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RESEARCH ARTICLE

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Association between dietary intake, body measurements, and urinary bone resorption markers in young adults with osteopenia and osteoporosis: a cross-sectional study

Mi-Hyun Kim, Mi-Kyeong Choi†

Professor, Department of Food and Nutrition, Kongju National University, Yesan, Korea

†Corresponding author
Mi-Kyeong Choi
Department of Food and Nutrition, Kongju National University, 54 Daehak-ro, Yesan 32439, Korea

Tel: +82-41-330-1462
Fax: +82-41-330-1469
E-mail: mkchoi67@kongju.ac.kr

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ABSTRACT

Objectives: Bone health in early adulthood, as individuals approach peak bone mass, plays a critical role in preventing osteoporosis later in life. This study aimed to investigate the associations between lifestyle and dietary factors, anthropometric measurements, and urinary bone resorption markers in young adults.

Methods: A cross-sectional study was conducted with 100 healthy Korean adults (50 men and 50 women) in their 20s and early 30s. Bone mineral density (BMD), anthropometric measurements, dietary intake (24-hour recall), and urinary bone resorption indicators (deoxypyridinoline and N-terminal telopeptide of type I collagen) were analyzed. Variables were compared between the osteopenia and osteoporosis groups (OSTEO group: 30% men and 60% women) and the healthy control group.

Results: Men in the OSTEO group were significantly taller than those in the control group ($P < 0.05$). Women in the OSTEO group had significantly lower body weight and body composition (muscle and body fat) than those in the normal group ($P < 0.01$). Men in the OSTEO group had a significantly higher intake of animal calcium (Ca) than those in the normal group ($P < 0.05$). Women in the OSTEO group had significantly higher dietary fiber, vitamin A, Ca, plant Ca, and potassium intake than did those in the normal group ($P < 0.05$). There were no significant differences in caffeinated beverage consumption, eating habits, or urinary bone resorption indicators between the OSTEO and control groups of either sex.

Conclusions: In our study of young South Korean adults, we observed low bone density levels, with particularly low BMD in taller men and underweight women. We found a higher nutrient intake in the OSTEO group, indicating the possibility of reverse causality, a phenomenon often found in cross-sectional studies. Therefore, there is a need to further elucidate dietary factors related to osteoporosis in young adults through prospective cohort studies involving a larger population.

KEYWORDS osteopenia, osteoporosis, coffee consumption, dietary intake, bone mineral density

Introduction

Bone grows and develops rapidly in adolescence, increasing by approximately 5%-10% annually in adulthood, reaching peak bone mass (PBM) in the early 30s [1]. The state of bone health after middle age is determined by the formation of PBM and the degree of bone loss experienced later in life [2]. Thus, PBM is a key determinant of skeletal health. Therefore, skeletal management that increases PBM completion by early adulthood is the best way to prevent fractures or osteoporosis due to age-related bone loss [3]. Significant variations in PBM or bone mineral density (BMD) have been reported in early adulthood, often attributed to individual eating habits given the expanded independent food choices associated with various types of residences and lifestyles [4-6].

Dietary factors that affect BMD have been reported to include calcium (Ca), magnesium, vitamin D, protein, sodium, and caffeine [7, 8]. It has been reported that excessive consumption of caffeinated beverages by young adults can negatively affect BMD by promoting urinary Ca excretion and deteriorating Ca balance when Ca intake is insufficient [9, 10]. In particular, college students foster a culture of coffee consumption, often consuming a large number of caffeinated beverages ranging from 1 to 10 cups a day for their stimulating effects and as a means of combating fatigue [11].

In contrast to the increase in caffeinated beverage consumption among young adults, milk intake is low. The 2021 Korea National Health and Nutrition Survey (KNHANES) reported that the daily milk intake of adults aged 19 years was 90.0 g, less than half a cup [12]. Ca is the most important nutrient for bone health. However, 2021 KNHANES reported that daily Ca intake was 486.3 mg [64.3% of the recommended intake (RI)] for adults, 533.0 mg (68.7% of the RI) for men, and 438.3 mg (60.0% of the RI) for women, which was insufficient to meet RI [12]. Considering the importance of Ca in bone functionality, a study on the bone status of young adults while they are nearing their PBM stage and its relationship with dietary intake status, dietary behavior, and coffee consumption, is paramount.

Accordingly, the purpose of this study was to evaluate the bone status by BMD of the calcaneus in young adults and to investigate the association of bone conditions with body size and composition, nutrient intake status, dietary behavior, including coffee consumption, and urinary bone resorption indicators by comparing an osteopenia or osteoporosis group with a normal group.

Methods

Ethics statement

This study was approved by the Institutional Review Board of Kongju National University (KNU_IRB_2020-57), and written informed consent was obtained from all participants.

1. Participants

Poster and announcement notices were used to recruit 50 healthy male and 50 healthy female young adults in their 20s and early 30s residing in Chungnam, Korea, from October to November 2020. The exclusion criteria were applicants who had been diagnosed with any disease and were under medication or diet control. This survey was conducted in compliance with institutional and national policies at intervals in the order of subject recruitment, in accordance with the social distancing policy due to the COVID-19 national disaster situation.

2. BMD measurement and bone status assessment

The BMD of the participants was measured in the left calcaneus using an ultrasonic BMD measuring device (SONOST 3000; Osteosys, Seoul, Korea). During the measurement, the socks or stockings were removed while sitting in a chair,

ultrasonic gel was applied to both sides of the ankle, and the legs were closely attached to the device to measure BMD in a stationary state for approximately 15 s. Using the measured BMD T-score values, - 1.0 or higher was classified as normal, - 2.5 to - 1.0 was classified as osteopenia, and - 2.5 or lower was classified as osteoporosis.

3. Anthropometric measurements

The height of the participants was measured using a height-measuring instrument (DS-102, Jenix, Seoul, Korea). Weight and body composition were measured using InBody (DX-505, Biospace, Seoul, Korea), with all metal substances removed from their bodies, in light clothes, and without shoes or socks. Body mass index (BMI) was calculated by dividing the measured weight (kg) by height squared (m^2).

4. Survey questionnaires

A trained dietitian conducted a dietary intake survey using a 24-hour recall method to investigate the foods consumed the day before the survey. To help study participants recall and increase the accuracy of their intake amounts, auxiliary tools, such as real-sized photos of ingredients, food, and containers, were used. Based on the survey data, daily food, energy, and nutrient intakes were analyzed using the nutrition analysis program Can-pro 5.0 (The Korean Nutrition Society, Seoul, Korea, 2016).

Additionally, various demographic and lifestyle factors and dietary habits were collected using a self-reported questionnaire. This questionnaire recorded information such as the participants' sex, age, frequency of consumption of each type of caffeinated drink listed, and details about their eating attitudes and habits. The respondents' consumption habits and preferences for the five categories of caffeinated beverages (black coffee, café latte or cappuccino, café mocha or white mocha, instant coffee, and green or black tea) were then evaluated using a 5-point Likert scale, with higher scores indicating stronger preference: 5 points for "like very much"; 4 points for "like"; 3 points for "neutral"; 2 points for "dislike"; and 1 point for "hate." The intake frequency was evaluated on a weekly basis using the following scale: 7 times "every day"; 5.5 times "five to six times a week"; 3.5 times "three to four times a week"; 1.5 times "one to two times a week"; and 0 for "rare." Eating attitude and habits were assessed using each of the seven questions on a 5-point Likert scale, with a higher score indicating a higher desirable condition: 5 points for "strongly agree"; 4 points for "agree"; 3 points for "neutral"; 2 points for "disagree"; and 1 point for "strongly disagree."

5. Spot urine collection and analysis

Spot urine was collected in a cup in the afternoon of the day of the investigation. Urinary creatinine (Cr) was analyzed with a Cobas 8000 (c702, Roche, Berlin, Germany) using a CREJ2 kit (Roche) based on the principle of the Jaffe reaction. The N-terminal telopeptide of type I collagen (NTx) was analyzed with VITROS (VITROS ECiQ, Ortho-Clinical Diagnostics, Bridgend, UK) using an NTx kit (Ortho-Clinical Diagnostics, Bridgend, UK) under the principle of competitive immune response. Deoxypyridinoline (DPD) was analyzed with an EIA reader (Sunrise, Tecan, Austria) using a competitive enzyme immunoassay METRA DPD EIA kit (Quidel, San Diego, USA).

6. Statistical analysis

All data are presented as mean, standard deviation, frequency, and percentage. To evaluate the accuracy and reliability of the questionnaire used in this study, Cronbach's α coefficient was analyzed, and the values for the preference and intake frequency of caffeinated beverages, dietary attitude, and dietary habit were 0.85, 0.63, 0.71, and 0.68, respectively. Differences between the osteopenia or osteoporosis group (OSTEO group) and the normal group were tested using Student's t-test for continuous variables and χ^2-test for categorical variables. We used an Analysis of Covariance (ANCOVA) to test for differences in energy-adjusted nutrient intake between the OSTEO and normal groups. The significance level for all tests was set at $P < 0.05$. All statistical analyses were conducted using SAS software (version 9.4, SAS Institute Inc., Cary, NC, USA).

Results

1. General characteristics and bone status

Table 1 shows the general characteristics of the bone status according to the BMD of the participants. In men, the mean height of the OSTEO group was significantly higher than that of the normal group ($P < 0.05$). In women, the body weight and composition (muscle and body fat) of the OSTEO group were significantly lower than those of the control group ($P < 0.01$). In men, 12 (24%) had osteopenia, and 3 (6%) had osteoporosis; in women, 27 (54%) and 3 (6%) had osteopenia and osteoporosis, respectively, showing significant differences between men and women ($P < 0.01$).

Table 1. Characteristics and body measurements in OSTEO and normal groups among men and women

Characteristics	Men (n = 50)		*P*-value[1]	Women (n = 50)		*P*-value[1]
	OSTEO (n = 15)	Normal (n = 35)		OSTEO (n = 30)	Normal (n = 20)	
Age	22.33 ± 0.90	22.54 ± 1.58	0.557	21.57 ± 2.11	20.80 ± 1.24	0.113
Height (cm)	177.50 ± 4.50	173.46 ± 5.49	0.016	159.43 ± 4.30	160.82 ± 4.85	0.294
Weight (kg)	76.36 ± 10.63	72.95 ± 10.12	0.288	54.50 ± 11.43	65.68 ± 13.30	0.003
BMI (kg/m2)	24.21 ± 3.03	24.20 ± 2.71	0.991	21.39 ± 4.02	25.36 ± 4.84	0.003
SMM (kg)	34.45 ± 4.38	32.05 ± 4.43	0.085	18.94 ± 3.01	22.18 ± 3.92	0.002
BFM (kg)	16.41 ± 5.65	16.52 ± 4.83	0.946	17.44 ± 7.55	23.85 ± 8.14	0.006
VFA (cm^2)	88.92 ± 21.93	85.20 ± 20.14	0.563	43.71 ± 26.58	68.57 ± 29.85	0.003
BQI	69.25 ± 10.00	100.09 ± 10.60	< 0.001	71.56 ± 9.38	93.23 ± 9.85	< 0.001
T-score	- 1.86 ± 0.54	- 0.21 ± 0.57	< 0.001	- 1.74 ± 0.50	- 0.58 ± 0.53	< 0.001
Z-score	- 1.95 ± 0.57	- 0.19 ± 0.60	< 0.001	- 1.82 ± 0.56	- 0.52 ± 0.60	< 0.001
Bone status	Men (n = 50)			Women (n = 50)		*P*-value[2]
Normal (T-score ≥ - 1.0)	35 (70.0)			20 (40.0)		
Osteopenia (- 2.5 ≤ T-score < -1.0)	12 (24.0)			27 (54.0)		0.005
Osteoporosis (T-score < - 2.5)	3 (6.0)			3 (6.0)		

Mean ± SD or n (%)
1) *P*-value by unpaired t-test
2) *P*-value by χ^2 test
OSTEO: osteopenia & osteoporosis, BMI: body mass index, SMM: skeletal muscle mass, BFM: body fat mass, VFA: visceral fat area, BQI: bone quality index

2. Daily energy and nutrient intakes

In men, animal Ca intake in the OSTEO group was significantly higher than in the control group ($P < 0.05$). In women, the daily intake of dietary fiber, vitamin A, Ca, plant Ca, and K in the OSTEO group was significantly higher than in the normal group ($P < 0.05$). After adjusting for energy intake, the intakes of carbohydrates, vitamin E, vitamin B_2, folic acid, phosphorus, iron, and plant iron were also significantly higher in the female OSTEO group than in the normal group (Table 2).

3. Preference and frequency of caffeinated beverages

In men, the preferences for café latte or cappuccino and total caffeinated beverages in the OSTEO group were significantly higher than those in the control group ($P < 0.01$). However, there was no significant difference in the preference for caffeinated beverages between the two groups in women or in their intake frequency in men and women (Table 3).

4. Eating attitude and eating habits

In men, the dietary attitude score of nutrition label checking and the average score of the OSTEO group were significantly higher than those of the control group ($P < 0.01$, $P < 0.05$). However, there was no significant difference in dietary attitude scores between the two groups of women. The dietary habits of both men and women were not significantly different between the OSTEO and control groups (Table 4).

Table 2. Comparison of daily energy and nutrient intake between OSTEO and normal groups in men and women

	Men (n = 50)						Women (n = 50)					
	OSTEO (n = 15)		Normal (n = 35)		*P*-value[1]	Adjusted *P*-value[2]	OSTEO (n = 30)		Normal (n = 20)		*P*-value[1]	Adjusted *P*-value[2]
Energy (kcal)	2,392.68 ±	660.51	2,211.67 ±	775.72	0.434	-	1,748.18 ±	582.91	1,893.34 ±	599.94	0.398	-
Carbohydrate (g)	307.85 ±	60.66	261.18 ±	111.69	0.064	0.187	247.09 ±	93.43	214.75 ±	79.51	0.210	0.005
Fat (g)	90.15 ±	41.59	79.26 ±	37.42	0.366	0.641	55.25 ±	24.24	58.87 ±	28.93	0.634	0.924
Protein (g)	84.84 ±	33.97	76.73 ±	29.85	0.403	0.722	61.60 ±	23.01	57.38 ±	21.89	0.520	0.091
Dietary fiber (g)	19.34 ±	8.48	16.71 ±	8.22	0.310	0.499	18.73 ±	8.35	12.46 ±	5.16	0.002	0.000
Vitamin A (mg RAE)	456.56 ±	274.60	365.48 ±	252.02	0.260	0.397	372.34 ±	287.02	245.71 ±	147.63	0.047	0.019
Vitamin D (mg)	2.70 ±	2.75	2.51 ±	5.29	0.870	0.909	3.21 ±	3.18	4.97 ±	10.88	0.490	0.548
Vitamin E (mg)	21.09 ±	10.76	20.65 ±	11.74	0.901	0.836	18.28 ±	10.45	14.48 ±	6.72	0.124	0.035
Vitamin K (mg)	100.67 ±	76.48	93.95 ±	80.36	0.785	0.835	75.59 ±	56.03	61.86 ±	50.27	0.381	0.316
Vitamin C (mg)	62.81 ±	46.55	42.07 ±	34.37	0.086	0.128	66.56 ±	57.37	48.65 ±	87.69	0.427	0.351
Vitamin B_1 (mg)	2.37 ±	1.01	1.97 ±	0.87	0.158	0.241	1.48 ±	0.59	1.24 ±	0.74	0.213	0.101
Vitamin B_2 (mg)	1.75 ±	1.01	1.46 ±	0.75	0.260	0.421	1.35 ±	0.66	1.11 ±	0.57	0.192	0.049
Niacin (mg)	16.46 ±	7.39	13.84 ±	7.08	0.242	0.386	12.20 ±	4.90	11.64 ±	4.88	0.696	0.274
Vitamin B_6 (mg)	1.65 ±	0.70	1.45 ±	0.62	0.329	0.486	1.37 ±	0.58	1.46 ±	0.98	0.708	0.943
Folate (mg)	403.29 ±	211.80	356.65 ±	179.36	0.429	0.661	367.25 ±	210.76	269.28 ±	143.48	0.076	0.026
Vitamin B_{12} (mg)	8.57 ±	6.81	6.07 ±	7.22	0.260	0.327	5.56 ±	3.85	9.03 ±	15.37	0.335	0.301
Calcium (mg)	547.94 ±	355.41	408.46 ±	283.44	0.147	0.221	564.54 ±	494.33	331.69 ±	231.00	0.030	0.019
Plant calcium (mg)	236.26 ±	172.67	227.98 ±	182.56	0.882	0.784	255.41 ±	157.90	165.47 ±	101.67	0.018	0.003
Animal calcium (mg)	311.67 ±	240.21	180.49 ±	161.73	0.028	0.037	309.13 ±	466.88	166.23 ±	224.62	0.156	0.148
Phosphorus (mg)	1168.53 ±	525.70	1063.31 ±	420.81	0.456	0.851	928.41 ±	367.81	816.65 ±	287.32	0.258	0.029
Sodium (mg)	4,199.53 ±	1,563.34	3,597.55 ±	1,587.89	0.223	0.355	3,333.52 ±	1,359.37	2,934.29 ±	1,396.91	0.319	0.080
Potassium (mg)	2,353.38 ±	835.12	1,979.84 ±	816.66	0.148	0.216	2,221.47 ±	1,051.47	1,466.26 ±	529.30	0.002	0.000
Iron (mg)	14.98 ±	7.75	13.05 ±	5.82	0.339	0.536	13.56 ±	7.32	10.03 ±	4.88	0.065	0.002
Plant iron (mg)	8.93 ±	4.22	8.09 ±	3.85	0.497	0.751	9.61 ±	5.57	7.10 ±	3.76	0.084	0.004
Animal iron (mg)	6.04 ±	4.73	4.96 ±	3.47	0.369	0.530	3.94 ±	2.75	2.93 ±	2.41	0.189	0.072
Zinc (mg)	10.49 ±	4.56	8.89 ±	4.02	0.221	0.352	7.81 ±	3.45	6.70 ±	2.86	0.240	0.052
Copper (mg)	671.09 ±	490.37	604.95 ±	454.17	0.647	0.963	603.37 ±	299.88	547.02 ±	388.75	0.566	0.250
Selenium (mg)	86.03 ±	55.06	74.70 ±	44.61	0.447	0.701	67.45 ±	36.62	71.98 ±	48.90	0.710	0.937
Cholesterol (mg)	339.69 ±	270.74	315.10 ±	268.44	0.768	0.974	329.84 ±	261.41	312.35 ±	226.97	0.808	0.487

Mean ± SD
1) *P*-value by unpaired t-test
2) Energy-adjusted *P*-value by analysis of covariance
OSTEO: osteopenia & osteoporosis

Table 3. Comparison of preference and intake frequency of caffeinated beverages between OSTEO and normal groups in men and women

	Men (n = 50)		*P*-value	Women (n = 50)		*P*-value
	OSTEO (n = 15)	Normal (n = 35)		OSTEO (n = 30)	Normal (n = 20)	
Preference						
Black coffee	4.00 ± 1.13	3.11 ± 1.55	0.052	3.00 ± 1.46	3.55 ± 1.32	0.182
Café latte or cappuccino	3.93 ± 1.10	2.89 ± 0.99	0.002	3.13 ± 1.22	3.35 ± 1.27	0.548
Café mocha or white mocha	3.40 ± 1.18	2.77 ± 0.97	0.056	2.90 ± 1.03	3.10 ± 1.17	0.526
Instant coffee	3.00 ± 1.31	2.91 ± 1.09	0.812	2.90 ± 1.16	3.10 ± 1.21	0.559
Green or black tea	3.73 ± 1.22	3.17 ± 1.15	0.127	3.90 ± 0.92	3.80 ± 1.11	0.730
Total	18.07 ± 4.23	14.86 ± 3.41	0.007	15.83 ± 3.71	16.90 ± 3.73	0.325
Intake frequency						
Black coffee	2.43 ± 2.21	1.97 ± 2.32	0.516	1.47 ± 2.30	2.05 ± 2.43	0.394
Café latte or cappuccino	1.70 ± 2.09	0.77 ± 1.09	0.121	0.75 ± 1.14	0.40 ± 0.91	0.257
Café mocha or white mocha	0.67 ± 1.47	0.50 ± 1.08	0.656	0.20 ± 0.52	0.23 ± 0.55	0.871
Instant coffee	0.20 ± 0.53	0.39 ± 0.67	0.343	0.48 ± 1.00	0.50 ± 1.30	0.959
Green tea or black tea	1.40 ± 1.93	0.87 ± 1.73	0.342	1.00 ± 1.11	1.23 ± 1.77	0.616
Total	6.40 ± 5.37	4.50 ± 3.45	0.140	3.90 ± 3.14	4.40 ± 3.30	0.591

Mean ± SD
P-value by unpaired t-test
Preference is scored from 1 (hate) to 5 (like very much). Frequency is scored as 7 (every day), 5.5 (5-6 times/week), 3.5 (3-4 times/week), 1.5 (1-2 times/week), and 0 (rarely).
OSTEO: osteopenia & osteoporosis

Table 4. Comparison of eating atttitudes and habits between OSTEO and normal groups in men and women

	Men (n = 50)		*P*-value	Women (n = 50)		*P*-value
	OSTEO (n = 15)	Normal (n = 35)		OSTEO (n = 30)	Normal (n = 20)	
Eating attitude						
I try to eat breakfast regularly every day	2.20 ± 1.32	1.83 ± 0.92	0.259	1.97 ± 1.33	1.70 ± 0.86	0.432
I try to eat an adequate amount of meals	3.60 ± 0.63	3.31 ± 0.83	0.241	3.43 ± 0.97	3.15 ± 0.88	0.299
I try not to eat snacks from after dinner until I go to bed	2.53 ± 1.06	2.71 ± 1.18	0.611	2.73 ± 1.20	2.50 ± 1.40	0.531
I tend to eat slowly and leisurely	2.87 ± 1.25	2.91 ± 0.92	0.881	3.47 ± 1.14	3.65 ± 0.99	0.559
I try to eat evenly without unbalanced meals	4.13 ± 0.92	3.60 ± 1.01	0.084	3.57 ± 0.97	3.75 ± 1.21	0.556
When I eat, I think about the combination of food	2.87 ± 1.13	2.43 ± 1.12	0.211	2.77 ± 1.10	2.30 ± 0.80	0.111
When I purchase food, I try to check the nutrition label	3.00 ± 0.93	1.77 ± 0.84	0.003	2.53 ± 1.33	2.35 ± 1.35	0.637
Average	3.03 ± 0.56	2.65 ± 0.49	0.021	2.92 ± 0.68	2.77 ± 0.48	0.391
Eating habits						
I eat grain at every meal	4.53 ± 0.83	4.09 ± 0.92	0.112	4.10 ± 1.03	4.15 ± 1.09	0.870
I eat meat at every meal	4.00 ± 0.93	3.69 ± 0.90	0.267	3.73 ± 1.01	3.85 ± 1.14	0.706
I eat side dishes of vegetables besides *Kimchi* every day	3.73 ± 0.96	3.57 ± 0.95	0.584	3.40 ± 0.93	3.60 ± 0.75	0.428
I eat seaweed at every meal	2.47 ± 0.99	2.31 ± 0.72	0.544	2.20 ± 0.61	2.60 ± 0.94	0.103
I do not eat processed food often	2.20 ± 0.86	2.23 ± 0.77	0.908	2.50 ± 1.04	2.15 ± 1.04	0.250
I do not eat snacks often	3.00 ± 1.00	2.74 ± 0.98	0.402	2.50 ± 0.97	2.80 ± 1.40	0.375
I do not eat out often	2.13 ± 0.92	2.49 ± 1.04	0.262	2.37 ± 1.10	2.20 ± 0.95	0.582
Average	3.15 ± 0.41	3.02 ± 0.43	0.305	2.97 ± 0.45	3.05 ± 0.58	0.594

Mean ± SD
P-value by unpaired t-test
The score ranges from 1 (strongly disagree) to 5 (strongly agree) on a Likert scale.
OSTEO: osteopenia & osteoporosis

5. Bone resorption indicators

As shown in Fig. 1, there were no significant differences in urinary bone resorption indicators between the OSTEO and control groups in either men or women.

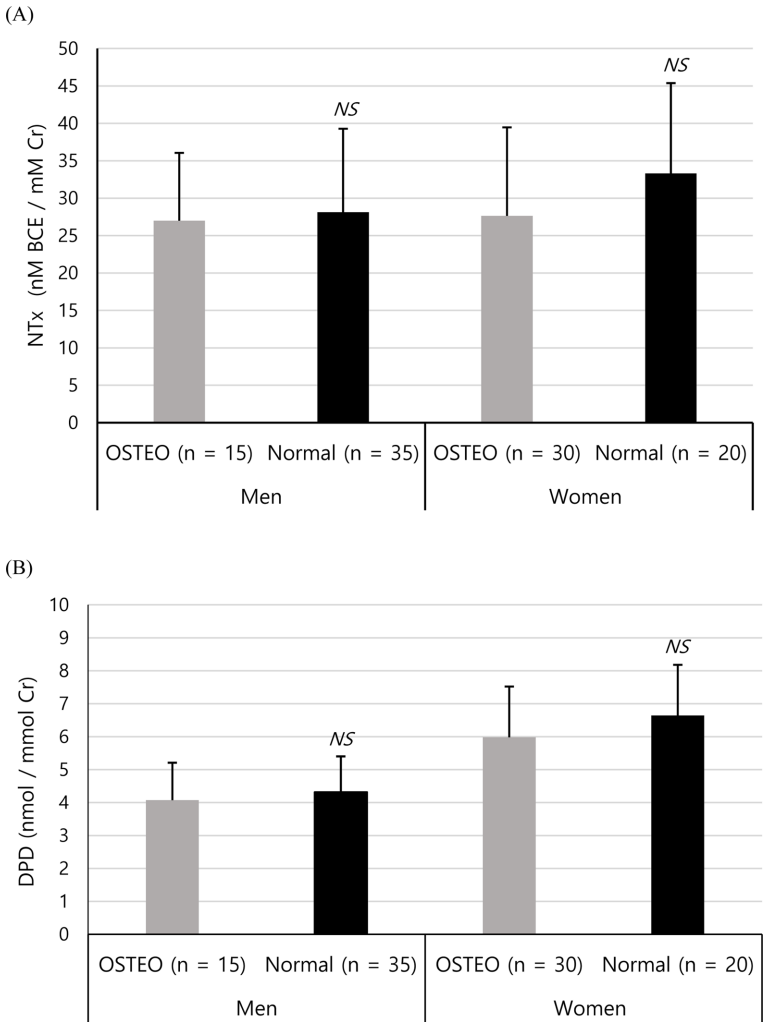

Fig. 1. Comparison of bone resorption indicators (NTx (A) and DPD (B)) in the urine between OSTEO and normal groups in men and women. OSTEO: osteopenia & osteoporosis, NTx: N-terminal telopeptide of type I collagen, DPD: deoxypyridinoline, *NS*: not significant by unpaired t-test

Discussion

Among the study participants, 30% of men and 60% of women met the criteria for osteopenia or osteoporosis, showing a significant difference between men and women. In men, the mean height of the OSTEO group was significantly higher than that of the normal group. In women, the body weight and composition (muscle and body fat) of the OSTEO group were significantly lower than those of the control group. According to one study, increased adult height in men was associated with later puberty [13], which in turn is a recognized risk factor for fracture [14-16]. It has been speculated that late-maturing boys have lower sex steroid levels during puberty that may persist into adulthood [16]. Consequently, low levels of androgens and estrogen could predispose individuals to osteoporosis and increase the risk of fractures later in life [16, 17]. Conversely, in

women, low body weight, lean body mass, and body fat, rather than height, were significant risk factors for low BMD. According to the results of previous studies targeting female college students, the average weight of the normal group was significantly higher than that of the osteoporosis risk group [3, 18], which was consistent with the results of this study. Edelstein & Barrett-Corener [19] also reported that bone density increases as weight increases. DeSimone *et al.* [20] reported that body weight exerts a load on the skeleton and positively affects bone density, and weight has a higher correlation with bone density than height. On the other hand, body fat produces estrogen, and estrogen plays a central role in preventing osteoporosis [21, 22]. Increased body fat also contributes to an increase in total mass, which puts a mechanical load on bones and contributes to BMD [23, 24]. There is also a possible role for leptin, which is mainly produced by the adipose tissue, in the positive association between circulating leptin and BMD [22, 25, 26]. Furthermore, lean mass contributes to total mass, increasing the bone load. It has also been suggested that a high percentage of skeletal muscle mass is likely associated with high physical activity, stimulating an increase in BMD [27]. In a study of premenopausal women from the Pacific Islands, lean mass was the strongest predictor of BMD, while many established contributors to bone health, such as Ca, physical activity, protein, and vitamin C, were not associated with BMD [28]. Our results suggest that low body weight, muscle mass, and body fat in young adult women may be associated with osteopenia and low BMD.

In our study, there was no significant difference in the urinary excretion of DPD and NTx between the OSTEO and normal groups in both men and women. Bone turnover markers were reported to be significantly different in elderly individuals with osteopenia and osteoporosis compared to healthy elderly individuals, whereas there was no difference in BMD [29]. Islamoglu *et al.* [30] reported that a low-protein diet had a negative effect on bone structure by significantly decreasing NTx levels in postmenopausal women with osteopenia. However, our study was conducted in healthy young adults with active bone turnover, and the OSTEO group was mainly composed of participants with osteopenia whose bone condition was not serious.

In men, the preference for caffeinated beverages in the OSTEO group was significantly higher than that in the control group, but not in women. However, the intake frequency of caffeinated beverages in men and women did not differ significantly between the OSTEO and control groups. The association between caffeine or coffee intake and BMD has been inconsistent among studies [31-34]. Caffeine is known to increase Ca excretion through the kidneys and intestines; however, there is no evidence that caffeine has any detrimental effects on bone status or Ca economy among individuals consuming the recommended daily allowance level of Ca [35]. Conlisk & Galuska [36] reported that the average caffeine intake from coffee, tea, and caffeinated drinks in young adult women was 99.9 mg/day, which was not significantly associated with BMD. It was also reported that participants with high coffee consumption (over 4 cups a day) had a 4% lower BMD at the proximal femur compared with low or non-coffee consumers in older men, but not in women [37]. Taken together, when Ca intake is insufficient, caffeine intake through coffee or beverages has a negative effect on bone density, which appears to be greater in men than in women. Although coffee preference was high in the OSTEO group, there was no significant difference in the frequency of direct coffee consumption.

Inadequate nutrient intake is an important risk factor for osteopenia and osteoporosis. In this study, the average Ca intake in the OSTEO group was 547.9 mg in men and 564.5 mg in women. Although these values were not significantly lower than those in the normal group, they remained below the recommended intake (800 mg for Korean men aged 19-39 years, 700 mg for Korean women aged 19-37 years) [38]. These results are similar to recent KNHANES data for men but higher for women [12]. Interestingly, in our study, animal Ca intake in the male OSTEO group was significantly higher than that in the normal group. In women, the daily intake of dietary fiber, vitamins A, Ca, plant Ca, and K, mostly derived from plant foods, in the OSTEO group were significantly higher than in the normal group ($P < 0.05$). Although the difference was not statistically significant, the energy intake of the female OSTEO group was lower than that of the control group. Thus, we conducted an additional comparison of nutrient intake between the two groups adjusted for energy intake. After adjustment, there was no significant difference in the male groups; however, in females, the intake of carbohydrates, vitamin E, vitamin B_2, folic acid, phosphorus, iron, and plant iron was also significantly higher in the OSTEO group. This indicated that the overall dietary

quality and nutritional density tended to be higher in the OSTEO group than in the normal group. In addition, the eating attitudes and eating habits of both men and women in the OSTEO group were not significantly different from those in the normal group, except for the eating attitude of males in the OSTEO group. In fact, the OSTEO group tended to have more favorable dietary attitudes and behaviors than the normal group, which is consistent with the observed lower quality of nutrient intake within the normal group. The findings in the normal group raise concerns that people who are confident in their BMD or health status in early adulthood, when genetics and body size play a large role in the status, may be at risk of negative consequences for their future BMD and health if they maintain an unhealthy lifestyle.

Our study had several limitations. First, the cross-sectional nature of this study inherently limited our ability to establish causal relationships between various risk factors, osteoporosis, and osteopenia in young adults, thereby introducing the potential for reverse causality. Specifically, our study showed that the OSTEO group had more favorable dietary habits and better nutrient intake than did the normal group. This could be because individuals with health issues consciously or subconsciously modify their dietary habits because of health issues. Second, differential misreporting of dietary intake based on body weight could also be possible, with underweight females in the OSTEO group potentially overreporting, and overweight individuals in the normal group may underreport their intake. Consequently, these biases could influence the observed higher nutrient intake and better dietary behaviors in the OSTEO group. Third, BMD, the main dependent variable, was measured by quantitative ultrasound of the calcaneus instead of the major sites of the femoral neck and lumbar spine using DXA measurements; therefore, interpretation of the prevalence of osteopenia and osteoporosis may be less reliable. Finally, this study did not analyze bone formation-related biomarkers, which may reflect the current status of bone formation. As the participants were still in the bone-forming stage, analyzing bone formation-related biomarkers in conjunction with bone resorption markers may help explain their current bone status. Despite these limitations, this study has strengths in its novel examination of the correlations between comprehensive dietary habits, body components, and an array of objective bone biomarkers, specifically in young Korean adults with an elevated risk of osteoporosis. By integrating these multidimensional factors, our research provides a scientific contribution to understanding susceptibility to osteoporosis in this age group.

Conclusion

The observations from this study indicated that our study participants had comparatively lower levels of BMD. In young adult males with greater stature and in young adult females, a leaner physique was associated with lower BMD. The findings of this study suggest the potential for reverse causality, a common occurrence in cross-sectional research, especially in relation to the differential association between dietary factors, including dietary Ca sources, and BMD in men and women. Interestingly, the OSTEO group, despite having a lower BMD, consumed a diet rich in nutrients and exhibited healthier dietary attitudes than the normal group. Therefore, further research is warranted to elucidate the complex interactions between dietary factors and the risk of osteoporosis in young adults. Specifically, comprehensive prospective cohort studies with larger populations should be conducted to address these discrepancies and offer more conclusive insights.

ORCID

Mi-Hyun Kim: https://orcid.org/0000-0002-0805-0630
Mi-Kyeong Choi: https://orcid.org/0000-0002-6227-4053

Conflict of interest

There are no financial or other issues that might lead to conflict of interest.

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Data availability

The participants of the study did not give written consent for their data to be shared publicly. Due to the sensitive nature of the research, supporting data is not available.

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