods or food groups, based on nutrient profiles or culinary uses according to the common food groups classified in the Korean nutrient database.[28] Grains and grain products were divided into four subgroups to address the following types of staple foods:[29] white rice, whole grains, noodles and dumplings and flour and bread. Kimchi, a Korean traditional fermented cabbage commonly eaten as a side dish, was placed in a discrete food group. The percentages of total daily energy intake from 22 foods or food groups were entered into the factor analysis as explainable variables.

The PROC FACTOR procedure in SAS was used to derive dietary patterns. The number of factors was determined on the basis of eigenvalues ($>$ 1.5), a scree plot and interpretability of the derived factors. An orthogonal transformation (the Varimax rotation function in SAS) was used to rotate the factor correlation matrix to obtain a simpler structure with greater interpretability. Factor scores of each dietary pattern were calculated for each subject as the sum of the products of factor loading coefficients and the standardised caloric contribution of daily intake of each food or food group associated with that pattern. Thus, subjects with high scores for a dietary pattern have a greater tendency to adhere to that pattern compared with those with a lower score. Factor names were given that reflected the food group with the high-positive loadings on the factor.

Health examination and BMD measurements

The BMDs (g/cm^2) of the whole arm, whole leg, whole pelvis, lumbar spine and whole body were measured using dual-energy X-ray absorptiometry (DEXA; Lunar Radiation, Madison, WI, USA; and Delphi W; Hologic, Boston, MA, USA). These devices were maintained using standardised quality control procedures, as recommended by the manufacturer, to ensure that the BMD calibration remained constant.[30] The coefficient of variation for the BMD measurements based on reproducibility scans was ⩾1.0%.[31] The 'low BMD group' was defined as subjects with a T-score of −1.0 or less in measurements of the whole pelvis or lumbar spine when the maximum BMD value for Asian (Japanese) populations aged ⩾20 years was used as a reference.[32]

Body weight (kg) was measured using a digital scale to the nearest 0.1 kg with the participant in light clothing and wearing no shoes. Height (cm) was measured to the nearest 0.1 cm using a stadiometer with the subject standing with heels together, legs straight, shoulders relaxed and head positioned such that the gaze was straight ahead. Body mass index was calculated as the weight divided by the height squared (kg/m^2).

A self-reported questionnaire was used to acquire information on known risk factors for bone health, such as health-related lifestyles (smoking, alcohol consumption and physical activity), reproductive history for women and medical history in general.[33] After completion of the questionnaire, a face-to-face interview was performed to clarify incomplete or ambiguous responses.

Statistical analyses

Continuous data are expressed as means and s.d. and categorical data as percentages. The mean differences in the selected general characteristics of subjects, collected as continuous variables, between males and females were compared using the generalised linear model, adjusting for age. The distribution differences in the general characteristics of subjects, collected as categorical variables, were assessed using the χ^2-test. Correlations of dietary pattern scores with BMD and nutrient intakes were calculated using partial Pearson's correlations with age, body mass index and energy intake as covariates. Differences across quartiles of the dietary pattern scores were determined using the generalised linear model (Scheffe's test for multiple comparisons).

A multivariable-adjusted logistic regression analysis was conducted to determine the odds ratios (ORs) and 95% confidence intervals (CIs) for the likelihood of having a low BMD across the quartile categories of each dietary pattern score, adjusting for covariates known to be associated with bone health. The association between BMD and dietary pattern score was evaluated using a mixed linear regression analysis, adjusted for family and twin status for a random-effect model[34] and for other known potential confounding variables for a fixed-effect model. The covariates known to be associated with low BMD, such as age, body size (weight and height adjusted for weight residual), energy intake, smoking, alcohol consumption and physical activity, as well as menopausal status in women, were selected from the previous studies.[35–37]

All statistical analyses were performed using the SAS software (ver. 9.3; SAS Institute Inc., Cary, NC, USA). Statistical significance was set at $P < 0.05$.

RESULTS

The general characteristics and the bone health status of the study participants are described in Table 1. The mean ages were 47.2 and 45.9 years for the men and women, respectively. The proportions of subjects with low BMD were 30.2% in the men and 30.7% in the women. Among the women, 34.8% were postmenopausal.

Four dietary patterns were identified by factor analysis, and we named them according to the food groups that had high-positive loadings: 'Rice and kimchi'; 'Eggs, meat and flour'; 'Fruit, milk and whole grains'; and 'Fast food and soda'. The 'Rice and kimchi' dietary pattern was correlated with high consumption of white rice, kimchi, garlic and onions, fish and shellfish, legumes, and vegetables and mushrooms and with low consumption of bread and snacks. The 'Eggs, meat and flour' pattern was loaded heavily with oil and seasoning, eggs, processed meats, meat and poultry, noodles and dumplings and bread and snacks. The 'Fruit, milk and whole grains' pattern featured high-positive loadings for fruits, potatoes, whole grains, dairy foods, vegetables and mushrooms

Table 1. General characteristics of the study subjects

	Men (n = 716)	Women (n = 1102)	All (n = 1818)
Age (years)	47.2 (12.8)	45.9 (11.9)	46.4 (12.3)
Height (cm)	169.0 (6.1)	156.8 (5.8)	161.6 (8.4)
Weight (kg)	70.5 (10.1)	57.6 (8.8)	62.7 (11.2)
Waist circumference (cm)	85.5 (7.8)	78.6 (8.9)	81.3 (9.1)
BMI (kg/m^2)	24.6 (2.9)	23.4 (3.4)	23.9 (3.2)
BMD (g/cm^2)			
Whole arm	1.011 (4.454)	0.804 (3.535)	0.885 (3.923)
Whole leg	1.255 (0.119)	1.081 (0.121)	1.149 (0.147)
Whole pelvis	1.139 (0.148)	1.076 (0.142)	1.101 (0.148)
Lumbar spine	0.991 (0.161)	0.941 (0.164)	0.960 (0.164)
Whole body	1.167 (0.160)	1.079 (0.153)	1.113 (0.161)
Prevalence of low BMD in the whole body (%)	30.2	30.7	30.1
Post-menopausal women (%)	—	34.8	
Smoking habit			
Never (%)	28.3	91.6	68.1
Ex-smoker (%)	36.3	3.7	15.8
Current smoker (%)	35.4	4.7	16.1
Drinking habit (%)			
Never	13.0	39.8	29.3
< 4 Times per month	8.8	9.4	9.1
⩾3 Times per week	78.2	50.8	61.6
Physical exercise (%)			
⩽2 Per week	57.4	66.4	62.9
⩾3 Per week	42.6	33.6	37.1
Education level (%)			
⩽Junior high school	19.3	27.1	24.0
⩽High school	29.7	35.0	32.9
⩾College	51.0	37.9	43.1

Abbreviations: BMI, body mass index; BMD, bone mineral density. Values are expressed as means (s.d.). All other values are presented as percentages.

Table 2. Factor loading[a] matrix of food groups for major factors in subjects of the twin and family study

Food or food groups	Dietary patterns			
	Factor 1	Factor 2	Factor 3	Factor 4
	Rice and kimchi	Eggs, meat and flour	Fruit, milk and whole grains	Fast food and soda
White rice	0.35			
Kimchi	0.32			
Garlic and onion	0.24			
Fish and shellfish	0.26			
Soy products	0.22			
Vegetables and mushrooms	0.20		0.24	
Oils and seasonings		0.31		
Eggs		0.34		
Processed meat		0.29		
Meat and poultry		0.20	− 0.20	
Flour-based food		0.25	− 0.20	
Bread and snacks	− 0.20	0.25		
Fruits			0.31	
Potatoes			0.28	
Whole grains			0.27	
Milk, yoghurt and cheese			0.26	
Nuts			0.22	
Alcohol			− 0.25	
Pizza and hamburgers				0.48
French fries				0.48
Soda and coffee				0.34
Sweet fruit juice				0.22
Variance of intake explained (%)	10.0	8.4	7.1	5.6

[a]Factor loading scores of − 0.20 and +0.20 are not shown.

and nuts and negative loadings for meat and poultry and noodles and dumplings. The 'Fast food and soda' pattern was characterised by high-positive loadings for pizza and hamburgers, French fries, soda and coffee and sweet fruit juice. The factor loading scores, which reflected the correlation coefficients between dietary patterns and food groups, are presented in Table 2. These dietary patterns explained 31.1% of the total variance in food intake: 10.0, 8.4, 7.1 and 5.6% for the 'Rice and kimchi', 'Eggs, meat and flour', 'Fruit, milk and whole grains' and 'Fast food and soda' dietary patterns, respectively.

Table 3 presents the partial Pearson's correlation coefficients between dietary pattern scores and BMD, adjusted for age, gender and energy intake as covariates, and between nutrient intake and BMD of the lowest and highest quartiles of the dietary pattern score. The 'Rice and kimchi' pattern was significantly positively associated with the BMD of the whole arm and whole leg, and the 'Eggs, meat and flour' pattern was negatively associated with the BMD of the whole arm. The 'Fruit, milk and whole grains' pattern showed a positive association with the BMDs at all sites measured.

The nutrient intakes of the highest quartile group of 'Rice and kimchi' and 'Fast food and soda' dietary pattern scores did not differ from those of the lowest quartile group (Table 3). The highest quartile group of 'Eggs, meat and flour' dietary pattern showed lower intakes of vitamin C than did the lowest quartile group. The highest quartile group of 'Fruit, milk and whole grains' dietary pattern scores had higher intakes of carbohydrate, protein, calcium, iron, phosphorus, potassium and vitamin C than did the lowest quartile group.

Multivariate-adjusted ORs and CIs for low BMD of the whole body across the four dietary patterns are presented in Table 4. In men, the 'Fruit, milk and whole grains' dietary pattern was inversely associated with the likelihood of having a low whole-body BMD. After adjustment for age, body size (weight and height adjusted for weight residual) and energy intake, the risk of having a low whole-body BMD was reduced by 64% in subjects in the highest pattern score quartile compared with those in the lowest quartile (OR = 0.36, 95% CI = 0.22–0.61, P for trend < 0.0001). This association persisted in model 2, which included several additional confounders (smoking status, alcohol consumption and physical activity; OR = 0.38, 95% CI = 0.22–0.67, P for trend = 0.0004). In women, compared with the lowest quartile of the 'Fruit, milk and whole grains' dietary pattern score, the highest quartile of this pattern showed a decreased risk of having low BMD after adjustment for age, body size (weight and height adjusted for weight residual) and energy intake (OR = 0.51, 95% CI = 0.33–0.78, P for trend = 0.0122). This significant association remained after additional adjustment for possible confounding factors, such as smoking status, alcohol consumption, physical activity and menopausal status (OR = 0.45, 95% CI = 0.28–0.72, P for trend = 0.0128). The other patterns ('Rice and kimchi', 'Eggs, meat and flour' and 'Fast food and soda') were not significantly associated with the risk of low BMD in men or women.

Table 3. Pearson's correlation coefficients between dietary pattern scores and bone mineral density and nutrients and between mean BMD and nutrient intakes of the lowest and highest quartiles of dietary pattern score

		Rice and kimchi			*Eggs, meat and flour*	
	r[a]	*Q1*	*Q4*	r	*Q1*	*Q4*
BMD						
Whole arm (g/cm^2)	0.088***	0.744 ± 0.106	0.768 ± 0.120**,[b]	− 0.048*	0.739 ± 0.111	0.758 ± 0.113
Whole leg (g/cm^2)	0.050*	1.134 ± 0.147	1.161 ± 0.154*	− 0.041	1.126 ± 0.163	1.165 ± 0.143
Whole pelvis (g/cm^2)	0.038	1.091 ± 0.154	1.112 ± 0.148	− 0.020	1.062 ± 0.155	1.119 ± 0.137
Lumbar spine (g/cm^2)	0.045	0.953 ± 0.169	0.968 ± 0.160	− 0.023	0.927 ± 0.180	0.964 ± 0.136
Whole body (g/cm^2)	0.017	1.109 ± 0.172	1.120 ± 0.160	0.035	1.087 ± 0.184	1.138 ± 0.180
Nutrient intakes						
Energy (kcal)	0.231***	1616.0 ± 469.6	1641.0 ± 499.6	0.519***	1574.5 ± 450.0	1612.4 ± 520.0
Carbohydrate (g)	0.181***	243.9 ± 71.2	247.7 ± 75.3	− 0.313***	242.6 ± 77.8	240.1 ± 70.2
Protein (g)	0.257***	62.3 ± 22.4	63.5 ± 23.2	0.074**	60.5 ± 23.1	62.5 ± 23.8
Fat (g)	− 0.173***	41.0 ± 20.1	39.4 ± 18.2	0.404***	37.7 ± 17.0	40.4 ± 19.1
Calcium (mg)	0.130***	465.4 ± 214.1	485.6 ± 217.1	− 0.055**	450.5 ± 193.3	442.2 ± 184.1
Iron (mg)	0.175***	12.1 ± 4.5	12.7 ± 6.5	− 0.056**	12.6 ± 6.0	12.3 ± 5.9
Phosphorus (mg)	0.244***	895.2 ± 303.2	914.2 ± 321.0	0.037	866.7 ± 298.9	890.9 ± 317.6
Sodium (mg)	0.446***	3701.0 ± 1308.2	3801.9 ± 1449.0	0.026	3566.7 ± 1303.2	3751.4 ± 1458.6
Potassium (mg)	0.297***	2374.1 ± 837.8	2416.4 ± 855.2	− 0.110***	2359.1 ± 838.2	2350.6 ± 805.4
Thiamine (mg)	− 0.018	1.1 ± 0.5	1.2 ± 0.6	0.048*	1.1 ± 0.6	1.1 ± 0.5
Riboflavin (mg)	− 0.030	1.0 ± 0.6	1.0 ± 0.8	0.103***	1.0 ± 0.7	1.0 ± 0.5
Vitamin C (mg)	0.141***	91.3 ± 64.6	94.5 ± 60.9	− 0.130***	101.0 ± 103.6	87.2 ± 55.6**
		Fruit, milk and whole grains			*Fast food and soda*	
	r	*Q1*	*Q4*	r	*Q1*	*Q4*
BMD						
Whole arm (g/cm^2)	0.109***	0.741 ± 0.104	0.769 ± 0.113***	− 0.041	0.748 ± 0.115	0.759 ± 0.102
Whole leg (g/cm^2)	0.151***	1.126 ± 0.146	1.174 ± 0.150***	0.010	1.138 ± 0.153	1.163 ± 0.139
Whole pelvis (g/cm^2)	0.108***	1.079 ± 0.146	1.120 ± 0.148***	− 0.028	1.080 ± 0.145	1.115 ± 0.137
Lumbar spine (g/cm^2)	0.102***	0.937 ± 0.159	0.989 ± 0.174***	− 0.008	0.933 ± 0.154	0.973 ± 0.149
Whole body (g/cm^2)	0.116***	1.087 ± 0.156	1.143 ± 0.167***	0.025	1.097 ± 0.152	1.134 ± 0.173
Nutrient intakes						
Energy (kcal)	− 0.014	1633.3 ± 496.8	1569.7 ± 493.4	0.148***	1566.2 ± 497.6	1624.7 ± 502.0
Carbohydrate (g)	0.011	241.8 ± 79.7	242.5 ± 72.6*	− 0.120***	238.4 ± 75.4	244.4 ± 78.4
Protein (g)	0.403***	60.4 ± 21.5	64.5 ± 26.3*	0.255***	59.8 ± 21.7	63.9 ± 25.1
Fat (g)	− 0.108***	41.0 ± 19.8	37.8 ± 17.5	0.190***	38.4 ± 18.6	40.3 ± 19.4
Calcium (mg)	0.422***	450.1 ± 213.1	559.8 ± 208.6**	0.068***	442.8 ± 207.1	453.5 ± 192.1
Iron (mg)	0.196***	12.3 ± 5.1	13.5 ± 6.6*	0.030	12.3 ± 6.1	12.3 ± 4.9
Phosphorus (mg)	0.365***	878.7 ± 285.6	905.5 ± 320.2*	0.031	898.9 ± 307.1	863.3 ± 312.2
Sodium (mg)	− 0.170***	3813.9 ± 1499.4	3634.3 ± 1362.9	− 0.117***	3862.9 ± 1375.3	3571.7 ± 1379.7
Potassium (mg)	0.607***	2372.8 ± 864.5	2417.5 ± 839.5*	0.038	2353.3 ± 889.7	2367.4 ± 798.7
Thiamine (mg)	0.153***	1.1 ± 0.6	1.1 ± 0.5	0.039	1.1 ± 0.5	1.1 ± 0.5
Riboflavin (mg)	0.149***	1.0 ± 1.0	1.1 ± 0.8	0.011	1.0 ± 0.7	1.0 ± 0.8
Vitamin C (mg)	0.444***	88.3 ± 57.7	106.2 ± 49.1*	0.089***	89.8 ± 59.1	95.1 ± 87.4

[a]Partial Pearson's correlation, including age, gender, BMI and energy intake (excluding energy variables) as covariates. [b]Calculated using the generalised linear model and a *post hoc* Scheffé test. * $P < 0.05$, ** $P < 0.01$ and *** $P < 0.001$.

Table 5 shows the multivariable-adjusted associations between the dietary pattern score and BMD. In men, the 'Rice and kimchi' pattern score was positively associated with whole-arm BMD ($\beta = 0.008$, 95% CI = 0.002–0.013) and the 'Fruit, milk and whole grains' pattern score with BMDs of the whole leg ($\beta = 0.014$, 95% CI = 0.007–0.021), whole pelvis ($\beta = 0.015$, 95% CI = 0.006–0.024), lumbar spine ($\beta = 0.016$, 95% CI = 0.005–0.027) and whole body ($\beta = 0.017$, 95% CI = 0.008–0.027). In women, the BMDs of the whole arm ($\beta = 0.007$, 95% CI = 0.003–0.011), whole leg ($\beta = 0.012$, 95% CI = 0.006–0.018) and whole body ($\beta = 0.007$, 95% CI = 0.000–0.015) showed a significantly positive association with the 'Fruit, milk and whole grains' dietary pattern score. Moreover, the whole-arm BMD was positively associated with the 'Rice and kimchi' dietary pattern score ($\beta = 0.006$, 95% CI = 0.001–0.009).

DISCUSSION

Among Korean adults from the Healthy Twin Cohort, part of the Korean Genomic Epidemiologic Study, we identified four distinct dietary patterns (Rice and kimchi; Eggs, meat and flour; Fruit, milk and whole grains; and Fast food and soda), which accounted for 31.1% of the total variance in food intake. In our study, the 'Fruit, milk and whole grains' dietary pattern was associated with a decreased risk of having a low BMD among Korean adults, and the associations remained after adjusting for known confounding factors.

Factor analysis is a robust and meaningful technique for dietary pattern analysis and is useful for understanding the role of dietary patterns in health and disease.[38] However, subjective decisions such as the grouping of foods, the rotational method, the number of components to be retained and their subsequent labelling have

Table 4. Multivariate odds ratios and 95% confidence intervals for the likelihood of having a low bone mineral density across quartile categories of dietary pattern scores

	Q1	*Q2*		*Q3*		*Q4*		*P for trend*
		OR	*(95% CI)*	*OR*	*(95% CI)*	*OR*	*(95% CI)*	
Men								
Factor 1: Rice and kimchi								
Model 1	1(ref)	0.95	(0.58, 1.56)	1.25	(0.77, 2.03)	0.74	(0.45, 1.23)	0.4465
Model 2	1(ref)	1.04	(0.59, 1.80)	1.24	(0.72, 2.13)	0.62	(0.35, 1.10)	0.1855
Factor 2: Eggs, meat and flour								
Model 1	1(ref)	0.71	(0.44, 1.16)	0.89	(0.55, 1.45)	0.62	(0.37, 1.05)	0.2294
Model 2	1(ref)	0.80	(0.46, 1.39)	0.89	(0.51, 1.56)	0.65	(0.36, 1.18)	0.2667
Factor 3: Fruit, milk and whole grains								
Model 1	1(ref)	0.94	(0.59, 1.49)	0.67	(0.41, 1.07)	0.36	(0.22, 0.61)	< 0.0001
Model 2	1(ref)	0.86	(0.51, 1.45)	0.70	(0.41, 1.20)	0.38	(0.22, 0.67)	0.0004
Factor 4: Fast food and soda								
Model 1	1(ref)	0.86	(0.52, 1.42)	1.31	(0.80, 2.16)	1.38	(0.82, 2.76)	0.2258
Model 2	1(ref)	0.96	(0.54, 1.69)	1.42	(0.80, 2.50)	1.47	(0.81, 3.09)	0.1327
Women								
Factor 1: Rice and kimchi								
Model 1	1(ref)	0.98	(0.64, 1.49)	1.10	(0.73, 1.65)	0.94	(0.62, 1.44)	0.8589
Model 2	1(ref)	0.87	(0.56, 1.37)	1.09	(0.70, 1.71)	1.05	(0.67, 1.67)	0.6667
Factor 2: Eggs, meat and flour								
Model 1	1(ref)	1.19	(0.79, 1.79)	0.91	(0.59, 1.42)	1.04	(0.66, 1.63)	0.6748
Model 2	1(ref)	1.17	(0.75, 1.82)	0.92	(0.57, 1.48)	1.06	(0.65, 1.72)	0.8350
Factor 3: Fruit, milk and whole grains								
Model 1	1(ref)	0.77	(0.51, 1.16)	0.94	(0.63, 1.41)	0.51	(0.33, 0.78)	0.0122
Model 2	1(ref)	0.63	(0.41, 0.99)	0.86	(0.55, 1.32)	0.45	(0.28, 0.72)	0.0128
Factor 4: Fast food and soda								
Model 1	1(ref)	0.81	(0.54, 1.22)	0.74	(0.48, 1.13)	0.79	(0.51, 1.23)	0.1155
Model 2	1(ref)	0.76	(0.49, 1.18)	0.79	(0.50, 1.24)	0.80	(0.50, 1.29)	0.2386

Abbreviations: CI, confidence interval; OR, odds ratio. Model 1 adjusted for age, body size (weight and height adjusted for weight residual) and energy intake. Model 2 adjusted for the same variables as Model 1 in addition to smoking, alcohol consumption, and physical activity, and for women, menopausal status.

Table 5. Regression coefficient of dietary pattern score on bone mineral density

	Rice and kimchi		*Eggs, meat and flour*		*Fruit, milk and whole grains*		*Fast food and soda*	
	β^a	*95% CI for* β	β	*95% CI for* β	β	*95% CI for* β	β	*95% CI for* β
Men								
Whole arm	0.008	(0.002, 0.013)	0.002	(−0.004, 0.007)	0.005	(−0.000, 0.011)	− 0.004	(−0.010, 0.001)
Whole leg	0.005	(−0.002, 0.012)	0.003	(−0.004, 0.010)	0.014	(0.007, 0.021)	− 0.002	(−0.009, 0.005)
Whole pelvis	0.007	(−0.002, 0.015)	0.000	(−0.009, 0.009)	0.015	(0.006, 0.024)	− 0.006	(−0.014, 0.003)
Lumbar spine	0.009	(−0.002, 0.020)	0.000	(−0.011, 0.011)	0.016	(0.005, 0.027)	0.000	(−0.011, 0.010)
Whole body	0.004	(−0.006, 0.014)	0.009	(−0.001, 0.019)	0.017	(0.008, 0.027)	− 0.001	(−0.011, 0.008)
Women								
Whole arm	0.006	(0.001, 0.009)	− 0.003	(−0.007, 0.002)	0.007	(0.003, 0.011)	− 0.002	(−0.006, 0.002)
Whole leg	0.004	(−0.002, 0.011)	− 0.003	(−0.010, 0.004)	0.012	(0.006, 0.018)	0.001	(−0.005, 0.007)
Whole pelvis	0.003	(−0.004, 0.010)	0.000	(−0.008, 0.007)	0.005	(−0.001, 0.012)	− 0.007	(−0.014, 0.000)
Lumbar spine	− 0.002	(−0.011, 0.007)	− 0.005	(−0.015, 0.004)	0.008	(−0.001, 0.016)	−0.009	(−0.017, 0.000)
Whole body	0.003	(−0.005, 0.011)	0.004	(−0.005, 0.013)	0.007	(0.000, 0.015)	0.005	(−0.003, 0.013)

[a] β (95% CI) was estimated by using a linear-mixed regression, with adjustments for family structure and twins for the random-effect model and for age, body size (weight and height adjusted for weight residual), energy intake, smoking, alcohol consumption and physical activity, as well as menopausal status in women, for the fixed-effect model.

been pointed out as weaknesses of factor analysis.[14] Although the dietary patterns in the current study cannot be compared directly with those of other studies because of differences in the processes, they are similar to those reported previously.[39–42] The 'Fruit, milk and whole grains' pattern identified in this study is similar to dietary patterns derived from previous studies. The 'healthy diet' pattern of Scottish post-menopausal women[23] and Japanese premenopausal women,[43] with high loadings of fruit, vegetables, rice or pasta, fish and dairy foods, showed a beneficial effect on bone health. It was also similar to the 'dietary approaches to stop hypertension' diet, characterised by a calcium-rich and low-sodium diet that emphasises fruits, vegetables, nuts and dairy products. Lin *et al.*[44] reported that subjects who consumed the dietary approaches to stop hypertension diet showed significantly reduced bone turnover rates. In this study, the 'Fruit, milk and whole grains' dietary pattern score was significantly and positively associated with high consumption of dairy products, such as milk, yoghurt and cheese. The 'Fruit, milk and whole grains' dietary pattern was also highly correlated with a variety of food or food groups, such as fruits, vegetables, mushrooms, potatoes, whole grains and nuts. Thus, the 'fruit, milk and whole grains' dietary pattern was significantly correlated with calcium, protein, iron, potassium and vitamin contents. The protein and minerals rich in this pattern are important nutrients for the fundamental architecture of the bone.[3] The positive effects of calcium supplementation and dairy food on bone health have been well established.[45–48]

Several previous studies have demonstrated positive effects of fruits and vegetables on bone health.[49–51] Fruits and vegetables may act on bones by providing base buffers against excess dietary metabolic acids, increasing osteoclast activity[52] and decreasing the body's pH to the physiological range that promotes bone resorption.[53] In the Women's Health Initiative study, a low-fat and high-fruit, -vegetable, and -grain diet intervention modestly reduced the risk of multiple falls and slightly lowered hip BMD in post-menopausal women aged 50–79 years old.[54] However, Pedone *et al.*[55] reported no relationship between dietary acid load and BMD in elderly women. Further studies on the mechanism(s) of dietary acids in bone metabolism are needed.

We conducted additional analyses to examine the effects of single nutrients (calcium, potassium, protein, phosphorus and sodium) or foods/food groups (white rice, kimchi, garlic and onion, fish and shellfish, soya food, vegetable, oils, eggs, meat and poultry, fruits, nuts and soda and coffee) on bone health. Neither the nutrients nor foods/food groups individually were significantly associated with a risk of low BMD in men or women (data not shown). A reason the dietary patterns showed significant effects on bone health, whereas single nutrients, foods or food groups did not, may be the complex or synergistic effect achieved by combining food/food groups on bone health. In addition, the combined effects of the dietary pattern on bone health would reflect overall dietary behaviours, which may explain a mixture of social, cultural, environmental, health, economic and lifestyle factors.[56]

The 'Rice and kimchi' dietary pattern score significantly increased the whole-arm BMD in men (0.008 g/cm^2/unit) and women (0.006 g/cm^2/unit). The increased BMD according to the 'Rice and kimchi' dietary pattern score may be explained by eating foods such as vegetables, soy products and fish and shellfish that provide adequate protein, vitamins and minerals. However, the 'Rice and kimchi' dietary pattern was significantly associated with whole-arm BMD only and not with other BMD measurements. Previous studies have reported similar results that certain nutrients or foods significantly improved bone health at a specific bone site but not other bone measurement sites.[57] For example, soy isoflavone extract increased the lumbar spine bone health of menopausal women but had no significant effect on femoral neck, total hip or trochanter bone health.[58] Further research on the mechanism(s) underlying the effects of diet on specific bone sites is needed.

The current study has several strengths. This is the first Asian study to identify an association between dietary patterns and whole-body BMD. In addition, we assessed the patterns using 3-day food records, which provide detailed and accurate information regarding the types of foods and beverages consumed, whereas most population studies on dietary patterns have used food frequency questionnaires. The food record method is often regarded as the 'gold standard' against which other dietary assessment methods are validated.[59]

There are also several limitations to this study. First, the results cannot demonstrate a causal or resultant relationship among dietary patterns because of the cross-sectional design. Thus, these results need confirmation from prospective or interventional studies to assess the effects of dietary patterns on the prevention and/or treatment of osteoporosis. Second, although our analysis included known potential variables that can affect bone health in terms of environmental and genetic factors, residual confounding variables may still exist.

In conclusion, we identified four dietary patterns, of which the 'Fruit, milk and whole grains' dietary pattern, characterised by high consumption of fruits, vegetables, dairy products and whole grains, was positively associated with a reduced risk of low BMD and with an increased BMD at most of the bone sites measured. These results indicate that dietary pattern-based strategies have the potential to promote bone health.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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AUTHOR CONTRIBUTIONS

S Shin: contributed to data analyses and wrote the draft of the manuscript; J Sung: collected data and provided significant advice; H Joung: conceived of and designed the study and critically reviewed the manuscript.

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