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Association of eggs with dietary nutrient adequacy and cardiovascular risk factors in US adults

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Abstract

Objective: Whole eggs are rich sources of several micronutrients. However, it is not well known how egg consumption contributes to overall nutrient adequacy and how it may relate to CVD risk factors. Therefore, the present study aimed to determine how whole egg consumption contributes to nutrient intakes and to assess its association with CVD risk factors in US adults.
Design: Cross-sectional study.
Setting: The study was conducted using data from the National Health and Nutrition Examination Survey (NHANES) 2003–2012, a nationally representative survey of the US civilian population.
Participants: Adults who completed two dietary recalls and provided information on relevant sociodemographic factors were included in the study (*n* 21 845).
Results: Approximately 73 % of adults were classified as whole egg consumers. Egg consumption was associated with greater intakes of protein, saturated fat, mono- and polyunsaturated fats, Fe, Zn, Ca, Se, choline, and several other vitamins and minerals. Egg consumption was associated with a higher likelihood of meeting or exceeding recommendations for several micronutrients. Egg intake was positively associated with dietary cholesterol consumption, but not with serum total cholesterol (TC) when adjusted for multiple potential confounders. In multiple linear regression analyses, TAG, TAG:HDL-cholesterol and TC:HDL-cholesterol were significantly lower with greater egg consumption. Egg consumption had no significant relationship with LDL-cholesterol or C-reactive protein, but was associated with higher BMI and waist circumference.
Conclusions: Whole eggs are important dietary contributors of many nutrients and had either beneficial or non-significant associations with most CVD risk biomarkers examined.

Keywords
National Health and Nutrition Examination Survey
US adults
Eggs
CVD
Cholesterol
Nutrient adequacy

CVD is a public health crisis in the USA and is currently cited as an underlying cause of one out of every three deaths in the USA(1). Diet is well recognized as a major lifestyle factor that can influence CVD risk, but public perceptions and scientific guidance regarding the most heart-healthy eating patterns has evolved over time. In particular, eggs have undergone major shifts in perceived suitability for a heart-healthy diet in recent decades. While eggs are good sources of high-quality protein and many key micronutrients including choline, carotenoids, Se, and vitamins A and D, eggs also contain roughly 200 mg of cholesterol each, which has been flagged as a potential problem for those at risk for CVD since high blood cholesterol levels are an important risk factor for the disease(2).

The 2015–2020 Dietary Guidelines for Americans no longer include the 300 mg recommended daily limit for dietary cholesterol from previous editions, but still advise Americans to 'eat as little dietary cholesterol as possible while consuming a healthy eating pattern'(3). Removal of this limit is reflective of recent studies reporting that lowering dietary cholesterol may have relatively little effect on serum LDL-cholesterol (LDL-C), especially in comparison to other more efficacious dietary strategies(4). However, a recent meta-analysis of forty interventional and prospective cohort studies on this topic indicated that dietary cholesterol should not be completely disregarded as a CVD risk factor(5). That analysis showed that dietary cholesterol was not associated with increased risk of incident CVD, yet it statistically significantly increased serum total cholesterol (TC), LDL-C and the ratio of LDL-C to HDL-cholesterol (HDL-C). Importantly, results across studies in the meta-analysis were heterogeneous, and experts have suggested that adopting healthy dietary patterns

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should be emphasized over simply adhering to dietary cholesterol limits[6].

Therefore, eggs may be suitable for inclusion in a healthy dietary pattern, especially since they contain high-quality protein and several of the nutrients of concern for underconsumption outlined in the 2015–2020 Dietary Guidelines for Americans, including Ca, Fe, Mg, K, and vitamins A, D and E. However, it is not well established how eggs contribute to overall nutrient adequacy among Americans and whether their consumption is related to CVD risk in US adults. An analysis of data from the National Health and Nutrition Examination Survey (NHANES III, 1988–1994) showed that egg consumers tended to have greater intakes of most key micronutrients compared with non-consumers and that egg consumption was associated with lower serum TC concentration[7]. However, that analysis did not examine the relationship between egg intake and other biomarkers of CVD risk. Additionally, other studies have reported that Americans' egg consumption patterns have changed significantly in the last decade, and that overall per capita egg consumption increased by 11 % from 2001–2002 to 2011–2012[8]. Given the current public health significance of CVD in the USA, and in light of shifting dietary patterns and nutritional recommendations, it is necessary to examine how eggs fit into Americans' diets and how they may be related to CVD risk. Therefore, the overall goal of the present study was to assess the nutritional significance of eggs in the American diet and to estimate the association between whole egg consumption and CVD risk factors. The central hypothesis of the study was that increased whole egg consumption is positively associated with nutrient adequacy of micronutrients such as folate, vitamin B_{12}, vitamin E, lutein plus zeaxanthin, Se and choline, and that an inverse association will be observed between egg intake and CVD risk related to increased concentrations of these nutrients as well as improved CVD risk biomarkers.

Methods

Participants

The present study utilized data from US adults aged 19 years or older from NHANES 2003–2012. NHANES uses a stratified, multistage probability sampling design with weighting to allow for nationally representative estimates to be generated for the civilian non-institutionalized US population. Response rates in NHANES generally vary from 70 to 80 %, and sampling weights are created to account for differential probabilities of selection and non-response[9,10]. Exclusion criteria for the current analysis were women who were pregnant or lactating, those whose dietary recalls were coded as unreliable or incomplete, women taking oestrogen replacement therapy, and those whose recalls were coded as 'much more than usual' or 'much less than usual' so as to obtain the most accurate assessment of usual intake.

Dietary intake data

Nutrient intakes were estimated from 24 h dietary recall interviews conducted in NHANES 2003–2012. Dietary recalls were conducted by trained interviewers using the US Department of Agriculture's Automated Multiple-Pass Method. The first dietary recalls were conducted in person at mobile examination centres and the second recalls were conducted by telephone approximately 3–10 d after the first dietary recall. The US Department of Agriculture's National Nutrient Database for Standard Reference (SR) is the major source of food composition data in the USA. The US Department of Agriculture's Food and Nutrient Database for Dietary Studies (FNDDS) is the underlying database used to code dietary intake and to calculate nutrients for NHANES dietary data. Using the nutrient intake data generated in NHANES from these databases, individuals' dietary intakes were classified as either meeting or failing to meet the Estimated Average Requirement, the amount of a nutrient that is estimated to meet the requirement of half of the healthy individuals of a specific age, sex and life stage[11]. There are insufficient data to establish an Estimated Average Requirement for choline and vitamin K, so participants were classified as meeting or failing to meet the Adequate Intake for these nutrients.

Estimation of egg intake

The FNDDS is based on nutrient values in the SR, and the associations between FNDDS foods and items from the SR are documented in NHANES data files. Searching these files allows for the determination of which SR items compose the foods and food mixtures included in FNDDS. To determine participants' whole egg consumption using dietary data from NHANES, the following procedure was applied. First, to find all food codes containing eggs, SR descriptions were searched for 'egg'. SR items that were composed entirely of egg, such as 'egg, whole, cooked, hard-boiled', were assumed to contain 100 % egg. SR descriptions that included the word 'egg' and that contained a mixture of foods were examined further to determine the percentage of egg in the item. The Nutrition Data System for Research (NDSR) software was utilized for this process in addition to searches on popular recipe websites to determine typical egg content for these mixed items. For example, the SR code for the item 'shrimp egg foo yung' was assumed to contain 21·05 % egg by weight based on the standard recipe used in NDSR for the item 'egg foo yung with sauce, with shrimp'. Similar procedures were performed for each distinct SR code containing 'egg' in its name. Foods containing only egg whites, egg yolks or egg substitutes were not included as egg sources in the analysis; only whole egg sources were considered in the definition of egg consumption for the present study. Next, FNDDS food files were searched for foods containing the SR codes designated as containing egg. Using the percentage of egg in each identified SR code and the percentage of the SR code present in the food, the percentage of egg by weight in each food was calculated. Finally, individuals' egg consumption was calculated by summing the egg weight contributed by each food recorded in the dietary recall.

CVD risk factors and biochemical analyses

Waist circumference (WC), height, weight and blood pressure were measured in mobile examination centres. Using height and weight values, BMI was calculated as kg/m^2. Blood nutrient concentrations as well as TC, TAG, HDL-C and C-reactive protein were measured following the methods described in the NHANES laboratory procedures[12]. LDL-C was calculated using the Friedewald formula: LDL-C = TC − HDL-C − TAG/5[2]. Ratios of TC to HDL-C and TAG to HDL-C were also calculated.

Statistical analysis

Statistical analyses were conducted with the statistical software package SAS version 9.4 and the Survey Data Analysis for multistage sample designs professional software package (SUDAAN; Research Triangle Institute, Research Triangle Park, NC, USA), using SAS survey procedures including the appropriate weight, strata, domain and cluster variables to account for the complex survey design used in NHANES. Egg consumption was categorized into tertiles according to the distribution of participants. The χ^2 test was used to assess the distribution of categorical variables. ANOVA was used to compare means for interval-scale variables and to test differences in egg consumption by sociodemographic and lifestyle characteristics. Arithmetic means of micronutrient intakes of sociodemographic subgroups were calculated, and standard errors were calculated by the linearization (Taylor series) variance estimation method for population parameters in SUDAAN. ANOVA and t tests were used to compare means for interval-scale variables and to test differences between egg consumption groups. Mean blood nutrient concentrations and CVD risk factors by level of egg consumption were also calculated after log transformation. Multivariate linear regression analyses were performed to determine correlations between egg consumption and cardiovascular risk markers while controlling for other potential confounders including dietary factors that could be correlated with egg intake such as saturated fat and total energy intakes. P values reported were two-tailed and statistical significance was defined as $P < 0{\cdot}05$.

Results

Approximately 73 % of adults were classified as whole egg consumers, with mean intake of 43·1 (se 1·0) g/d among all adults and 59·3 (se 1·3) g/d among egg consumers. Distribution of egg intake was skewed to the right, with a median egg intake of 27·6 g/d among egg consumers. Differences in egg consumption patterns were noted among adults of different socio-economic and demographic groups (Table 1). Men were more likely than women to be high consumers of eggs, and those in older age groups were more likely to be egg consumers than those in younger age groups. Differences in egg consumption patterns also existed among ethnicities, with African Americans consuming eggs more frequently than any other group. Dietary supplement users were also more likely to be egg consumers than those not taking dietary supplements. Adults with CHD or diabetes were more likely to consume eggs than those without these diseases, and those who were overweight or obese were more likely to consume eggs than those with a BMI under 25 kg/m^2. Higher incomes and alcohol intake were positively associated with egg intake, while cigarette smoking and physical activity appeared to be negatively associated with egg consumption.

Higher consumption of eggs was associated with greater intakes of most essential vitamins and minerals examined after adjusting for gender, ethnicity, age, alcohol consumption, smoking status, dietary supplement use, total energy intake, income and physical activity level (Table 2). With adjustment for the same confounders, egg consumption was also associated with a lower prevalence of falling below the Estimated Average Requirement or Adequate Intake (Table 3). Egg consumption appeared to have the strongest relationship with the likelihood of meeting nutrient recommendations for choline, vitamin A and vitamin B_{12}. For these nutrients, the prevalence of meeting the intake recommendation was 26·5, 13·3 and 10·7 percentage points greater among high consumers of eggs compared with non-consumers, respectively.

Egg consumption was not significantly associated with blood nutrient concentrations of most nutrients examined, except for positive trends with serum folate, erythrocyte folate, and lutein plus zeaxanthin (Table 4). After adjusting for gender, race, alcohol consumption status, smoking status, dietary supplement use, age, total energy intake, BMI, income, physical activity, diabetes, CHD and arthritis, there were no significant trends across tertiles of egg consumption for any of the CVD risk factors examined except apo B, which was highest among the middle tertile of egg consumers (Table 4).

In multivariable linear regression models, egg intake showed no significant association with systolic or diastolic blood pressure, HDL-C, LDL-C, TC or C-reactive protein after adjusting for several potential confounders (Table 5). Greater egg consumption was associated with statistically significant decreases in TAG, and modest but statistically

Table 1 Sociodemographic, lifestyle and health-related characteristics by level of egg consumption among US adults aged ≥19 years, National Health and Nutrition Examination Survey (NHANES) 2003–2012 (*n* 21 845)

		Level of egg consumption								
		Non-consumers		Tertile 1		Tertile 2		Tertile 3		
Characteristic	Total *n*	*n*	Weighted %	*n*	Weighted %	*n*	Weighted %	*n*	Weighted %	*P* value*
Total	21 845	5871		5320		5334		5320		
Gender										<0·0001
Men	11 329	3003	27·1	2515	22·9	2754	24·4	3057	25·6	
Women	10 516	2868	27·7	28	28·3	2882	26·5	1901	17·5	
Age (years)										<0·0001
19–39	7668	2302	30·7	1821	24·6	1899	24·4	1646	20·4	
40–59	6725	1761	26·7	1586	24·7	1767	26·5	1611	22·2	
≥60	7452	1808	23·6	1973	28·2	1970	25·6	1701	22·7	
Ethnicity										<0·0001
Non-Hispanic White	10 633	2943	28·0	2849	26·5	2696	25·1	2145	20·4	
Non-Hispanic Black	4459	998	22·0	1151	26·4	1206	27·5	1104	24·1	
Mexican-American & Hispanic	5321	1514	28·3	1057	19·7	1390	25·0	1360	27·0	
Others	1432	416	27·2	323	24·1	344	27·6	349	21·0	
Income†										0·0030
PIR < 1·30	7874	2308	30·0	1811	23·9	1911	24·0	1844	22·1	
1·30 ≥ PIR ≤ 3·50	7715	2010	27·1	1922	25·8	2033	25·4	1750	21·7	
PIR > 3·50	6256	1553	26·0	1647	26·3	1692	26·5	1364	21·3	
BMI (kg/m^2)										0·0003
BMI < 18·5	672	202	33·9	175	27·0	163	23·4	132	15·7	
18·5 ≤ BMI < 25·0	6299	1731	28·2	1595	26·6	1622	25·7	1351	19·6	
25 ≤ BMI < 30·0	7288	1951	27·4	1825	25·9	1840	24·9	1672	21·8	
BMI ≥ 30·0	7586	1987	26·1	1785	24·1	2011	26·1	1803	23·8	
Alcohol consumption										<0·0001
≥12 drinks per year	14 224	3729	27·0	3416	25·0	3619	25·1	3460	22·9	
<12 drinks per year	5520	1513	27·7	1453	27·4	1499	27·0	1055	18·0	
Smoking status‡										0·0077
Current smoker	4559	1296	28·8	1057	25·1	1072	23·4	1134	22·7	
Current non-smoker	17 285	4574	27·0	4323	25·7	4564	26·0	3824	21·3	
Dietary supplement use§										0·0053
Yes	10 491	2647	26·2	2684	26·1	2789	26·3	2371	21·5	
No	11 341	3221	28·7	2694	25·0	2843	24·6	2583	21·8	
Physical activity level‖										0·0004
1	5720	1489	25·5	1398	25·8	1448	24·3	1385	24·5	
2	2773	763	27·6	695	26·3	684	24·6	631	21·5	
3	2891	833	30·7	695	24·4	684	23·1	679	21·8	
4	2843	822	28·5	648	24·6	630	21·4	743	25·5	
CHD										0·0103
Yes	950	213	23·1	267	30·1	239	24·7	231	22·2	
No	20 018	5357	27·4	4895	25·4	5206	25·6	4560	21·6	
Diabetes										0·0009
Yes	2549	612	24·4	579	22·7	673	27·0	685	26·0	
No	18 892	5159	27·7	4705	25·8	4855	25·4	4173	21·2	
Arthritis										0·0003
Yes	5808	1446	24·9	1560	27·7	1519	24·7	1283	22·7	
No	15 209	4137	28·0	3616	24·5	3940	24·2	3516	23·3	

PIR, poverty income ratio.
**P* values determined from χ^2 test between subgroups.
†Income assessed as ratio of the median family income to the poverty index. A PIR < 1·30 is required to be eligible for food assistance programmes and a PIR < 1·85 is required to be eligible for the Special Supplemental Nutrition Program for Women, Infants, and Children.
‡Current smokers defined as those currently smoking cigarettes on at least 'some days'.
§Dietary supplement use defined as those taking any dietary supplements including vitamins, minerals or other dietary supplements at the time of interview.
‖Physical activity levels, expressed using the MET (metabolic equivalent of task) score, were calculated by combining the intensity level of the leisure-time activities reported, mean duration and frequency.

significant decreases in TAG:HDL-C and TC:HDL-C. Egg consumption was also associated with statistically significant increases in both WC and BMI.

Discussion

The present study demonstrates that whole egg consumption is associated with greater likelihood of meeting nutrient recommendations for many key micronutrients. As has been documented previously, the present study shows that a large proportion of Americans fail to meet recommended intakes for many nutrients[13,14], but the results also indicate that the likelihood of meeting the Estimated Average Requirement or Adequate Intake for many nutrients is significantly higher than among whole egg consumers than among non-consumers, especially for choline, vitamin A, vitamin B_{12}, Zn and riboflavin. This is

Table 2 Mean daily nutrient intakes by level of egg consumption among US adults aged ≥19 years, National Health and Nutrition Examination Survey (NHANES) 2003–2012 (*n* 21 845)

Nutrient	Level of egg consumption: All (*n* 21 845)	Non-consumers (*n* 5871)	Tertile 1 (*n* 5320)	Tertile 2 (*n* 5334)	Tertile 3 (*n* 5320)	*P* for trend*
Egg intake (g/d), mean	43·1	0·0	4·5	28·0	152·0	<0·0001
Range	0·0–1761·4	0·0–0·0	0·1–10·7	10·7–55·6	55·6–1761·4	
Macronutrients and lipids						
Protein (g/d)	84·9	78·8	78·6	87·8	95·8	<0·0001
Carbohydrates (g/d)	262·9	251·3	258·3	273·4	270·9	<0·0001
Total fat (g/d)	81·7	71·8	75·7	85·4	95·9	<0·0001
Saturated fat (g/d)	26·82	24·0	24·5	27·9	31·5	<0·0001
Monounsaturated fat (g/d)	29·81	26·1	27·6	31·1	35·3	<0·0001
Polyunsaturated fat (g/d)	17·99	15·6	17·2	18·9	20·8	<0·0001
Cholesterol (mg/d)	290·3	178·8	199·6	300·5	510·5	<0·0001
Vitamins						
Vitamin A (μg/d)	660·7	614·7	632·5	651·9	755·1	<0·0001
Thiamin (mg/d)	1·7	1·7	1·6	1·8	1·8	<0·0001
Riboflavin (mg/d)	2·3	2·1	2·1	2·3	2·6	<0·0001
Niacin (mg/d)	26·1	25·7	25·4	26·7	26·9	<0·0001
Folate (μg DFE/d)	568·4	562·1	561·1	580·8	570·9	<0·0001
Vitamin B_6 (mg/d)	2·1	2·1	2·1	2·1	2·2	<0·0001
Vitamin B_{12} (mg/d)	5·5	5·3	5·3	5·4	6·2	0·0108
Vitamin D (μg/d)	4·9	4·4	4·5	4·8	5·9	<0·0001
Vitamin E (mg α-TE/d)	109·6	105·2	107·1	113·0	113·8	0·0045
Vitamin K (μg/d)	109·6	105·2	107·1	113·0	113·8	0·80
Minerals						
Mg (mg/d)	303·2	295·1	291·7	306·7	321·6	<0·0001
P (mg/d)	1394·1	1311·0	1294·3	1426·0	1567·8	<0·0001
Fe (mg/d)	970·0	947·8	916·2	981·6	1042·9	<0·0001
Ca (mg/d)	970·0	947·8	916·2	981·6	1042·9	<0·0001
Zn (mg/d)	12·3	11·8	11·8	12·5	13·3	0·0420
Se (μg/d)	114·8	101·1	103·7	121·5	136·1	<0·0001
Carotenoids						
Lycopene (μg/d)	5849·9	5346·8	5645·2	6502·3	5985·2	0·0036
Lutein + zeaxanthin (μg/d)	1573·6	1459·4	1508·4	1579·3	1773·9	0·0019
α-Carotene (μg/d)	453·5	446·8	453·7	432·2	405·9	0·25
β-Carotene (μg/d)	2260·2	2261·2	2303·3	2250·7	2222·2	0·43
β-Cryptoxanthin (μg/d)	106·4	97·0	103·0	112·7	114·6	0·54
Other components						
Choline (mg/d)	336·5	270·7	278·7	341·6	470·8	<0·0001

DFE, dietary folate equivalents; α-TE, α-tocopherol equivalents.
*Adjusted for gender, ethnicity, age, alcohol consumption status, smoking status, dietary supplement use, total energy intake, income and physical activity level.

in agreement with an older analysis that examined NHANES III data collected during 1988–1994, showing that eggs were an important source of many micronutrients in the American diet[7]. Similarly, other work examining NHANES data has demonstrated that high-quality protein sources such as eggs are vital for achieving protein recommendations as well as micronutrient recommendations[15].

Other studies have indirectly examined the nutritional contribution of eggs to American diets by comparing the diets of individuals with different breakfast choices. Two studies examining adults' breakfast patterns using NHANES data suggested that breakfast patterns consisting of ready-to-eat cereals, grains, low-fat dairy and fruit were associated with better overall nutritional quality than breakfast patterns that included eggs[16,17]. Conversely, the present study, which accounts for egg consumption at all eating occasions, suggests that egg consumers may be more successful in achieving the recommendations for key micronutrients than those who avoid eggs. This apparent discrepancy is indicative of the wide variability in egg consumption patterns and may suggest that consumption of eggs at different eating occasions may be associated with varied accompanying dietary choices.

The present study also differs from several previous reports due to its inclusion of a wider variety of egg sources. In FNDDS, each food is assigned to one of nine major food groups: (i) milk products, (ii) meat/poultry/fish, (iii) eggs, (iv) legumes/nuts/seeds, (v) grain products, (vi) fruits, (vii) vegetables, (viii) fats/oils and (ix) sweets/beverages. Whereas many previous studies examining egg intake considered only foods categorized in the egg food group[7,8], the present study includes many additional sources of eggs that may fall into other food groups such as egg-containing sandwiches, soups, pies or other mixed dishes. Therefore, the more exhaustive methods used in the present study may provide a more accurate assessment of Americans' egg consumption.

While these results show that whole eggs contribute meaningfully to the micronutrient intakes of many

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Table 3 Percentage of US adults aged ≥19 years falling below dietary micronutrient recommendations by level of egg consumption, National Health and Nutrition Examination Survey (NHANES) 2003–2012 (*n* 21 845)*,†

	Level of egg consumption					
Nutrient	All (*n* 21 845)	Non-consumers (*n* 5871)	Tertile 1 (*n* 5320)	Tertile 2 (*n* 5334)	Tertile 3 (*n* 5320)	*P* for trend
Vitamin D	93·4	93·6	94·5	94·0	91·4	0·07
Choline	88·6	95·8	96·0	91·0	69·3	<0·0001
Vitamin E	84·9	87·0	86·2	84·7	81·1	0·27
Vitamin K	69·6	74·7	69·4	65·2	68·4	0·0006
Mg	57·5	59·6	59·6	55·7	53·9	<0·0001
Vitamin A	51·9	57·3	54·2	50·8	44·0	<0·0001
Ca	49·4	50·9	54·0	48·7	43·4	<0·0001
Zn	25·7	29·4	28·5	23·9	20·3	<0·0001
Vitamin B_6	20·3	22·4	22·2	20·1	15·8	0·07
Folate	21·7	26·1	22·9	18·5	18·4	0·0088
Thiamin	15·1	19·5	16·2	12·4	11·6	0·73
Vitamin B_{12}	14·7	18·6	18·3	13·3	7·9	<0·0001
Riboflavin	7·4	11·6	9·2	5·3	2·8	<0·0001
Niacin	6·8	8·5	7·0	5·8	5·8	0·0002
Fe	6·7	10·4	7·1	5·2	3·7	<0·0001
Se	4·8	8·5	5·9	2·9	1·2	<0·0001
P	4·2	6·4	5·5	2·8	1·2	<0·0001

*Based on the Estimated Average Requirement, or Adequate Intake when an Estimated Average Requirement has not been established (choline and vitamin K).
†Adjusted for gender, ethnicity, age, alcohol consumption status, smoking status, dietary supplement use, total energy intake, income and physical activity level.

Americans, the results show that egg consumption is not related to blood nutrient concentrations for many of the nutrients examined. This is not unexpected, as blood concentrations of many of the nutrients assessed, such as Ca and P, are tightly controlled through homeostatic mechanisms[18,19]. One notable exception is the significant, positive association between egg intake and plasma lutein plus zeaxanthin. Lutein and zeaxanthin are believed to prevent damage that can lead to age-related macular degeneration[20], and may also exert neuroprotective effects through reduction of oxidative stress and inflammation[21]. In addition to higher total intakes of lutein plus zeaxanthin in higher egg consumers, the positive trend in plasma level of these carotenoids with egg consumption may also be related to the high bioavailability of lutein and zeaxanthin from eggs compared with other top sources such as kale, spinach, peas and brussels sprouts[20]. Egg consumption was also positively associated with both serum folate and erythrocyte folate, two biomarkers that are known to be influenced by diet as well as physiological factors including age and disease state[22]. Therefore, because folate consumption tended to be greater in adults with greater egg intake, it is unsurprising that erythrocyte folate, which is particularly useful as an indicator of long-term folate status, was strongly associated with whole egg consumption in the present study.

The association of whole egg intake with biomarkers of CVD risk was mixed in the present study, which suggests that whole egg consumption is not associated with blood pressure or blood concentrations of TC, HDL-C, LDL-C, insulin or fasting glucose. Egg intake was inversely associated with serum TAG in multivariable regression models, but egg consumption was also associated with higher BMI and WC. Overall, these findings add to a growing body of complex and inconsistent data on this topic. A recent meta-analysis examining forty studies on this topic published from 1979 to 2013 pointed out that the available literature is highly heterogeneous, and that the data are insufficient for drawing well-supported conclusions regarding the effects of egg intake or dietary cholesterol on CVD risk[5]. Another systematic review of the most recent literature (2005–2015) reported that egg consumption tends to be related to non-significant increases in CVD risk factors in interventional trials, and that among observational studies, there is no consensus of any association between egg consumption and CVD risk[23].

Other meta-analyses, however, have indicated that egg consumption may either protect against or have no relationship with CVD risk. A 2016 meta-analysis showed that ‘high’ consumption of eggs (usually defined as one egg daily) was associated with a 12 % reduction in stroke risk compared with low egg intake (usually defined as less than two eggs weekly) based on data from seven prospective cohort studies[24]. That analysis also investigated the relationship between egg intake and CHD risk, and found no clear association among seven prospective cohorts. A 2013 meta-analysis of prospective cohort studies found that consumption of up to one egg per day was not associated with risk of either stroke or CHD[25]. Furthermore, a 2018 meta-analysis showed that higher egg consumption (7+ eggs/week) had no association with

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Table 4 Mean blood nutrient, lipid and glucose levels by level of egg consumption among US adults aged ≥19 years, National Health and Nutrition Examination Survey (NHANES) 2003–2012 (*n* 21 845)*,†

		Level of egg consumption								
		Non-consumers		Tertile 1		Tertile 2		Tertile 3		
	Total *n*	Mean	SE	Mean	SE	Mean	SE	Mean	SE	*P* for trend
Nutrients										
Fe (μg/dl)	20 594	79·8	1·01	79·8	1·01	80·6	1·01	80·6	1·01	0·14
Zn (μmol/l)	1344	12·4	1·01	12·5	1·02	12·7	1·02	12·7	1·01	0·82
P (mg/dl)	20 605	3·7	1·00	3·7	1·00	3·7	1·00	3·7	1·00	0·20
K (mmol/l)	20 606	4·0	1·00	4·0	1·00	4·0	1·00	4·0	1·00	0·16
Ca (mmol/l)	20 608	9·5	1·00	9·5	1·00	9·5	1·00	9·5	1·00	0·07
Se (μg/l)	3657	131·6	1·01	133·0	1·01	134·3	1·01	133·0	1·01	0·08
Vitamin A (μg/dl)	7197	58·6	1·01	57·4	1·01	59·1	1·01	58·6	1·01	0·09
Vitamin B_6 (nmol/l)	16 510	49·9	1·02	49·4	1·02	49·9	1·02	49·4	1·02	0·71
Vitamin B_{12} (pmol/l)	11 080	487·8	1·02	478·2	1·01	478·2	1·01	487·8	1·02	0·30
Serum folate (nmol/l)	20 661	14·0	1·01	15·0	1·02	14·6	1·01	15·0	1·01	0·0321
Erythrocyte folate (ng/ml)	20 803	387·6	1·01	387·6	1·02	379·9	1·01	391·5	1·01	0·0021
α-Carotene (μg/dl)	7193	2·7	1·04	2·7	1·04	2·8	1·04	2·6	1·05	0·88
β-Carotene (μmol/l)	3561	11·8	1·06	12·9	1·06	12·7	1·05	11·6	1·04	0·63
β-Cryptoxanthin (μg/dl)	7171	7·2	1·03	7·0	1·02	7·2	1·03	7·2	1·03	0·18
Lycopene (μg/dl)	7153	38·5	1·02	37·0	1·02	39·3	1·02	38·1	1·02	0·15
Lutein + zeaxanthin (μg/dl)	7179	13·5	1·03	13·7	1·02	14·4	1·02	15·2	1·02	< 0·0001
25(OH)D (nmol/l)	8848	62·8	1·01	63·4	1·02	62·2	1·02	62·2	1·02	0·67
Vitamin E (μmol/l)	7197	1199·9	1·02	1199·9	1·01	1236·5	1·01	1236·5	1·02	0·41
Blood lipids and glucose markers										
TC (mg/dl)	20 684	192·5	1·00	192·5	1·00	192·5	1·00	192·5	1·00	0·50
TAG (mg/dl)	10 074	114·4	1·01	113·3	1·02	113·3	1·02	114·4	1·02	0·34
HDL-C (mg/dl)	17 013	50·4	1·01	50·9	1·01	50·4	1·01	49·9	1·01	0·36
LDL-C (mg/dl)	9851	110·0	1·01	110·0	1·01	110·0	1·01	110·0	1·01	0·84
TC:HDL-C	17 013	3·8	1·01	3·8	1·01	3·8	1·01	3·9	1·01	0·53
TAG:HDL-C	8334	2·3	1·01	2·2	1·01	2·2	1·02	2·3	1·02	0·37
LDL-C:HDL-C	8158	2·1	1·01	2·1	1·01	2·1	1·01	2·1	1·01	0·35
Fasting glucose (mg/dl)	10 156	101·5	1·01	100·5	1·01	101·5	1·01	104·6	1·01	0·16
Insulin (uU/ml)	9965	9·3	1·02	9·2	1·02	9·3	1·02	9·8	1·02	0·57
Apo B (mg/dl)	8356	90·0	1·01	90·0	1·01	90·9	1·01	89·1	1·01	0·0021

25(OH)D, 25-hydroxyergocaciferal (25-hydroxyvitamin D_2) + 25-hydroxycholecalciferol (25-hydroxyvitamin D_3); TC, total cholesterol; HDL-C, HDL-cholesterol; LDL-C, LDL-cholesterol.
*Data presented as mean and SE after log transformation.
†Analyses adjusted for gender, race, alcohol consumption status, smoking status, dietary supplement use, age, total energy intake, BMI, income, physical activity, diabetes, CHD and arthritis.

Table 5 Association between cardiovascular disease risk factors and egg consumption among adults aged ≥ 19 years, National Health and Nutrition Examination Survey (NHANES) 2003–2012 (*n* 21 845)

	Estimated difference in CVD risk factor with additional consumption of one egg*					
	Model 1†			Model 2‡		
	Difference	95 % CI	*P* value	Difference	95 % CI	*P* value
Blood pressure (mmHg)						
Systolic	−0·01	−0·14, 0·13	0·94	0·01	−0·14, 0·16	0·88
Diastolic	0·05	−0·06, 0·16	0·41	0·08	−0·03, 0·19	0·16
WC (cm)	0·32	0·14, 0·51	0·0009	0·25	0·07, 0·44	0·0069
BMI (kg/m^2)	0·14	0·05, 0·22	0·0017	0·11	0·03, 0·19	0·0080
HDL-C (mg/dl)	0·07	−0·02, 0·16	0·14	0·08	−0·02, 0·17	0·12
LDL-C (mg/dl)	−0·24	−0·62, 0·14	0·22	−0·18	−0·54, 0·18	0·33
TC (mg/dl)	−0·32	−0·68, 0·03	0·07	−0·29	−0·66, 0·08	0·12
TAG (mg/dl)	−1·67	−2·74, −0·60	0·0025	−1·75	−2·87, −0·63	0·0025
TAG:HDL-C	−0·04	−0·07, −0·01	0·0203	−0·04	−0·08, −0·01	0·0190
TC:HDL-C	−0·02	−0·02, −0·01	0·0005	−0·02	−0·03, −0·01	0·0011
CRP (mg/l)	0·00	−0·02, 0·01	0·63	−0·01	−0·02, 0·01	0·35

WC, waist circumference; HDL-C, HDL-cholesterol; LDL-C, LDL-cholesterol; TC, total cholesterol; CRP, C-reactive protein.
*Based on additional consumption of one medium egg (44 g) per day.
†Model 1: adjusted for age, gender, ethnicity, physical activity, income, smoking, alcohol consumption, BMI, energy intake and dietary supplement use (no adjustment for BMI when assessing BMI and WC).
‡Model 2: model 1 with additional adjustment for saturated fat intake, fibre intake, arthritis, CHD and diabetes.

CVD or all-cause mortality, and that it was associated with a slight but statistically significant reduction in stroke risk[26].

Although much research indicates that eggs are either associated with modest protective effects in relation to CVD risk or have no association with CVD risk, some studies have raised concerns that egg consumption should be approached more cautiously in those at risk for diabetes[24,27]. One meta-analysis found an increased risk of CHD associated with egg intake among diabetic patients (relative risk associated with one-egg increase = 1·54; 95 % CI 1·14, 2·09), but statistical power was limited in this subgroup due to a limited number of studies[25]. Another report examining six original studies of egg consumption and CVD risk in patients with or at risk for type 2 diabetes concluded that consumption of up to twelve eggs weekly had no effect on major CVD risk factors including TC, LDL-C, TAG, fasting glucose, insulin and C-reactive protein[28]. Another review has pointed out that in most studies, egg consumption has had no negative effects on glycaemic control when tested in various populations including those who are obese or diabetic[29]. Therefore, more research is needed to clarify inconsistencies between studies, but there is currently insufficient evidence to support egg restriction among diabetics or those at risk for diabetes to reduce CVD risk[30].

One surprising finding of the present study was that egg consumption was positively associated with both BMI and WC. Several studies have suggested that eggs may actually be useful for weight management through promotion of satiety. In both children and adults it was shown that after an egg-based breakfast, people consumed significantly less energy later in the day than when consuming an isoenergetic grain-based breakfast such as cereal, oatmeal or bagels[31,32]. Multiple studies have also indicated that egg consumption at breakfast may reduce hunger during the rest of the day compared with a grain-based breakfast, assessed through both subjective measures of hunger and plasma grehlin[32–34]. Additionally, an analysis of weight changes over time in men and women from three large prospective cohort studies showed that egg consumption was not significantly associated with weight[35]. Therefore, the positive association noted in the present study of egg consumption with BMI and WC should be interpreted with caution given the strong existing evidence of eggs' potential usefulness in weight management. It is also possible that the association observed here between egg consumption and BMI is related to residual confounding that was not controlled for in the analysis. One study using NHANES 2001–2008 data found that egg consumers had higher WC and BMI than egg non-consumers; however, dietary pattern analysis revealed that this relationship was driven by a small subset of egg consumers whose dietary patterns were characterized by relatively high intakes of animal products and grains, suggesting that other foods consumed along with eggs may confound the relationship between eggs and WC or BMI[36]. Therefore, consideration should be given to total dietary patterns in addition to individual foods and/or nutrients, and additional studies are needed to better understand the relationships between egg consumption and various health markers.

In summary, the present study suggests that whole eggs contribute meaningfully to the nutritional quality of Americans' diets. Whole egg consumption appears to have no significant relationship with most of the CVD risk factors examined in the study, but egg consumption was associated with lower TAG, TC:HDL-C and TAG:HDL-C, all indicative of protection against CVD. However, egg consumption was also associated with higher BMI and WC, two indicators of increased CVD risk. Overall, the current literature on this topic contains mixed findings, but generally demonstrates no significant relationship between egg consumption on CVD risk, which supports the removal of the dietary cholesterol limitation in the most updated version of the Dietary Guidelines for Americans. The current study generally supports this revised dietary guidance. Importantly, the present study relies on cross-sectional survey data that are not suitable for determining causality between egg consumption and CVD risk markers. The study may also be limited due to self-reported dietary data collected on only two days as well as the inability to account for potential variability in nutrient composition of eggs based on the laying hens' diet or other factors[37]. Strengths of the current study include its use of several years of survey data from a nationally representative data source and its comprehensive examination of egg intake from both major and minor sources across all food groups in the FNDDS. Future research efforts should seek to clarify the mixed findings in the current literature regarding eggs and CVD risk markers through closer examination of populations that may be more sensitive to egg intake, such as hyper-responders to dietary cholesterol and those with genetic polymorphisms affecting cholesterol metabolism. Additionally, studies with long-term follow-up, careful control for confounding factors including lifestyle factors and other elements of individuals' dietary patterns, and with rigorous methods of dietary data collection will allow for better assessment of the relationship between eggs and CVD risk.

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