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ORIGINAL ARTICLE

The association between metabolic syndrome and peanuts, pine nuts, almonds consumption: The Ansan and Ansung Study

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Abstract

Background Previous studies reported an inverted relationship between nut consumption and the incidence of metabolic syndrome (MetS). The present study investigated the incidental risk for MetS according to peanut, almond, and fine nut consumption in the Korean population.

Methods In a community-based Korean cohort, 5306 Korean adults were divided into four groups according to their peanut, almond, and fine nut intake (<1/month, 1/month–0.5/week, 0.5–1/week, and ≥1/week, in which one serving = 15 g) and were followed-up for 10 years. A Cox proportional hazard model was used to evaluate the hazard ratios (HRs) with confidence intervals (CI) for MetS in each study group. Age subgroup (≥50 or <50 years) analysis was also conducted.

Results The age and multivariable-adjusted HRs with 95% CIs for MetS showed a significant inverse dose–response relationship between peanut, almond, and fine nut intake and the incidence of MetS in men and women (multivariable-adjusted HRs [95% CI] in men; 0.91 [0.76–1.09] in 1/month–0.5/week, 1.03 [0.80–1.31] in 0.5–1/week, 0.72 [0.56–0.93] in ≥1/week and in women; 0.81 [0.65–1.003] in 1/month–0.5/week, 0.76 [0.54–1.07] in 0.5–1/week, 0.57 [0.41–0.79] ≥1/week)). Subgroup analysis showed a significant difference in middle-aged men (≥1/week) and old-aged women (≥0.5/week).

Conclusion The results of the present study suggested that peanut, almond, and fine nut intake (≥15 g/week) may be inversely related to incidence risk of MetS in the Korean general population. Additionally, the association between nut consumption and MetS incidence risk may differ in sex and age subgroups.

Keywords Metabolic syndrome · Peanut · Almond · Fine nut

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Introduction

Metabolic syndrome (MetS), a cluster of metabolic disorders such as abdominal obesity, insulin resistance, high blood pressure, hyperglycemia, and dyslipidemia, was first described in Western countries. However, the prevalence of MetS has rapidly increased in the Asia-Pacific region [1, 2]. In most Asian countries, about one-fifth of the adult population has MetS and the prevalence is increasing steadily [2]. The age-adjusted prevalence of MetS in South Korea, for instance, increased from 24.9% in 1998 to 31.3% in 2007 [3]. As in Western countries, obesity, physical inactivity, and population aging are the major contributors to the rapid increase of MetS in the Asia-Pacific region [1, 2]. Along with these risk factors, dietary pattern is also a risk factor for MetS [4–8]. The consumption of inexpensive and readily available fast foods is closely related to MetS components such as abdominal obesity, high blood pressure, dyslipidemia, and elevated fasting glucose [9–11].

Conversely, diets rich in dietary fiber and unsaturated fat (e.g., fruits, whole grains, vegetables, nuts, and fish) lower the risk of MetS, [6, 7, 12–18] and the importance of the consumption of these healthy foods has been emphasized in many countries.

Previous epidemiological and intervention studies have reported high nut consumption to be associated with a decreased incidence of MetS regardless of race and dietary patterns [15–18]. Nut intake lowers total cholesterol (TC), low-density lipoprotein (LDL) cholesterol, and triglyceride (TG) [18–20] levels, as well as blood pressure [21], and insulin resistance [22]. Nut intake, therefore, should be encouraged in Asian populations. However, the average nut consumption (peanut, walnut, almond, pine-nut, etc.) except for chestnuts (2.0 g/day for men and 1.6 g/day for women) was less than 3 g/day among Korean men and women aged 40 years or older in 2016 Korean National Health and Nutrition Examination Survey (KNHANES) and was a relatively low consumption compared to those of Western countries [16, 18, 23, 24]. Although a previous study based on the Ansan and Ansung cohort conducted in Korea showed that a healthy dietary pattern including high nut consumption was related to a lower risk of MetS [23], the participants were classified into just two groups: nut consumption or no nut consumption. Therefore, several questions remain unresolved. We hypothesized that in a population with relatively low nut consumption, even infrequent nut consumption may be related with low incidence of MetS.

Research design and methods

Study population

All subjects were participants of the Korean Genome and Epidemiology Study (KoGES) Ansan and Ansung Study, a population-based, epidemiological study of rural and urban communities in South Korea. The baseline survey of the KoGES Ansan and Ansung study was completed in 2001–2002 and follow-up surveys were conducted every 2 years. Initially, a total of 10,038 participants aged 40–69 years participated in the study. Of these 10,038 participants, 471 had a serious underlying disease (e.g., myocardial infarction, stroke, or cancer) and 430 had missing food frequency questionnaire values. We also excluded participants with the upper 0.5% and lower 0.5% energy intakes as outliers ($n = 92$). An additional 464 participants with missing values in import covariates such as fasting glucose, body mass index (BMI), history of hypertension, and 2669 participants with missing baseline MetS data were also excluded. During the 10-year follow-up period, 606 participants were excluded due to follow-up loss or incomplete follow-up data. Finally, 5306 participants were enrolled in the present study. All subjects participated in the study voluntarily and provided informed consent. Ethical approvals for the study protocol and analysis of the data were obtained from the institutional review board of Kangbuk Samsung Hospital.

Clinical and biochemical measurements

The collected study data included a medical history and sociodemographic information provided by a self-administered questionnaire, anthropometric measurements, and laboratory biochemical measurements. All study participants were also asked to respond to a health-related behavior questionnaire, which included topics on alcohol consumption, smoking, and exercise. Physical activity was divided into two categories: regular exercise (≥90 min of at least moderate intensity exercise per week) or inactive. The questions about alcohol intake included the frequency of alcohol consumption on a weekly basis and the typical amount that was consumed on a daily basis (g/day). All participants were asked about their socioeconomic status including income and those who earned more than 4 million won (3450 US dollars) per month were classified as high-income earners. The smoking status was divided into three categories: never, former, and current smoker. Type 2 diabetes mellitus (T2DM) was defined as a fasting serum glucose level of at least 126 mg/dL, serum A1C level of at least 6.5%, 2 h glucose level of at least 200 mg/dL, or the participant having ever been diagnosed with diabetes. Hypertension was defined as the participant having ever been diagnosed with hypertension or as having a measured blood pressure (BP) ≥140/90 mmHg during the initial examination. BP was measured in both arms with the participant in a seated position after relaxing for at least 10 min. There was a 5-min resting period between each measurement. The arithmetic mean values of the BPs were used to define the systolic and diastolic BPs. Participant height and weight were also measured and BMI was calculated (kg/m^2).

After fasting overnight for 12 h, the plasma concentrations of glucose, TC, TG, and high-density lipoprotein (HDL) cholesterol (HDL-C) were measured enzymatically using a 747 Chemistry Analyzer (Hitachi, Tokyo, Japan). The A1C level was measured by high-performance liquid chromatography (VARIANT II; Bio-Rad Laboratories, Hercules, CA). C-reactive protein concentration was measured by turbidimetric immunoassay (HITACHI Automatic Analyzer 7600, Hitachi, Japan and ADVIA 1650 Auto Analyzer, Siemens, USA). The presence of MetS was determined according to the joint interim statement of the International Diabetes Federation Task Force on Epidemiology and Prevention. Elevated BP was defined as a systolic BP (SBP) and diastolic BP (DBP) ≥130/85 mmHg; elevated fasting serum glucose level was defined as ≥100 mg/dL; high serum TG were defined as ≥150 mg/dL; and low HDL-cholesterol levels were defined as <40 mg/dL in men and <50 mg in women. The presence of visceral obesity was defined according to the criteria of the Korean Society of the Study of Obesity (waist circumference ≥90 cm for men and ≥85 cm for women) [25]. MetS was defined as the presence of three or more of the above components in baseline and follow-up examinations. The detailed methods and characteristics of the study population were as described previously [26].

Dietary pattern and nut consumption assessments

Dietary intake was assessed by semi-quantitative food frequency questionnaire (FFQ) [27]. Participants were asked to identify how frequently they had consumed 103 food items during the previous year as well as to choose the average portion size. The food consumption frequency including nut consumption was composed of nine categories (i.e., never or rarely, once a month, two or three times a month, once or twice a week, three or four times a week, five or six times a week, once a day, twice a day, and three times a day) and three serving sizes for each food (e.g., the nut serving size was categorized as 7.5, 15, or 22.5 g). Food photographs with usual intake portions also were included to increase participant understanding and study reliability. All participants asked about their intake of peanuts, pine nuts, and almonds, which were categorized as nuts. The Ansan and Ansung cohort collected data on these three types of nuts as they are frequently consumed by Koreans. One serving of nuts was 15 g and the frequency of consumption was classified as rare (<1 serving/month), 1 serving/month–0.5 serving/week (≥1 serving/month and <0.5 serving/week), or 0.5–1 serving/week (≥0.5 and <1 serving/week), ≥1 serving/week. In our study, the highest nut consumption group was ≥1 serving/week due to the small number of participants with consumption more than twice per week. All nutrients were total energy adjusted using the residual method [28]. Nutrient intakes were calculated using the 2011 nutrient database of the Korean Nutrition Society (CAN-pro 4.0, Computer Aided Analysis Program 4.0 for professionals; Korean Society of Nutrition, Seoul, Korea), which was based on the seventh edition of the Korean Food Composition Table [29]. The validity and reproducibility of the FFQ were previously evaluated in 124 Korean subjects [30].

Statistical analysis

Data are presented as age-adjusted means ± standard error (SE) within study groups for continuous variables and as proportions (%) for categorical variables. The main clinical characteristics were compared among groups using a general linear model with post hoc analysis (Tukey's multiple comparison) for continuous variables and Cochran–Mantel–Haenszel test for categorical variables. All comparisons were performed with age adjustment. A trend analysis was also performed by treating the median value of each group as a continuous variable; a multivariable linear regression model used for continuous variables, while the Cochran–Armitage trend test was used for categorical variables. All trend analyses were based on the median nut consumption in each study group (0, 3.5, 8.75, or 22.5 g/week).

A Cox proportional hazards model was used to calculate the age-adjusted and multivariable-adjusted hazard ratios (HRs) for MetS and their 95% confidence intervals (CI) in each study groups. The models were adjusted for multiple covariates including age, diabetes mellitus, hypertension, regular exercise, BMI, smoking, alcohol intake (g/day), total energy intake, carbohydrate intake, and income. The covariates of the multivariable model were selected for the presence of significant differences between groups or established risk factors for MetS. The incidence cases of MetS, person-years, and incidence density (incidence cases per 1000 person-years) were also calculated in each group. Subgroup analyses were also conducted in middle (40–49 years) and old (50–69 years) age groups to assess the differences these groups, especially in women. Finally, trend analysis for the Cox proportional hazard model was conducted in all analyses. All statistical analyses were performed using R 3.5.1 (R Foundation for Statistical Computing, Vienna, Austria) and $P < 0.05$ was considered statistically significant in all analyses.

Results

A total of 2684 men and 2622 women were enrolled in the present study. The mean ages of the men and women included in the study population were 50.9 ± 8.7 and 50.3 ± 8.5 years, respectively. The baseline clinical characteristics with age-adjusted values of the study population are presented in Table 1. More than half of the men (55.7%) and two-thirds of the women (69.3%) consumed peanuts, pine nuts, and almonds less than once a month. Only 11.9% of male and 8.6% of female participants reported having more than one serving per week. The average consumption was 6.6 g/week in men and 5.1 g/week in women. The biochemical and clinical characteristics suggested differences between men and women (e.g., fasting glucose level). However, some features showed the same patterns in men and women. TG levels were not significantly different between groups, while HDL-C differed significantly in both sexes. The incidence of MetS also showed an inverse dose–response relationship across study groups in men and

Table 1 Age-adjusted characteristics of the study population stratified by nut consumption

Serving	Rare (<1/month)	1/month–0.5/week	0.5–1/week	≥1/week	$P_{difference}$	$P_{for\ trend}$
Men						
No. of each group	1596	532	236	320		
Age (year)	51.8 ± 0.2^{a}	49.5 ± 0.4^{bc}	48.5 ± 0.6^{b}	50.7 ± 0.5^{ac}	<0.001	0.003
Fasting glucose (mg/dL)	85.6 ± 0.4^{a}	85.9 ± 0.7^{a}	86.2 ± 1.0^{a}	90.2 ± 0.9^{b}	<0.001	<0.001
Total cholesterol (mg/dL)	187.3 ± 0.9^{a}	193.4 ± 1.5^{b}	194.5 ± 2.3^{b}	197.8 ± 1.9^{b}	<0.001	<0.001
TG (mg/dL)	149.4 ± 2.3^{a}	148.0 ± 4.0^{a}	147.5 ± 6.0^{a}	140.8 ± 5.2^{a}	0.558	0.131
HDL-C (mg/dL)	45.5 ± 0.2^{a}	45.6 ± 0.4^{a}	45.7 ± 0.6^{ab}	47.7 ± 0.6^{b}	0.003	<0.001
BMI (kg/m^2)	23.4 ± 0.1^{a}	23.6 ± 0.1^{a}	23.6 ± 0.2^{a}	23.6 ± 0.1^{a}	0.002	0.269
WC (cm)	81.2 ± 0.2^{a}	81.3 ± 0.3^{a}	81.5 ± 0.4^{a}	81.2 ± 0.4^{a}	0.696	0.831
Systolic BP (mmHg)	118.7 ± 0.4^{a}	117.4 ± 0.7^{a}	117.0 ± 1.0^{a}	118.1 ± 0.9^{a}	<0.001	0.371
Diastolic BP (mmHg)	79.6 ± 0.3^{a}	79.4 ± 0.5^{a}	79.0 ± 0.7^{a}	79.6 ± 0.6^{a}	0.412	0.862
Average alcohol use (g/day)	16.6 ± 0.7^{a}	18.3 ± 1.2^{a}	18.8 ± 1.8^{ab}	23.9 ± 1.6^{b}	<0.001	<0.001
Current smoking (%)	53.3%	44.0%	44.9%	45.9%	<0.001	0.001
Regular exercise (%)	49.3%	32.9%	39.4%	32.2%	<0.001	<0.001
High income (%)	7.3%	12.8%	12.3%	15.9%	<0.001	<0.001
T2DM (%)	6.1%	4.5%	4.2%	10.0%	0.008	0.122
Hypertension (%)	23.4%	18.8%	16.1%	20.3%	0.183	0.023
Nut consumption (g/week)	0.03 ± 0.4^{a}	3.8 ± 0.6^{b}	9.5 ± 1.0^{c}	41.6 ± 0.8^{d}	<0.001	<0.001
Total calorie intake (kcal/day)	1870 ± 14^{a}	1973 ± 24^{b}	2004 ± 36^{b}	2211 ± 31^{c}	<0.001	<0.001
Carbohydrate intake (g/day)	353 ± 0.9^{a}	347.0 ± 1.5^{b}	344.4 ± 2.2^{b}	333.5 ± 1.9^{c}	<0.001	<0.001
Fat intake (g/day)	30.2 ± 0.2^{a}	32.7 ± 0.4^{b}	33.7 ± 0.6^{b}	36.8 ± 0.5^{c}	<0.001	<0.001
Protein intake (g/day)	65.2 ± 0.3^{a}	66.9 ± 0.4^{b}	67.7 ± 0.7^{b}	70.3 ± 0.6^{c}	<0.001	0.002
Incidence of MetS (*n*, [%])	528 (33.1%)	160 (30.1%)	76 (32.2%)	76 (23.8%)	0.009	0.003
Women						
No. of each group	1817	404	175	226		
Age (year)	50.9 ± 0.2^{a}	49.1 ± 0.4^{b}	48.2 ± 0.6^{b}	49.2 ± 0.6^{b}	<0.001	<0.001
Fasting glucose (mg/dL)	81.5 ± 0.3^{a}	81.0 ± 0.6^{a}	80.0 ± 0.9^{a}	82.5 ± 0.8^{a}	0.166	0.493
Total cholesterol (mg/dL)	185.3 ± 0.8^{a}	187.9 ± 1.7^{ab}	184.5 ± 2.5^{ab}	191.7 ± 2.2^{b}	0.088	0.011
TG (mg/dL)	117.4 ± 1.2^{a}	117.3 ± 2.6^{a}	110.3 ± 4.0^{a}	114.7 ± 3.5^{a}	0.212	0.277
HDL-C (mg/dL)	48.1 ± 0.2^{a}	48.5 ± 0.5^{a}	47.8 ± 0.8^{a}	49.8 ± 0.8^{a}	0.166	0.039
BMI (kg/m^2)	24.0 ± 0.1^{a}	24.0 ± 0.1^{a}	23.4 ± 0.2^{a}	24.0 ± 0.2^{a}	0.120	0.492
WC (cm)	78.0 ± 0.2^{a}	77.4 ± 0.4^{a}	76.8 ± 0.6^{a}	76.9 ± 0.5^{a}	0.001	0.025
Systolic BP (mmHg)	114.6 ± 0.4^{a}	113.5 ± 0.8^{a}	112.4 ± 1.2^{a}	113.4 ± 1.0^{a}	<0.001	0.120
Diastolic BP (mmHg)	75.3 ± 0.2^{a}	74.8 ± 0.5^{a}	75.1 ± 0.8^{a}	74.8 ± 0.7^{a}	0.061	0.400
Average alcohol use (g/day)	1.3 ± 0.1^{a}	1.6 ± 0.3^{ab}	0.8 ± 0.4^{a}	2.4 ± 0.3^{b}	0.004	0.012
Current smoking (%)	3.3%	3.0%	4.0%	4.0%	0.870	0.572
Regular exercise (%)	36.3%	26.5%	31.4%	27.0%	0.003	0.003
High income (%)	5.4%	8.9%	9.1%	12.8%	0.001	<0.001
T2DM (%)	3.0%	1.2%	1.1%	2.7%	0.252	0.210
Hypertension (%)	16.1%	11.9%	11.4%	10.2%	0.158	0.002
Nut consumption (g/week)	0.01 ± 0.3^{a}	3.7 ± 0.6^{b}	9.6 ± 0.9^{c}	44.4 ± 0.8^{d}	<0.001	<0.001
Total calorie intake (kcal/day)	1732 ± 14^{a}	1916 ± 29^{b}	1956 ± 44^{b}	2153 ± 39^{c}	<0.001	<0.001
Carbohydrate intake (g/day)	354.6 ± 0.9^{a}	350.8 ± 1.8^{ab}	347.0 ± 2.7^{b}	337.5 ± 2.4^{c}	<0.001	<0.001
Fat intake (g/day)	28.3 ± 0.2^{a}	30.5 ± 0.5^{b}	31.4 ± 0.7^{b}	34.8 ± 0.7^{c}	<0.001	<0.001
Protein intake (g/day)	65.1 ± 0.2^{a}	67.4 ± 0.5^{b}	68.5 ± 0.8^{b}	68.7 ± 0.7^{b}	<0.001	<0.001
Incidence of MetS (*n*, [%])	548 (30.2%)	98 (24.3%)	35 (20.0%)	41 (18.1%)	0.001	<0.001

Continuous variables are expressed as age-adjusted mean values (±SE) except age and categorical variables are expressed as percentage (%)

TC total cholesterol, *TG* triglyceride, *HDL-C* high-density lipoprotein cholesterol, *BMI* body mass index, *WC* waist circumference, *BP* blood pressure, *T2DM* type 2 diabetes mellitus women. Macronutrient intake (carbohydrates, fat, and protein) were strongly correlated with peanuts, pine nuts, and almond intake.

The incidence case, person-years, incidence density, and age-adjusted and multivariable-adjusted HRs of each group are shown in Table 2. The age and multivariable-adjusted HRs with 95% CIs for MetS showed a significant inverse dose–response relationship between peanut/pine nut/almond consumption and the incidence of MetS in men and women and trend analyses also showed significant results (multivariable-adjusted HRs [95% CI] in men; 0.91 [0.76–1.09] in 1/month–0.5/week, 1.03 [0.80–1.31] in 0.5–1/week, 0.72 [0.56–0.93] in ≥1/week and in women; 0.81 [0.65–1.003] in 1/month-0.5/week, 0.76 [0.54–1.07] in 0.5–1/week, 0.57 [0.41–0.79] ≥1/week). The results of subgroup analyses are presented in Table 3. Age subgroup analysis showed opposite results in men and women. In men, a significant difference was observed in the middle-aged group, whereas a significant finding was observed in the old-aged group of women. Interestingly, the 1/month–0.5/week consumption group in old-aged women had a significant difference and the ≥1/week group had the lowest multivariable-adjusted HRs in subgroup analysis (multivariable-adjusted HRs [95% CI] in old-aged women; 0.77 [0.57–1.04] in 1/month–0.5/week, 0.56 [0.33–0.96] in 0.5–1/week, 0.46 [0.29–0.74] in ≥1/week).

Discussion

Many studies have reported the inverse correlation between nut consumption and the incidence of MetS. A recent cross-sectional study conducted in Spain reported that the consumption more than one serving (28 g) of nuts per week is inversely related to the likelihood of MetS [31]. Similarly, the Tehran Lipid and Glucose Study, a longitudinal population-based study conducted in Iran, showed that nut intake was inversely correlated with the incidence of MetS [15]. A number of randomized controlled trials, as well as cohort studies, have reported that tree nut intake lowers TG and fasting blood glucose level, a major component of MetS [18]. Although previous studies showed subtle controversial results [17, 18], systemic reviews support the beneficial effect of nut intake in the prevention of MetS [18, 32]. The amount of nut consumption related to a reduced risk of MetS varied from 25–100 g/day [18] However, most of the previous studies were conducted in populations with relatively high nut consumption. Therefore, our results demonstrate that a relatively high consumption of nuts was inversely associated with the incidence of MetS even in a population with low nut consumption.

In the present study, the consumption of more than one (15 g) serving of peanuts/pine nuts/almonds per week was related to a lower risk of MetS. A previous study based on the third Korea National Health and Nutrition Examination Survey (KNHANES III) suggested that a carbohydrate-rich (>70% of total energy intake) dietary pattern in Koreans was associated with high prevalence of T2DM and low HDL-cholesterol level [33]. Therefore, first, we concerned that high consumption of nuts with high monounsaturated fatty acids (MUFAs)/polyunsaturated fatty acids (PUFAs) may be associated with lower risk of MetS in the Korean general population. However, in our study, nuts intake of study participants was too small to significantly increase the overall MUFA/PUFA intake (average 5–6 g/day and minimum 2 g/day in ≥1/week consumption group). The

Table 2 Hazard ratios (HRs) and 95% confidence intervals (CIs) for the incidence of metabolic syndrome according to nut intake

Serving	Rare (<1/month)	1/month–0.5/week	0.5–1/week	≥1/week	*P* for trend
Men (no. of each group)	1596	532	236	320	
Age adjusted	1.00 (Reference)	0.85 (0.71–1.02)	0.96 (0.75–1.22)	0.71 (0.56–0.90)	0.007
Multivariable Model	1.00 (Reference)	0.91 (0.76–1.09)	1.03 (0.80–1.31)	0.72 (0.56–0.93)	0.019
Incidence cases	528	160	76	76	
Person year	11,382	3990	1716	2321	
Incidence density	46.4	40.1	44.3	32.7	
Women (no. of each group)	1817	404	175	226	
Age adjusted	1.00 (Reference)	0.76 (0.61–0.94)	0.66 (0.47–0.93)	0.56 (0.41–0.77)	<0.001
Multivariable Model	1.00 (Reference)	0.81 (0.65–1.003)	0.76 (0.54–1.07)	0.57 (0.41–0.79)	<0.001
Incidence cases	548	98	35	41	
Person year	13298	3220	1354	1794	
Incidence density	41.2	30.4	25.9	22.9	

Multivariable Model: age, T2DM, hypertension, regular exercise, BMI, smoking, alcohol intake (g/day), total calorie intake, carbohydrate intake (%), income

Incidence density: incidence cases per 1000 person-year

Table 3 Hazard ratios (HRs) and 95% confidence intervals (CIs) for the incidence of metabolic syndrome according to nut intake (subgroup analyses)

Serving	Rare (<1/month)	1/month–0.5/week	0.5–1/week	≥1/week	*P* for trend
Age < 50					
Men (no. of each group)	808	322	153	175	
Age adjusted	1.00 (Reference)	0.79 (0.63–1.00)	0.92 (0.68–1.24)	0.58 (0.41–0.82)	0.003
Multivariable Model	1.00 (Reference)	0.86 (0.67–1.09)	0.96 (0.70–1.30)	0.56 (0.39–0.79)	0.002
Incidence cases	278	94	49	37	
Person year	5883	2464	1118	1327	
Incidence density	47.3	38.1	43.8	27.9	
Women (no. of each group)	999	248	115	141	
Age adjusted	1.00 (Reference)	0.76 (0.56–1.03)	0.71 (0.45–1.12)	0.62 (0.40–0.95)	0.023
Multivariable Model	1.00 (Reference)	0.88 (0.64–1.20)	0.93 (0.59–1.48)	0.69 (0.44–1.08)	0.140
Incidence cases	228	46	20	22	
Person year	7721	2046	893	1141	
Incidence density	29.5	22.5	22.4	19.3	
Age ≥ 50					
Men (no. of each group)	788	210	83	145	
Age adjusted	1.00 (Reference)	0.94 (0.71–1.23)	0.98 (0.66–1.47)	0.88 (0.63–1.23)	0.470
Multivariable Model	1.00 (Reference)	0.97 (0.73–1.28)	1.18 (0.78–1.77)	0.94 (0.65–1.36)	0.872
Incidence cases	250	66	27	39	
Person year	5499	1525	599	994	
Incidence density	45.5	43.3	45.1	39.2	
Women (no. of each group)	818	156	60	85	
Age adjusted	1.00 (Reference)	0.76 (0.56–1.02)	0.55 (0.33–0.93)	0.50 (0.31–0.79)	0.001
Multivariable Model	1.00 (Reference)	0.77 (0.57–1.04)	0.56 (0.33–0.96)	0.46 (0.29–0.74)	<0.001
Incidence cases	320	52	15	19	
Person year	5577	1174	491	652	
Incidence density	57.4	44.3	32.5	29.1	

Multivariable Model: age, T2DM, hypertension, regular exercise, BMI, smoking, alcohol intake (g/day), total calorie intake, carbohydrate intake (%), income

Incidence density: incidence cases per 1000 person-year

beneficial effect of components of nuts other than high MUFAs/PUFAs consumption such as polyphenolic compounds (e.g., resveratrol), amino acid arginine which is the precursor of nitric oxide, and antioxidants through decreasing insulin resistance, lowering BP, and anti-inflammatory effects [21, 22, 34] can be another explanation of the inverse association between nuts consumption and MetS incidence risk in the present study. However, these components may be also not enough high for the strength of the association in this study. Therefore, we could not rule out a possibility that unmeasured confounders such as health-related dietary patterns not included in our FFQ still remained, although lifestyles including smoking, alcohol intake, physical activity, socioeconomic (e.g. income), and balance macronutrient factor (e.g. carbohydrate intake) were adjusted in the multivariable model in the present study. We have additionally adjusted for MetS-related dietary factors (soda drink intake, calcium intake, egg intake, and fiber intake), but there was no difference from the original model (data not shown). This association needs to be confirmed in other prospective studies and by integrative analysis considering interrelationships between lifestyles.

In the present study, the ≥1/week consumption group had the highest total energy intake among study groups. It may be due to a Korean food culture which nuts are not staple food, not ingredient of the main dishes, and generally used as snacks. Therefore, individual with high nut intake is more likely to have additional energy. However, interestingly, there was no difference between BMI and waist circumference across nuts intake groups in the baseline survey. Additional energy intake from nuts consumption may not be related to weight gain. This possibility was also reported in the previous several intervention studies to examine the beneficial effect of nuts on plasma lipid profiles; in most studies, regardless of the additional energy intakes during nuts supplementation, body weight did not increase or much less increase expected. They suggested that there may be some unabsorbed energy in nuts that negated the energy imbalance due to much high nut consumption. It could partly explain the inverse association with MetS incidence risk in the highest nut consumption group despite of high energy intake. Nevertheless, we suggested that it is more appropriate to maintain energy balance by replacing some other foods with nuts.

Our results also suggested that the beneficial effect of peanut, almond, and pine nut intake can vary in age and gender subgroups. The subgroup analyses showed a statistically significant difference in middle-aged men and old-aged women. In particular, old-aged women had the lowest HRs for MetS among study groups and the 0.5–1/week consumption group in old-aged women also showed a significant difference. It is well-known that postmenopausal women have an increased risk for MetS [35, 36], and our study result also showed an increased incidence density of MetS in old-aged women. Menopause is associated with abdominal obesity, increased TG, and decreased HDL-cholesterol level, which are components of MetS [35]. Therefore, it is possible that the beneficial effect of peanut, almond, and pine nuts is markedly increased in postmenopausal women. We conducted a subgroup analysis to investigate the differences in subgroups of women, but men also showed different outcomes in age subgroup analyses. Although we cannot explain the underlying etiology, our findings suggest complicated relationships between nut consumption and the risk of MetS.

The merits of the present study are the large sample size and well-organized FFQ and clinical data in a Korean general population. Nonetheless, several limitations should be considered. First, the peanut, almond, pine nut, and other food intake were assessed by a single baseline FFQ. Our findings may not reflect habitual food intake and changes in dietary pattern in the follow-up examination. Second, the amount of nuts intake in the present study is too small to affect MUFA/PUFA consumption. The KoGES FFQ data were limited to peanut, almond, and pine nut consumption, and total nut consumption of the study population may be greater than the sum of the peanut, almond, and pine nut consumption. Third, the results of this study could not rule out that other lifestyle patterns and dietary habits associated with high nutritional intake have a protective effect on MetS. Thus, this finding needs to be verified in the large-scale cohort studies among other various populations. Finally, our study population did not include young adults (<40 years). Given the rapidly increasing prevalence of MetS in young Asian populations, this may be another weakness of the present study.

In conclusion, the results of our study suggested that a relatively small amount consumption (15 g/week) of peanuts, almonds, and pine nuts is inversely associated with a risk of MetS in a Korean general population. It may be more evident in old-aged women and a very small consumption (7.5–15 g/week).

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Author contributions JYJ coordinated the study, analyzed the data, and wrote the manuscript as a first author. C-MO played role in analyzing data and verifying the results. SKP, J-MC, and J-HR participated in reviewing manuscript. JK took a part in analyzing nutrient data and participated in reviewing manuscript. MKK is the guarantor of this work and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study. Ethical approval.

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References

1. M.G. Saklayen, The global epidemic of the metabolic syndrome. Curr. Hypertens. Rep. **20**(2), 12 (2018)
2. P. Ranasinghe, Y. Mathangasinghe, R. Jayawardena, A.P. Hills, A. Misra, Prevalence and trends of metabolic syndrome among adults in the Asia-Pacific region: a systematic review. BMC Public Health **17**(1), 101 (2017)
3. S. Lim, H. Shin, J.H. Song et al. Increasing prevalence of metabolic syndrome in Korea: the Korean National Health and Nutrition Examination Survey for 1998-2007. Diabetes Care. **34** (6), 1323–1328 (2011)
4. S. Akter, A. Nanri, N.M. Pham, K. Kurotani, T. Mizoue, Dietary patterns and metabolic syndrome in a Japanese working population. Nutr. Metab. (Lond.). **10**(1), 30 (2013)
5. A.J. Baxter, T. Coyne, C. McClintock, Dietary patterns and metabolic syndrome—a review of epidemiologic evidence. Asia Pacific J. Clin. Nutr. **15**(2), 134–142 (2006)
6. M.L. Leite, A. Nicolosi, Dietary patterns and metabolic syndrome factors in a non-diabetic Italian population. Public Health Nutr. **12** (9), 1494–1503 (2009)
7. J.H. Choi, H.D. Woo, J.H. Lee, J. Kim, Dietary patterns and risk for metabolic syndrome in Korean women: a cross-sectional study. Medicine (Baltimore). **94**(34), e1424 (2015)
8. K. Kim, S.H. Yun, B.Y. Choi, M.K. Kim, Cross-sectional relationship between dietary carbohydrate, glycaemic index,

glycaemic load and risk of the metabolic syndrome in a Korean population. Br. J. Nutr. **100**(3), 576–584 (2008)
9. Y. Zhao, L. Wang, H. Xue, H. Wang, Y. Wang, Fast food consumption and its associations with obesity and hypertension among children: results from the baseline data of the Childhood Obesity Study in China Mega-cities. BMC Public Health **17**(1), 933 (2017)
10. Z. Bahadoran, P. Mirmiran, F. Hosseini-Esfahani, F. Azizi, Fast food consumption and the risk of metabolic syndrome after 3-years of follow-up: Tehran Lipid and Glucose Study. Eur. J. Clin. Nutr. **67**(12), 1303–1309 (2013)
11. R.D. Mendonça, A.C. Lopes, A.M. Pimenta, A. Gea, M.A. Martinez-Gonzalez, M. Bes-Rastrollo, Ultra-processed food consumption and the incidence of hypertension in a Mediterranean cohort: The Seguimiento Universidad de Navarra Project. Am. J. Hypertens. **30**(4), 358–366 (2017)
12. J.Y. Shin, J.Y. Kim, H.T. Kang, K.H. Han, J.Y. Shim, Effect of fruits and vegetables on metabolic syndrome: a systematic review and meta-analysis of randomized controlled trials. Int J. Food Sci. Nutr. **66**(4), 416–425 (2015)
13. S.A. Hong, M.K. Kim, Relationship between fruit and vegetable intake and the risk of metabolic syndrome and its disorders in Korean women according to menopausal status. Asia Pac. J. Clin. Nutr. **26**(3), 514–523 (2017)
14. N. Babio, M. Bulló, J. Salas-Salvadó, Mediterranean diet and metabolic syndrome: the evidence. Public Health Nutr. **12**(9A), 1607–1617 (2009)
15. S. Hosseinpour-Niazi, S. Hosseini, P. Mirmiran, F. Azizi. Prospective study of nut consumption and incidence of metabolic syndrome: Tehran Lipid and Glucose Study. Nutrients 9(10), 23–29 (2017)
16. C.E. O'Neil, D.R. Keast, T.A. Nicklas, V.L. Fulgoni III, Nut consumption is associated with decreased health risk factors for cardiovascular disease and metabolic syndrome in U.S. adults: NHANES 1999-2004. J. Am. Coll. Nutr. **30**(6), 502–510 (2011)
17. R. Hassannejad, N. Mohammadifard, I. Kazemi, M. Mansourian, M. Sadeghi, H. Roohafza, N. Sarrafzadegan, Long-term nuts intake and metabolic syndrome: a 13-year longitudinal population-based study. Clin Nutr. pii: S0261–5614(18) 1246–1252 (2018)
18. S. Blanco Mejia, C.W. Kendall, E. Viguiliouk, L.S. Augustin, V. Ha, A.I. Cozma, A. Mirrahimi, A. Maroleanu, L. Chiavaroli, L.A. Leiter, R.J. de Souza, D.J. Jenkins, J.L. Sievenpiper, Effect of tree nuts on metabolic syndrome criteria: a systematic review and meta-analysis of randomised controlled trials. BMJ Open. **4**(7), e004660 (2014)
19. J. Sabaté, K. Oda, E. Ros, Nut consumption and blood lipid levels: a pooled analysis of 25 intervention trials. Arch. Intern Med. **170** (9), 821–827 (2010)
20. D.J.A. Jenkins, C.W.C. Kendall, B. Lamarche, M.S. Banach, K. Srichaikul, E. Vidgen, S. Mitchell, T. Parker, S. Nishi, B. Bashyam, R.J. de Souza, C. Ireland, S.C. Pichika, J. Beyene, J.L. Sievenpiper, R.G. Josse, Nuts as a replacement for carbohydrates in the diabetic diet: a reanalysis of a randomised controlled trial. Diabetologia **61**(8), 1734–1747 (2018). https://doi.org/10.1007/s00125-018-4628-9
21. N. Yazdekhasti, N. Mohammadifard, N. Sarrafzadegan, D. Mozaffarian, M. Nazem, M. Taheri, The relationship between nut consumption and blood pressure in an Iranian adult population: Isfahan Healthy Heart Program. Nutr. Metab. Cardiovasc. Dis. **23** (10), 929–936 (2013)
22. P. García-Lorda, I. Megias Rangil, J. Salas-Salvadó, Nut consumption, body weight and insulin resistance. Eur. J. Clin. Nutr. **57**(Suppl 1), S8–S11 (2003)
23. I. Baik, M. Lee, N.R. Jun, J.Y. Lee, C. Shin, A healthy dietary pattern consisting of a variety of food choices is inversely associated with the development of metabolic syndrome. Nutr. Res. Pract. **7**(3), 233–241 (2013)
24. J. Aranceta, C. Pérez Rodrigo, A. Naska, V.R. Vadillo, A. Trichopoulou, Nut consumption in Spain and other countries. Br. J. Nutr. **96**(Suppl 2), S3–S11 (2006)
25. H.S. Park, C.Y. Park, S.W. Oh, H.J. Yoo, Prevalence of obesity and metabolic syndrome in Korean adults. Obes. Rev. **9**, 104–107 (2008)
26. J.Y. Jung, C.M. Oh, J.H. Ryoo, J.M. Choi, Y.J. Choi, W.T. Ham, S.K. Park, The influence of prehypertension, hypertension, and glycated hemoglobin on the development of type 2 diabetes mellitus in prediabetes: the Korean Genome and Epidemiology Study (KoGES). Endocrine **59**, 593–601 (2018)
27. Y. Ahn, J.E. Lee, H.Y. Paik, H.K. Lee, I. Jo, K. Kim, Development of a semi-quantitative food frequency questionnaire based on dietary data from the Korea National Health and Nutrition Examination Survey. Nutr. Sci. **6**, 173–184 (2003)
28. W. Willett, *Nutritional Epidemiology*, 3rd edn. (Oxford University Press, New York, 2013)
29. Korean National Academy of Agricultural Science. *Food Composition Table*, 7th edn. (Rural Development Administration, Suwon, 2007) (in Korean)
30. Y. Ahn, E. Kwon, J. Shim, M. Park, Y. Joo, K. Kimm et al. Validation and reproducibility of food frequency questionnaire for Korean genome epidemiologic study. Eur. J. Clin. Nutr. **61**, 1435–1441 (2007)
31. N. Ibarrola-Jurado, M. Bulló, M. Guasch-Ferré, E. Ros, M.A. Martínez-González, D. Corella, M. Fiol, J. Wärnberg, R. Estruch, P. Román, F. Arós, E. Vinyoles, L. Serra-Majem, X. Pintó, M.I. Covas, J. Basora, J. Salas-Salvadó; PREDIMED Study Investigators, Cross-sectional assessment of nut consumption and obesity, metabolic syndrome and other cardiometabolic risk factors: the PREDIMED study. PLoS ONE **8**(2), e57367 (2013)
32. H. Li, X. Li, S. Yuan, Y. Jin, J. Lu, Nut consumption and risk of metabolic syndrome and overweight/obesity: a meta-analysis of prospective cohort studies and randomized trials. Nutr. Metab. (Lond.) **15**, 46 (2018)
33. S.H. Park, K.S. Lee, H.Y. Park, Dietary carbohydrate intake is associated with cardiovascular disease risk in Korean: analysis of the third Korea National Health and Nutrition Examination Survey (KNHANES III). Int J. Cardiol. **139**(3), 234–240 (2010)
34. Z. Yu, V.S. Malik, N. Keum et al. Associations between nut consumption and inflammatory biomarkers. Am. J. Clin. Nutr. **104**(3), 722–728 (2016)
35. M.C. Carr, The emergence of the metabolic syndrome with menopause. J. Clin. Endocrinol. Metab. **88**(6), 2404–2411 (2003)
36. Z. Jouyandeh, F. Nayebzadeh, M. Qorbani, M. Asadi, Metabolic syndrome and menopause. J. Diabetes Metab. Disord. **12**(1), 1 (2013)