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ORIGINAL ARTICLE

Association of urinary sodium/creatinine ratio with bone mineral density in postmenopausal women: KNHANES 2008–2011

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Abstract Accumulating evidence shows that high sodium chloride intake increases urinary calcium excretion and may be a risk factor for osteoporosis. However, the effect of oral sodium chloride intake on bone mineral density (BMD) and risk of osteoporosis has been inadequately researched. The aim of the present study was to determine whether urinary sodium excretion (reflecting oral sodium chloride intake) associates with BMD and prevalence of osteoporosis in postmenopausal women. This cross-sectional study involved a nationally representative sample consisting of 2,779 postmenopausal women who participated in the Korea National Health and Nutritional Examination Surveys in 2008–2011. The association of urinary sodium/creatinine ratio with BMD and other osteoporosis risk factors was assessed. In addition, the prevalence of osteoporosis was assessed in four groups with different urinary sodium/creatinine ratios. Participants with osteoporosis had significantly higher urinary sodium/creatinine ratios than the participants without osteoporosis. After adjusting for multiple confounding factors, urinary sodium/creatinine ratio correlated inversely with lumbar spine BMD ($P = 0.001$). Similarly, when participants were divided into quartile groups according to urinary sodium/creatinine ratio, the average BMD dropped as the urinary sodium/creatinine ratio increased. Multiple logistic regression analysis revealed that compared to quartile 1, quartile 4 had a significantly increased prevalence of lumbar spine osteoporosis (odds ratios 1.346, P for trend $= 0.044$). High urinary sodium excretion was significantly associated with low BMD and high prevalence of osteoporosis in lumbar spine. These results suggest that high sodium chloride intake decreases lumbar spine BMD and increases the risk of osteoporosis in postmenopausal women.

Keywords Urinary sodium excretion · Osteoporosis · Bone mineral density · Postmenopausal women

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Introduction

Osteoporosis is a metabolic bone disease that is characterized by low bone mass and micro-architectural deterioration of the bone tissue [1]. It is recognized as a major health problem, especially in postmenopausal women. Estrogen deficiency is widely known to be the most important cause of osteoporosis in postmenopausal women [2, 3]. Bone mineral density (BMD) is also influenced by many factors that relate to calcium homeostasis, including diet, exercise, and vitamin D levels [4–6]. Specifically, several lines of evidence suggest that high sodium chloride intake increases urinary calcium excretion and may be a risk factor for osteoporosis [7, 8]. Furthermore, several studies described that the increase in urinary calcium excretion due to high sodium chloride intake is especially marked in postmenopausal women with osteoporosis [9, 10].

Most sodium and calcium re-absorption occurs in two nephron segments, the proximal tubule and the thick

ascending limb of Henle's loop. In the proximal tubule, reabsorption of sodium and fluid increases the concentration of calcium in the tubule lumen. High calcium concentration in tubule lumen increases the driving force for passive absorption [11]. In the thick ascending limb of Henle's loop, sodium absorption is accomplished by Na–K–2Cl cotransport. Sequential secretion and recycling of K^+ renders the tubule lumen electropositive, which in turn increases calcium absorption through the paracellular pathway. Therefore, a decrease in sodium absorption is accompanied by a decrease in calcium absorption due to the reduction in transepithelial voltage. Consequentially, high sodium chloride intake increases urinary calcium excretion by decreasing renal sodium absorption [12, 13]. Moreover, high sodium chloride intake is frequently associated with a high intake of acidifying animal-based food and less frequently with a high intake of alkalizing plant-based food [14]. High dietary acid load may also aggravate osteoporosis by increasing urinary calcium excretion, especially when it is associated with high sodium chloride intake [15, 16].

Accumulating evidence shows that oral sodium intake correlates positively with urinary calcium excretion [8, 10, 17]. However, it is almost impossible to measure oral sodium intake exactly. Instead, 24 h urine sodium excretion is measured because in the absence of hydration problems 24 h urine sodium excretion is approximately equal to oral sodium intake [18, 19]. However, the 24 h urine sodium excretion measurements are not widely used because of their associated high costs and inconvenience. For this reason, the measurement of spot urine sodium that is corrected by urinary creatinine levels (which compensates for variations in urinary volume) is widely used instead of 24 h urine sodium excretion measurements [18, 20].

Despite the links between high sodium chloride intake and osteoporosis described above, only a few studies have actually assessed the relationship between oral sodium chloride intake and osteoporosis [21–27]. Since they yielded discrepant findings, the present study was performed to determine whether urinary sodium excretion correlates with BMD and osteoporosis prevalence in postmenopausal women. For this, the data of the South Korean postmenopausal women who participated in the Korea National Health and Nutrition Examination Survey (KNHANES) in 2008–2011 were analyzed.

Materials and methods

Data source and participants

The study was based on KNHANES 2008, 2009, 2010, and 2011 data. KNHANES is a cross-sectional, population-based, and nationwide survey that is regularly conducted by the Division of Chronic Disease Surveillance of the Korea Centers for Disease Control and Prevention, which takes random samples of subjects from 600 allocated districts of South Korea. BMD was measured in 15,322 subjects (7,028 males and 8,294 females) in the 2008–2011 KNHANES. We initially selected 4,156 postmenopausal women. Subjects who had severe chronic renal disease (estimated GFR < 30), artificial menopause (e.g., hysterectomy), or a medical history of current or previous osteoporosis treatment were excluded. Subjects with no or incomplete data for BMD or urine and blood samples were also excluded. The final number of subjects enrolled in the study was 2,779. All survey participants signed an informed consent form.

Measurements of biochemical and clinical variables

Blood samples and spot urine samples were collected after 8 h fasting and transported to the Neodin Medical Institute in Seoul, Korea. Urine sodium and creatinine levels were measured by using a Hitachi automatic analyzer 7600 (Hitachi Ltd., Tokyo, Japan). The sodium/creatinine ratio was calculated as the spot urine sodium level divided by the spot urine creatinine level. To estimate gross salt intake per day from spot urine, the urinary sodium/creatinine ratio was multiplied by the mean value of 24 h urine creatinine levels in Korean women [28]. Serum parathyroid hormone (PTH) levels were measured by using the chemiluminescence immunoassay method (Diasorin Inc., MN, USA). Serum 25-hydroxyvitamin D ($25(OH)D_3$) was measured by using the radioimmunoassay method (Diasorin) with a gamma counter (1470 Wizard; PerkinElmer, Turku, Finland). Body height and weight were measured by trained staff members during the health examination. Body mass index (BMI) was calculated as weight divided by the height squared. The blood pressure of the right arm was measured three times while the subject was seated by using a mercury sphygmomanometer (Baumanometer; W. A. Baum, Copiague, NY, USA). The final blood pressure was calculated as the average of the second and third blood pressure readings. Hypertension (HTN) was defined according to the guidelines of the Joint National Committee (JNC) 7 as blood pressure >140/90 or already diagnosed high blood pressure [29]. The glomerular filtration rate was estimated by using the modification of diet in renal disease (MDRD) equation. The demographic and personal medical data were collected by using standardized health questionnaires. These data included age, smoking history, alcohol consumption, menopause age, history of osteoporosis treatment, and other past medical history. Smokers were categorized into three groups (never, current, and ex-smokers). A heavy drinker was defined as one who consumed more than 30 g of alcohol daily.

BMD measurement

BMD of lumbar spine, total femur, and femoral neck was measured by using dual-energy X-ray absorptiometry (DXA; QDR 4500A; Hologic Inc., Waltham, MA, USA) at mobile examination centers. DXA instruments were calibrated as described previously [30], and the reference values of National Health and Nutrition Examination Survey (NHANES) were obtained using this method [31]. DXA calibrations were maintained via an internal referencing system. Participants put on light clothes without shoes or jewelry during BMD measurements. Participants who had been exposed to radiological contrast or nuclear medicine testing in the preceding week were excluded. The results were analyzed using the standard techniques of the Korean Society of Osteoporosis and Hologic Discovery software (version 13.1). Osteoporosis in postmenopausal women was defined on the basis of World Health Organization criteria as a *T* score of less than −2.5. Osteopenia was defined as a *T* score between −1.0 and −2.5. A *T* score above −1.0 was defined as normal [32].

Statistical analyses

All continuous data were presented as mean ± standard deviation (SD), and all categorical data were presented as numbers and percentages. Statistical analysis was performed by using SPSS 18.0 software (SPSS Inc., Chicago, IL, USA). The subject groups were compared in terms of demographic and clinical variables by Student's *t* test and χ^2 test. Multivariable linear regression analysis models were used to estimate the correlation between BMD and urinary sodium excretion. The models were adjusted for known osteoporosis risk factors, namely, age, height, weight, duration of menopause, blood pressure, PTH level, $25(OH)D_3$ level, smoking status, and alcohol consumption. Participants were also divided into quartiles (Q1–4) on the basis of their urinary sodium/creatinine ratio, and the four groups were compared with respect to their baseline characteristics by using analysis of variance (ANOVA) for continuous variables and the χ^2 test for categorical variables. To estimate the odds ratio (ORs) of osteoporosis in each quartile, multivariable logistic regression models were used. In all statistical tests, *P* values < 0.05 were considered to indicate statistical significance.

Results

General characteristics of the participants

The baseline characteristics of the 2,779 postmenopausal women are presented in Table 1. Their mean age was 62.7 ± 8.8 years, and 1,235 had osteoporosis. The participants with osteoporosis were significantly older than the participants without osteoporosis and had significantly lower mean height, weight, and BMI. They also had significantly higher systolic and lower diastolic blood pressure. The two groups did not differ in terms of plasma total cholesterol levels. The participants with osteoporosis had significantly lower glomerular filtration rates and higher plasma PTH levels, but the two groups did not differ in plasma $25(OH)D_3$ levels. While the two groups had similar urinary sodium levels, the participants with osteoporosis had significantly lower urinary creatinine levels, meaning that these patients had significantly higher urinary sodium/creatinine ratios and estimated salt intakes than the subjects without osteoporosis. The participants with osteoporosis had significantly longer total menopause durations. They were more also more likely to be current smokers and less likely to be heavy drinkers than participants without osteoporosis. The participants with osteoporosis were also more likely to have hypertension and diabetes and had significantly lower BMDs of the lumbar spine, the total femur, and the femoral neck than the participants without osteoporosis.

Correlation between urinary sodium/creatinine ratio and BMD

Unadjusted multivariable regression analysis revealed that lumbar spine, total femur, and femoral neck BMDs all correlated negatively and significantly with urinary sodium/creatinine ratio (all $P < 0.001$; Table 2). After adjustment for age, height, weight, menopause duration, and blood pressure (model 1), lumbar spine BMD continued to correlate significantly and negatively with urinary sodium/creatinine ratio ($P = 0.001$, model 1), but the total femur and femoral neck BMDs no longer correlated significantly with urinary sodium/creatinine ratio. Even after further adjustment for PTH level, $25(OH)D_3$ level, smoking status, and alcohol consumption in addition to the variables introduced in model 1 (model 2), the significant negative correlation between lumbar spine BMD and urinary sodium/creatinine ratio continued to be observed ($P = 0.001$).

Differences between urinary sodium/creatinine ratio quartiles in terms of BMD and other variables

The participants were then divided into quartiles on the basis of their urinary sodium/creatinine ratio. The urinary sodium/creatinine ratios in each quartile were 0.84–17.32 in Q1, 17.32–26.52 in Q2, 26.52–38.05 in Q3, and 38.05–136.29 mmol/mmol in Q4. The mean urinary sodium/creatinine ratio and estimated salt intake in Q4 were almost five times that in Q1 (Table 3). Mean age

Table 1 Baseline characteristics and bone mineral densities of postmenopausal women in KNHANES 2008–2011

	Postmenopausal women			
	Total (n = 2,779)	No osteoporosis (n = 1,544)	Osteoporosis (n = 1,235)	P value
Age (years)	62.7 ± 8.8	59.0 ± 7.3	67.4 ± 8.2	<0.001*
Height (cm)	153.6 ± 5.7	155.1 ± 5.4	151.6 ± 5.6	<0.001*
Weight (kg)	57.1 ± 8.4	59.6 ± 7.9	54.1 ± 7.9	<0.001*
BMI (kg/m^2)	24.2 ± 3.2	24.8 ± 3.1	23.5 ± 3.1	<0.001*
Systolic BP (mmHg)	128.0 ± 18.1	126.6 ± 18.0	129.9 ± 18.0	<0.001*
Diastolic BP (mmHg)	78.2 ± 9.9	79.1 ± 9.9	77.2 ± 9.8	<0.001*
Total cholesterol (mmol/L)	201.6 ± 36.6	202.4 ± 36.6	200.6 ± 36.6	0.200
Glomerular filtration rate (mL/min per 1.73 m^2)	85.2 ± 16.3	86.2 ± 15.3	83.9 ± 17.3	<0.001*
PTH (pg/mL)	68.4 ± 30.2	65.8 ± 29.0	71.6 ± 31.3	<0.001*
25(OH)D_3 (ng/mL)	18.0 ± 6.8	18.2 ± 6.7	17.8 ± 7.0	0.157
Urinary sodium, (mmol/L)	129.3 ± 48.7	130.8 ± 50.6	127.4 ± 46.2	0.061
Urinary creatinine (mmol/L)	5.6 ± 3.2	5.8 ± 3.2	5.4 ± 3.1	<0.001*
Urinary sodium/creatinine ratio (mmol/mmol)	29.7 ± 17.6	28.5 ± 16.4	31.1 ± 18.9	<0.001*
Estimated salt intake (g/days)	8.6 ± 5.0	8.2 ± 4.7	9.0 ± 5.4	<0.001*
Duration of menopause (years)	13.4 ± 10.3	9.1 ± 7.9	18.8 ± 10.3	<0.001*
Smoking history (never/ex-/current), n (%)	2,564/46/169 (92.3 %/1.7 %/6.0 %)	1,446/27/71 (93.7 %/1.7 %/4.6 %)	1,118/19/98 (90.5 %/1.5 %/7.9 %)	0.001*
Heavy drinker, n (%)	23 (0.8 %)	17 (1.1 %)	6 (0.5 %)	<0.001*
HTN, n (%)	1437 (51.7 %)	718 (46.5 %)	719 (58.2 %)	<0.001*
DM, n (%)	348 (12.5 %)	170 (11.0 %)	178 (14.4 %)	0.008*
Lumbar spine BMD (g/cm^2)	0.805 ± 0.139	0.887 ± 0.109	0.703 ± 0.099	<0.001*
Total femur BMD (g/cm^2)	0.780 ± 0.116	0.855 ± 0.081	0.685 ± 0.079	<0.001*
Femoral neck BMD (g/cm^2)	0.629 ± 0.108	0.695 ± 0.084	0.547 ± 0.073	<0.001*

All data are expressed as mean ± standard deviation or number (%)

All P values were obtained by using Student's t test or χ^2 test

BMD bone mineral density, *BMI* body mass index, *BP* blood pressure, *DM* diabetes mellitus, *HTN* hypertension

* $P < 0.05$ (statistical significance)

Table 2 Association between bone mineral density and urinary sodium/creatinine ratio

β (P value)	Sodium/creatinine ratio		
	Lumbar spine	Total femur	Femoral neck
Unadjusted	$\beta = -0.101$* ($P < 0.001$)	$\beta = -0.080$* ($P < 0.001$)	$\beta = -0.074$* ($P < 0.001$)
Model 1	$\beta = -0.053$* ($P = 0.001$)	$\beta = -0.014$ ($P = 0.338$)	$\beta = -0.004$ ($P = 0.766$)
Model 2	$\beta = -0.056$* ($P = 0.001$)	$\beta = -0.019$ ($P = 0.203$)	$\beta = -0.008$ ($P = 0.618$)

Model 1: adjusted for age, height, weight, menopause duration, and systolic and diastolic blood pressure

Model 2: adjusted for age, height, weight, menopause duration, systolic and diastolic blood pressure, parathyroid hormone level, 25(OH)D_3 level, smoking status, and alcohol consumption

Data were analyzed by multivariable regression analysis

β standardized regression coefficient

* $P < 0.05$ (statistical significance)

increased with quartile in ascending order (i.e., from Q1 to Q4) while average height and weight decreased slightly but significantly. However, a significant trend in mean BMI was not observed. The average systolic and diastolic blood pressures increased with quartile. A significant trend in mean total cholesterol levels was not observed. The glomerular filtration rate increased significantly with quartile, but plasma PTH and 25(OH)D_3 levels did not exhibit significant trends. Menopause duration increased with quartile, but the frequency of current smoker status and heavy drinker status did not exhibit significant trends. Hypertension prevalence exhibited an increasing trend except for patients in Q1, but this was not significant. Diabetes mellitus prevalence did not exhibit a significant trend. Osteoporosis and osteopenia prevalence increased significantly with quartile. Osteoporosis at lumbar spine was significantly increased, but not at total femur and femoral neck. However, lumbar spine, total femur, and femoral neck BMD all dropped significantly with quartile (Fig. 1). The trend of decreasing BMD with quartile in ascending order was significant for the (Fig. 1a) lumbar spine (P for trend < 0.001), (Fig. 1b) total femur (P for trend $= 0.001$), and (Fig. 1c) femoral neck (P for trend $= 0.002$).

Osteoporosis prevalence of urinary sodium/creatinine ratio quartiles

Table 4 shows the multiple logistic regression-derived ORs and 95 % confidence intervals (CIs) for osteoporosis in the lumbar spine, total femur, and femoral neck for each quartile relative to Q1. In an unadjusted model, the ORs of osteoporosis in the lumbar spine increased significantly with quartile (P for trend < 0.001). Compared to Q1, Q4 had a significant increase in the prevalence of lumbar spine osteoporosis (OR $= 1.654$, 95 % CI 1.306–2.093). These findings were also observed after controlling for age,

Table 3 Baseline characteristics of the quartiles divided according to urinary sodium/creatinine ratio

	Q1 ($n = 694$)	Q2 ($n = 695$)	Q3 ($n = 695$)	Q4 ($n = 695$)	P value
Urinary sodium/creatinine ratio (mmol/mmol)	11.5 ± 3.9	21.8 ± 2.7	31.9 ± 3.2	53.4 ± 15.7	<0.001*
Estimated salt intake (g/days)	3.3 ± 1.1	6.3 ± 0.8	9.2 ± 0.9	15.4 ± 4.5	<0.001*
Age (years)	61.8 ± 9.0	62.0 ± 8.6	62.6 ± 8.8	64.4 ± 8.5	<0.001*
Height (cm)	154.2 ± 5.6	153.8 ± 5.6	153.3 ± 5.9	152.9 ± 5.8	<0.001*
Weight (kg)	58.1 ± 8.3	56.5 ± 8.1	56.9 ± 8.6	57.0 ± 8.4	0.018*
BMI (kg/m^2)	24.4 ± 3.2	23.9 ± 3.1	24.2 ± 3.2	24.4 ± 3.1	0.701
Systolic BP (mmHg)	124.9 ± 16.8	126.4 ± 17.6	128.4 ± 18.2	132.5 ± 18.8	<0.001*
Diastolic BP (mmHg)	77.0 ± 9.2	77.8 ± 9.5	78.4 ± 9.8	79.8 ± 10.8	<0.001*
Total cholesterol (mmol/L)	202.2 ± 35.9	199.4 ± 38.3	203.0 ± 36.3	201.8 ± 35.8	0.833
Glomerular filtration rate (mL/min per 1.73 m^2)	81.8 ± 14.7	83.8 ± 16.2	86.1 ± 15.6	88.9 ± 17.6	<0.001*
PTH (pg/mL)	69.1 ± 28.8	69.9 ± 35.5	67.1 ± 25.5	67.6 ± 30.1	0.354
25(OH)D_3 (ng/mL)	17.8 ± 7.1	18.3 ± 6.9	18.0 ± 6.6	18.1 ± 6.6	0.371
Duration of menopause (years)	12.4 ± 10.2	12.7 ± 9.8	13.3 ± 10.3	15.2 ± 10.5	<0.001*
Smoking history (never/ex-/current), n (%)	638/8/48 (91.9 %/1.2 %/6.9 %)	632/15/48 (90.9 %/2.2 %/6.9 %)	640/11/44 (92.1 %/1.6 %/6.3 %)	654/12/29 (94.1 %/1.7 %/4.2 %)	0.212
Heavy drinker, n (%)	8 (1.2 %)	5 (0.7 %)	6 (0.9 %)	4 (0.6 %)	0.189
HTN, n (%)	370 (53.3 %)	330 (47.4 %)	336 (48.3 %)	401 (57.7 %)	0.096
DM, n (%)	83 (11.9 %)	86 (12.3 %)	92 (13.2 %)	87 (12.5 %)	0.661
Osteopenia and osteoporosis, n (%)	577 (83.1 %)	587 (84.5 %)	583 (83.9 %)	614 (88.3 %)	0.013*
Osteoporosis, n (%)	286 (41.2 %)	308 (44.3 %)	294 (42.3 %)	347 (49.9 %)	0.004*
Lumbar spine osteoporosis, n (%)	163 (23.5 %)	189 (27.2 %)	194 (27.9 %)	234 (33.7 %)	<0.001*
Total femur osteoporosis, n (%)	17 (2.4 %)	25 (3.6 %)	20 (2.9 %)	32 (4.6 %)	0.061
Femoral neck osteoporosis, n (%)	123 (17.7 %)	124 (17.8 %)	113 (16.3 %)	147 (21.2 %)	0.184

All data are expressed as mean ± standard deviation or number (%)

All P values were obtained by using analysis of variance and χ^2 test

BMI body mass index, *BP* blood pressure, *DM* diabetes mellitus, *HTN* hypertension

* $P < 0.05$ (statistical significance)

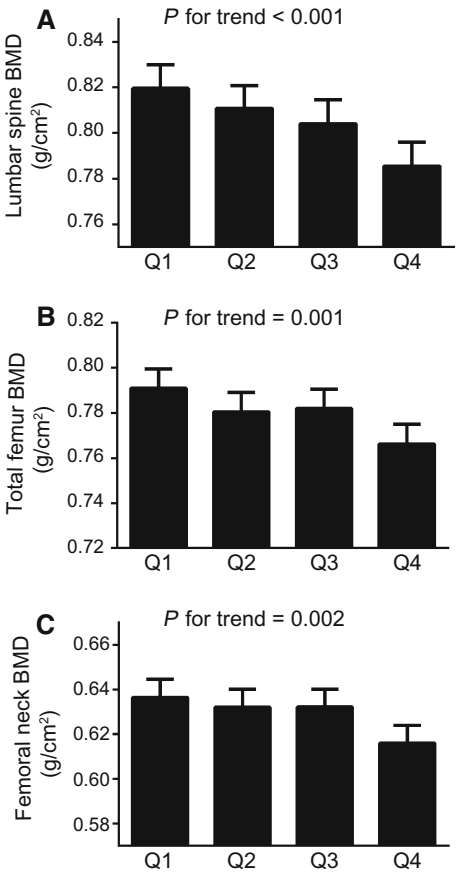

Fig. 1 Association between bone mineral density of lumbar spine (**a**), total femur (**b**), and femoral neck (**c**) with urinary sodium/creatinine ratio quartiles

height, weight, menopause duration, blood pressure, PTH level, 25(OH)D_3 level, smoking status, and alcohol consumption (OR = 1.346, 95 % CI 1.028–1.763, *P* for trend = 0.044). However, these findings were not observed for osteoporosis in the total femur or femoral neck, regardless of whether the model was unadjusted (total femur OR = 1.922, 95 % CI 1.057–3.495, *P* for trend = 0.062; femoral neck OR = 1.245, 95 % CI 0.954–1.626, *P* for trend = 0.184) or fully adjusted for confounding factors (total femur OR = 1.596, 95 % CI 0.808–3.155, *P* for trend = 0.345; femoral neck OR = 0.858, 95 % CI 0.622–1.184, *P* for trend = 0.180). Taken together, these results showed that elevated urinary sodium excretion associated significantly with increased osteoporosis in the spine.

Discussion

The present study showed that participants with osteoporosis had higher urinary sodium/creatinine ratios than participants without osteoporosis and that there was a significant negative correlation between urinary sodium/creatinine ratio and BMD in postmenopausal women. These results suggest that high dietary sodium chloride intake may be an important risk factor for osteoporosis.

Several studies have shown that there is a significant positive correlation between oral sodium chloride intake (represented by urinary sodium excretion) and urinary calcium excretion [8, 10, 33]. Although the positive correlation between oral sodium chloride intake and urinary calcium excretion is well-established, it remains unclear whether oral sodium chloride intake actually correlates with BMD and the risk of osteoporosis. The studies on this issue have yielded somewhat discrepant findings. A study of 124 postmenopausal women showed that urinary sodium excretion was inversely correlated with changes in BMD at hip and ankle sites over a 2-year period [23]. However, no relationship was found at the spine or at any other sites. In a study of 258 women and 169 men, high oral sodium chloride intake was associated with increased ultradistal radius BMD in men (but not in other measured sites), but not in women [24]. Moreover, other studies found no significant relationship between oral sodium chloride intake and BMD [21, 22, 25–27]. However, these were relatively small and medium scale studies. By contrast, in the present large-scale study of postmenopausal women (n = 2,779), urinary sodium excretion was found to correlate significantly with both BMD and osteoporosis prevalence in lumbar spine. These correlations remained statistically significant after the adjustment for multiple confounding factors such as age, height, weight, blood pressure, and PTH and 25(OH)D_3 levels. To our knowledge, this is the largest of the studies that investigates the correlation between urinary sodium excretion and osteoporosis. Although the significant association between urinary sodium excretion and osteoporosis only related to the lumbar spine, this is highly clinically significant because the lumbar spine is the most important axial bone to be affected in osteoporosis. Moreover, trabecular bone (such as that in the lumbar spine) is more likely to be affected by postmenopausal osteoporosis than cortical bone (such as that in the femur).

The present study showed that urinary sodium excretion did not correlate with serum PTH levels. In the normal physiological state, high oral sodium chloride intake increases urinary calcium excretion and reduces serum calcium concentration, and consequently increases serum PTH levels [34, 35]. However, this adaption of the parathyroid to urinary calcium loss does not appear in all individuals. Most studies show that in postmenopausal women, particularly those who have osteoporosis, the increased urinary calcium excretion in response to urinary sodium excretion is not accompanied by serum PTH elevation [9, 36–39]. These observations may explain our

Table 4 Association between urinary sodium/creatinine ratio and the ORs of osteoporosis at each site

(A) Lumbar spine osteoporosis					
ORs	Lumbar spine				
	Q1	Q2	Q3	Q4	*P* for trend
Unadjusted	1	1.217 (0.955–1.550)	1.261 (0.991–1.606)	1.654* (1.306–2.093)	<0.001*
Model 1	1	1.116 (0.852–1.463)	1.104 (0.842–1.448)	1.347* (1.031–1.760)	0.039*
Model 2	1	1.127 (0.858–1.480)	1.103 (0.839–1.450)	1.346* (1.028–1.763)	0.044*
(B) Total femur osteoporosis					
ORs	Total femur				
	Q1	Q2	Q3	Q4	*P* for trend
Unadjusted	1	1.486 (0.795–2.777)	1.180 (0.613–2.272)	1.922 (1.057–3.495)	0.062
Model 1	1	1.462 (0.727–2.943)	0.908 (0.437–1.888)	1.450 (0.745–2.820)	0.510
Model 2	1	1.507 (0.737–3.083)	0.960 (0.456–2.022)	1.596 (0.808–3.155)	0.345
(C) Femoral neck osteoporosis					
ORs	Femoral neck				
	Q1	Q2	Q3	Q4	*P* for trend
Unadjusted	1	1.008 (0.766–1.327)	0.901 (0.681–1.193)	1.245 (0.954–1.626)	0.184
Model 1	1	0.910 (0.660–1.256)	0.683 (0.490–0.950)	0.834 (0.606–1.146)	0.127
Model 2	1	0.913 (0.659–1.265)	0.680 (0.486–0.950)	0.858 (0.622–1.184)	0.180

Multivariable regression logistic model 1: adjusted for age, height, weight, menopause duration, and systolic and diastolic blood pressure

Multivariable regression logistic model 2: adjusted for age, height, weight, period of menopause, systolic and diastolic blood pressure, parathyroid hormone and $25(OH)D_3$ levels, smoking status, and alcohol consumption

All data are expressed as odds ratio (95 % confidence interval)

* $P < 0.05$ (statistical significance)

failure to detect a correlation between urinary sodium excretion and PTH levels in postmenopausal women. However, we cannot make any firm conclusions about this now, because we did not obtain data on urinary calcium loss, which could be a relevant confounding factor in this study because our results showed higher serum PTH levels in patients with osteoporosis. Therefore, to elucidate the mechanism responsible for high sodium chloride intake-induced osteoporosis, it will be necessary to evaluate serum calcium levels and urinary calcium excretion in a future KNHANES survey.

Although the present study has the advantage of being a large population-based study, it has several limitations. First, its cross-sectional design means that it cannot show the causal relationship between urinary sodium excretion and osteoporosis. Second, because urinary and serum calcium concentrations were not measured in the KNHANES survey, we could not determine whether urinary sodium excretion correlated with urinary calcium loss. Third, the KNHANES survey did not distinguish between the different kinds of diuretic medication used by participants with hypertension, and thus this study could not eliminate an influence of such medications on the results. In another Korean study, the proportion of diuretic users among antihypertensive drug users was only 30 % [40]. Therefore, excluding all subjects with hypertension would have made it difficult to generalize the results to other postmenopausal populations. It will be necessary to perform a further study to exclude a diuretic effect. Fourth, we used the spot urine sodium/creatinine ratio to estimate oral sodium chloride intake. Although urinary sodium levels were corrected by urinary creatinine levels, spot urine samples do not correspond exactly to 24 h urine samples.

In conclusion, the present study showed that in postmenopausal women, urinary sodium/creatinine ratio correlated significantly and negatively with BMD, specifically

in the lumbar spine, and that high sodium chloride intake increased the prevalence of osteoporosis in postmenopausal women.

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