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A Comparison of Egg Consumption with Other Modifiable Coronary Heart Disease Lifestyle Risk Factors: A Relative Risk Apportionment Study

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Guidelines from the American Heart Association (AHA) recommend that healthy adults limit their intake of dietary cholesterol to less than 300 mg per day. Since a large egg contains about 71% of that amount, the AHA recommends restricting egg consumption unless dietary cholesterol intakes from other sources are limited. We applied a risk apportionment approach to estimate the contribution of egg consumption and other modifiable lifestyle risk factors (e.g., smoking, poor diet, minimal exercise, and alcohol intake) to coronary heart disease (CHD) risk at the population level. Specifically, we categorized the U.S. adult population ages 25+ into distinct risk groups based on the prevalence of modifiable lifestyle risk factors and applied an apportionment model, typically used to assess risk contribution at the individual level, to estimate the contribution of egg intake to CHD risk. Our analysis shows that the combination of modifiable lifestyle risk factors accounts for less than 40% of the population CHD mortality. For the majority of U.S. adults age 25+, consuming one egg a day accounts for <1% of CHD risk. Hence, focusing on decreasing egg intake as an approach to modify CHD risk would be expected to yield minimal results relative to changing other behaviors such as smoking and other dietary habits.

KEY WORDS: Apportionment model; coronary heart disease; egg intake; modifiable lifestyle risk factors

1. INTRODUCTION

The American Heart Association (AHA)[1] has identified several risk factors for coronary heart disease (CHD), including nonmodifiable factors, such as older age, male gender, and heritable factors (including race and ethnicity); and modifiable or potentially treatable factors such as smoking, physical inactivity, excess weight, high blood pressure, high blood cholesterol, and type 2 diabetes mellitus. Other factors that appear to play a role in CHD risk include diet, alcohol, and, for women, menopausal hormone therapy (HT).[2] Despite the identification of several potentially modifiable causal factors for CHD, an emphasis on "behavioral" CHD risk reduction has focused on the reduction of dietary saturated fat and cholesterol to lower plasma cholesterol levels. Guidelines from the AHA recommend that healthy adults limit their intake of dietary cholesterol to less than 300 mg per day. Since a large egg contains about 210 mg of cholesterol (Table I), or about 71% of the corresponding daily recommended value (DRV), the AHA recommends restricting egg consumption unless dietary cholesterol intakes from other sources, such as meats, poultry, and dairy products, are limited.[3] The rationale behind the recommendation stems, in part, from findings from epidemiological

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Nutrients	Units	Nutrient Composition of One Large Egg[a] (50 g)	Percent of Recommended DRV[b,c,d]
Energy	kcal	72	
Protein	g	6.29	13%
Total lipid (fat)	g	4.97	8%
Iron, Fe	mg	0.92	5%
Phosphorus, P	mg	96	10%
Selenium, Se	mcg	15.8	23%
Riboflavin	mg	0.239	14%
Pantothenic acid	mg	0.719	7%
Folate, total	mcg	24	6%
Choline, total	mg	125.5	30%
Vitamin B-12	mcg	0.65	11%
Vitamin A, IU	IU	244	5%
Vitamin D	IU	18	5%
Fatty acids, total saturated	g	1.55	7.8%
Fatty acids, total monounsaturated	g	1.905	
Fatty acids, total polyunsaturated	g	0.682	
Cholesterol	mg	212	71%
Tryptophan	g	0.083	24%
Threonine	g	0.278	21%
Isoleucine	g	0.336	27%
Leucine	g	0.544	20%
Lysine	g	0.457	18%
Methionine	g	0.19	15%
Cystine	g	0.136	11%
Phenylalanine	g	0.341	15%
Tyrosine	g	0.25	11%
Valine	g	0.43	27%
Histidine	g	0.154	17%

Table I. Selected Nutrient Content of Eggs (Nutrients Where One Egg Contributes at Least 5% of the DRV)

[a] *Source:* USDA National Nutrient Database for Standard Reference, Release 19 (2006). Available at: http://www.nal.usda.gov/fnic/foodcomp/cgi-bin/list_nut_edit.pl[1].
[b] DRV values based on 2000-calorie diet.
[c] FDA Nutrition Labeling Manual—A Guide for Developing and Using Data Bases (1998). Available at: http://www.cfsan.fda.gov/~dms/nutrguid.html.
[d] Institute of Medicine of the National Academies. Dietary Reference Intakes: Macronutrients. Available at: http://www.iom.edu/Object.File/Master/7/300/Webtablemacro.pdf.

survey data of a relationship between dietary cholesterol intake and CHD risk[4,5] and from metabolic studies showing that an increase in dietary cholesterol resulted in an increase in plasma total and LDL cholesterol.[6,7] Similarly, the National Cholesterol Education Program (NCEP) recommends reducing egg yolk consumption to <2 per week[8] as a way to reduce (blood) LDL cholesterol in individuals at increased risk for CHD.

Evaluation of observational epidemiologic studies that used simple regression analyses indicated a positive relationship between dietary cholesterol and CHD risk whereas results of multiple regression analyses tended to find no association.[9–13] A cross-sectional study[14] found that egg consumption was not associated with elevated serum cholesterol concentrations. In addition, three prospective studies showed that after adjustment for other potential risk factors, there was no significant overall association between egg consumption and risk of stroke or CHD[15] or risk of stroke or cardiovascular disease.[16,17]

A review of epidemiologic studies by Kritchevsky and Kritchevsky[18] concluded that "*when dietary confounders were considered, no association was seen between egg consumption at levels up to 1 + egg per day and the risk of* CHD *in nondiabetic men and women*" (p. 549S) and a review by McNamara[19]

concluded that "*egg restrictions would be predicted to have little effect on plasma cholesterol levels or on CHD risk*" (p. 546S). Furthermore, meta-analyses by Howell *et al.*[20] and Clarke *et al.*[21] showed that saturated fat, not dietary cholesterol, is the major contributor to high blood cholesterol levels in the general population. Given the epidemiological and clinical evidence[22] it is unclear whether an intervention strategy of limiting egg consumption in healthy adults would lead to a significant reduction in LDL levels or CHD risk.[23–25]

Eggs are a good source of high quality protein (containing all the essential amino acids needed by the human body), and of all the B vitamins and folate, as well as the fat-soluble vitamins A, D, and E, and contain most of the minerals that the human body requires for health, particularly iodine, zinc, calcium, and iron. Song and Kerver[14] showed that nonconsumers of eggs were less likely than egg consumers to meet the recommended daily allowances for these vitamins. Eggs also contain lutein and zeaxanthin, two carotenoids thought to help prevent cataracts and age-related macular degeneration[26] and are rich in choline, which plays an important role in memory development[27] and helps maintain normal homocysteine levels.[28] Healthy adults with normal cholesterol levels who avoid or limit egg consumption may be missing an affordable and convenient source of these nutrients.[29] We therefore conducted this study to assess the impact of egg intake on CHD risk compared to the impact of other modifiable CHD risk factors.

2. METHODS

2.1. Risk Apportionment Model Approach

Several techniques have been proposed to calculate the proportionate contribution of two or more potential causal factors to the overall excess risk of a given disease.[30–37] These techniques divide the combined population impact of multiple risk factors into components that can be attributed to the respective individual exposures while taking into account the potential interrelations among the factors. These partitioning approaches have been applied primarily in regulatory and litigation-related decision-making settings to quantify the excess disease that is associated with an agent, and/or to provide a profile of the type of individual who is likely to contract a disease after being exposed to the agent.[38]

An approach proposed by Chase *et al.*[31] considered the simple case of two factors A and B, with associated relative risks RR_A and RR_B and provided an apportioning method that assumed that the combined risk from causes A and B is additive. Chase *et al.*[31] and Grimson[34] extended the approach to allow for multiplicative effects of two factors A and B and to incorporate risk from other causes. Specifically:

$$AS_A = \frac{W_A \times (RR_A - 1) \times (RR_B - 1) + (RR_A - 1)}{RR_A \times RR_B},$$

$$AS_B = \frac{W_B \times (RR_A - 1) \times (RR_B - 1) + (RR_B - 1)}{RR_A \times RR_B},$$

where W_A and W_B are weights used to apportion the "combined" risk from causes A and B. Grimson[34] presented two alternatives for apportioning the combined risk (i.e., the values assigned to W_A and W_B). The first assigns equal shares to causes A and B, that is:

$$W_A = W_B = 1/2,$$

while the second, also proposed by Chase *et al.*,[31] apportions the combined risk proportionately to excess risks:

$$W_A = \frac{RR_A - 1}{RR_A + RR_B - 2} \text{ and } W_B = \frac{RR_B - 1}{RR_A + RR_B - 2}.$$

The weighted models presented above are the better models to use in cases where the additivity assumption of the combined risk from the multiple causes does not hold. The "proportional weights" model makes better use of the data than the alternative, "equal weights" model that splits the interaction terms equally among the corresponding risk factors.[39] For the case of n factors, the model estimates assigned share (AS_i) associated with the ith risk factor as:

$$AS_i = \frac{(RR_i - 1) + \sum_{j \neq i} w_{i|j} \times [(RR_i - 1) \times (RR_j - 1)] + \sum_{j \neq i} \sum_{k \neq i, k \neq j} w_{i|jk} \times [(RR_i - 1) \times (RR_j - 1) \times (RR_k - 1)] + \cdots + w_{i|1\ldots n} \times (RR_i - 1) \times \cdots \times (RR_n - 1)}{RR_1 \cdots RR_n - 1}$$

where

$$w_{i|j} = \frac{RR_i - 1}{RR_i + RR_j - 2},$$

$$w_{i|jk} = \frac{RR_i - 1}{RR_i + RR_j + RR_k - 3}, \quad \text{and}$$

$$w_{i|1\ldots n} = \frac{RR_i - 1}{\sum_j (RR_j - 1)}.$$

2.2. CHD Risk Factors and Estimated Relative Risks (RR)

To implement the techniques described above to quantify the relative contribution of various CHD risk factors, including egg consumption, to CHD, RR estimates for these risk factors are needed. Established risk factors for CHD identified by the AHA[1] are listed in Table II. The lifestyle factors identified by Harvard researchers as being important in the primary prevention of CHD in women are generally similar to those listed by the AHA, including physical activity (exercise), maintaining a body mass index (BMI) of less than 25 kg/m^2, abstaining from smoking, consuming a moderate amount of alcohol, and adhering to a diet characterized by low trans fat intake, low glycemic load, high intakes of cereal fiber, marine $n-3$ fatty acids and folate, and a high ratio of polyunsaturated fat (PUFA) to saturated fat (SatFat) intake.[40] The AHA did not include dietary factors other than alcohol on their list of major risk factors for CHD. Other recommendations and guidelines for primary prevention of CHD or total cardiovascular disease (CVD) have identified similar risk factors.[41,42] Furthermore, these factors have been shown to be predictive of CHD risk in prospective cohort studies of men and women.[41,43,44]

Several studies have estimated the relative risk for CHD associated with the risk factors listed above. There was considerable variability across studies with respect to study size, geographic location, characteristics of the study population (e.g., population-based versus high risk), the extent of adjustment for potential confounding factors, and study design. In light of this, we used multivariate-adjusted relative risk estimates for "modifiable lifestyle factors" derived from the same population to the extent possible. Specifically, we identified relevant data from the populations studied in the Nurses' Health Study (NHS) (women) and the Health Professionals Follow-up Study (HPFS) (men) conducted by Harvard researchers.

For diet, rather than focusing on specific foods, we used the derived "diet scores," where a higher score corresponds to a diet that is lower in trans fat, higher in fruits, vegetables, and fiber, and has higher ratios of chicken and fish to meat, and/or PUFA to saturated fat.[40,44] Multivariate-adjusted relative risks for egg intake were estimated for males and females (separate models) in these studies by Hu *et al.*[45] Data on the association between parental history of myocardial infarction and incident coronary disease in men and women in these cohorts were reported by Colditz *et al.*[46,47] For data on

Table II. Established Risk Factors for CHD

Factor	High Risk Group(s)
Nonmodifiable Risk Factors	
Increasing age	Age 65 and older
Sex	Males
Hereditary factors	Positive family history of heart disease in a first degree relative
Race/ethnicity	African-American race, Mexican Americans, American Indians
Modifiable, Controllable, or Treatable Risk Factors	
Tobacco smoke	Smokers
Blood cholesterol	High levels
Blood pressure	High blood pressure/hypertension
Physical activity level	Inactivity
Body weight/body mass	Overweight or obese
Diabetes	Type 2 diabetes mellitus
Alcohol[a]	Excessive alcohol consumption[b]

[a]AHA considers alcohol and stress to be "contributing factors" to risk of CHD. These factors are described as "associated with increased risk of cardiovascular disease, but their significance and prevalence haven't yet been precisely determined." Furthermore, these factors may have their effect by influencing other established risk factors.
[b]Moderate alcohol consumption associated with decreased risk of CHD.

Table III. CVD Risk Factors and Estimated Relative Risks: Females

Factor	Description	RR	95% CI	Reference
Egg[a] consumption	Never	1.0	(Reference)	Hu *et al.*[15]
	≥2/day	0.76	(0.43–1.35)	(Text)
Egg consumption	1/day versus none	1.05	NA	Derived using the 3-steps process described in the text
Diet	Poor diet (first, second, & third quintiles)	1.46	NA	Extrapolated from estimates in Stampfer *et al.*[40]
	Good diet (fourth & fifth quintiles)	1.00	Reference	
Smoking	Current smokers	3.33	NA	Extrapolated from estimates in Stampfer *et al.*[40]
	Former or nonsmoker	1.00	Reference	
BMI (overweight)	≥25 Kg/m^2	1.35	NA	Extrapolated from estimates in Stampfer *et al.*[40]
	<25 Kg/m^2	1.0	Reference	
Exercise	<3.5 h/wk	1.24	NA	Extrapolated from estimates in Stampfer *et al.*[40]
	≥3.5 h/wk	1.0	Reference	
Alcohol	Consumption (g/day)			Stampfer *et al.*[40]
	0	1.65	(1.39–1.95)	(Table I)
	0.1–5.0	1.41	(1.18–1.68)	
	5.1–10.0	1.26	(1.00–1.60)	
	>10.0	1.0	(Reference)	
Family history	Parental history of MI at age 60 or younger versus no family history	Nonfatal MI 2.8	(1.8–4.3)	Colditz *et al.*[46]
	Parental history of MI age 60 or younger versus no family history	Fatal CHD 5.0	(2.7–9.2)	(Table III)
Age	Per year increment	1.04	(1.03–1.06)	Wilson *et al.*[49] (Table V)
Blood pressure	Normal	1.00	(Reference)	Wilson *et al.*[49]
	High normal	1.34	(0.88–2.05)	(Table V)
	Hypertension stage I	1.75	(1.21–2.54)	
	Hypertension stage II	2.19	(1.46–3.27)	
Diabetes	Yes/no	1.80	(1.18–2.74)	Wilson *et al.*[49] (Table V)
Lipid profile	LDL mg/dL			Wilson *et al.*[49]
	<130	1.00	(Reference)	(Table V)
	130–159	1.24	(0.84–1.81)	
	≥160	1.68	(1.17–2.40)	
Lipid profile	HDL mg/dL			Wilson *et al.*[49]
	<35	2.08	(1.33–3.25)	(Table V)
	35–59	1.00	(Reference)	
	≥60	0.64	(0.47–0.87)	

[a]As discussed in text, an alternative estimate of the CHD RR associated with egg consumption was derived by modeling the pathway {egg consumption → dietary cholesterol → serum cholesterol → CHD}.

biologic markers of risk and/or clinical conditions, we relied upon data from the Framingham Heart Study (FHS).[48,49] Data from the FHS have been used in coronary event prediction models for use in general clinical settings. Wilson *et al.*[49] reported multivariate-adjusted relative risks for major CHD risk factors among males and females (reported separately) in the FHS.

The data we extracted from the studies summarized above for use in our model are presented in Table III (for females) and Table IV (for males). The categories used for all risk factors except the diet scores are self-explanatory. The diet scores are based on data published by Stampfer *et al.*,[40] Hu *et al.*,[45] and Chiuve *et al.*[44] For males, we considered two scores. The first reflects the "prudent diet" score[45] while the second is based on the Alternate Healthy Eating Index (AHEI).[44] The prudent diet score was derived by first classifying 131 food items into 40 food groups and using factor analysis to define two diet patterns, a "prudent" diet, characterized by a higher intake of vegetables, legumes, whole grains, fruit, fish, and poultry, and a "Western" diet, characterized by a higher intake of red meat, processed meat, refined grains, sweets and dessert, French fries, and high-fat dairy products. The other

Table IV. CVD Risk Factors and Estimated Relative Risks: Males

Factor	Description	RR	95% CI	Reference
Egg[a] consumption	Never	1.0	(Reference)	Hu *et al.*[15]
	≥2/day	1.10	(0.67–1.79)	(Text)
Egg consumption				Derived using the 3-steps process described in the text
	1/day versus none	1.06	NA	
Diet	AHEI diet score			Chiuve *et al.*[44]
	<42.4	1.0	(Reference)	(Table I)
	≥42.4	0.84	(0.77–0.92)	
Smoking	Current smoker	1.0	(Reference)	
	Former or nonsmoker	0.47	(0.42–0.54)	
BMI (overweight)	<25 Kg/m^2	0.70	(0.64–0.77)	
	≥25 Kg/m^2	1.0	(Reference)	
Exercise	<3.5 h/wk	1.0	(Reference)	
	≥3.5 h/wk	0.83	(0.74–0.92)	
Alcohol	5–30 g/day	0.79	(0.73–0.87)	
	<5 g/day or >30 g/day	1.0	(Reference)	
Family history	Maternal history of MI at age 50 or younger versus no family history	Fatal and nonfatal MI	(2.20–13.60)	Colditz *et al.*[46]
		5.40		(Table III)
	Paternal history of MI at age 50 or younger versus no family history	Fatal and nonfatal MI	(1.20–4.10)	
		2.20		
Age	Per year increment	1.05	(1.04–1.06)	Wilson *et al.*[49] (Table V)
Blood pressure	Normal	1.00	(Reference)	Wilson *et al.*[49]
	High normal	1.32	(0.98–1.78)	(Table V)
	Hypertension stage I	1.73	(1.32–2.26)	
	Hypertension stage II	1.92	(1.42–2.59)	
Diabetes	Yes/no	1.47	(1.04–2.08)	Wilson *et al.*[49] (Table V)
Lipid profile	LDL mg/dL			Wilson *et al.*[49]
	<130	1.00	(Reference)	(Table V)
	130–159	1.19	(0.91–1.54)	
	≥160	1.74	(1.36–2.24)	
Lipid profile	HDL mg/dL			Wilson *et al.*[49]
	<35	1.46	(1.15–1.85)	(Table V)
	35–59	1.00	(Reference)	
	≥60	0.61	(0.41–0.91)	

[a]As discussed in text, an alternative estimate of the CHD RR associated with egg consumption was derived by modeling the pathway {egg consumption → dietary cholesterol → serum cholesterol → CHD}.

diet score, the AHEI, is a modification of the Healthy Eating Index (HEI), created by the U.S. Department of Agriculture (USDA). The AHEI gives a score to several key food components, i.e., multivitamin use; percent energy from trans fat; ratio of polyunsaturated to saturated fat intake; ratio of chicken and fish to red meat intake; daily servings of alcohol, fruits, vegetables, and vegetable proteins; and cereal fiber intakes. We use the AHEI score in the current study.

For females, we present a composite measure combining scores for trans fat and glycemic load, cereal fiber intake, marine $n-3$ fatty acids, folate, and ratio of polyunsaturated to saturated fat.[40] For each of these six dietary factors, we followed a method similar to that used by Stampfer *et al.*[40] and assigned individual women a score of 1–5 corresponding to the quintile of intake, with 5 representing the most favorable quintile. The combined score was then based on the sum of the quintile values for each of these nutrients.

We could not identify published relative risk estimates for the NHS based on comparisons of women in high versus low exposure groups similar to those derived by Chiuve *et al.*[44] We therefore used the estimates derived by Stampfer *et al.*[40] to derive

relative risk for high versus low exposure groups for diet, smoking, BMI and physical activity. Specifically, we used linear regression to model RR as a function of exposure category and derived RR estimates for high versus low exposure categories for the following risk factors: diet (lower three quintiles versus upper two quintiles), smoking (current versus former and nonsmokers), overweight (BMI $\geq$ 25 versus BMI $<$ 25), and physical activity ($<$3.5 hours/week versus $\geq$3.5 hours per week).

The estimated RRs for CHD associated with various levels of egg consumption were less than 1.0 and would have implied a "protective" effect of eggs for females and, hence, could not be used in the apportionment model to estimate the relative contribution of egg consumption to the increased risk of CHD. Further, it is the cholesterol contribution from the egg that is of interest. We therefore considered another approach to estimate the RR associated with egg consumption. Specifically: we derived alternate estimate by considering the following causal "pathway":

$$\uparrow \text{Egg consumption} \overset{①}{\Rightarrow} \uparrow \text{Dietary cholesterol consumption} \overset{②}{\Rightarrow} \uparrow \text{Serum cholesterol} \overset{③}{\Rightarrow} \uparrow \text{CHD risk.}$$

We examined the information available for each of the three steps in the above pathway. Specifically:

- Step 1: From egg consumption to dietary cholesterol consumption:

Data from USDAs Nutrient Databank[50] indicates that one large egg contains 212 mg of dietary cholesterol. Hence, we assumed that eating one egg per day increases dietary cholesterol intake by 212 mg per day.

- Step 2: From dietary cholesterol to serum cholesterol:

McNamara[19] reviewed cholesterol feeding studies and derived an estimate of the dose adjusted plasma cholesterol response of 2.2 mg/dL (95% CI 1.9–2.5) per 100 mg per day dietary cholesterol. This estimate is consistent with other predictive equations, which had estimated slopes ranging from 2.2 to 4.5 mg/dL per 100 mg per day dietary cholesterol[19] and with the estimate derived by Sonneberg *et al.*[51] from males in the Framingham cohort study. In our model, we used the estimated slope and associated 95% CI derived by McNamara. Hence, in our derivation, we assumed that consumption of one large egg per day results in an estimated increase of 4.7 m/dL (95% CI: 4.0–5.3) in serum cholesterol (=212 (mg of dietary cholesterol per day) $\times$ 2.2 (95% CI: 1.9–2.5) (mg/dL per 100 mg per day dietary cholesterol)/100).

- Step 3: From serum cholesterol to CHD RR:

Estimates of RR for CHD associated with serum cholesterol were derived by Wilson *et al.*[49] Specifically, the estimated relative risk rose from 1.00 for total cholesterol levels $<$200 mg/dL to 1.31 (95% CI: 1.01–1.68) in men and 1.51 (95% CI: 1.01–2.24) in women with total cholesterol levels ranging from 200 to 239 mg/dL to 1.90 (95% CI: 1.47–2.47) in men and 1.72 (95% CI: 1.15–2.56) in women with total cholesterol levels $>$240 mg/dL. We derived an estimate of the relative increase in RR associated with 1 mg/dL increase in serum cholesterol levels by fitting a linear regression model[3] to the RR estimates (and confidence limits) derived by Wilson *et al.* Specifically, we estimated an increase of 0.0067 (CI: 0.0037–0.0106) (males) and 0.0049 (CI: 0.0012–0.0104) (females) in the RR for CHD per 1 mg/dL increase in serum cholesterol. We combined these slopes factors with the estimates (and associated 95% CI) derived in Steps and 1 and 2 above and calculated a RR for CHD associated with the consumption of 1 egg per day (using 0 egg per day as the reference level) of 1.03 (CI: 1.01–1.20) for males and 1.02 (CI: 1.00–1.20) for females.

2.3. Model Implementation

Since the magnitude of the relative risk estimates differs by sex, we created separate models for males and females. Further, since the purpose of the current study is to assess the potential impact of reducing egg consumption as an intervention strategy to reduce CHD mortality, we chose to focus primarily on modifiable "lifestyle" risk factors and potentially treatable risk factors. Specifically, the lifestyle risk factors currently included in the model are:

1. Smoking.
2. Alcohol consumption.
3. Exercise.
4. Overweight or obese.

[3] We used the midpoint of the serum cholesterol categories in Wilson *et al*. The lower limit of the $<$200 mg/dL category (150 mg/dL) and the maximum of the $\geq$240 mg/dL category (380 mg/dL) were obtained from Elias *et al.*[52]

5. Poor diet score.
6. Egg consumption.

The potentially treatable risk factors that are also included in the model are:

1. Blood pressure.
2. Serum LDL.
3. Serum HDL.

If information about the presence/absence of the above listed modifiable/treatable risk factors is known for an individual or a group of individuals with similar risk profiles, then the contribution of egg intake (relative to the contribution from other known risk factors) to CHD risk can be established. In this article, we implemented the model and described the results for groups of U.S. adults with similar "lifestyle" risk attributes.

Additional data and methods used in this second setting to assess public health impact are described below.

2.4. Public Health Impact Assessment

Using this model, the contribution of egg intake to CHD mortality can be estimated for groups of individuals with similar CHD risk profiles. Using the National Heath and Nutrition Examination Survey (NHANES) 1999–2000 and 2001–2002 data,[53] we categorized the U.S. adults age 25 and older into groups of individuals based on the commonality of their lifestyle modifiable risks (i.e., smoking, exercise, overweight or obese, and diet). NHANES is a program of studies designed to assess the health and nutritional status of adults and children in the United States. The survey combines interviews and physical examinations. Since 1999, NHANES has been conducted annually and examines a nationally representative sample of about 5,000 persons each year. The NHANES interview includes demographic, socioeconomic, dietary, and health-related questions. NHANES uses a complex multistage probability sample designed to be representative of the civilian U.S. population. The NHANES survey oversamples minorities, low-income groups, adolescents (12–19 years), and adults 60 years of age and older. Statistical weights derived by the National Center for Health Statistics (NCHS) are used to adjust for nonresponse and this differential probability of selection.

We extracted the demographic, smoking, exercise, anthropometric, and dietary data from the 1999–2000 and 2001–2002 NHANES surveys and recoded these variables to create dichotomous exposure categories similar to those summarized in Tables III and IV. Specifically, we used the 24-hour consumption data to derive an index similar to the AHEI for males ages 25 years or more,[44,54] and a diet score similar to that described above for the NHS for females ages 25 years or more.[40] However, while the indices used by Chiuve *et al.*,[44] McCullough *et al.*,[54] and Stampfer *et al.*[40] are based on food frequency consumption data, we based our indices on the 24-hour dietary recall data that were reported in NHANES.

In particular, for males, we emulated the approach described by McCullough *et al.*[54] and derived a diet score for males based on the number of servings per day of fruits and fruit juices, vegetables and vegetable juices, nuts and soy protein, and alcohol; the ratio of the amount of fish and poultry consumed per day to the amount of other meat consumed per day, and the PUFA/SatFat ratio; and the transfat intake (as% of energy) and fiber intake. We also classified subjects based on their use of supplements (yes/no). Following an approach similar to that described by McCullough *et al.*[54] scores ranging from 1 to 10 were then assigned to these derived intake estimates, except for supplement use, where nonusers were assigned a score of 2.5 points, and users a score of 7.5 points. The component scores were summed to obtain a total AHEI-type score ranging from 4.9 (worst) to 82.2 (best).

For females, we emulated the approach used by Stampfer *et al.*[40] to derive a diet score. Specifically, we estimated intakes of trans fat, cereal fiber, folate (dietary folate only, even though Stampfer *et al.* included folate from supplement use too), glycemic load, and the ratio of PUFA/SatFat. Note that Stampfer *et al.* also included a quintile score for marine $n-3$ fatty acid intakes; however, the majority of women had no reported $n-3$ fatty acid consumption from fish in the NHANES 24 h dietary survey, so we excluded that nutrient from our analysis. We then categorized these intakes into quintiles (with higher quintile scores representing lower risk) and summed these quintile scores across nutrients for a total score. That total score was further recategorized into quintiles.

For physical activity, we used information from NHANES on whether the survey participants did vigorous or moderate physical activity over the previous month as a surrogate for the number of hours of exercise per week.

For each group of U.S. adults with similar lifestyle risk factors, we applied the risk

apportionment model (described above) to estimate the impact of egg intake on CHD mortality risk relative to the impact by other CHD risk factors that are also present in each risk group (i.e., the assigned shares, AS). In this derivation, ***we assumed that all subjects in each group consume one egg per day***. For each combination of risk factors (including egg consumption), we also derived an estimate of the combined relative risk, assuming a multiplicative model. We then estimated the population attributable risk (PAR) corresponding to each combination of risk factors. Specifically, we estimated the PAR as: $p(r-1)/(1+p(r-1))$, where (p) represents the population prevalence of the combination of risk factors and (r) represents the estimate of the relative risk associated with the combination of risk factors. We then computed the contribution of each risk factor to the PARs by multiplying the PARs by the assigned shares (AS) corresponding to these factors. Confidence intervals for the estimated AS and PARs were derived using the confidence intervals around the RR for egg consumption derived above.

3. RESULTS

3.1. Prevalence of Modifiable Lifestyle Risk Factors Among U.S. Adults and Risk Groups

3.1.1. U.S. Females Age 25+

Using data from 1999 to 2000 and 2001 to 2002 NHANES we categorized the U.S. adult females age 25 and older into groups based on their lifestyle modifiable risks (i.e., smoking, exercise, overweight or obese, and diet). The majority of U.S. females 25 years of age or older (>86%; >86 million individuals) have one or more of the four modifiable lifestyle risk factors for CHD risks. We present in Table V the 11 most common combinations of lifestyle risk factors among U.S. females ages 25 years or more. Present among these risk groups are the following mutually exclusive CHD lifestyle risk factor combinations:

Three or more risk factors:

1. 12% are inactive, overweight or obese, and have poor diets (Risk Group I).
2. 10% are smokers, inactive, overweight or obese, and have poor diets (Risk Group J).
3. 9% are smokers, inactive, overweight or obese, and have poor diets (Risk Group K).

Two risk factors only:

1. 14% are overweight and have poor diets (Risk Group H).
2. 7% are smokers and have poor diets (Risk Group G).
3. 5% are smokers and overweight or obese (Risk Group F).
4. 4% are inactive and overweight or obese (Risk Group E).

One risk factor only:

1. 8% have poor diets (Risk Group D).
2. 7% are overweight or obese (Risk Group C).
3. 4% are smokers (Risk Group B).

No risk factors:

1. Only 6% of females 25 years of age or older have none of the four lifestyle CHD risk factors listed above (Risk Group A).

3.1.2. U.S. Males Age 25+

The majority of U.S. males 25 years of age or older (>85%; >80 million individuals) have one or more modifiable lifestyle risk factors for CHD. We present in Table VI the 10 most common combinations of lifestyle risk factors among U.S. males ages 25 years or more. Present among these risk groups are the following mutually exclusive CHD lifestyle risk factor combinations:

Three or more risk factors:

1. 18% are smokers, overweight or obese, and have poor diets (Risk Group I).
2. 12% are smokers, inactive, overweight or obese, and have poor diets (Risk Group J).
3. 7% are smokers, inactive, and have poor diets (Risk Group G).
4. 6% are inactive, overweight or obese, and have poor diets (Risk Group H).

Two risk factors only:

1. 16% are overweight and have poor diets (Risk Group F).
2. 7% are smokers and overweight or obese (Risk Group D).
3. 7% are smokers and have poor diets (Risk Group E).

One risk factor only:

1. 6% are overweight or obese (Risk Group B).
2. 6% have poor diets (Risk Group C).

Table V. Prevalence of Lifestyle Preventable Risk Factors, U.S. Females 25+, NHANES 1999–2002

Number of Risk Factors	Population Scenarios	Risk Factors and Shares of CHD Risk				Percent of U.S. Females with Risk Factor(s)	2005 Population Estimate
		Inactive	Current Smoker	BMI > 25 Kg/m^2	Low Diet Score		
None	A					6%	5,713,695
One factor	B		Yes			4%	4,255,847
	C			Yes		7%	6,907,736
	D				Yes	8%	8,206,356
Two factors	E	Yes		Yes		4%	4,406,048
	F		Yes	Yes		5%	4,893,226
	G		Yes		Yes	7%	7,033,362
	H			Yes	Yes	14%	14,197,699
Three or more factors	I	Yes		Yes	Yes	12%	11,791,259
	J		Yes	Yes	Yes	10%	9,636,328
	K	Yes	Yes	Yes	Yes	9%	9,394,106
Total						86%	86,435,663

Table VI. Prevalence of Lifestyle Preventable Risk Factors, U.S. Males 25+, NHANES 1999–2002

Number of Risk Factors	Risk Group	CHD Risk Factor and Shares of CHD risk				Percent of U.S. Males 25+ with Risk Factor(s)	2005 Population Estimates
		Inactive	Current Smoker	BMI > 25 Kg/m^2	Low Diet (AHEI[a]) Score		
None	A					3%	3,160,467
One factor	B			Yes		6%	5,708,058
	C				Yes	6%	5,411,676
Two factors	D		Yes	Yes		7%	6,601,470
	E		Yes		Yes	7%	6,137,045
	F			Yes	Yes	16%	14,451,582
Three or more factors	G	Yes	Yes		Yes	7%	6,756,293
	H	Yes		Yes	Yes	6%	5,738,272
	I		Yes	Yes	Yes	18%	17,099,162
	J	Yes	Yes	Yes	Yes	12%	11,627,648
Total						89%	82,691,673

[a]AHEI: Alternate Healthy Eating Index.

No risk factors:

1. Only 3% have none of the lifestyle CHD risk factors (Risk Group A).

3.1.3. Population Attributable Risk

Population attributable risks (PARs) are useful metrics for estimating the proportion of disease cases that could be prevented (theoretically) if one or more risk factors for the disease were to be reduced or eliminated. We estimated the PARs for the combinations of risk factors described above.

3.1.4. Assigned Shares

We derived estimates of the assigned shares (AS) corresponding to the risk factors in each risk factor combination (results not shown) and computed the contribution of each risk factor to the PARs by multiplying the PARs by the AS corresponding to these factors.

3.1.5. U.S. Females Age 25+

The PARs for the combination of modifiable CHD risk factors that are present in the U.S. adult population plus eating one egg a day were estimated for the 11 risk groups (described earlier). These 11 groups represent over 86% of the U.S. female population aged 25 years and older. These results are summarized in Table VII. Note that for diseases with multiple risk factors, PARs for individual risk factors can sum to more than 1.[55]

Table VII. Apportioned CHD Mortality Risks Among Lifestyle Risk Factors, U.S. Females 25+

Population Scenarios	2005 Population	Population Attributable Risks (CI)[a]	Risk Factors and Shares[b] (CI) of CHD Risk				
			Inactive	Current Smoker	BMI > 25 Kg/m^2	Low Diet Score	One Egg/Day
A	5,713,695	0.1% (0.03%–1.1%)					0.1% (0.03%–1.1%)
B	4,255,847	9.2% (9%–11.3%)		9.1% (9%–10.4%)			0.1% (0.02%–0.9%)
C	6,907,736	2.5% (2.4%–4.1%)			2.4% (2.4%–2.6%)		0.1% (0.03%–1.5%)
D	8,206,356	3.8% (3.7%–5.8%)				3.6% (3.6%–4%)	0.2% (0.04%–1.8%)
E	4,406,048	3% (2.9%–4.2%)	1.2% (1.2%–1.3%)		1.7% (1.7%–1.9%)		0.1% (0.02%–1.1%)
F	4,893,226	14.9% (14.6%–17.6%)		12.9% (12.7%–14.5%)	1.9% (1.9%–2.1%)		0.1% (0.01%–1.1%)
G	7,033,362	21.7% (21.4%–25.3%)		18.1% (17.9%–20%)		3.5% (3.5%–3.8%)	0.1% (0.02%–1.5%)
H	14,197,699	12.5% (12.2%–16.2%)			5.3% (5.2%–5.6%)	7% (6.9%–7.5%)	0.3% (0.06%–3.1%)
I	11,791,259	14.9% (14.6%–18.5%)	3.3% (3.3%–3.5%)		4.9% (4.8%–5.2%)	6.5% (6.4%–7%)	0.2% (0.04%–2.8%)
J	9,636,328	35.3% (34.9%–39.8%)		26.7% (26.4%–28.9%)	3.6% (3.6%–3.7%)	4.9% (4.9%–5.2%)	0.1% (0.03%–1.9%)
K	9,394,106	40.5% (40%–44.9%)	2.4% (2.4%–2.5%)	29% (28.8%–31.2%)	3.7% (3.7%–3.9%)	5.2% (5.1%–5.4%)	0.1% (0.04%–1.9%)

[a]The CI intervals reflect the PAR estimates derived using the lower and upper limits of the 95% CI presented in McNamara[19] and Wilson *et al.*[43]

[b]The shares corresponding to each risk factors are derived by multiplying the PAR with the AS corresponding to each risk factor.

The highest PAR for CHD mortality corresponds to risk groups J and K. In group J, the combination of three lifestyle risk factors: smoking, overweight or obesity, and poor diet, and consuming one egg per day resulted in a PAR of 35.3% (34.9%–39.8%). In group K, the combination of the same risk factors as in I, plus inactivity resulted in a PAR of 40.5% (40.0%–44.9%). The combination of smoking, poor diet, and egg intake in group G resulted in a PAR of 21.7% (21.4%–25.3%), while the combination of smoking, overweight or obesity, and egg intake risk factors in group F resulted in a PAR of 14.9% (14.6%–17.6%), and that of inactivity, overweight or obesity, poor diet, and egg intake in group I resulted in a PARs of 14.9% (14.6%–18.5%). The PAR for egg intake as the only risk factor present in group A is the smallest among the 10 risk groups, at 0.1% (0.03%–1.1%).

3.1.6. U.S. Males Age 25+

PARs were estimated for each of the 10 unique combinations of risk factors + consumption of 1 egg per day. These 10 risk factor combinations represent over 85% of U.S. males 25+. The results are summarized in Table VIII.

The highest PAR for CHD mortality corresponds to risk groups I and J. In group I, the combination of three lifestyle risk factors: smoking, overweight or obesity, and poor diet, and consumption of one egg a day resulted in a PAR of 33.4% (32.8%–38.1%). In group J, the combination of the same risk factors as in I, plus being inactive resulted in a PAR of 30.2% (29.6%–34.3%). The combination of smoking, inactivity, poor diet, and egg intake in group G and the combination of smoking, overweight or obesity, and egg intake in group D resulted in PARs of 13.4% (13.1%–16.1%) and 13.1% (12.8%–15.8%), respectively. Overweight or obesity, poor diet, and egg intake together resulted in a PAR of 10.4% (10.0%–13.9%) (group F). In conjunction with egg intake, the single risk factors, overweight or obesity (group B) and poor diet (group C), had relatively low PARs, at <5%. The PAR for egg intake as a single risk factor (group A) was the smallest among the 10 risk groups, at 0.1% (0.03%–0.7%).

Table VIII. Apportioned CHD Mortality Risks Among Lifestyle Risk Factors, U.S. Males 25+

Population Scenarios	2005 Population	Population Attributable Risks (CI)[a]	Risk Factors and Shares[b] (CI) of CHD Risk				
			Inactive	Current Smoker	BMI > 25 Kg/m^2	Low Diet Score	One Egg/Day
A	3,160,467	0.1% (0.03%–0.7%)					0.1% (0.03%–0.7%)
B	5,708,058	2.8% (2.6%–4.2%)			2.6% (2.6%–2.9%)		0.2% (0.1%–1.3%)
C	5,411,676	1.3% (1.2%–2.4%)				1.1% (1.1%–1.2%)	0.2% (0.1%–1.2%)
D	6,601,470	13.1% (12.8%–15.8%)		9.4% (9.2%–10.3%)	3.6% (3.5%–3.8%)		0.2% (0.1%–1.6%)
E	6,137,045	9.6% (9.3%–11.8%)		8% (7.9%–8.9%)		1.4% (1.3%–1.4%)	0.2% (0.1%–1.5%)
F	14,451,582	10.4% (10%–13.9%)			6.9% (6.8%–7.4%)	3.1% (3%–3.2%)	0.4% (0.1%–3.4%)
G	6,756,293	13.4% (13.1%–16.1%)	1.7% (1.7%–1.8%)	9.9% (9.8%–10.9%)		1.6% (1.6%–1.7%)	0.2% (0.1%–1.8%)
H	5,738,272	6.4% (6.1%–8.2%)	1.5% (1.5%–1.6%)		3.3% (3.2%–3.5%)	1.4% (1.4%–1.5%)	0.2% (0.1%–1.6%)
I	17,099,162	33.4% (32.8%–38.1%)		21.6% (21.5%–23%)	8.1% (8%–8.4%)	3.2% (3.2%–3.3%)	0.4% (0.1%–3.5%)
J	11,627,648	30.2% (29.6%–34.3%)	2.8% (2.8%–2.8%)	18% (17.7%–19.2%)	6.5% (6.5%–6.9%)	2.5% (2.5%–2.6%)	0.3% (0.1%–2.7%)

[a]The CI intervals reflect the PAR estimates derived using the lower and upper limits of the 95% CI presented in McNamara[19] and Wilson *et al.*[43]

[b]The shares corresponding to each risk factors are derived by multiplying the PAR with the AS corresponding to each risk factor.

4. DISCUSSION

The practice of modern public health is increasingly moving away from the "one cause-one disease" approach toward consideration of the multifactorial etiology of health-related states and events.[56,57] In order to develop effective interventions, it is necessary to weigh the relative importance of recognized risk factors and to focus on those that contribute most to risk, that is, the risk factors with the biggest RR and/or the risk factors that are the most prevalent. Although nonmodifiable risk factors, such age, ethnicity, and family history, are useful in identifying groups that are at high risk for CHD, intervention strategies should target modifiable risk factors, such as environmental exposure, diet, smoking, and other lifestyle factors. Other risk factors, such as diabetes and elevated blood pressure, that may play a role in the etiology and progression of the disease of interest may also be considered in such interventions.

In this study, we utilized existing methods to construct a risk apportionment tool to calculate the proportionate contribution of modifiable and treatable CHD risk factors at the individual level and at the population level. Our model required that the CHD risk attributes of the population under consideration be known or estimable. Using this approach, we were able to estimate the contribution of egg intake to an individual's CHD risk given various combinations of CHD risk attributes, as well as to the U.S. population based on the prevalence of these factors among the U.S. adult population.

Based on the prevalence of modifiable lifestyle risk factors among the U.S. adult population we categorized the majority of the U.S. population ages 25+ into 10 (males) or 11 (females) distinct risk groups, representing >85% and >86% of U.S. males and females 25+, respectively. Applying the risk apportionment model given these existing modifiable lifestyle risk factors in U.S. adults, we found that the highest PARs were approximately 33% in the group of U.S. males 25+ with smoking, overweight or obesity, poor diet, and egg consumption; and 30% in the group with these same risk factors plus being inactive. The corresponding estimates for females were 35 and 41%, respectively. Based on our results, it appears that the combination of these modifiable lifestyle risk factors accounts for about 30–40% of the population CHD mortality and that other CHD risk

factors, such as potentially treatable factors (hypertension, diabetes, blood lipid profile) and unavoidable risk factors (genetics, age) would account for the remaining share (60–70%).

Across all risk groups that represent over 85% of U.S. males age 25 and older, and 86% of U.S. females of similar ages, consumption of one egg per day contributes to less than 1% of the CHD mortality risk.

Since the RR for smoking is much larger than the RR associated with the other modifiable risk factors considered in this article, and hence its impact may be masking the impact of egg consumption, we repeated the analysis focusing on the nonsmoking adult population 25 years or older. Across all risk groups that represent over 89% and 88% of the nonsmoking female and male populations age 25 and older, respectively, consumption of one egg per day contributes to less than 1% of the CHD mortality risk (data not shown).

One of the major considerations for applying the risk apportionment approach is the selection of appropriate risk factors and estimates of relative risks. We developed the CHD risk apportionment model with this major precaution in mind and only included in our model established CHD risk factors and used only multivariate-adjusted relative risk estimates derived from the same population, mainly from the NHS and HPFS. It should also be noted that although we made an effort to choose data that are based on large studies with long follow-up periods and carefully collected information, as currently implemented, our risk apportionment model and results are deterministically based on the central estimates of relative risks. Additional uncertainties stemming from our selection of studies, our treatment of the data from these studies, or our translation of findings from these studies to the NHANES population (such as the approach used to translate results from food frequency questionnaires to 24-hour diets) have not been accounted for in our analysis. In addition, the stepwise approach we used to estimate the RR for CHD associated with egg consumption did not adjust for the fact that egg intake increases HDL levels,[21,58] provides lutein, which is related to lower CHD risk,[59] and is a source of choline, which is related to lower homocysteine levels.[28] These factors would be predicted to decrease CHD risk.

Despite these limitations, based on the findings that adding an egg per day to the diet contributes very little to CHD risk as compared to other modifiable risk factors, it would appear that wide-sweeping recommendations to restrict egg consumption to avoid CHD risk may not have the desired result, especially when the nutritional benefits of eggs are considered. Efforts to maximize healthy behaviors related to smoking, exercise, weight, and other aspects of diet are likely to have a greater impact on CHD incidence and mortality in the United States.

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