Egg consumption in relation to cardiovascular disease and mortality: the Physicians’ Health Study

Luc Djoussé and J Michael Gaziano

ABSTRACT

Background: A reduction in dietary cholesterol is recommended to prevent cardiovascular disease (CVD). Although eggs are important sources of cholesterol and other nutrients, limited and inconsistent data are available on the effects of egg consumption on the risk of CVD and mortality.

Objective: We aimed to examine the association between egg consumption and the risk of CVD and mortality.

Design: In a prospective cohort study of 21,327 participants from Physicians’ Health Study I, egg consumption was assessed with an abbreviated food questionnaire. Cox regression was used to estimate relative risks.

Results: In an average follow-up of 20 y, 1550 new myocardial infarctions (MIs), 1342 incident strokes, and 5169 deaths occurred. Egg consumption was not associated with incident MI or stroke in a multivariate Cox regression. In contrast, adjusted hazard ratios (95% CI) for mortality were 1.0 (reference), 0.94 (0.87, 1.02), 1.03 (0.95, 1.11), 1.05 (0.93, 1.19), and 1.23 (1.11, 1.36) for the consumption of <1, 1, 2–4, 5–6, and ≥7 eggs/wk, respectively (P for trend < 0.0001). This association was stronger among diabetic subjects, in whom the risk of death in a comparison of the highest with the lowest category of egg consumption was twofold (hazard ratio: 2.01; 95% CI: 1.26, 3.20; P for interaction = 0.09).

Conclusions: Infrequent egg consumption does not seem to influence the risk of CVD in male physicians. In addition, egg consumption was positively related to mortality, more strongly so in diabetic subjects, in the study population.

INTRODUCTION

Coronary artery disease (CAD) remains the leading cause of death in the United States. Because elevated LDL cholesterol has been identified as a major risk factor for CAD, dietary guidelines to prevent CAD emphasize the reduction in dietary cholesterol to <300 mg/d (1, 2). Egg is a major source of dietary cholesterol with an average egg containing ≈200 mg cholesterol. On the other hand, eggs contain other nutrients such as minerals, folate, B vitamins, proteins, and monounsaturated fatty acids (3, 4) that could reduce the risk of CAD. Whereas some studies have shown positive associations between dietary and serum cholesterol (5–9), others did not find any effect (7, 10, 11). There is a large variability in individual response to dietary cholesterol (11–13). In addition, the effect of dietary cholesterol on LDL cholesterol observed in positive studies is modest compared with the LDL-raising effects of saturated and trans fatty acids (14, 15).

Limited and inconsistent data have been reported on the association between egg consumption and CAD. Among 514 Australian Aborigines, consumption of >2 eggs/wk was associated with a 2.6 times greater risk of CAD in a prospective analysis (16). Mann et al (17) reported a 2.7 times greater risk of death with higher egg consumption (>6 eggs/wk) among British persons. In contrast, other large prospective cohorts with longer follow-ups did not observe any association between egg consumption and CAD or mortality (18–21). Because eggs could serve as a good source for vitamins, proteins, and other nutrients in the United States, it is important to determine the net benefit or harm of egg consumption as whole food (as opposed to individual component of eggs such as cholesterol). In the current project, we sought to prospectively assess whether egg consumption was associated with a greater risk of myocardial infarction (MI), stroke, and all-cause mortality. In addition, we assessed the influence of type 2 diabetes and history of hypercholesterolemia as possible effect modifiers of these associations.

SUBJECTS AND METHODS

Study population

The current project used data from the Physicians’ Health Study (PHS) I, which was a randomized, double-blind, placebo-controlled trial using a 2 × 2 factorial design to study low-dose aspirin and β-carotene for the primary prevention of cardiovascular disease (CVD) and cancer among US male physicians. A detailed description of PHS I was previously published (22). Briefly, 261,248 US male physicians aged 40–85 y were invited to participate in the clinical trial in 1981. After exclusion of subjects with a history of stroke, gout, MI, transient ischemic attack, cancer (except nonmelanoma skin cancer), peptic ulcer, current liver or kidney disease, and current use of trial treatments, 261,248 were enrolled and randomly assigned to receive or not receive placebo or low-dose aspirin and β-carotene, and 260,706 subjects completed follow-up through 1995 (23). Study assessment methods are detailed elsewhere (22). The current analysis included 21,327 men who participated in follow-up visits, completed the biopsy component of the antioxidant study, and provided dietary information in 1986–87.

Subjects and Methods

Background: A reduction in dietary cholesterol is recommended to prevent cardiovascular disease (CVD). Although eggs are important sources of cholesterol and other nutrients, limited and inconsistent data are available on the effects of egg consumption on the risk of CVD and mortality.

Objective: We aimed to examine the association between egg consumption and the risk of CVD and mortality.

Design: In a prospective cohort study of 21,327 participants from Physicians’ Health Study I, egg consumption was assessed with an abbreviated food questionnaire. Cox regression was used to estimate relative risks.

Results: In an average follow-up of 20 y, 1550 new myocardial infarctions (MIs), 1342 incident strokes, and 5169 deaths occurred. Egg consumption was not associated with incident MI or stroke in a multivariate Cox regression. In contrast, adjusted hazard ratios (95% CI) for mortality were 1.0 (reference), 0.94 (0.87, 1.02), 1.03 (0.95, 1.11), 1.05 (0.93, 1.19), and 1.23 (1.11, 1.36) for the consumption of <1, 1, 2–4, 5–6, and ≥7 eggs/wk, respectively (P for trend < 0.0001). This association was stronger among diabetic subjects, in whom the risk of death in a comparison of the highest with the lowest category of egg consumption was twofold (hazard ratio: 2.01; 95% CI: 1.26, 3.20; P for interaction = 0.09).

Conclusions: Infrequent egg consumption does not seem to influence the risk of CVD in male physicians. In addition, egg consumption was positively related to mortality, more strongly so in diabetic subjects, in the study population.

INTRODUCTION

Coronary artery disease (CAD) remains the leading cause of death in the United States. Because elevated LDL cholesterol has been identified as a major risk factor for CAD, dietary guidelines to prevent CAD emphasize the reduction in dietary cholesterol to <300 mg/d (1, 2). Egg is a major source of dietary cholesterol with an average egg containing ≈200 mg cholesterol. On the other hand, eggs contain other nutrients such as minerals, folate, B vitamins, proteins, and monounsaturated fatty acids (3, 4) that could reduce the risk of CAD. Whereas some studies have shown positive associations between dietary and serum cholesterol (5–9), others did not find any effect (7, 10, 11). There is a large variability in individual response to dietary cholesterol (11–13). In addition, the effect of dietary cholesterol on LDL cholesterol observed in positive studies is modest compared with the LDL-raising effects of saturated and trans fatty acids (14, 15).

Limited and inconsistent data have been reported on the association between egg consumption and CAD. Among 514 Australian Aborigines, consumption of >2 eggs/wk was associated with a 2.6 times greater risk of CAD in a prospective analysis (16). Mann et al (17) reported a 2.7 times greater risk of death with higher egg consumption (>6 eggs/wk) among British persons. In contrast, other large prospective cohorts with longer follow-ups did not observe any association between egg consumption and CAD or mortality (18–21). Because eggs could serve as a good source for vitamins, proteins, and other nutrients in the United States, it is important to determine the net benefit or harm of egg consumption as whole food (as opposed to individual component of eggs such as cholesterol). In the current project, we sought to prospectively assess whether egg consumption was associated with a greater risk of myocardial infarction (MI), stroke, and all-cause mortality. In addition, we assessed the influence of type 2 diabetes and history of hypercholesterolemia as possible effect modifiers of these associations.

SUBJECTS AND METHODS

Study population

The current project used data from the Physicians’ Health Study (PHS) I, which was a randomized, double-blind, placebo-controlled trial using a 2 × 2 factorial design to study low-dose aspirin and β-carotene for the primary prevention of cardiovascular disease (CVD) and cancer among US male physicians. A detailed description of PHS I was previously published (22). Briefly, 261,248 US male physicians aged 40–85 y were invited to participate in the clinical trial in 1981. After exclusion of subjects with a history of stroke, gout, MI, transient ischemic attack, cancer (except nonmelanoma skin cancer), peptic ulcer, current liver or kidney disease, and current use of trial treatments, 261,248 were enrolled and randomly assigned to receive or not receive placebo or low-dose aspirin and β-carotene, and 260,706 subjects completed follow-up through 1995 (23). Study assessment methods are detailed elsewhere (22). The current analysis included 21,327 men who participated in follow-up visits, completed the biopsy component of the antioxidant study, and provided dietary information in 1986–87.

Design: In a prospective cohort study of 21,327 participants from Physicians’ Health Study I, egg consumption was assessed with an abbreviated food questionnaire. Cox regression was used to estimate relative risks.

Results: In an average follow-up of 20 y, 1550 new myocardial infarctions (MIs), 1342 incident strokes, and 5169 deaths occurred. Egg consumption was not associated with incident MI or stroke in a multivariate Cox regression. In contrast, adjusted hazard ratios (95% CI) for mortality were 1.0 (reference), 0.94 (0.87, 1.02), 1.03 (0.95, 1.11), 1.05 (0.93, 1.19), and 1.23 (1.11, 1.36) for the consumption of <1, 1, 2–4, 5–6, and ≥7 eggs/wk, respectively (P for trend < 0.0001). This association was stronger among diabetic subjects, in whom the risk of death in a comparison of the highest with the lowest category of egg consumption was twofold (hazard ratio: 2.01; 95% CI: 1.26, 3.20; P for interaction = 0.09).

Conclusions: Infrequent egg consumption does not seem to influence the risk of CVD in male physicians. In addition, egg consumption was positively related to mortality, more strongly so in diabetic subjects, in the study population.
33,223 physicians were enrolled in an 18-wk run-in period. At the end of the run-in period, 22,071 subjects were randomly assigned to 1 of 4 treatment arms: low-dose aspirin, β-carotene, both agents, or placebo. For the current project, after the exclusion of 744 subjects with missing data on egg consumption (n = 151) or covariates (n = 593), the final sample consisted of 21,327 participants.

Each participant provided written informed consent. The study protocol was approved by the Institutional Review Board of Brigham and Women’s Hospital.

**Assessment of egg consumption**

Information on egg consumption was self-reported by using a simple abbreviated semi-quantitative food-frequency questionnaire. Participants were asked to report their average egg consumption during the past year. Possible response categories included rarely or never, 1–3 times/mo, 1 time/wk, 2–4 times/wk, 5–6 times/wk, daily, and >2 times/d. This information was obtained at baseline and 24, 48, 72, 96, and 120 mo after randomization.

**Ascertainment of cardiovascular events and death in the Physicians’ Health Study I**

A questionnaire was mailed to each participant every 6 mo during the first year and annually thereafter to gather information on compliance with the intervention and the occurrence of new medical diagnoses including MI, stroke, and death. For participants who did not return the follow-up questionnaire within 5–6 wk of the initial mailing, a follow-up questionnaire was sent to them. If necessary, third and fourth questionnaires were sent to nonrespondents, and then they were telephoned in an attempt to obtain the follow-up information if there was still no response to the mailed questionnaires. If the follow-up information was not obtained by questionnaires or telephone call, the vital status of the corresponding participant was ascertained. A letter and return postcard were also mailed to the participants at the 6-mo interval between annual mailings. Participants were asked to return the postcard if they experienced any major problems affecting their participation in the study.

All cardiovascular endpoints were adjudicated by the Endpoint Committee of the PHS, which included cardiologists and neurologists. MI was confirmed on the basis of World Health Organization criteria modified to use cardiac enzyme tests. When participants died, death certificates were obtained for confirmation and review of cause of death. Additional information was obtained from the participants’ next of kin and from medical records after the proper permission was obtained from the next of kin. Both the cause of death on death certificates and additional information from the next of kin and medical records were used by the Endpoint Committee. Details on endpoint validation in the PHS were previously published (23–26).

**Other variables**

Demographic data were collected at baseline. Information on comorbidity (ie, atrial fibrillation, hypertension, and diabetes mellitus) was collected through annual follow-up questionnaires as described above. Data on selected foods such as fruit, vegetables, and breakfast cereals; physical activity; smoking; alcohol consumption; parental history of premature MI; and history of hypercholesterolemia were obtained at baseline.

**Statistical analysis**

Because there was a reasonable correlation between reported egg consumption at baseline and at 24 mo (weighted kappa: 0.51), we substituted missing values at baseline by using reported egg consumption at 24 mo in 113 subjects. We grouped adjacent categories to allow a sufficient number of person-times per category of egg consumption and to maintain a gradient of exposure. Thus, we classified each subject into one the following categories of egg consumption: <1 egg/wk, 1 egg/wk, 2–4 eggs/wk, 5–6 eggs/wk, and ≥7 eggs/wk. For each endpoint (MI, stroke, or death), we calculated person-time of follow-up from baseline until the first occurrence of an endpoint, death, or a censoring date (ie, the date of receipt of the last follow-up questionnaire). Within each egg consumption group, we calculated the incidence rate of each endpoint by dividing the number of cases by the corresponding person-time. We used Cox proportional hazard models to compute multivariate-adjusted hazard ratios (HRs) (and corresponding 95% CIs) by using subjects in the lowest category of egg consumption as the reference group. We assessed confounding by using a 10% change in HRs. Assumptions for the proportional hazard models were tested (by including main effects and product terms of covariates and a log-transformed time factor) and were met (P > 0.05 for all). We obtained the P values for linear trend by assigning the median value of egg consumption in each category to a new variable that was used in the Cox model (we assigned values of 0, 1, 3, 5.5, and 7 for the lowest to the highest egg consumption, respectively). The initial model controlled for age. The parsimonious model also controlled for body mass index (continuous), smoking (never, past, or current smoker), and history of hypertension (yes or no). The final multivariate model also controlled for hypercholesterolemia (yes or no), parental history of premature MI (yes or no), diabetes mellitus (yes or no), atrial fibrillation (yes or no), breakfast cereal consumption (0, 1, 2–6, or ≥7 servings/wk), alcohol consumption (<1, 1–4, 5–6, or ≥7 drinks/wk), vegetable consumption (<3, 3–4, 5–6, 7–13, or ≥14 servings/wk), use of multivitamins (never, past, or current), and physical activity (<1, 1, 2–4, or ≥5 times/wk). Two-way interaction between egg consumption and treatment assignment was evaluated by including main effect and their product term in the regression model (P > 0.05 for all).

In secondary analyses, we examined the association between egg consumption and types of stroke (ischemic or hemorrhagic) and possible effect modification by diabetes mellitus and hypercholesterolemia with the use of stratified analyses. In addition, we excluded subjects with a follow-up time of ≤2 y. Finally, we repeated the main analysis by using updated egg consumption at 24, 48, 72, 96, and 120 mo in a time-dependent Cox model. All analyses were completed with the use of SAS software (version 9.1; SAS Institute, Cary, NC). Significance was set at 0.05.

**RESULTS**

Among 21,327 participants in PHS I, the mean ± SD age at randomization was 53.7 ± 9.5 y (range: 40–86 y). The median egg consumption was 1/wk in this population. Baseline characteristics of the study participants are presented in **Table 1**. Frequent consumption of eggs was associated with older age; higher body mass index; higher vegetables and lower breakfast cereal consumption; higher proportions of current drinkers, smokers,
TABLE 1
Characteristics of 21,327 participants by category of egg consumption in the Physicians’ Health Study

<table>
<thead>
<tr>
<th>Variables</th>
<th>&lt;1/wk (n = 4564)</th>
<th>1/wk (n = 6627)</th>
<th>2–4/wk (n = 6983)</th>
<th>5–6/wk (n = 1421)</th>
<th>≥7/wk (n = 1732)</th>
<th>P for trend (^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>53.0 ± 9.3 (^2)</td>
<td>53.4 ± 9.3</td>
<td>53.6 ± 9.5</td>
<td>54.1 ± 9.4</td>
<td>56.8 ± 10.1</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>BMI (kg/m(^2))</td>
<td>24.5 ± 2.6</td>
<td>24.7 ± 2.7</td>
<td>24.9 ± 2.7</td>
<td>25.2 ± 2.9</td>
<td>25.0 ± 3.2</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Vegetable intake (servings/wk)</td>
<td>7.9 ± 5.0</td>
<td>8.0 ± 4.6</td>
<td>8.2 ± 4.6</td>
<td>8.2 ± 4.6</td>
<td>8.6 ± 5.1</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Breakfast cereal ≥7 times/wk (%)</td>
<td>24.1</td>
<td>24.0</td>
<td>15.9</td>
<td>10.8</td>
<td>11.8</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Parental history of premature MI (%)</td>
<td>10.8</td>
<td>9.1</td>
<td>9.5</td>
<td>7.2</td>
<td>7.2</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Hypercholesterolemia (%)</td>
<td>13.6</td>
<td>12.2</td>
<td>11.3</td>
<td>10.8</td>
<td>10.5</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Current smoking (%)</td>
<td>8.0</td>
<td>9.8</td>
<td>12.0</td>
<td>14.9</td>
<td>16.7</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Current alcohol drinking (%)</td>
<td>71.0</td>
<td>75.0</td>
<td>75.5</td>
<td>74.5</td>
<td>73.9</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Exercise ≥1 time/wk (%)</td>
<td>71.8</td>
<td>72.6</td>
<td>72.9</td>
<td>72.7</td>
<td>69.9</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>History of diabetes (%)</td>
<td>1.2</td>
<td>1.8</td>
<td>2.0</td>
<td>2.3</td>
<td>5.2</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>History of hypertension (%)</td>
<td>21.9</td>
<td>23.8</td>
<td>23.9</td>
<td>25.4</td>
<td>28.5</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>History of atrial fibrillation (%)</td>
<td>1.3</td>
<td>1.5</td>
<td>1.3</td>
<td>1.8</td>
<td>1.3</td>
<td>0.67</td>
</tr>
<tr>
<td>Current use of multivitamins (%)</td>
<td>20.0</td>
<td>18.6</td>
<td>19.9</td>
<td>20.2</td>
<td>24.0</td>
<td>0.001</td>
</tr>
<tr>
<td>Aspirin assignment (%)</td>
<td>49.5</td>
<td>49.5</td>
<td>50.3</td>
<td>51.6</td>
<td>50.1</td>
<td>0.22</td>
</tr>
</tbody>
</table>

\(^1\) P for trend values were obtained from ANOVA or a logistic regression model.
\(^2\) \(\bar{x} \pm SD\) (all such values).

and multivitamin users; higher prevalence of diabetes and hypertension; and lower prevalence of exercise, hypercholesterolemia, and parental history of premature CAD. During an average follow-up of 20 y, 1550 new MIs (7.3%), 1342 incident strokes (6.3%), and 5169 deaths (24.2%) occurred in this cohort. In multivariate Cox regression model, egg consumption was not associated with incident MI (Table 2), total stroke (Table 3), or types of stroke. From the lowest to the highest category of egg consumption, multivariate-adjusted HRs (95% CI) for ischemic stroke were 1.0; 1.03 (0.86, 1.23); 1.08 (0.91, 1.28); 1.11 (0.86, 1.43); and 0.99 (0.78, 1.26), respectively (\(P\) for trend 0.74). Corresponding values for hemorrhagic stroke were 1.0; 0.66 (0.44, 1.00); 0.92 (0.63, 1.36); 1.29 (0.76, 2.20); and 1.07 (0.65, 1.78), respectively (\(P\) for trend 0.11). Whereas egg consumption of up to 6 eggs/wk was not associated with the risk of all-cause mortality, consumption of ≥7 eggs/wk was associated with a 23% greater risk of death than consumption of ≤6 eggs/wk as associated with a 23% greater risk of death among control for confounders (Table 4). The exclusion of subjects whose follow-up times were ≤2 y, and the use of the time-dependent Cox model with updated egg consumption over time did not alter the results (data not shown).

In stratified analyses, a history of hypercholesterolemia at baseline did not influence the relation between egg consumption and MI, stroke, or total deaths (data not shown). However, when stratified by prevalent diabetes at baseline, there was significantly stronger association between egg consumption and all-cause mortality among subjects with prevalent diabetes than among those without diabetes (Table 5). Compared with the lowest category of egg consumption, the intake of ≥7 eggs/wk was associated with a 23% greater risk of death in the absence of prevalent diabetes, whereas the corresponding risk of death in the presence of prevalent diabetes was 100% greater (\(P\) for interaction between diabetes and egg consumption = 0.029 in the parsimonious model and 0.09 in the multivariate-adjusted model; Table 5). For MI, multivariate-adjusted HRs (95% CI) were 1.0; 1.07 (0.92, 1.25); 1.16 (0.99, 1.34); 1.13 (0.90, 1.42); and 0.91 (0.73, 1.14) from the lowest to the highest category of egg consumption, respectively (\(P\) for trend = 0.97) in the absence of prevalent diabetes. Corresponding values among subjects with diabetes were 1.0; 1.39 (0.61, 3.21); 1.45 (0.64, 3.28); 1.82 (0.66, 5.03); and 1.06 (0.43, 2.64), respectively (\(P\) for trend = 0.93; \(P\)

---

**TABLE 2**
Hazard ratios (and 95% CIs) for myocardial infarction according to egg consumption

<table>
<thead>
<tr>
<th>Egg consumption</th>
<th>Cases</th>
<th>Hazard ratio (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;1/wk</td>
<td>291</td>
<td>1.0</td>
</tr>
<tr>
<td>1/wk</td>
<td>474</td>
<td>1.10 (0.95, 1.27)</td>
</tr>
<tr>
<td>2–4/wk</td>
<td>546</td>
<td>1.21 (1.05, 1.40)</td>
</tr>
<tr>
<td>5–6/wk</td>
<td>115</td>
<td>1.24 (1.00, 1.54)</td>
</tr>
<tr>
<td>≥7/wk</td>
<td>124</td>
<td>1.02 (0.83, 1.27)</td>
</tr>
<tr>
<td>P for linear trend</td>
<td></td>
<td>0.21</td>
</tr>
</tbody>
</table>

\(^1\) Adjusted for age, BMI (continuous), smoking (never, past, or current smoker), and history of hypertension.
\(^2\) Adjusted as in model 1 plus vitamin intake, alcohol consumption (<1, 1–4, 5–6, or ≥7 drinks/wk), vegetable consumption (<3, 3–4, 5–6, 7–13, or ≥14 servings/wk), breakfast cereal (0, 1, 2–6, or ≥7 servings/wk), physical activity (<1, 1–4, or ≥5 times/wk), treatment arm (4 groups), atrial fibrillation (yes or no), diabetes mellitus (yes or no), hypercholesterolemia (yes or no), and parental history of premature myocardial infarction (yes or no).
In this prospective cohort, we showed that frequent egg consumption in the UK, with or without diabetes, was associated with a greater risk of all-cause mortality in a dose-response fashion. Among physicians with diabetes, baseline hypercholesterolemia was a risk factor for death. Furthermore, we found no association between egg consumption and stroke. In contrast, egg consumption was associated with a greater risk of death among people consuming 7 or more eggs per week. In those consuming 1–5 eggs per week, the risk of death was 2.6 times greater with the consumption of 7 or more eggs per week.

There are several limitations to this study. First, the sample size was small and the follow-up period was relatively short. Second, the study was conducted in the UK and may not be generalizable to other populations. Third, the study was observational and therefore cannot establish causality. Finally, the study did not account for potential confounding factors such as age, sex, and lifestyle factors.

Despite these limitations, this study provides some evidence that frequent egg consumption may be associated with a greater risk of all-cause mortality, particularly among people with diabetes. Further research is needed to confirm these findings and to better understand the mechanisms underlying this association.
adjusted odds ratios were 1.0, 1.2, and 0.8 for intakes of 1 egg/wk in women, egg consumption was not associated with MI: age-
egg/wk in women. In a case-control study among 936 Italian
sociation between egg consumption and CAD among 912 men
and women after 16 y of follow-up (18). The average consump-
tion of eggs was associated with an increase in LDL peak diam-
eter and a decrease in smaller LDL subfraction, which suggests
that egg consumption may lead to a less atherogenic lipoprotein
profile (13, 33). In the same study, 5 of the children with LDL

### Table 5

<table>
<thead>
<tr>
<th>Egg consumption</th>
<th>Cases</th>
<th>Model 1</th>
<th>Cases</th>
<th>Model 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1/week</td>
<td>971</td>
<td>1.0</td>
<td>29</td>
<td>1.0</td>
</tr>
<tr>
<td>1/week</td>
<td>1408</td>
<td>0.92 (0.85, 1.00)</td>
<td>61</td>
<td>1.20 (0.77, 1.87)</td>
</tr>
<tr>
<td>2–4/week</td>
<td>1605</td>
<td>0.99 (0.92, 1.08)</td>
<td>80</td>
<td>1.30 (0.85, 1.99)</td>
</tr>
<tr>
<td>5–6/week</td>
<td>341</td>
<td>0.99 (0.88, 1.12)</td>
<td>25</td>
<td>2.48 (1.44, 4.27)</td>
</tr>
<tr>
<td>≥7/week</td>
<td>581</td>
<td>1.23 (1.11, 1.37)</td>
<td>68</td>
<td>1.55 (1.00, 2.40)</td>
</tr>
<tr>
<td>P for linear trend</td>
<td>&lt;0.0001</td>
<td></td>
<td>0.009</td>
<td>0.0005</td>
</tr>
</tbody>
</table>

1 Difference in effect between diabetic and nondiabetic subjects: P for interaction = 0.029 (model 1) and 0.09 (model 2).
2 Adjusted for age, BMI (continuous), smoking (never, past, or current smoker), and history of hypertension.
3 Adjusted as in model 1 plus vitamin intake, alcohol consumption (<1, 1–4, 5–6, or ≥7 drinks/wk), vegetable consumption (<3, 3–4, 5–6, 7–13, or ≥14 servings/wk), breakfast cereal (0, 1, 2–6, or ≥7 servings/wk), physical activity (<1, 1–2, or ≥3 times/wk), treatment arm (4 groups), atrial fibrillation (yes or no), hypercholesterolemia (yes or no), and parental history of premature myocardial infarction (yes or no).

In contrast, data from the Framingham study showed no association between egg consumption and CAD among 912 men and women after 16 y of follow-up (18). The average consumption in the Framingham study was approximately 6 eggs/wk in men and 4 eggs/wk in women. In a case-control study among 936 Italian women, egg consumption was not associated with MI: age-adjusted odds ratios were 1.0, 1.2, and 0.8 for intakes of <1, 1–2, and >2 eggs/wk, respectively (27). In a large Japanese cohort of 5186 women and 4077 men, Nakamura et al. (20) reported no association between egg consumption and all-cause mortality or CVD deaths in men after 14 y of follow-up. Little effect was also observed in women in that study. Other large cohorts reported no association between egg consumption and CAD, stroke, or mortality (19, 28). However, in these later studies, there was suggestive evidence for a greater risk of CVD among subjects with diabetes. Qureshi et al. (28) reported a 2 times greater risk of CAD in persons reporting an intake of ≥6 eggs/wk than in those reporting an intake of <1 egg/wk. In addition, Hu et al. (19) reported a 2 times greater risk of CAD with consumption of >1 egg/wk than with that of <1 egg/wk in 37 851 diabetic men from the Health Professionals Follow-up Study after adjustment for potential confounders. In the same report, the corresponding risk of CAD was 49% greater in diabetic women from the Nurses’ Health Study. These findings in persons with diabetes are consistent with our report of a dose-response association between egg consumption and all-cause mortality in PHS I participants with prevalent diabetes at baseline. Could a biological mechanism help explain the positive association between egg consumption and CVD or mortality in persons with diabetes?

Overall, epidemiologic studies suggest that, among hyperresponders, dietary cholesterol from egg leads to a modest increase in serum LDL- and HDL-cholesterol concentrations and to no effect on the ratio of LDL to HDL cholesterol (8, 29–32). It is estimated that each additional 100-mg intake of dietary cholesterol results in an increase of 1.9 mg/dL in LDL and of 0.4 mg/dL in HDL (32). It is notable that this estimation does not take into account the effects of saturated fat or the type of response to dietary cholesterol. In addition, in randomized trials, consumption of eggs was associated with an increase in LDL peak diameter and a decrease in smaller LDL subfraction, which suggests that egg consumption may lead to a less atherogenic lipoprotein profile (13, 33). In the same study, 5 of the children with LDL phenotype B shifted to pattern A (low-risk pattern) (13). However, other investigators did not report an effect of egg consumption on LDL subfraction (29). Because of the wide variability in individual responses to dietary cholesterol (hyperresponders or hyporesponders), it is not known whether such differential responses to egg consumption could selectively influence glucose metabolism and thus help understand our findings of increased risk of death among people with diabetes in particular. Furthermore, it has been shown that baseline cholesterol influences individual response to dietary cholesterol (with higher baseline serum cholesterol leading to lower effects of dietary cholesterol) (34). At present, we can only speculate that, among diabetic subjects, dietary cholesterol may perhaps lead to a less favorable lipoprotein profile in terms of serum concentration and particle size, with a shift to smaller and dense LDL particle size, which may lead to accelerated atherosclerosis and its complications. Testing of such a hypothesis in an experimental design among persons with diabetes is warranted.

The present study had additional limitations. We did not exclude unmeasured confounding or residual confounding as a possible explanation of the observed positive association among persons with diabetes. In particular, we were not able to examine the effects of saturated fat, markers of insulin resistance, lipids, and other nutrients or relevant biomarkers on the observed association. Whereas the lack of a detailed dietary questionnaire in the present study prevented control for energy and other major nutrients, the Nurses’ Health Study and the Health Professionals’ Follow-up Study (19) accounted for total energy intake. Changes of dietary patterns may lead to a spurious association between baseline exposure and incident outcome. In the data in the present study, we used time-dependent Cox regression model to update reported egg consumption at 24, 48, 72, 96, and 120 mo after randomization. Such an exposure update over time led to similar conclusions, which suggests that these findings are robust. The fact that the sample in the current study consisted of male physicians who may have different behaviors than the general population limits the generalizability of these findings. In addition, the fact that these physicians were knowledgeable about the dietary cholesterol content of eggs may have led to a higher probability of adopting other healthful behaviors, which would attenuate any unfavorable effect of egg consumption. However, this hypothesis is not consistent with the lower frequency of
exercise and intake of breakfast cereals and the higher proportion of smokers among frequent egg consumers. Similar data were reported in the Health Professionals’ Follow-up Study (19). Because we had few cases of CAD and stroke, we did not have sufficient power to detect an interaction between prevalent diabetes and egg consumption for the risk of MI or total stroke and subtypes of stroke. Nevertheless, the large sample size, the longer duration of follow-up, and the robustness of the findings in sensitivity analyses are strengths of the present study.

In conclusion, these data suggest that the consumption of ≤6 eggs/wk has no major effect on the risk of CVD and mortality and that the consumption of ≥7 eggs/wk is associated with a modestly greater risk of total mortality in US male physicians. However, among male physicians with diabetes, any egg consumption is associated with a greater risk of all-cause mortality, and there was suggestive evidence for a greater risk of MI and stroke. Confirmation of these findings in the general population and among diabetic subjects, along with the investigation of possible biologic mechanisms, is warranted.

We are indebted to the participants in PHS I for their outstanding commitment and cooperation and to the entire PHS staff for their expert and unfailing assistance.

The authors’ responsibilities were as follows—LD: designed the study, obtained funding, conducted data analyses, and drafted the manuscript; JMG: obtained funding, collected data, provided significant advice on data analysis, and critically reviewed the manuscript. Neither of the authors had a personal or financial conflict of interest.

REFERENCES


