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Dietary Intake Ratios of Calcium-to-Phosphorus and Sodium-to-Potassium Are Associated with Serum Lipid Levels in Healthy Korean Adults

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Abstract

The purpose of this study was to identify food sources for major minerals such as calcium (Ca), phosphorus (P), sodium (Na) and potassium (K), and to evaluate the relationship between dietary intake of these minerals and serum lipids in healthy Korean adults. A total of 132 healthy men and women completed a physical examination and dietary record and provided blood samples for lipid profile analysis. Results showed the following daily average mineral intakes: 373.4 mg of calcium, 806.0 mg of phosphorous, 3685.8 mg of sodium, and 1938.3 mg of potassium. The calcium-to-phosphorus and sodium-to-potassium ratio was about 0.5 and 2.0, respectively. The primary sources for each mineral were: vegetables (24.9%) and fishes (19.0%) for calcium, grains (31.4%) for phosphorus, seasonings (41.6%) and vegetables (27.0%) for sodium, and vegetables (30.6%) and grains (18.5%) for potassium. The correlation analysis, which has been adjusted for age, gender, total food consumption, and energy intake, showed significantly positive correlations between Ca/P and serum HDL cholesterol levels, between Na intake and the level of serum total cholesterol, and between Na/K and the level of serum cholesterol and LDL cholesterol. Our data indicates that the level of mineral consumption partially contributes to serum lipid profiles and that a diet consisting of a low Ca/P ratio and a high Na/K ratio may have negative impacts on lipid metabolism.

Key words: calcium, phosphorus, sodium, potassium, serum lipids

INTRODUCTION

A number of epidemiological studies and clinical trials have reported that the intake of calcium and sodium and their metabolism are closely related to the incidence and pathology of cardiovascular diseases, including hypertension, atherosclerosis and dyslipidemia (1-3). Several epidemiological studies have demonstrated that calcium intake was inversely associated with the probability of having high blood pressure. A clinical study with hypertensive patients showed that a calcium supplementation of more than 1,000 mg per day lowered the blood pressure in patients who tended to have low dietary calcium intake (4-8). Also, the increase of calcium intake in hypertensive and obese subjects resulted in a 4.9 kg reduction of body fat (9), indicating that the simultaneous role of calcium in blood pressure, body fat and weight control could result in a marked reduction in the risk of hypertension and other related metabolic diseases. Subsequently, a number of animal and mechanistic studies show that calcium combines dietary fat with bile acids to prevent fat absorption (10,11) and reduce serum cholesterols (12), suggesting that calcium intake is effective in reducing blood lipid levels.

Sodium is a well-known element, which is closely and positively related to high blood pressure by increasing extracellular fluid volume. Sodium is also highly associated with kidney and heart failure (13-15). Many studies recommend a low-sodium diet to prevent and treat hypertension and related cardiovascular diseases (14-16). However the role of low dietary sodium in lipid metabolism and its relationship to cardiovascular disease is not well established and remains controversial. Evidence provided in several clinical trials suggest that high salt intake can lead to a higher risk of cardiovascular disease, independent of its effect on blood pressure, while a low sodium diet increases HDL-cholesterol (17,18). However, data from several studies indicate that a diet excessively low in sodium may even increase total cholesterol, LDL-cholesterol, and triglyceride in serum by decreasing total blood volume (19-21). Metabolism of calcium and sodium, independent of their role in blood lipids, are also affected by their counteractive nutrients, phosphorus and potassium, respectively (22-25). However, very few studies have researched how the interaction of these nutrients in a particular dietary pattern is implicated in blood lipid metabolism.

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The traditional dietary pattern of Koreans has been considered healthy due to the prevalent intake of various types of vegetables. However, a higher intake of phytic acid and phosphorus from vegetables, and lack of dairy products in the Korean diet have raised concerns regarding a lack of calcium utilization (26). Moreover, the Korean National Health and Nutrition Examination Survey (KNHANES) has pointed out that sodium intake in the Korean diet is high due to fermented foods such as kimchi, soybean paste, pepper paste, and soy sauce (26). Although a high consumption of vegetables and fruit may prevent excessive sodium intake, as expected, the consumption ratio of sodium to potassium in the traditional Korean diet is in fact far greater than 1.0. Such an unbalanced mineral intake has been associated with the high prevalence of hypertension among elderly Koreans. However, the consequence of a typical unbalanced mineral intake in Korean diet has not been described in the context of blood lipid levels.

Therefore, this study has two aims: 1) to evaluate calcium, sodium, phosphorous and potassium intake from daily meals in healthy Korean adults and assess calcium-to-phosphorus and sodium-to-potassium intake ratios; 2) to explore the relationship between the aforementioned mineral status and biochemical indices of serum lipids.

MATERIALS AND METHODS

Subjects

Healthy men and women between the ages of 20～69 were recruited and informed about the purpose, procedure and duration of this study. Of those who consented to the study, subjects who had an illness based on previous medical history or those currently taking medications were excluded. As a result, a total of 132 subjects (60 males and 72 females) completed all procedures for this study.

Anthropometric measurement and dietary intake analysis

The height and weight of the subjects, wearing light underclothes and no shoes, were measured twice using an automatic scale (JENIX, Seoul, Korea) and the mean values of the measurements were calculated. Subjects were interviewed by professionally trained research staff and the 3-day dietary intake of the subjects was recorded on a 24 hour basis. The type of food, food ingredients and portion size during a regular day were analyzed for each meal: breakfast, lunch, dinner, and snack. Food models and pictures were used to help experimental participants accurately recall the food they had eaten. Nutrient intake including calcium, phosphorus, sodium, and potassium were calculated using CAN-Pro 3.0 program, developed by the Korean Nutrition Society.

Blood sample analysis

A fasting blood sample of 20 mL was taken from the subjects and put into a CBC bottle and test tube. The serum was then separated by centrifugation for 15 minutes at 3,000 rpm. Hemoglobin and hematocrit levels were measured by an automatic cell counter (CELL-DYN 1600, Abbott, North Chicago, IL, USA). The Burette method by kit (Boehringer Mannheim Co., Mannheim, Germany) was used for analyzing total protein levels. For measuring serum albumin levels, we used a commercial kit (Boehringer Mannheim Co.) which utilizes the principles that Brocresol-green is formed when albumin is at pH 4.2. Colored products were analyzed using an automatic biochemical analyzer (HITACHI 747, Tokyo, Japan). Blood urea nitrogen (BUN) and alkaline phosphatase (ALP) based on the urease-kinetic and enzymatic methods were also measured using a commercial kit (DAIICHI, Tokyo, Japan) and the same automatic biochemical analyzer. Blood glucose level in each subject was analyzed using the glucose oxidase-peroxidase coupled enzyme assay kit (DAIICHI). Triglyceride and cholesterol levels were analyzed by an enzymatic method using a kit (DAIICHI). For the HDL-cholesterol level, we separated LDL and VLDL after serum precipitation using the dextran sulfate-Mg^{2+} method and then used an enzymatic-based analysis kit (DAIICHI). LDL-cholesterol was calculated using the Friedewald formula from the measured levels of triglyceride, cholesterol, and HDL-cholesterol (27).

Statistical analysis

We used the SAS program (version 9.1, SAS Institute, Cary, NC, USA) to calculate the averages and standard deviations for all groups. A statistical t-test was employed to find differences between men and women and Pearson's correlation coefficient was used to determine the correlation between variables. All statistical significances were verified as $p<0.05$.

RESULTS

General characteristics

The average age, height, weight, and body mass index (BMI) were 41.9 years, 170.3 cm, 71.7 kg, 24.7 kg/m^2 for men and 39.8 years, 157.0 cm, 56.3 kg, 22.9 kg/m^2 for women, respectively. The average height, weight, and BMI of men were significantly higher than those of women (Table 1).

Table 1. Anthropometric measurements of the subjects

Variables	Men (n=62)	Women (n=70)	Total subject (n=132)	Significance
Age (yr)	41.9±17.1	39.8±17.4	40.8±17.2	NS
Height (cm)	170.3±5.7	157.0±7.1	163.0±9.3	p<0.001
Weight (kg)	71.7±12.7	56.3±7.9	63.3±12.9	p<0.001
BMI (kg/m^2)	24.7±3.9	22.9±3.2	23.7±3.7	p<0.01

Data are presented as mean±SD.
NS: not significant. BMI: body mass index.

Daily energy and nutrient intakes

The daily intakes of total food and energy for men were significantly higher than those for women (1034.7 g vs. 867.6 g, p<0.05; 1788.7 kcal vs. 1425.1 kcal, p<0.01). Daily intakes of protein and carbohydrates for men were also significantly higher than those for women (67.0 g vs. 53.9 g, p<0.05; 275.8 g vs. 212.1 g, p<0.01). However, lipid intake was not significantly different between men and women (Table 2).

Daily mineral intakes

The daily mean intakes of minerals by the subjects were 373.4 mg for calcium, 806.0 mg for phosphorus, 3685.8 mg for sodium, and 1938.3 mg for potassium (Table 3). Intake ratios of calcium-to-phosphorus and sodium-to-potassium were 0.4 and 2.1 for men and 0.5 and 1.9 for women, respectively. In addition, phosphorus levels between men and women were significantly different (901.1 mg vs. 729.3 mg).

Mineral intake patterns from each food group

Table 4 shows mineral intake patterns from each food group by the subjects. The majority of calcium was acquired from vegetables (24.9%) and fishes and shellfishes (19.0%). Phosphorus was mainly acquired from grains (31.4%) but also from general food intake. Sodium was primarily acquired from seasonings (41.6%) and vegetables (27.0%), while potassium was mostly acquired from vegetables (30.6%) and grains (18.5%).

Blood levels of biochemical indices

The mean levels of biochemical indices of the subjects were within the normal range. While serum levels of albumin, BUN, and triglyceride were significantly higher in men, HDL-cholesterol was higher in women. Hemoglobin and hematocrit levels in men were significantly higher compared to women (Table 5).

Correlation among mineral intakes, general characteristics, and food/nutrient intakes

When assessing for a relationship between mineral in-

Table 2. Mean daily energy and nutrient intakes by the subjects

Variables	Men (n=62)	Women (n=70)	Total subject (n=132)	Significance
Food (g)	1034.7±469.1	867.6±353.4	942.2±415.6	p<0.05
Energy (kcal)	1788.7±768.3	1425.1±495.7	1587.4±654.6	p<0.01
Protein (g)	67.0±30.3	53.9±25.0	59.7±28.1	p<0.05
Animal protein (g)	28.9±19.3	26.4±18.5	27.5±18.8	NS
Plant protein (g)	38.1±20.4	27.4±12.6	32.2±17.3	p<0.01
Fat (g)	45.3±30.3	39.2±23.3	41.9±26.7	NS
Animal fat (g)	20.4±19.2	18.4±15.1	19.3±17.0	NS
Plant fat (g)	24.9±24.0	20.7±14.0	22.6±19.2	NS
Carbohydrate (g)	275.8±120.7	212.1±77.7	240.6±103.7	p<0.01
Dietary fiber (g)	17.1±9.4	14.0±8.2	15.4±8.8	NS
Cholesterol (mg)	279.5±228.1	224.7±169.7	249.2±198.8	NS

Data are presented as mean±SD.
NS: not significant.

Table 3. Mean daily mineral intakes by the subjects

Variables	Men (n=62)	Women (n=70)	Total subject (n=132)	Significance
Calcium (mg)	408.3±222.9	345.2±214.6	373.4±219.6	NS
Phosphorus (mg)	901.1±436.5	729.3±333.4	806.0±390.6	p<0.05
Ca/P	0.4±0.1	0.5±0.2	0.5±0.1	NS
Sodium (mg)	4098.4±2132.7	3353.2±1995.0	3685.8±2081.7	NS
Potassium (mg)	2016.1±1023.8	1875.6±1005.3	1938.3±1011.4	NS
Na/K	2.1±0.6	1.9±1.0	2.0±0.8	NS

Data are presented as mean±SD.
NS: not significant.

Table 4. Mineral intakes from each food group by the subjects (n=132)

Food group	Food (g)	(%)[1)]	Calcium (mg)	(%)	Phosphorus (mg)	(%)	Sodium (mg)	(%)	Potassium (mg)	(%)
Grains	335.5±192.7	(35.6)	66.1±60.5	(17.7)	252.8±154.9	(31.4)	601.1±697.0	(16.3)	359.3±186.3	(18.5)
Potatoes and starch	32.4±58.8	(3.4)	5.0±12.5	(1.3)	15.6±24.6	(1.9)	3.9±15.6	(0.1)	117.0±197.6	(6.0)
Sugars and sweetener	4.9±7.1	(0.5)	0.9±5.3	(0.2)	1.6±7.9	(0.2)	0.9±4.2	(0.0)	5.0±23.9	(0.3)
Pulses	25.1±50.0	(2.7)	28.3±53.7	(7.6)	40.1±71.8	(5.0)	7.1±40.1	(0.2)	87.5±163.2	(4.5)
Nuts and seeds	2.1±11.1	(0.2)	1.8±3.7	(0.5)	4.7±33.9	(0.6)	1.1±7.3	(0.0)	6.0±30.3	(0.3)
Vegetables	221.1±166.3	(23.5)	93.0±80.9	(24.9)	101.8±74.5	(12.6)	995.3±1022.4	(27.0)	592.6±437.7	(30.6)
Mushrooms	0.8±3.0	(0.1)	0.1±0.2	(0.0)	1.1±3.2	(0.1)	0.1±0.3	(0.0)	7.2±21.7	(0.4)
Fruits	32.3±75.4	(3.4)	3.1±7.8	(0.8)	5.4±13.0	(0.7)	1.3±3.7	(0.0)	57.8±138.2	(3.0)
Meat	62.1±64.6	(6.6)	5.7±6.7	(1.5)	104.4±108.2	(13.0)	85.3±163.8	(2.3)	144.8±149.9	(7.5)
Eggs	26.0±34.1	(2.8)	12.9±19.8	(3.5)	44.8±59.3	(5.6)	36.6±62.1	(1.0)	31.5±41.4	(1.6)
Fishes and shellfishes	52.5±72.1	(5.6)	71.1±98.6	(19.0)	136.4±171.3	(16.9)	344.1±580.6	(9.3)	189.5±248.3	(9.8)
Seaweed	3.2±12.7	(0.3)	7.6±19.3	(2.0)	6.4±11.6	(0.8)	37.5±108.4	(1.0)	80.4±230.9	(4.2)
Milk	47.0±96.7	(5.0)	59.6±113.5	(16.0)	48.3±92.6	(6.0)	32.8±65.8	(0.9)	62.8±137.9	(3.2)
Oils and fats	6.8±6.4	(0.7)	0.0±0.1	(0.0)	0.0±0.1	(0.0)	0.7±4.3	(0.0)	0.1±0.6	(0.0)
Beverages	65.0±163.2	(6.9)	1.4±4.0	(0.4)	5.9±22.9	(0.7)	4.7±20.9	(0.1)	18.2±45.0	(0.9)
Seasonings	25.4±20.3	(2.7)	16.9±18.5	(4.5)	36.5±37.2	(4.5)	1533.2±1085.9	(41.6)	178.7±297.0	(9.2)
Total intake	942.2±415.6	(100)	373.4±219.6	(100)	806.0±390.6	(100)	3685.8±2081.7	(100)	1938.3±1011.4	(100)

Data are presented as mean±SD.
[1)]Contribution percent of total intake.

Table 5. Biochemical indices in blood of the subjects

Variables	Men (n=62)	Women (n=70)	Total subject (n=132)	Range	Normal range	Significance
Hemoglobin (g/dL)	15.5±1.1	13.1±1.1	14.2±1.6	9.5～17.4	12～17	p<0.001
Hematocrit (%)	46.2±3.2	39.8±2.9	42.7±4.4	33～53.6	36～52	p<0.001
Serum						
Total protein (g/dL)	7.3±0.4	7.2±0.5	7.2±0.4	6～8.2	6～8.2	NS
Albumin (g/dL)	4.7±0.2	4.6±0.3	4.7±0.3	3.5～5.2	3.4～5.6	p<0.01
BUN (mg/dL)	12.7±2.9	11.5±2.9	12.0±3.0	5～20.5	5～24	p<0.05
ALP (IU/L)	144.1±75.6	123.2±55.7	132.7±65.9	42～342	103～335	NS
Glucose (mg/dL)	96.3±23.6	91.3±12.9	93.6±18.6	69～211	70～120	NS
Triglyceride (mg/dL)	137.0±86.6	86.8±48.8	109.3±72.5	33～405	≤150	p<0.001
Total cholesterol (mg/dL)	193.0±29.5	186.7±34.0	189.6±32.1	118～264	≤200	NS
HDL-cholesterol (mg/dL)	53.2±13.8	60.1±10.2	57.0±12.4	30～110	40～60	p<0.01
LDL-cholesterol (mg/dL)	113.9±25.2	107.6±29.3	110.4±27.6	55～174	≤130	NS

Data are presented as mean±SD.
NS: not significant. BUN: blood urea nitrogen. ALP: alkaline phosphatase.

take and general characteristics of all subjects shown in Table 6, the intake of calcium, sodium, and potassium significantly correlated with age. Moreover, the intakes of calcium and sodium also displayed a significantly positive correlation to BMI. Regarding the relationship between mineral (Ca, P, Na and K) intake and total food

Table 6. Correlations between mineral intakes, general characteristics, and food/nutrient intakes of the subjects (n=132)

Variables	Calcium	Phosphorus	Ca/P	Sodium	Potassium	Na/K
Age	0.2272*	0.1477	0.1527	0.3829***	0.2406**	0.2314*
Height	0.0341	0.1484	-0.1581	-0.0298	-0.0527	-0.0971
Weight	0.1724	0.1966	-0.0071	0.1484	0.0579	-0.0048
BMI	0.2143*	0.1648	0.1043	0.2364*	0.1278	0.0648
Intakes of Food	0.7744***	0.8536***	0.1094	0.7134***	0.7546***	0.0005
Energy	0.7094***	0.8905***	-0.0377	0.7017***	0.7404***	-0.0650
Protein	0.7587***	0.9560***	-0.0715	0.7627***	0.7946***	-0.0475
Fat	0.5014***	0.7010***	-0.1287	0.4274***	0.4824***	-0.1176
Carbohydrate	0.6450***	0.7518***	0.0477	0.6839***	0.7032***	-0.0101

Data are presented as Pearson's correlation coefficient.
BMI: body mass index.
*p<0.05, **p<0.01, ***p<0.001.

Table 7. Correlations between mineral intakes and blood parameters adjusted by sex, age, food intake, and energy intake of the subjects (n=132)

Variables	Calcium	Phosphorus	Ca/P	Sodium	Potassium	Na/K
Hemoglobin	-0.0585	-0.0514	-0.0466	-0.0420	-0.1067	0.0495
Hematocrit	-0.0889	-0.1048	-0.0583	-0.1403	-0.1360	-0.0283
Serum						
Total protein	-0.0741	0.1270	-0.1047	0.0660	0.0315	0.0104
Albumin	-0.0544	0.0030	-0.0561	0.0780	-0.0946	0.2329*
BUN	0.0865	0.0220	0.0946	0.0066	0.0366	-0.0374
ALP	-0.0927	-0.1189	-0.0323	-0.2388*	-0.1219	-0.1370
Glucose	0.1013	0.2270*	0.0105	0.1443	0.1319	-0.0932
Triglyceride	-0.0436	0.0107	-0.0830	0.0237	0.0892	-0.0430
Total cholesterol	0.1827	0.1086	0.1735	0.2738**	0.0133	0.2881**
HDL-cholesterol	0.1628	-0.0037	0.2240*	0.0784	-0.0886	0.1848
LDL-cholesterol	0.1213	0.1078	0.1038	0.2523*	0.0155	0.2540*

Data are presented as Pearson's correlation coefficient.
BUN: blood urea nitrogen, ALP: alkaline phosphatase.
*$p<0.05$, **$p<0.01$.

consumption and major nutrient intake of all subjects, significantly positive correlations were noted between all variables. However, no significant correlation between calcium-to-phosphorus or sodium-to-potassium ratios to other variables was noted except for the positive correlation between sodium-to-potassium with age.

Correlation between mineral intake and blood parameters

Regarding the relationship between mineral intake and blood parameters of all subjects shown in Table 7, phosphorus intake displayed a significant and positive correlation to serum glucose, while sodium intake had a significantly positive correlation to serum cholesterol. Calcium-to-phosphorus ratio had a significant and positive correlation to HDL-cholesterol. Sodium-to-potassium correlated significantly with serum levels of albumin, total cholesterol, and LDL-cholesterol in a positive manner.

DISCUSSION

This study investigated the average intake of several major minerals (calcium, sodium, phosphorus and potassium) present in the normal diet of healthy Korean adults. By correlation analysis, the implication of these consumed minerals in lipid metabolism was also investigated. Additional findings were also reported regarding the differences between men and women's anthropometric measurement, food and energy consumption. Analysis of dietary patterns among subjects revealed that carbohydrate and protein intake was higher in men than women. High consumption of plant proteins, which is abundant in rice or crop plants in a typical Korean diet, appeared to be related to higher total food intake in men, leading to greater energy intake, body weight and BMI compared to women. Interestingly, no significant differences in the consumption of fat and cholesterol attributable to animal proteins were noted between men and women. Although serum fat and lipid metabolism are known to be primarily affected by major nutrients (carbohydrates, lipids and proteins), which provide energy, lipid metabolism is also affected by many of ionic compounds (Ca^+, K^+, HPO_4^-, Na^+), which changes cellular function, signaling and absorption of macronutrients. By showing the relationship and correlations between intake levels of major minerals and serum lipid parameters, this study suggests that changes in lipid metabolism can be partially affected by the intake of major minerals.

According to the KNHANES, most intake of nutrients are close to the intake recommendations, but the individual calcium intake is lower than the recommended intake for all age groups except for toddlers (aged 1～2) (26). In addition, sodium intake is much higher than the recommended intake (26). The problematic incidence of low calcium intake among Koreans stems from the large reliance on crops and vegetables in the traditional Korean diet (26). This study provides consistent findings that the average daily calcium intake by the subjects was 373.4 mg, much lower than the recommended intake of 700～750 mg (28). The greatest source of daily calcium intake was in vegetables (24.9%), followed by fish (19.0 %), grains (17.7%), and milk/dairy products (16.0%). This calcium intake pattern is somewhat different compared to KNHANES, which reports that milk and dairy products are primary food sources for calcium supplementation. However the average consumption of milk in Korean adults is 74.0 g per day, corresponding to only one-third of a cup of milk. Our data indicates poor calcium availability within main food sources and highlights the low consumption of milk and dairy products in a typical Korean diet. The amount of phosphorus intake coincides with calcium absorption (29,30) and should be balanced by calcium levels. Koreans' phosphorous intake has been rising due to higher consumption of processed food and an increased frequency of dining-out (26). The 2009 KNHANES showed that daily phosphorous intake in Koreans has increased while their calcium intake has decreased, lowering the calcium-to-phosphorous ratio to 1:2.4 (26). This study also demonstrated that the phosphorous intake of the subjects was 806.0 mg, higher than the recommended intake of 700 mg, resulting in a very low calcium-to-phosphorous ratio (0.5).

Many animal experiments, epidemiological studies, and clinical trials have confirmed that excessive sodium intake is related to hypertension, a major risk factor for cardiovascular diseases (15,31,32). Nevertheless, the 2009 KNHANES shows that the average sodium intake of Koreans over 19 years of age was 5040.4 mg, which was 357.6% of the adequate intake amount (26). The sodium intake of the subjects in this study was 3685.8 mg, 245.7% of the adequate intake for Koreans. The major sources of dietary sodium were from seasoning (41.6%) and vegetables (27.0%), which was consistent with the national nutrition survey (26). According to previous reports, the daily potassium intake necessary for preventing hypertension, stroke, and myocardial infarction is 2.7 ~3.1 g, which corresponds to the proper sodium-to-potassium ratio of 1.0 (33). However, the subjects in this study failed to meet the 3.5 g of adequate potassium intake (1938.3 mg). Moreover, the high sodium intake increased the sodium-to-potassium ratio to 2.0. In this study, the main source of potassium came from vegetables (30.6%) and grains (18.5%). Interestingly, vegetables were the major sources for both sodium and potassium. For instance, a fermented vegetable such as Kimchi is made with fresh vegetables that are abundant in potassium but also high in sodium. Therefore, reducing the sodium-to-potassium intake ratio can be achieved by eating fresh fruits and vegetables and whole grains in coordination with low intake of high-salt seasonings and fermented vegetables.

Previous studies have identified individual roles for calcium and sodium in lipid metabolism related to hypertension or bone metabolism (34-36). Initially, Wang et al. demonstrated that dietary intake of calcium was associated with lowering the risk of hypertension (36). According to Reid et al., postmenopausal women under fracture treatment who took 1 g of calcium per day for a year, showed a significant increase in serum HDL-cholesterol levels and HDL/LDL-cholesterol ratios compared to the control group (34). A study by Choi et al. addressed the consumption ratio of these minerals in the Korean diet and its association to serum cholesterol levels, finding that the calcium-to-phosphorus ratio was related to serum total cholesterol levels in a positive fashion in 354 Korean adults (35). The lipid lowering effects of calcium are further supported by animal and cell culture studies showing the blockage of intestinal fat absorption (37,38), inhibition of fatty acid release in adipocytes (39,40), expansion of triglyceride stores and the inhibition of 1,25-(OH_2)-D levels (9). Consistent with these findings, our study also demonstrated the positive correlation between calcium intake and BMI in study subjects. Since the increase of BMI could be derived from the increase in bone density, which is also affected by calcium consumption (41), additional analysis regarding bone parameters should be performed. Also, we could find the correlation between phosphorus intake and serum glucose because our findings demonstrated that phosphorus supplementation reduces glucose utilization (42) and that many phosphate compounds are necessary in energy metabolism and regulation of blood glucose (43).

Sodium has been studied as a major cause of hypertension, although few reports have shown that a low sodium diet significantly lowers total LDL-cholesterol levels (44), while improving glucose tolerance possibly by its counteraction to potassium (45). In this study, sodium intake positively correlated with LDL-cholesterol, consistent with a previous study (44), but also negatively correlated with serum alkaline phosphates, which are prominent bone biomarkers as well as indicators of liver function. This finding may due to the fact that sodium intake causes calcinuria and excretion of core minerals important in bone formation (41).

Our current study showed that rather than observing calcium or sodium effects as single nutrients, interactions of these minerals with phosphorus and potassium held a close relationship with changes in blood lipid levels. Since lipid levels are also affected by several other nutrients, such as carbohydrates, fats, and proteins, people with an ideal diet containing balanced nutrient levels will have a greater probability of having the ideal ratio of these minerals, leading to an improved lipid profile. Nevertheless, accruing data on mineral intake and blood lipid levels at multiple time points through a systematic longitudinal study is necessary to accurately explain the correlation between mineral intake and lipid levels.

The current study reported the average intake of calcium, sodium, phosphorus and potassium, and the consumption ratios of these minerals from typical Korean diets. Positive correlations between the calcium-to-phosphorus ratio and serum HDL-cholesterol, between sodium intake levels and serum total cholesterol levels, and between sodium-to-potassium ratio and LDL-cholesterol levels were found. The current pattern of low calcium and high sodium intake in the typical Korean diet acts as negative factors for blood lipids. These results propose strong modifications in food choices to achieve balanced mineral intakes by increasing the calcium-to-phosphorous ratio and decreasing the sodium-to-potassium ratio. Also, rather than a single particular mineral, low calcium-to-phosphorous ratios and high sodium-to-potassium ratios should be taken into account when assessing for nutrients that affect lipid metabolism. Further research is needed to identify the role of macronutrients (carbohydrates, lipids and proteins) and several phytochemicals in the Korean diet with regards to mineral bioavailability, and how their interactions affect serum lipid metabolism.

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REFERENCES

1. Parikh P, McDaniel MC, Ashen MD, Miller JI, Sorrentino M, Chan V, Blumenthal RS, Sperling LS. 2005. Diets and cardiovascular disease: an evidence-based assessment. *J Am Coll Cardiol* 45: 1379-1387.
2. Vaskonen T. 2003. Dietary minerals and modification of cardiovascular risk factors. *J Nutr Biochem* 14: 492-506.
3. Surtees PG, Wainwright NW, Luben R, Day NE, Khaw KT. 2005. Prospective cohort study of hostility and the risk of cardiovascular disease mortality. *Int J Cardiol* 100: 155-161.
4. Larsson SC, Virtamo J, Wolk A. 2011. Potassium, calcium, and magnesium intakes and risk of stroke in women. *Am J Epidemiol* 174: 35-43.
5. Lee JS, Park J, Kim J. 2011. Dietary factors related to hypertension risk in Korean adults-data from the Korean national health and nutrition examination survey III. *Nutr Res Pract* 5: 60-65.
6. McCarron DA. 1997. Role of adequate dietary calcium intake in the prevention and management of salt-sensitive hypertension. *Am J Clin Nutr* 65: 712S-716S.
7. Griffith LE, Guyatt GH, Cook RJ, Bucher HC, Cook DJ. 1999. The influence of dietary and nondietary calcium supplementation on blood pressure: an updated meta-analysis of randomized controlled trials. *Am J Hypertens* 12: 84-92.
8. Hjerpsted J, Leedo E, Tholstrup T. 2011. Cheese intake in large amounts lowers LDL-cholesterol concentrations compared with butter intake of equal fat content. *Am J Clin Nutr* 94: 1479-1484.
9. Zemel MB, Shi H, Greer B, Dirienzo D, Zemel PC. 2000. Regulation of adiposity by dietary calcium. *FASEB J* 14: 1132-1138.
10. de Wit NJ, Bosch-Vermeulen H, de Groot PJ, Hooiveld GJ, Bromhaar MM, Jansen J, Muller M, van der Meer R. 2008. The role of the small intestine in the development of dietary fat-induced obesity and insulin resistance in C57BL/6J mice. *BMC Med Genomics* 1: 14.
11. Centeno V, de Barboza GD, Marchionatti A, Rodriguez V, de Talamoni NT. 2009. Molecular mechanisms triggered by low-calcium diets. *Nutr Res Rev* 22: 163-174.
12. Vaskonen T, Mervaala E, Sumuvuori V, Seppanen-Laakso T, Karppanen H. 2002. Effects of calcium and plant sterols on serum lipids in obese Zucker rats on a low-fat diet. *Br J Nutr* 87: 239-245.
13. Cirillo M, Lombardi C, Laurenzi M, De Santo NG. 2002. Relation of urinary urea to blood pressure: interaction with urinary sodium. *J Hum Hypertens* 16: 205-212.
14. Campbell N, Correa-Rotter R, Neal B, Cappuccio FP. 2011. New evidence relating to the health impact of reducing salt intake. *Nutr Metab Cardiovasc Dis* 21: 617-619.
15. Susic D, Frohlich ED. 2012. Salt consumption and cardiovascular, renal, and hypertensive diseases: clinical and mechanistic aspects. *Curr Opin Lipidol* 23: 11-16.
16. Thorvaldsen P, Asplund K, Kuulasmaa K, Rajakangas AM, Schroll M. 1995. Stroke incidence, case fatality, and mortality in the WHO MONICA project. World Health Organization Monitoring Trends and Determinants in Cardiovascular Disease. *Stroke* 26: 361-367.
17. Rodriguez CJ, Bibbins-Domingo K, Jin Z, Daviglus ML, Goff DC Jr, Jacobs DR Jr. 2011. Association of sodium and potassium intake with left ventricular mass: coronary artery risk development in young adults. *Hypertension* 58: 410-416.
18. Liebson PR, Grandits GA, Dianzumba S, Prineas RJ, Grimm RH Jr, Neaton JD, Stamler J. 1995. Comparison of five antihypertensive monotherapies and placebo for change in left ventricular mass in patients receiving nutritional-hygienic therapy in the Treatment of Mild Hypertension Study (TOMHS). *Circulation* 91: 698-706.
19. Luft FC, Weinberger MH. 1997. Heterogeneous responses to changes in dietary salt intake: the salt-sensitivity paradigm. *Am J Clin Nutr* 65: 612S-617S.
20. Catanozi S, Rocha JC, Nakandakare ER, Passarelli M, Mesquita CH, Silva AA, Dolnikoff MS, Harada LM, Quintao EC, Heimann JC. 2001. The rise of the plasma lipid concentration elicited by dietary sodium chloride restriction in Wistar rats is due to an impairment of the plasma triacylglycerol removal rate. *Atherosclerosis* 158: 81-86.
21. Catanozi S, Rocha JC, Passarelli M, Guzzo ML, Alves C, Furukawa LN, Nunes VS, Nakandakare ER, Heimann JC, Quintao EC. 2003. Dietary sodium chloride restriction enhances aortic wall lipid storage and raises plasma lipid concentration in LDL receptor knockout mice. *J Lipid Res* 44: 727-732.
22. Joint national committee on prevention deatohbp. 1997. The sixth report of Joint national committee on prevention, detection, evaluation and treatment of high blood pressure (JNC VI). *Arch Intern Med* 157: 2413-2446.
23. Sax L. 2001. The institute of medicine's "dietary reference intake" for phosphorus: a critical perspective. *J Am Coll Nutr* 20: 271-278.
24. Larsson SC, Orsini N, Wolk A. 2011. Dietary potassium intake and risk of stroke: a dose-response meta-analysis

of prospective studies. *Stroke* 42: 2746-2750.
25. Taylor JG, Bushinsky DA. 2009. Calcium and phosphorus homeostasis. *Blood Purif* 27: 387-394.
26. The Ministry of Health and Welfare, Korean Center for Disease Control and Prevention. 2010. National Health Statistics. Korea Center for Disease Control and Prevention.
27. Friedewald WT, Levy RI, Fredrickson DS. 1972. Estimation of the concentration of low-density lipoprotein cholesterol in plasma, without use of the preparative ultracentrifuge. *Clin Chem* 18: 499-502.
28. The Korean Nutrition Society. 2010. Dietary reference intake for Koreans.
29. Ito S, Ishida H, Uenishi K, Murakami K, Sasaki S. 2011. The relationship between habitual dietary phosphorus and calcium intake, and bone mineral density in young Japanese women: a cross-sectional study. *Asia Pac J Clin Nutr* 20: 411-417.
30. Yamamoto S, Ishida H. 2009. Phosphorus-rich foods and bone. *Clin Calcium* 19: 1829-1836.
31. He J, Ogden LG, Vupputuri S, Bazzano LA, Loria C, Whelton PK. 1999. Dietary sodium intake and subsequent risk of cardiovascular disease in overweight adults. *JAMA* 282: 2027-2034.
32. McAdams DM, Coresh J, Woodward M, Butler KR, Kao WH, Mosley TH Jr, Hindin M, Anderson CA. 2011. Hypertension status, treatment, and control among spousal pairs in a middle-aged adult cohort. *Am J Epidemiol* 174: 790-796.
33. World Health Organization. 2003. Diet, nutrition and the prevention of the chronic diseases. Report of a joint WHO/FAO expert consultation.
34. Reid IR, Ames R, Mason B, Bolland MJ, Bacon CJ, Reid HE, Kyle C, Gamble GD, Grey A, Horne A. 2010. Effects of calcium supplementation on lipids, blood pressure, and body composition in healthy older men: a randomized controlled trial. *Am J Clin Nutr* 91: 131-139.
35. Choi MK, Lee WY, Park JD. 2005. Relation among mineral (Ca, P, Fe, Na, K, Zn) intakes, blood pressure, and blood lipids in Korean adults. *Korean J Nutr* 38: 827-835.
36. Wang L, Manson JE, Buring JE, Lee IM, Sesso HD. 2008. Dietary intake of dairy products, calcium, and vitamin D and the risk of hypertension in middle-aged and older women. *Hypertension* 51: 1073-1079.
37. Khaw KT, Barrett-Connor E. 1987. Dietary potassium and stroke-associated mortality. A 12-year prospective population study. *N Engl J Med* 316: 235-240.
38. Weder AB, Egan BM. 1991. Potential deleterious impact of dietary salt restriction on cardiovascular risk factors. *Klin Wochenschr* 69(Suppl 25): 45-50.
39. Jones BH, Kim JH, Zemel MB, Woychik RP, Michaud EJ, Wilkison WO, Moustaid N. 1996. Upregulation of adipocyte metabolism by agouti protein: possible paracrine actions in yellow mouse obesity. *Am J Physiol* 270: E192-E196.
40. Xue BZ, Wilkison WO, Mynatt RL, Moustaid N, Goldman M, Zemel MB. 1999. The agouti gene product stimulates pancreatic [beta]-cell Ca^{2+} signaling and insulin release. *Physiol Genomics* 1: 11-19.
41. Ginty F, Flynn A, Cashman KD. 1998. The effect of dietary sodium intake on biochemical markers of bone metabolism in young women. *Br J Nutr* 79: 343-350.
42. Johnston SL, Williams SB, Southern LL, Bidner TD, Bunting LD, Matthews JO, Olcott BM. 2004. Effect of phytase addition and dietary calcium and phosphorus levels on plasma metabolites and ileal and total-tract nutrient digestibility in pigs. *J Anim Sci* 82: 705-714.
43. Schmid AI, Szendroedi J, Chmelik M, Krssak M, Moser E, Roden M. 2011. Liver ATP synthesis is lower and relates to insulin sensitivity in patients with type 2 diabetes. *Diabetes Care* 34: 448-453.
44. Obarzanek E, Sacks FM, Vollmer WM, Bray GA, Miller ER III, Lin PH, Karanja NM, Most-Windhauser MM, Moore TJ, Swain JF, Bales CW, Proschan MA. 2001. Effects on blood lipids of a blood pressure-lowering diet: the Dietary Approaches to Stop Hypertension (DASH) Trial. *Am J Clin Nutr* 74: 80-89.
45. Ekinci EI, Cheong KY, Dobson M, Premaratne E, Finch S, Macisaac RJ, Jerums G. 2010. High sodium and low potassium intake in patients with type 2 diabetes. *Diabet Med* 27: 1401-1408.

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