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REVIEW

Association between Egg Consumption and Metabolic Disease

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Abstract The effect of high egg intake on metabolic syndrome (MetS), a major risk factor for cardiovascular disease (CVD), has not been clearly elucidated. This study was conducted to review the literature related to egg consumption and the risk of metabolic disease as well as to examine the association between high egg intake and MetS in Korean adults. A literature review was conducted using published papers in PubMed and EMBASE through December 2017. We have reviewed 26 articles, which were associated with egg consumption and metabolic diseases, and found that the results were controversial. Therefore, we analyzed data from 23,993 Korean adults aged 19 yrs and older. MetS was defined based on criteria from the Adult Treatment Panel III. Egg consumption of 4-6 times/wk and 1 time/day were significantly associated with reduced prevalence of MetS (Odds ratio (OR)=0.82; 95% Confidence interval (CI)=0.71-0.95 for 4-6 times/wk, OR=0.83; 95% CI=0.69-0.99 for 1 time/day) compared to those who consumed eggs less than once monthly. However, consuming two or more eggs per day was not associated with MetS. As for the components of MetS, an egg intake of once daily decreased the prevalence of abdominal obesity and an intake of 2-7 eggs weekly was shown to prevent a reduction in the high-density lipoprotein cholesterol levels. This study suggests that while consuming eggs 4-7 times weekly is associated with a lower prevalence of MetS, consuming two or more eggs daily is not associated with a reduced risk for MetS.

Keywords egg consumption, metabolic syndrome, Korean

Introduction

Metabolic syndrome (MetS) is described as a group of risk factors that increases the risk of metabolic diseases, such as hypertension, cardiovascular disease (CVD), and diabetes (Bansilal et al., 2015; Galassi et al., 2006). MetS, as a precursor for CVD, should be controlled in order to extend life expectancy (Wilson et al., 2005). A diagnosis of MetS requires possessing at least three of the five risk factors including

a large waist circumference, high blood pressure, a high triglyceride level, a low high-density lipoprotein cholesterol (HDL-C) level, and a high fasting blood glucose level (Grundy et al., 2004).

Diets high in cholesterol, saturated fat, and trans-fatty acid can raise blood cholesterol levels, which may induce an abnormal blood lipid and blood glucose metabolism. This has been linked with the MetS as well as CVD (Appleby et al., 1999). A higher intake of cholesterol significantly increased the risk of CVD in women with type 2 diabetes (T2D) (Tanasescu et al., 2004). Many foods that come from animals contain cholesterol and saturated fats. Among them, eggs are high in cholesterol and are not only commonly consumed but are also readily available in Korea (EFSA, 2010).

Up to now, many studies conducted to evaluate the effects of egg intake on chronic diseases, but the results are controversial. A meta-analysis reported that a high egg intake was associated with a high risk for CVD and diabetes (Li et al., 2013). However, another meta-study reported that egg consumption is not associated with the risk for CVD or cardiac mortality but increased the risk for T2D in the general population (Shin et al., 2013). Previous individual research studies have reported that the consumption of 1 egg/day will not have an effect on the risk for coronary heart disease (CHD) or stroke (Djoussé et al., 2009). Furthermore, an egg consumption of greater than once daily increased the risks for heart failure and T2D (Larsson et al., 2015; Shi et al., 2011). However, a Japanese cohort study didn't show any relationship between egg intake and the risk for CVD or mortality (Nakamura et al., 2006). Blesso et al. (2013a) suggested that eggs may protect against MetS by raising HDL-C levels and reducing inflammation. Another study has suggested that addition of egg to diet has no such relationship or even reduced plasma insulin levels and insulin resistance (Djoussé et al., 2010). On the other hand, eggs contain many essential nutrients such as bioactive protein, phospholipids, lutein and zeaxhanthin (Andersen, 2015). Studies carried out by far have overall produced inconsistent results regarding egg consumption and the risks for CVD, diabetes and MetS.

To our best knowledge, only a few studies have been conducted to examine the relationship between high egg intake and MetS in Korea (Shin et al., 2017; Woo et al., 2016). The previous two studies in Korea were conducted in middle-aged and elderly people in limited areas and did not report the effects of eating more than two eggs on the MetS.

Thus, this study was conducted to summarize the literature on egg consumption and the risk of metabolic disease as well as to examine the association between high egg intake on MetS and its components in Korean adults.

Materials and Methods

Data sources and searches

We searched for past research related with egg consumption and metabolic disease in adults from the earliest available online indexing though December 2017. We identified published articles in PubMed (http://www.ncbi.nlm.nih.gov/pubmed) and EMBASE (http://www.embase.com/). The terms "egg intake", "egg consumption" combined with "metabolic syndrome", "CHD", "CVD ", and "diabetes mellitus" were used.

Study selection

We retrieved 46 articles from PubMed and EMBASE. Among them, 20 articles were excluded for one of the following reasons: review articles (n=4), systematic review (n=2), meta-analysis (n=7), case-control study (n=1), or used same subjects in randomized controlled trial (RCT) (n=6). Finally, 26 articles were reviewed: RCT (n=5), prospective study (cohort study) (n=18), and cross-sectional study (n=3).

Study design and population

This study was based on data obtained from the Korea National Health and Nutrition Examination Survey (KNHANES) 2007-2011. This survey was performed by the Korea Centers for Disease Control and Prevention (KCDC). All survey participants signed an informed consent. The KDCD Institutional Review Board (IRB) approved the utilized protocol.

Among 42,347 subjects who participated in the KNHANES survey between 2007 and 2011, we excluded those less than 19 years of age (n=10,635), pregnant/lactating women (n=309), those with missing waist circumference (n=1,928), triglyceride (n=1,271), blood glucose (n=51), blood pressure (n=20) or energy intake data (n=3,414), subjects with unrealistic daily caloric intakes, including <500 or ≥6,000 kcal (n=231) and subjects lacking egg intake frequency data (n=495). Hence, a total of 23,993 subjects were included in the final analysis (9,793 men and 14,200 women).

Definition of MetS

A diagnosis of MetS was made based on the criteria from the National Cholesterol Education Program Adult Treatment Panel III (NCEP-ATP III). Accordingly, one must possess at least three of the following five components: (1) a waist circumference ≥102 cm (male) or 88 cm (female), (2) blood pressure ≥130/85 mmHg or taking hypertension medicine, (3) a triglyceride (TG) level ≥150 mg/dL or taking medicine for hyperlipidemia, (4) a HDL-C level <40 mg/dL (male) or 50 mg/dL (female), (5) fasting blood glucose >110 mg/dL or taking an antidiabetic drug (Grundy et al., 2004).

Anthropometric measurements

Body mass index (BMI) was calculated as weight/height^2 (kg/m^2). We defined obesity as BMI≥25 kg/m^2, consistent with proposals from the Asia-Pacific region of the World Health Organization (WHO, 2000) and criteria from the KCDC.

Dietary assessment and egg intake

Dietary assessment used a qualitative food frequency questionnaire (FFQ) for the past year. The FFQ consisted of a list of 63 commonly-consumed food items in Korea with frequencies of food intake in nine categories (almost never, 6-11 times/year, 1 time/month, 2-3 times/month, 1 time/week, 4-6 times/week, 1 time/day, 2 times/day, and 3 times/day). There were a very small number of subjects who ate three or more eggs per day. Therefore, we re-categorized the frequency of egg intake as ≤1 time/month, >1 time/month – <1 time/week, 1 time/week, 2-3 times/week, 4-6 times/week, 1 time/day, and ≥2 times/day.

Covariates

The KNHANES has three different parts: a health interview, a health examination, and a nutrition survey. All parts were performed by well-trained medical staff, interviewers, and dieticians. Health examinations such as body measurements, laboratory tests and blood pressure were measured by medical staff. Health interviews and nutrition surveys were conducted via face-to-face interviews. Data for alcohol drinking, smoking, physical activity, and menopause status only were self-reported. More detailed information for measurements of the KNHANES survey is available (Kweon et al., 2014). Sociodemographic information including age, sex, education, and income level were collected via health interviews. With regards to income level, the KCDC provided four categories on the basis of the equivalized income (total household income / the square root of the number of household members). Income level was categorized from 1st (lowest) to 4th (highest) in a

dataset provided by the KCDC. Education level was classified into four groups: elementary school, middle school, high school, and college or higher degree.

Alcohol consumption was categorized based on the frequency and amount consumed per occasion. Heavy drinkers were defined as those who consumed alcohol twice or more per week and had at least seven drinks per occasion (for men) or five drinks per occasion (for women). Alcohol intake was classified into non-drinker, less than once a month, more than once a month-less than heavy drinker, and heavy drinkers. Smoking status was classified as non-, past, current (<1 pack per day), or current (≥1 pack per day) smoker. Physical activity was categorized as no exercise, regular walks, regular moderate activity, or regular vigorous activity. Menopausal status was categorized as either yes or no.

Disease history questionnaires were completed using face-to-face interviews. Chronic disease status was dichotomized into subjects diagnosed by physicians with or taking medication(s) for the management of diabetes, cancer, myocardial infarction, stroke, angina pectoris, or chronic renal failure and those without such diagnoses or taking related medications.

Fasting blood glucose, TG, and HDL-C were measured using blood samples collected from subjects in the KNHANES health examination. Systolic blood pressure (SBP) and diastolic blood pressure (DBP) were twice measured by trained nurses. Nutrient intake data such as total energy intake, calcium, and vitamin C intake were obtained from the KNHANES raw data. For further detailed description of the KNHANES, please refer to the official English website (https://knhanes.cdc.go.kr/knhanes/eng/index.do).

Statistical analysis

Characteristics according to frequency of egg intake in the Korean population were analyzed. Means and standard errors of continuous variables were calculated. The proportions of each covariate for each group were calculated. *p*-values were calculated using the generalized linear model (GLM)/LSMEAN for continuous variables and Chi-square test for categorical variables. As for the variables with non-normality, we calculated a *p*-value with log-transformation. Differences between MetS and non-MetS groups were analyzed by *t*-tests and Chi-square tests for continuous variables and categorical variables, respectively.

We conducted weighted logistic regression to assess the association between frequency of egg intake and MetS. Odds ratio (OR) and 95% confidence interval were calculated. All covariates with a *p*-value <0.20 in univariate analysis were selected for multiple regression analyses. The multivariate models were adjusted for age, sex, BMI (continuous), income, education, alcohol consumption, smoking status, physical activity, menopausal status (women only), energy intake (continuous) and chronic disease status (yes or no). In addition, we examined the association between egg intake frequency and each component of MetS (abdominal obesity, hypertension, hyperglyceridemia, hypertriglyceridemia, and low HDL cholesterolemia). Tests of linear trend across egg intake frequency were conducted by assigning a median to each frequency and treating it as a continuous variable. All statistical tests were two-tailed and a *p*-value of <0.05 was considered statistically significant. All analyses were used SAS 9.4 (SAS institute Inc., USA).

Results and Discussion

Literature review

Table 1 showed the association between egg intake and metabolic diseases from the literature review. In most cross-sectional and cohort studies, a negative or null association between egg intake and metabolic diseases was observed. Only

Table 1. The main findings of studies for egg intakes and metabolic diseases

Author, year	Subjects	Country	Diseases/ outcomes	Exposure category	Control or reference category	Result	Main findings
Cross-sectional study							
Shi et al., 2011	1,308 men, 1,541 women aged ≥20 y	China	T2D	≥1 egg/d	<2 eggs/wk	N	The adjusted odds of T2D were 2.28 (95% CI, 1.14–4.54) for men, 3.01 (95% CI, 1.12-8.12) for women in ≥1 egg/day group compared with the <2 eggs/week group
Spence et al., 2012	1,262 subjects attending Canadian vascular prevention clinics	Canada	Plaque area	≥3 egg/d	<2 eggs/wk	N	The patients consuming <2 eggs/week of plaque area was 125 mm^2, versus 132 mm^2 in those consuming ≥3 eggs/week
Shin et al., 2017	130,420 subjects aged 40-69 years	Korea	Metabolic syndrome	7 eggs/wk	≤1 egg/wk	P	7 eggs/week group decreased the risk for MetS (OR, 0.77; 95% CI, 0.70-0.84) compared with ≤1 egg/week group in women
Cohort study							
Djousse et al., 2009	20,703 men, 36,295 women	USA	T2D	7 eggs/wk	<1 egg/wk	N	The HRs of T2D was 1.58 (95% CI, 1.25–2.01) in men, and 1.77 (95% CI, 1.28–2.43) in women with 7 eggs/week group compared with the <1 egg/week group.
Djousse and Gaziano, 2008a	21,275 subjects	USA	Heart failure	≥1 egg/d	<1 egg/wk	N	The incidences of HF significantly increased (HR, 1.64; 95% CI, 1.08–2.49) in ≥1 egg/day group compared with the <1 egg/week
Djousse and Gaziano, 2008b	21,327 subjects	USA	CVD and mortality	≥7 eggs/wk	<1 egg/wk	N	The adjusted Hazard ratio for mortality was 1.23 (95% CI, 1.11-1.36) in ≥7 eggs per week group compared with the <1 egg/week
Guo et al., 2017	2,512 subjects aged 45-59 years	UK	CVD, T2D, stroke, mortality	≥5 eggs/wk	Never or <1 egg/wk	N	The incidence of stroke increased with higher egg consumption among T2D and/or IGT sub-group (HR, 2.87; 95% CI, 1.13-7.27)
Hu et al., 1999	37,851 men aged 40-75 years, 80,082 women aged 34-59 years	USA	CHD	1 egg/d	<1 egg /wk	N	The incidences of CHD significantly increased (HR, 2.02; 95% CI, 1.05-3.87 in men, HR, 1.49; 95% CI, 0.88-2.52 in women) in 1 egg/day group compared with the <1 egg/week among diabetic subjects
Larsson et al., 2015	37,766 men, 32,805 women	Sweden	CVD	≥1 egg/d	0–3 eggs/mon	N	The incidences of CVD increased (HR, 1.99; 95% CI, 1.12-3.53 in men) in ≥1 egg/day group compared with the 0–3 egg /month group
Nakamura et al., 2006	Cohort I (27,439 men, 27 073 women) Cohort II (31,750 men, 30,665 women)	Japan	CHD	Almost every day	<1 egg/wk	N	Adjusted HRs revealed significantly associated with CHD (HR, 2.17; 95% CI, 1.22-3.85) in almost daily egg intake group compared with the <1 egg/week
Djousse et al., 2016	3,564 subjects	USA	T2D	≥5 eggs/wk	<1 egg/mon	N/ Null	Egg consumption was associated with T2D prevalence. Otherwise, prospective analysis did not show association of egg consumption and T2D incidence
Wallin et al., 2016	36,910 men aged 45–79 years	Sweden	T2D	≥5 egg/d	<1 egg/wk	Null	No significant differences in T2D incidence according to the egg intakes in prospective study
Díez-Espino et al., 2017	7,216 subjects aged 55–80 years	Spain	T2D	>4 eggs/d	<2 eggs/wk	Null	No significant differences in T2D incidence according to the egg intakes

Table 1. The main findings of studies for egg intakes and metabolic diseases (continued)

Author, year	Subjects	Country	Diseases/ Outcomes	Exposure category	Control or reference category	Result	Main findings
Cohort study(continued)							
Djousse et al., 2010	3,898 subjects	USA	T2D	Almost daily eat egg	Never	Null	No significant intergroup differences in T2D incidence
Goldberg et al., 2014	1,429 subjects	USA	Carotid Atheros-clerosis	≥2 eggs/d	Never or <1 egg/mon	Null	Low and moderate egg intake was inversely related to carotid atherosclerosis markers. No association showed in clinical vascular events.
Kurotani et al., 2014	27,248 men and 36,218 women aged 45–75 years	Japan	T2D	Highest egg intake	Lowest egg intake	Null	No significant intergroup differences in T2D incidence
Lajous et al., 2015	65,364 women	France	T2D	≥5 eggs/wk	non-consumer	Null	No association was showed between egg consumption and T2D risk.
Qureshi et al., 2007	9,734 subjects aged 25–74 years	USA	Ischemic stroke, CAD	≥6 eggs/wk	<1 egg/wk	Null	Consumption of ≥6 eggs /week didn't' increase the stroke and ischemic stroke risk
Zazpe et al., 2011	14,185 subjects	Spain	CVD	≥4 eggs/wk	Never or <1 egg/wk	Null	The association of egg consumption and the incidence of CVD was not found in the Mediterranean cohort.
Virtanen et al., 2015	2,332 men aged 42–60 years	Finland	T2D	>45 g egg/d	<14 g egg/d	P	The incidences of T2D decreased (HR, 0.62; 95% CI, 0.47-.0.82) in ≥45 g egg/day group compared with the<14 g egg/day group
Woo et al., 2016	2,887 subjects aged 40 years and over	Korea	Metabolic syndrome	≥3 eggs/wk	Never	P	The adjusted HRs of MetS was 0.46 (95% CI, 0.26–0.82) in men, 0.54 (95% CI, 0.31 –0.93) in women in with ≥3 eggs/week group compared with the never eaten group
Randomized Controlled Trial							
Fuller et al., 2015a	140 subjects	New Zealand	T2D	2 eggs/d for 6 d/wk	<2 eggs/wk	Null	High egg consumption didn't show any adverse effect on the lipid profile of T2D patients.
Blesso et al., 2013b	12 men, 25 women	USA	Metabolic syndrome	3 eggs/d during 12 wk	Equivalent amount of egg substitute during 12 wk	P	The risk of MetS was significantly decreased in both groups. And NFκ-a, amyloid significantly decreased in egg intake group only
Ballesteros et al., 2015	29 subjects aged 35-65 years	Mexico	T2D	1 egg/d with 472 mL lactose-free milk during 5 wk	40 g oatmeal with 472 mL lactose-free milk during 5 wk	P	AST(aspartate amino transferase) and TNF(Tumor necrosis factor)-alpha were significantly reduced during the egg consumption period
DiMarco et al., 2017	38 subjects(19 men, 19 women) aged 18-30 years	USA	Lipid profile	1, 2, and 3 eggs/d for 4 wk each	-	P	Decreased DBP, LDL-C, LDL-C/HDL-C, increased HDL-C with egg intake. Plasma choline increased dose-dependently with egg intake
Ratliff et al., 2008	28 overweight men aged 40–70 years	USA	Inflamma-tory markers	1 egg/d during 12 wk with CHO restriction diet	Placebo with CHO restriction diet	P	Plasma CRP decreased only in the egg treated group

CVD, cardiovascular disease; T2D, type 2 diabetes; IGT, impaired glucose tolerance; CHD, coronary heart disease; HF, heart failure; CHO, carbohydrate; OR, odds ratio; HR, hazard ratio; CI, confidence interval; DBP, diastolic blood pressure; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol; CRP, C-reactive protein; P, positive result; N, negative result; Null, null result.

one cross-sectional study (Shin et al., 2017) and 2 cohort studies (Virtanen et al., 2015; Woo et al., 2016) reported positive results. However, most RCT showed positive results for metabolic disease in egg consumption. The studies conducted in the USA and other Western countries, where a large amount of eggs are consumed, showed that egg intake has a negative or null impact on metabolic diseases. However, previous studies conducted in Korea have reported that egg intake has a positive effect on metabolic syndrome. Therefore, we conducted the analysis between high egg intake and MetS in Korean adults using a representative national data.

The association between egg consumption and metabolic disease in Korean adults

Table 2 showed the characteristics of this study subjects according to the frequency of egg intake. Frequent egg consumers tended to be younger, consumed more vitamin C, and were male. They were also more likely to regularly perform vigorous physical activity, and have a higher level of education. The characteristics of the study population according to the MetS status are shown in Table 3. Subjects without MetS tended to be younger; had a low BMI; consumed more energy, vitamin C, and egg; and were female. They were also more likely to be non-smokers, and have a higher level of education.

Table 4 shows the association of MetS and MetS components according to frequency of egg consumption. In multivariate models, compared to lower intake (≤1 time/week), an egg intake of 4-6 times or 7 times per week was significantly associated with a lower prevalence of MetS (OR=0.82; 95% CI=0.71-0.95 for 4-6 times/week; OR=0.83; 95% CI=0.69-0.99 for 1 time/day). As for each component of MetS, an egg intake of once daily was associated with lower prevalences of abdominal obesity (OR=0.77; 95% CI=0.63-0.96 for 1 time/day), hyperglyceridemia (OR=0.82; 95% CI=0.72-0.93 for 4-6 times/week), hypertriglyceridemia (OR=0.83; 95% CI=0.73-0.95 for 4-6 times/week), and low HDL cholesterolemia (OR=0.79; 95% CI=0.71-0.89 for 4-6 times/week; OR=0.83; 95% CI= 0.73-0.95 for 1 time/day) after adjusting for age, sex, BMI, energy intake, drinking, smoking, physical activity, education, income, chronic disease status, menopausal status (women only), and survey year. Consuming two or more eggs daily was not associated with MetS or MetS components.

Table 2. Characteristics of participants according to frequency of egg consumption in Korean adults aged 19 years and over

Frequency of egg intake	≤1/mon (n=3,790)	>1/mon – <1/wk (n=2,786)	1/wk (n=4,710)	2-3/wk (n=7,998)	4-6/wk (n=2,869)	1/d (n=1,731)	≥2/d (n=109)	*p*-value
Mean±SE								
Age (years)	60.92 ±0.24	55.23 ±0.28	50.16 ±0.22	46.39 ±0.17	43.14 ±0.28	43.57 ±0.36	40.11 ±1.44	<0.0001
Energy (kcal/d)	1,664.1 ±12.6	1,802.1 ±14.6	1,904.3 ±11.3	1,982.1 ±8.6	1,992.1 ±14.4	2,016.2 ±18.6	1,895.9 ±74.0	<0.0001
Vitamin C (mg/d)	88.09 ±1.52	99.73 ±1.77	105.83 ±1.36	111.27 ±1.04	116.57 ±1.74	114.84 ±2.24	117.94 ±8.93	<0.0001
Calcium intake (mg)	413.35 ±5.16	457.85 ±5.73	488.42 ±4.86	518.21 ±4.26	528.13 ±5.94	554.15 ±8.25	526.46 ±27.28	<0.0001
Body mass index (BMI, kg/m^2)	23.91 ±0.05	23.78 ±0.06	23.68 ±0.05	23.59 ±0.04	23.45 ±0.06	23.15 ±0.08	23.78 ±0.32	<0.0001
Waist circumference (cm)	83.10 ±0.16	82.40 ±0.19	81.57 ±0.14	80.90 ±0.11	79.89 ±0.19	79.09 ±0.24	80.85 ±1.00	<0.0001**
SBP (mmHg)	125.47 ±0.30	122.63 ±0.34	119.22 ±0.26	117.29 ±0.19	115.00 ±0.30	114.69 ±0.39	114.77 ±1.51	<0.0001
DBP(mmHg)	76.96 ±0.17	77.01 ±0.20	76.58 ±0.16	76.29 ±0.12	75.46 ±0.20	74.93 ±0.25	75.46 ±0.88	<0.0001

Table 2. Characteristics of participants according to frequency of egg consumption in Korean adults aged 19 years and over (continued)

Frequency of egg intake		≤1/mon (n=3,790)	>1/mon – <1/wk (n=2,786)	1/wk (n=4,710)	2-3/wk (n=7,998)	4-6/wk (n=2,869)	1/d (n=1,731)	≥2/d (n=109)	*p*-value
Fasting blood glucose (mg/dL)		101.61 ±0.42	100.26 ±0.49	98.37 ±0.35	96.75 ±0.25	94.10 ±0.33	95.01 ±0.50	95.42 ±2.33	<0.0001**
TG (mg/dL)		143.74 ±1.69	139.32 ±2.17	131.38 ±1.52	130.63 ±1.20	117.97 ±1.48	121.34 ±2.30	122.89 ±6.82	<0.0001**
HDL-C (mg/dL)		49.46 ±0.21	50.20 ±0.24	50.86 ±0.18	51.65 ±0.14	52.86 ±0.25	52.92 ±0.32	52.42 ±1.20	<0.0001**
Percent (%)									
Female		64.22	58.94	55.88	57.10	63.02	61.06	55.05	<0.001
Alcohol intake	Non-drinker	23.03	17.73	14.61	11.12	10.63	9.88	11.93	<0.001
	Less than once a month	36.23	34.13	31.89	31.26	34.19	33.39	32.11	
	Over once a month–less than heavy drinker	31.90	38.87	42.21	45.42	43.36	42.81	39.45	
	Heavy drinker[1)]	7.89	8.44	10.30	11.19	11.08	12.54	15.6	
Smoking	Non-smoker	62.80	60.88	58.13	58.41	63.02	59.16	59.63	<0.001
	Past smoker	12.51	12.17	13.82	11.33	10.32	12.42	7.34	
	Current smoker, <1 pack/d	9.68	9.26	10.23	11.97	10.53	11.61	17.43	
	Current smoker, ≥1 pack/d	6.83	8.04	8.39	8.85	7.63	8.78	10.09	
Physical activity	No exerciese	46.02	47.60	47.15	46.19	46.46	44.89	38.53	<0.001
	Regular walk	30.05	30.44	27.64	29.31	29.38	28.54	28.44	
	Regular moderate–activity	9.63	8.44	9.41	7.43	7.39	7.16	11.93	
	Regular vigorous–activity	13.17	12.53	14.80	16.13	15.89	17.62	20.18	
Education	Elementary school	57.84	43.29	27.30	17.69	10.98	9.59	9.17	<0.001
	Middle school	13.06	12.35	13.08	11.09	9.03	7.51	8.26	
	High school	17.07	21.57	27.45	32.38	32.69	33.97	39.45	
	College or higher degree	10.98	21.93	31.53	38.17	46.74	47.78	42.20	
Income	1st (Lowest)	31.00	26.53	22.29	21.38	22.20	20.85	27.52	<0.001
	2nd	24.70	27.42	24.16	24.37	23.77	23.51	26.61	
	3rd	22.40	24.41	25.50	26.21	24.89	25.82	20.18	
	4th (Highest)	19.50	19.38	26.41	26.44	27.74	28.02	22.02	
Chronic disease status[2)]		26.09	21.11	15.37	11.84	7.98	9.24	11.01	<0.0001
Survey year	2007	11.74	11.02	10.04	9.20	9.59	12.54	14.68	<0.0001
	2008	24.72	22.83	23.78	22.63	22.45	20.45	22.94	
	2009	26.36	22.94	26.48	25.42	24.50	28.42	22.02	
	2010	17.99	20.46	20.23	21.78	20.77	19.76	13.76	
	2011	19.18	22.76	19.47	20.97	22.69	18.83	26.61	

All data represent means±standard error or number (%) of participants.

** *p*-values were calculated with log transformation.

1) Heavy drinkers were those who consumed alcohol twice or more per week and had at least seven drinks per occasion (for men) or five drinks per occasion (for women).

2) Those who were diagnosed with or taking medicine for diseases such as diabetes, stroke, myocardial infarction, angina pectoris, chronic renal failure, and cancers.

SBP, systolic blood pressure; DBP, diastolic blood pressure; TG, triglyceride; HDL-C, high-density lipoprotein cholesterol.

Table 3. The characteristics of participants according to metabolic syndrome status in Korean adults aged 19 years and over

Characteristics		Metabolic syndrome (n=5,818)	Non-metabolic syndrome (n=18,175)	*p*-value
Mean±SE				
Age (yr)		59.34±0.17	46.79±0.12	<0.0001
Body mass index (BMI, kg/m^2)		26.1±0.04	22.84±0.02	<0.0001
Energy (kcal/d)		1,836.33±10.16	1,919±5.81	<0.0001
Vitamin C (mg/d)		100.85±1.16	107.81±0.71	<0.0001
Egg consumption (servings/wk)		1.76±0.03	2.38±0.02	<0.0001
Calcium intake (mg)		473.59±5.02	498.69±2.47	<0.0001
Waist circumference (cm)		89.86±0.11	78.56±0.07	<0.0001
SBP (mmHg)		131.13±0.22	115.26±0.12	<0.0001
DBP (mmHg)		81.16±0.14	74.79±0.07	<0.0001
Fasting blood glucose (mg/dL)		112.38±0.41	93.13±0.13	<0.0001
TG (mg/dL)		201.46±1.73	109.29±0.60	<0.0001
HDL-C (mg/dL)		43.53±0.14	53.68±0.09	<0.0001
Percent (%)				
Female		56.89	59.92	<0.0001
Alcohol intake	Non-drinker	20.52	12.32	<0.0001
	Less than once a month	33.31	32.91	
	Once a month–less than heavy drinker	34.14	43.77	
	Heavy drinker[1)]	11.00	10.05	
Smoking	Non-smoker	57.55	60.72	<0.0001
	Past smoker	13.61	11.54	
	Current, <1 pack per day	8.75	11.43	
	Current, ≥pack per day	9.11	7.91	
Physical activity	Do not exercise/walk sometimes	48.40	45.78	<0.0001
	Regularly walk	28.91	29.27	
	Regular moderate-level activity	8.70	8.14	
	Regular vigorous-level activity	13.03	15.74	
Education	Elementary school	46.41	21.40	<0.0001
	Middle school	13.92	10.62	
	High school	21.91	29.85	
	College or higher degree	16.90	37.39	
Income	1st (Lowest)	25.18	23.31	0.0014
	2nd	25.32	24.39	
	3rd	23.98	25.39	
	4th (Highest)	23.53	25.17	
Chronic disease status[2)]		35.84	8.61	
Menopause		46.05	22.27	
Survey year	2007	11.40	9.94	0.0049
	2008	21.97	23.37	
	2009	25.13	25.72	
	2010	20.25	20.48	
	2011	21.26	20.49	

All data represent means±standard error or number (%) of participants.

[1)] Heavy drinkers were those who consumed alcohol twice or more per week and had at least seven drinks per occasion (for men) or five drinks per occasion (for women).

[2)] Those who were diagnosed with or taking medicine for diseases such as diabetes, stroke, myocardial infarction, angina pectoris, chronic renal failure, and cancers.

SBP, systolic blood pressure; DBP, diastolic blood pressure; TG, triglyceride; HDL-C, high-density lipoprotein cholesterol.

Majority of previous studies focused mainly on egg consumption and T2D or CVD and the results were controversial (Djoussé et al., 2010; Hu et al., 1999; Li et al., 2013; Shin et al., 2013). A study of 4,568 African Americans concluded that consumption of five or more eggs per week was associated with a higher prevalence of diabetes mellitus (Smith et al., 2015).

Table 4. Odds ratio (OR) and 95% confidence interval (CI) for metabolic syndrome and individual components according to egg consumption frequency

Metabolic syndrome				
Frequency	Number	Cases	Age, sex-adjusted OR	Multivariate[1)] OR
≤1/mon	3,790	1,369	Reference	Reference
>1/mon - <1/wk	2,786	852	0.98 (0.88-1.10)	1.01 (0.89-1.14)
1/wk	4,710	1,178	0.94 (0.85-1.04)	0.98 (0.87-1.09)
2-3/wk	7,998	1,666	0.89 (0.81-0.98)	0.94 (0.84-1.04)
4-6/wk	2,869	464	0.76 (0.67-0.87)	0.82 (0.71-0.95)
1/d	1,731	270	0.71 (0.60-0.82)	0.83 (0.69-0.99)
≥2/d	109	19	0.97 (0.57-1.64)	0.97 (0.55-1.72)
	p-value for trend		0.171	0.439
Abdominal obesity				
Frequency	Number	Cases	Age, sex-adjusted OR	Multivariate OR
≤1/mon	3,790	1,339	Reference	Reference
>1/mon – <1/wk	2,786	873	0.97 (0.88-1.08)	1.01 (0.87-1.19)
1/wk	4,710	1,276	0.92 (0.83-1.01)	0.92 (0.80-1.06)
2-3/wk	7,998	2,005	0.92 (0.85-1.01)	0.96 (0.84-1.10)
4-6/wk	2,869	661	0.91 (0.81-1.02)	1.03 (0.86-1.22)
1/d	1,731	330	0.70 (0.61-0.81)	0.77 (0.63-0.96)
≥2/d	109	32	1.40 (0.91-2.15)	1.56 (0.84-2.91)
	p-value for trend		0.897	0.462
High blood pressure				
Frequency	Number	Cases	Age, sex-adjusted OR	Multivariate OR
≤1/mon	3,790	2,121	Reference	Reference
>1/mon – <1/wk	2,786	1,379	1.04 (0.93-1.16)	1.05 (0.94-1.18)
1/wk	4,710	1,918	0.94 (0.86-1.04)	0.98 (0.89-1.09)
2-3/wk	7,998	2,819	0.94 (0.86-1.03)	0.99 (0.90-1.09)
4-6/wk	2,869	824	0.86 (0.76-0.97)	0.95 (0.84-1.08)
1/d	1,731	477	0.77 (0.67-0.88)	0.88 (0.76-1.03)
≥2/d	109	28	0.84 (0.52-1.38)	0.86 (0.52-1.43)
	p-value for trend		0.114	0.354

Table 4. Odds ratio (OR) and 95% Confidence interval (CI) for metabolic syndrome and individual components according to egg consumption frequency (continued)

Hyperglyceridemia				
Frequency	Number	Cases	Age, sex-adjusted OR	Multivariate OR
≤1/mon	3,790	1,406	Reference	Reference
>1/mon – <1/wk	2,786	908	0.98 (0.88-1.09)	0.99 (0.89-1.11)
1/wk	4,710	1,348	0.98 (0.89-1.08)	0.98 (0.89-1.09)
2-3/wk	7,998	2,002	0.96 (0.88-1.05)	0.97 (0.88-1.07)
4-6/wk	2,869	553	0.80 (0.70-0.90)	0.82 (0.72-0.93)
1/d	1,731	347	0.81 (0.70-0.94)	0.87 (0.75-1.02)
≥2/d	109	25	1.11 (0.69-1.79)	1.12 (0.69-1.83)
	p-value for trend		0.630	0.842
Hypertriglyceridemia				
Frequency	Number	Cases	Age, sex-adjusted OR	Multivariate OR
≤1/mon	3,790	1,048	Reference	Reference
>1/mon – <1/wk	2,786	702	0.97 (0.86-1.09)	0.98 (0.87-1.10)
1/wk	4,710	1,045	0.90 (0.82-1.00)	0.94 (0.85-1.05)
2-3/wk	7,998	1,578	0.86 (0.78-0.94)	0.89 (0.81-0.99)
4-6/wk	2,869	479	0.77 (0.68-0.88)	0.83 (0.73-0.95)
1/d	1,731	298	0.79 (0.68-0.91)	0.89 (0.76-1.04)
≥2/d	109	25	1.20 (0.76-1.91)	1.22 (0.75-1.97)
	p-value for trend		0.686	0.915
Low HDL- cholesterolemia				
Frequency	Number	Cases	Age, sex-adjusted OR	Multivariate OR
≤1/mon	3,790	1,769	Reference	Reference
>1/mon – <1/wk	2,786	1,119	0.89 (0.81-0.99)	0.90 (0.81-1.00)
1/wk	4,710	1,680	0.84 (0.77-0.93)	0.89 (0.79-1.02)
2-3/wk	7,998	2,674	0.82 (0.76-0.90)	0.86 (0.79-0.95)
4-6/wk	2,869	891	0.76 (0.68-0.85)	0.79 (0.71-0.89)
1/d	1,731	550	0.79 (0.70-0.90)	0.83 (0.73-0.95)
≥2/d	109	35	0.91 (0.60-1.38)	0.83 (0.54-1.29)
	p-value for trend		0.080	0.078

[1)] Multivariate models were adjusted for age (continuous), sex (male or female), BMI (body mass index, continuous), energy intake (continuous), alcohol intake(non-drinker, less than once a month, over once a month-less than heavy drinker, and heavy drinkers), smoking (non-smoker, past smoker, current smoker (<1 pack per day), or current smoker (≥1 pack per day) smoker), physical activity (no exercise, regular walks, regular moderate activity, or regular vigorous activity), education (elementary school, middle school, high school, and college or higher degree), income (four categories on the basis of the equivalized income), chronic disease status (Those who were diagnosed with or taking medicine for diseases such as diabetes, stroke, myocardial infarction, angina pectoris, chronic renal failure, and cancers, yes or no) menopausal status (women only, yes or no), and survey year (2007, 2008, 2009, 2010, 2011).

HDL, high-density lipoprotein.

The Physicians' Health Study I (1982-2007) and the Women's Health Study (1992-2007) indicated that daily egg consumption (≥1 egg/day) was associated with an increased risk for T2D (Djoussé et al., 2009). Similarly, daily egg consumption (≥1 egg/day) was shown to increase heart failure risk by about 30% among Swedish males (Larsson et al., 2015). The China National Nutrition Survey reported that egg consumption of 1>time/day was increased a T2D prevalence (OR=2.28) in women and that plasma triglyceride and total cholesterol levels were significantly higher in women taking two or more eggs per week (Shi et al., 2011).

A Korean study reported that consuming ≥3 eggs per week decreased risk for MetS in middle and elderly Korean living in rural areas (RR=0.46 for men, RR=0.54 for women) (Woo et al., 2016). Moreover, Shin et al. (2017) reported that consumption of more than one egg per day was decreased MetS risk compared to those who consumed <1 egg per week in Korean women (OR=0.70). Unfortunately, a gender-stratified analysis was not carried out in this study as there was only a very small number of subjects in the daily egg intake group.

Egg is a nutrient-dense food containing high-quality protein, vitamins, minerals and several bioactive components such as phospholipids, sphingomyelin, lutein, zeaxanthin, and folate. These components regulate lipid absorption, hepatic lipid metabolism and help to increase HDL-C levels (Blesso et al., 2013c; Blesso, 2015). Although eggs are high in cholesterol, with the exact same egg intake, the response to dietary cholesterol may vary depending on the individual (Austin, 1994; Ballesteros et al., 2015). Pyorala (1987) suggested that individual bodies react differently to the type and amount of dietary cholesterol and to avoid excess accumulation of cholesterol in human bodies, compensation mechanisms such as inhibition of cholesterol synthesis or increase of cholesterol emission may occur. Different results on the association between egg consumption and cardio-metabolic risk were likely due to differences in diet intake patterns across countries. Most Koreans obtain 60% or more of their total energy intake from carbohydrates (https://knhanes.cdc.go.kr/knhanes/eng/index.do) and rice is the staple food. Blood glucose level is easily increased with such dietary habits, which is one of the risk factors for MetS. Although, egg intake has been increasing gradually up to about five times in the past 50 years (4.2 g/day in 1969, 26.3 g/day in 2011) (Ministry of Health and Welfare, 2001; Sook, 2003), egg consumption of Koreans remains lower than that of Americans (26.3 g/day in Korea vs. 40.5 g/day in the USA in 2011, respectively). Thus, the effect of egg cholesterol on MetS could be less than that for Western countries.

A recent study suggests that eggs can be used as part of a healthy diet in both the general population and the CVD risk group (Fuller et al., 2015b). Moreover, the World Health Organization (WHO, 2002) has reported that it is not necessary to limit egg yolk intake if fat and meat intake are controlled.

Our study has several strengths. First, this study is the first to evaluate the association between the consumption of two or more eggs per day and MetS in Korean adults. Secondly, our data is from a national sample of Korean adult population. Furthermore, there may have been less measurement errors because anthropometric data were measured using standardized equipment by well-trained health-care professionals.

One of the limitations of our study was that the data was obtained from a cross-sectional survey; hence, a causal-relationship cannot be proven and the effect of confounders cannot be completely eliminated even though the results of this study were adjusted for potential confounding factors. In addition, unintentional bias, such as recall errors may exist since the KNHANES nutrition survey is dependent on the subjects' memory and honesty.

Conclusion

Studies conducted abroad have concluded that the relationship between egg consumption and metabolic diseases has been controversial. However, studies conducted in Korea have reported positive effects of egg consumption on metabolic syndrome. This study also suggests that egg consumption of 4-7 times per week was associated with a lower prevalence of MetS, and consuming eggs twice or more daily was not associated with a reduced risk for MetS in Korean adults. These results suggest that frequent egg consumption has a beneficial effect on MetS in Korean adults.

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