



Modeling the Removal and Addition of Eggs in the Current US Diet is Linked to Choline and Lutein + Zeaxanthin Usual Intakes in Childhood

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ABSTRACT

Background: Limited data are available examining nutritional implications for removing/adding eggs in childhood dietary patterns. Additionally, usual intake data are lacking for choline and lutein + zeaxanthin in childhood.

Objectives: To determine usual intakes of choline and lutein + zeaxanthin in egg consumers and model the removal and addition of eggs within dietary patterns on choline and lutein + zeaxanthin intakes.

Methods: Data from the NHANES, 2011–2014, were analyzed in egg consumers (infants, $n = 130$; children/adolescents, $n = 980$) of various age groups during childhood. Additionally, a modeling analysis was conducted to examine choline and lutein + zeaxanthin intake following the removal and addition of eggs to the current American diet of children.

Results: Overall, modeling removal of eggs from the diet in all age groups examined showed decreases in choline intakes, resulting in significantly fewer subjects above the recommended Adequate Intake (AI) for choline. In contrast, the addition of 1 egg per week to the current American eating pattern resulted in nearly 10% more infants 6–23 months of age being above the AI for choline intake. The addition of 7 eggs per week to the current dietary pattern of infants would nearly achieve 100% of infants meeting the AI for choline. In children 2–8 years old, modeling an additional 7 eggs per week to the current dietary pattern resulted in approximately 94% of children being above the AI for choline, while the addition of 7 eggs per week increases the percentages above the AI to 23.0% and 52.4% in children aged 9–18 and 2–18 years, respectively. In children aged 2–8 and 2–18 years old, the addition of 7 eggs per week also showed meaningful increases in lutein + zeaxanthin usual intakes relative to the current dietary pattern (i.e., lutein + zeaxanthin increased from nearly 775 mcg/day to approximately 916 mcg/day and 780 mcg/day to approximately 931 mcg/day, respectively).

Conclusions: The current data support egg consumption as part of healthy dietary patterns to help meet established choline recommendations, while concurrently increasing lutein and zeaxanthin intakes in childhood. *Curr Dev Nutr* 2021;5:nzaa181.

Keywords: NHANES, eggs, infants, children, choline, lutein, zeaxanthin

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Abbreviations used: AI, Adequate Intake; CVD, cardiovascular disease; DGAC, Dietary Guidelines Advisory Committee; FNDDS, Food and Nutrition Database for Dietary Studies; WWEIA, What We Eat in America.

Introduction

Recommendations in the last 50 years have not been favorable in endorsing eggs as part of a healthy diet, with nutrition guidance likely attributed to the cholesterol contribution of eggs and negative associations to heart health (1). Common scientific rationale for avoiding eggs within the diet can be traced to American Heart Association guidance from the late 1960s to reduce egg consumption to less than 3 eggs/week to lower the risk of cardiovascular disease (CVD) (2). Nevertheless, a recent review has questioned previously accepted science around egg consumption and health, and has proposed that previous dietary

recommendations are no longer valid, as they were based on misconstrued and inferior evidence (2). Indeed, since the Dietary Guidelines for Americans 2010, recommendations for cholesterol intake have evolved from limiting cholesterol to ≤ 300 mg/day (3) to cholesterol not being a nutrient of concern for overconsumption (4, 5). Furthermore, the 2020 Dietary Guidelines Advisory Committee (DGAC) released food and nutrition recommendations for infants and toddlers that specifically recommended eggs as a first food in this age group, in addition to recommending eggs for pre-adolescents, adolescents, and pregnant and lactating women (6). In contrast, data from 6 prospective cohorts suggest that increased dietary cholesterol or whole egg intake

are linked with a greater risk of CVD and mortality from all-causes in a dose-dependent manner (7). Similarly, other published studies have reported eggs to be related with unfavorable health outcomes (8). In contrast to studies linking negative outcomes to egg intake, a large, prospective study in China reported that consumption of approximately 1 whole egg daily was linked to a decreased risk of CVD relative to individuals identified as nonconsumers of eggs. Additionally, the prospective findings revealed an 18% lower risk of CVD mortality and 28% reduced risk of stroke mortality in adults consuming eggs relative to adults avoiding eggs (9). A recent meta-analysis of 7 prospective studies showed that 1 whole egg per day (i.e., 7 whole eggs per week) was not associated with coronary heart disease compared to 2 whole eggs/week (10). Recent studies have also shown nutrient intake benefits associated with egg consumption in younger populations. Specifically, an analysis in infants using data from the US NHANES reported an association between egg consumption and growth, such that infant egg consumers had greater recumbent length when compared to infants who were not given eggs as part of the diet. Greater intakes of protein, DHA, α -linolenic acid, lutein/zeaxanthin, total choline, and vitamin B12 were also observed in infant egg consumers relative to nonconsumers (11). Likewise, data from NHANES in children 2–18 years old demonstrated similar associations, such that dietary patterns that included eggs were associated with greater amounts of protein, DHA, α -linolenic acid, potassium, selenium, phosphorus, total choline, lutein + zeaxanthin, riboflavin, vitamin E, vitamin D, and vitamin A, and lower total and added sugar intake, relative to eating patterns with no egg consumption (12).

Dietary guidance supports and encourages numerous protein-rich foods, including eggs, with the caveat that these foods be consumed with minimal added sugar, sodium, and solid fat (5). The nutrient-dense attributes of eggs are well documented, with one 50-gram serving of egg providing numerous bioavailable nutrients (12, 13), including being an important food source of choline, an underconsumed nutrient in the American population as indicated by the 2020 DGAC (6, 14). Eggs are also an important source of the carotenoids lutein and zeaxanthin (13), with accumulating evidence supporting increased intake to support eye function and protect against eye diseases (15–17).

Limited data have examined nutritional implications for removing and/or adding eggs in the diet of infants and children. Further, peer-reviewed studies contain inconsistencies in recommendations for eggs as part of dietary patterns, and are often misaligned with the current 2020 DGAC recommendations (6). Additionally, a recent review identified gaps in the scientific literature, highlighting the lack of usual intake data in childhood for choline (18). Therefore, the objective of the current analysis was to examine usual intakes for choline and lutein + zeaxanthin from modeling the removal and addition of eggs within the current and typical diets of US infants and children. An additional objective included assessing the proportion of the population meeting the Adequate Intake (AI) of choline during childhood following the removal and addition of eggs to the current dietary pattern.

Methods

Data were obtained from the US NHANES data set, a cross-sectional survey that collects nutritional, biochemical, physiological, and anthropometric data in noninstitutionalized, free-living Americans. NHANES

is a continuous research study overseen by the CDC (19). All ethics protocols, including all procedures mandated to obtain study consent from participants, have formerly been gathered and verified by the ethics committee of the CDC. The NHANES 2011–2012 and 2013–2014 data sets were merged for the study for infants aged 6 to 23 months and children/adolescents aged 2 to 18 years (20, 21). Nutrient data examined were from the USDA Food and Nutrient Database for Dietary Studies (FNDDS) database for NHANES 2011–2014 (22, 23). The FNDDS calculates food and beverage nutrient values in What We Eat in America (WWEIA) (24, 25). The WWEIA collection of data uses the Automated Multiple-Pass Method, which has been recognized and documented as a valid, accurate, efficient, and evidence-based procedure for nationally representative dietary surveys (25, 26). For the current research, the analysis focused on reliable and complete 24-hour dietary recall data from Day 1 (i.e., in-person interview) and Day 2 (i.e., offsite follow-up interview via a telephone call) (27). A study participant's actual intake can significantly vary from 1 day to the next; thus, usual intakes are more suited to ensure improved accuracy for nutrient adequacy analyses. As has been previously reported, assessments of nutrient adequacy in using NHANES data are facilitated by statistical adjustment methods to provide an estimate of the distribution of usual intakes from observed intakes, provided more than 1 day of intake data are available for the study analysis (28).

Study participants and egg definitions

Gender-combined data for infants, children, and adolescent egg consumers were assessed using the NHANES database (infants, $n = 130$; children/adolescents, $n = 980$). The definition of egg consumption focused on participants that included eggs, poached eggs, scrambled eggs, and omelets in their diet. Egg consumption was defined by FNDDS food codes classified in WWEIA category 2502, “eggs and omelets,” while FNDDS groups “egg substitutes” and “other poultry eggs” were excluded. Mixed-food dishes containing eggs (i.e., egg burritos, egg sandwiches, egg casseroles, egg breads, cakes, cookies, pastries, etc.) were not included in the analyses, with the aim of ascertaining a quantifiable amount of egg consumption.

Statistical methodology

SUDAAN 11.0 (Research Triangle Institute, Research Triangle Park, NC, USA) and SAS 9.2 (SAS Institute, Cary, NC, USA) statistical software were used to complete all statistical analyses. Survey weights were incorporated to develop nationally representative estimates for study participants, as well as adjustments to reflect the complex sample design of NHANES (29). Usual intake estimation used the National Cancer Institute method, version 2.1 (30). Adjusted means (\pm standard errors) for total choline and lutein + zeaxanthin intakes were determined in the various age groups. For choline, the percentage above the AI was also calculated. Least square means, standard errors, and lower/upper 99th confidence levels of choline and lutein + zeaxanthin for the daily total diet were generated. Data were interpreted such that when the 99th confidence levels did not overlap, changes in intakes were classified as meaningful. Egg foods (i.e., FNDDS food codes defined in WWEIA category 2502, “eggs and omelets”) were removed from the current dietary pattern at 0%, 25%, 50%, and 100% to generate energy and nutrient

TABLE 1 Mean demographic data for the infant and toddler population

Variable	Mean	SE
Age, months	16.59	0.52
Gender, male, %	48.29	5.50
PIR <1.35, %	47.90	6.04
1.35 ≤ PIR ≤ 1.85, %	8.27	3.74
PIR >1.85, %	43.83	6.53
"Other" WIC participant, %	58.17	6.22

Data are from infants and toddlers aged 6 to 23 months. Egg consumers sample, $n = 130$. Population $n = 1,086,438$. Mean refers to the least square mean. Abbreviations: PIR, Poverty Income Ratio; SE, standard error; WIC, Special Supplemental Nutrition Program of Women, Infants and Children.

intakes. A weighted composite of all egg USDA food codes from the sample population was used for modeling the addition of eggs into the current dietary patterns in infants and children. In the current modeling analyses, we evaluated the addition of 1, 3, 5, and 7 eggs per week in the various age groups.

Results

Population demographics

Study population demographics are summarized in [Tables 1](#) and [2](#). The mean age of infants and toddlers was approximately 16.6 months, while the mean age of children and adolescents was 9.3 years.

Energy and saturated fat intake with the removal and addition of eggs to the current dietary pattern

Approximately less than half of a large, 50 g egg was consumed in all age groups considered (i.e., about 1/3 of a large, 50 g egg was typically consumed) in the identified dietary pattern. Energy and saturated fat intakes were minimally reduced with the removal of eggs from the dietary pattern of infants and children. Specifically, energy intake with the removal of 100% of eggs from the diet resulted in a decrease of 22–27 kcal/day. Saturated fat decreased from 0.1 to 0.6 g/day. The addition of eggs in the dietary pattern resulted in an increase of 13 kcal/day (1 egg/week) to 90 kcal/day (7 eggs/week) for all age groups. The addition of eggs also resulted in an increase of 0.3 g of saturated fat (1 egg/week) to 2.2 g of saturated fat daily (7 eggs/week) in all age groups.

TABLE 2 Mean demographic data for the children and adolescent population

Variable	Mean	SE
Age, years	9.24	0.26
Gender, male, %	53.08	2.04
PIR <1.35, %	41.92	3.51
1.35 ≤ PIR ≤ 1.85, %	10.39	2.16
PIR >1.85, %	47.69	3.62
WIC participant, %	18.97	1.81

Data are from children and adolescents aged 2 to 18 years. Egg consumers sample, $n = 980$. Population, $n = 10,380,489$. Mean refers to the least square mean. Abbreviations: PIR, Poverty Income Ratio; SE, standard error; WIC, Special Supplemental Nutrition Program of Women, Infants and Children.

Choline intakes with removal of eggs from the current dietary pattern

The daily total choline intakes in infant egg consumers following removal of specified percentages of eggs from the current diet are summarized in [Table 3](#). Compared to current NHANES eating patterns (i.e., 0% egg removal) 51.1% of infants and 47.0%, 4.4%, and 22.1% of children aged 2–8, 9–18, and 2–18 years, respectively, are above the AI for choline, suggesting that a substantial proportion of this population is not meeting recommendations for choline intake. In general, removal of eggs from the diet in every age group examined showed further decreases in choline intake, such that complete elimination of eggs (i.e., 100% removal of eggs from the current diet) resulted in significantly fewer subjects above the AI for choline. Indeed, in infants, modeling 100% egg removal results in approximately 20% fewer infants above the AI for choline. Similarly, in children aged 2–8 and 2–18 years, removal of all egg from the current diet leads to approximately 16% and 9% fewer children, respectively, above the choline AI. While only 4.4% of children and adolescents 9–18 years of age meet recommendations for choline, removal of 100% of eggs from the diet results in only 1.4% of children being above the AI.

Lutein + zeaxanthin intakes with removal of eggs from the current dietary pattern

Daily lutein + zeaxanthin intakes in infant egg consumers following removal of specified percentages of eggs from the current diet are listed in [Table 4](#). Relative to the NHANES current eating patterns (i.e., 0% egg removal), removal of the various percentages resulted in lowered mean and usual intakes of lutein + zeaxanthin; however, 99th confidence level values did not support meaningful differences.

Choline intakes following the addition of eggs to the current dietary pattern

The daily total choline intakes in infant egg consumers following the addition of eggs to the current diet are summarized in [Table 5](#). Compared to current NHANES eating patterns (i.e., 0 eggs added), adding 1 additional egg per week resulted in nearly 10% more infants 6–23 months of age being above the AI for choline intake. Similarly, the addition of 3, 5, and 7 eggs per week resulted in meaningful increases in choline intake. For example, the addition of 7 eggs per week (or 1 egg per day) to the current dietary pattern of infants would nearly achieve 100% of infants meeting the AI for choline. Similar results are seen in children 2–8 years old, such that adding 7 eggs/week to the modeled dietary pattern results in approximately 94% of children being above the AI for choline. Choline intake in older children and adolescents was relatively poor; the current diet shows that only 4.4% of children aged 9–18 years and 22.1% of those aged 2–18 years were above the AI for choline. Adding 7 eggs/week to the current dietary pattern increased percentages above the AI to 23.0% and 52.4% in children aged 9–18 and 2–18 years, respectively.

Lutein + zeaxanthin intakes following the addition of eggs to the current dietary pattern

Daily lutein + zeaxanthin intakes in infant egg consumers following the addition of eggs to the current diet are summarized in [Table 6](#). Compared to current NHANES eating patterns (i.e., 0 eggs added),

TABLE 3 Total choline (mg/day) intakes following removal of eggs from the diet

% egg removal	Choline intake				Choline usual intake, mean	SE	% above AI
	Mean	SE	LCL99	UCL99			
6–23 months old							
0	182.34	4.35	170.35	194.33	194.28	3.69	51.1
25	175.76	3.87	165.09	186.43	186.21	3.47	46.7
50	169.18	3.49	159.55	178.81	179.06	3.22	41.6
100	156.02	3.17	147.28	164.75	164.47	3.44	31.5
2–8 years old							
0	224.85	3.37	215.55	234.15	237.27	2.89	47.0
25	218.05	2.97	209.87	226.24	229.95	2.54	43.3
50	211.26	2.63	204.01	218.50	222.70	2.31	39.2
100	197.66	2.24	191.47	203.84	208.38	2.13	30.8
9–18 years old							
0	273.42	4.72	260.42	286.42	260.93	3.85	4.4
25	266.04	4.52	253.58	278.50	255.11	3.67	3.4
50	258.66	4.37	246.62	270.70	248.36	3.45	2.5
100	243.90	4.22	232.26	255.55	234.04	3.44	1.4
2–18 years old							
0	253.36	2.97	245.18	261.54	251.56	2.68	22.1
25	246.22	2.84	238.40	254.04	244.39	2.54	19.8
50	239.08	2.75	231.49	246.67	237.37	2.37	17.6
100	224.80	2.74	217.26	232.35	223.36	2.40	13.5

Data are from infants/toddlers and children/adolescents, from NHANES 2011–2014. 0 = current egg intake with no eggs removed from the dietary modeling pattern. Data were interpreted such that when the 99th confidence levels did not overlap, changes in intakes were classified as meaningful. Choline intake includes Day 1 intake data; choline usual intake was determined using Day 1 and Day 2 intake data. AI for choline for different age groups examined is dependent on age and sex: birth to 6 months, male/female = 125 mg/day; 7–12 months, male/female = 150 mg/day; 1–3 years, male/female = 200 mg/day; 4–8 years, male/female = 250 mg/day; 9–13 years, male/female = 375 mg/day; 14–18 years, male = 550 mg/day; 14–18 years, female = 400 mg/day; 14–18 years, pregnant = 450 mg/day; and 14–18 years, lactating = 550 mg/day (30). Abbreviations: AI, Adequate Intake; LCL, lower confidence level; SE, standard error; UCL, upper confidence level.

adding 1 to 5 additional eggs per week shows increased usual intakes for every age group examined; however, in children aged 2–8 and 2–18 years, the addition of 7 eggs per week, or 1 egg per day, demonstrates meaningful increases in lutein + zeaxanthin usual intakes relative

to the current dietary pattern. For example, in children aged 2–8 and 2–18 years, lutein + zeaxanthin intakes increased from nearly 775 mcg/day to approximately 916 mcg/day and 780 mcg/day to approximately 931 mcg/day, respectively.

TABLE 4 Lutein + zeaxanthin (mcg/day) intakes following removal of eggs from the diet

% egg removal	Lutein + zeaxanthin intake				Lutein + zeaxanthin usual intake mean	SE
	Mean	SE	LCL99	UCL99		
6–23 months old						
0	595.04	45.32	470.11	719.97	560.29	31.85
25	581.87	45.26	457.11	706.63	539.42	31.19
50	568.69	45.25	443.97	693.42	521.22	31.15
100	542.35	45.39	417.24	667.46	481.95	30.68
2–8 years old						
0	693.60	28.63	614.68	772.52	775.22	25.03
25	680.26	28.51	601.67	758.85	757.10	25.28
50	666.92	28.44	588.54	745.30	742.62	24.35
100	640.23	28.41	561.92	718.54	711.54	24.37
9–18 years old						
0	891.81	46.15	764.60	1019.03	780.19	25.44
25	876.92	45.81	750.65	1003.20	763.93	24.40
50	862.03	45.50	736.61	987.45	749.79	23.57
100	832.24	44.98	708.26	956.23	721.57	23.90
2–18 years old						
0	809.95	32.57	720.18	899.72	779.30	22.86
25	795.70	32.44	706.27	885.13	760.30	22.54
50	781.45	32.34	692.30	870.59	746.72	21.27
100	752.94	32.20	664.19	841.69	718.48	21.87

Data are from infants/toddlers and children/adolescents; NHANES 2011–2014. 0 = current egg intake with no eggs removed from the dietary modeling pattern. Data were interpreted such that when the 99th confidence levels did not overlap, changes in intakes were classified as meaningful. Lutein + zeaxanthin intake includes Day 1 intake data; lutein + zeaxanthin usual intake was determined using Day 1 and Day 2 intake data. Abbreviations: LCL, lower confidence level; SE, standard error; UCL, upper confidence level.

TABLE 5 Total choline (mg/day) intakes following addition of eggs to the diet

Egg addition, eggs/week	Choline intake				Choline usual intake, mean	SE	% above AI
	Mean	SE	LCL99	UCL99			
6–23 months old							
0	182.34	4.35	170.35	194.33	194.28	3.69	51.1
1	196.70	4.35	184.71	208.69	207.73	3.42	60.3
3	225.42	4.35	213.44	237.41	236.14	3.66	79.4
5	254.15	4.35	242.16	266.13	264.22	3.50	92.9
7	282.17	4.35	270.88	294.85	292.35	3.56	98.2
2–8 years old							
0	224.85	3.37	215.55	234.15	237.27	2.89	47.0
1	239.21	3.37	229.92	248.51	251.69	2.87	55.0
3	267.93	3.37	258.64	277.23	280.15	3.12	71.0
5	296.65	3.37	287.36	305.95	307.81	2.86	85.0
7	325.38	3.37	316.08	334.67	336.29	2.86	93.8
9–18 years old							
0	273.42	4.72	260.42	286.42	260.93	3.85	4.4
1	287.78	4.72	274.78	300.78	275.29	3.95	5.7
3	316.50	4.72	303.50	329.51	304.02	3.95	9.5
5	345.22	4.72	332.22	358.23	333.04	3.95	15.0
7	373.94	4.72	360.94	386.95	361.64	3.77	23.0
2–18 years old							
0	253.36	2.97	245.18	261.54	251.56	2.68	22.1
1	267.72	2.97	259.54	275.90	265.69	2.65	26.0
3	296.44	2.97	288.27	304.62	294.68	2.63	35.1
5	325.16	2.97	316.99	333.34	322.47	2.48	43.8
7	353.89	2.97	345.71	362.06	351.08	2.44	52.4

Data are from infants/toddlers and children/adolescents; NHANES 2011–2014. 0 = current egg intake with no eggs removed from the dietary modeling pattern. Data were interpreted such that when the 99th confidence levels did not overlap, changes in intakes were classified as meaningful. Choline intake includes Day 1 intake data; choline usual intake was determined using Day 1 and Day 2 intake data. AI for choline for different age groups examined is dependent on age and sex: birth to 6 months, male/female = 125 mg/day; 7–12 months, male/female = 150 mg/day; 1–3 years, male/female = 200 mg/day; 4–8 years, male/female = 250 mg/day; 9–13 years, male/female = 375 mg/day; 14–18 years, male = 550 mg/day; 14–18 years, female = 400 mg/day; 14–18 years, pregnant = 450 mg/day; and 14–18 years, lactating = 550 mg/day (30). Abbreviations: AI, Adequate Intake; LCL, lower confidence level; SE, standard error; UCL, upper confidence level.

Discussion

The present modeling analysis corroborates previous findings that have demonstrated younger populations are not meeting established recommendations for choline. The study also shows how eggs can help reduce shortfall gaps in choline intake and improve the likelihood of meeting recommendations in younger Americans. Overall, modeling the removal of eggs from the diet in all examined age groups decreased intakes of choline, resulting in fewer participants above the AI for choline. In contrast, the addition of 1 egg per week to the current US dietary pattern resulted in nearly 10% more infants being above the AI for choline. Similarly, the addition of 3, 5, and 7 eggs per week resulted in substantial increases in choline intakes. Indeed, our modeling study contributes data to support the addition of 7 eggs per week (or 1 egg per day) to the current dietary pattern of infants, which would nearly achieve 100% of infants meeting the AI for choline. In children aged 2–8 years, modeling an additional 7 eggs per week to the current dietary pattern resulted in approximately 94% of children being above the AI for choline. Likewise, the current modeling analysis shows that eggs play a substantial role by helping to increase lutein + zeaxanthin intakes in children and adolescents. Adding 7 eggs per week to the diets of children aged 2–8 and 2–18 years elevates daily lutein + zeaxanthin intakes by approximately 18% and 19%, respectively.

The nutritional and biological significance of dietary choline is established and recognized by several studies and scientific reviews, in addition to being acknowledged by the National Academy of Medicine

(14, 18, 30). NHANES findings propose that a significant number of US children and adults are falling short of choline intake recommendations, thus further exacerbating overall nutrient intake shortfalls (30). Additionally, researchers have identified a shortage of evidence considering choline usual intakes within various stages of growth and development and overall health maintenance, with stress placed on establishing scientific initiatives that focus on nutrition research gaps in younger populations (18).

While a dietary reference intake has not been established for lutein or zeaxanthin, the 2015 Dietary Guidelines for Americans recommend consumption of vegetables and, in particular, dark green vegetables, as they represent a rich source of lutein and zeaxanthin. However, the 2015 Dietary Guidelines for Americans reported low mean intakes of vegetables across all age groups relative to recommendations, and children from 1 to 18 years of age all fall below dark green vegetable recommendations (5). Data from a large, multicenter, double-blind, randomized trial in adults found that the addition of 10 mg and 2 mg/day of lutein and zeaxanthin, respectively, resulted in significant reductions in risk for age-related macular degeneration (31). Numerous previous reviews have discussed the concentration of lutein + zeaxanthin in neural tissue and the biological impacts of these carotenoids, including on the physiological structure, anti-inflammation, and antioxidant activity (16, 18, 31, 32). Lutein + zeaxanthin are present throughout the eye, but appear to be concentrated within the fovea. The area surrounding and including the fovea, known as the macula, is of particular interest, since it is this region that controls visual acuity and damage to the macula can lead

TABLE 6 Lutein + zeaxanthin (mcg/day) following addition of eggs to the diet

Egg addition, eggs/week	Lutein + zeaxanthin intake				Lutein + zeaxanthin usual intake, mean	SE
	Mean	SE	LCL99	UCL99		
6–23 months old						
0	595.04	45.32	470.11	719.97	560.29	31.85
1	623.71	45.32	498.78	748.65	584.58	29.33
3	681.06	45.32	556.13	805.99	648.60	27.91
5	738.41	45.32	613.47	863.34	708.09	28.51
7	795.75	45.32	670.82	920.69	773.16	28.57
2–8 years old						
0	693.60	28.63	614.68	772.52	775.22	25.03
1	722.27	28.63	643.35	801.20	778.76	22.73
3	779.62	28.63	700.70	858.54	812.66	21.19
5	836.97	28.63	758.05	915.89	861.08	20.31
7	894.31	28.63	815.39	973.24	915.87	21.01
9–18 years old						
0	891.81	46.15	764.60	1019.03	780.19	25.44
1	920.49	46.15	793.27	1047.70	789.38	23.18
3	977.83	46.15	850.62	1105.05	834.14	22.39
5	1035.18	46.15	907.96	1162.40	885.95	21.69
7	1092.53	46.15	965.31	1219.74	945.54	21.88
2–18 years old						
0	809.95	32.57	720.18	899.72	779.30	22.86
1	838.62	32.57	748.86	928.39	786.09	20.26
3	895.97	32.57	806.20	985.74	822.74	19.26
5	953.32	32.57	863.55	1043.09	876.82	18.88
7	1010.66	32.57	920.89	1100.43	930.72	18.99

Data are from infants/toddlers and children/adolescents; NHANES 2011–2014. 0 = current egg intake with no eggs removed from the dietary modeling pattern. Data were interpreted such that when the 99th confidence levels did not overlap, changes in intakes were classified as meaningful. Lutein + zeaxanthin intake includes Day 1 intake data; lutein + zeaxanthin usual intake was determined using Day 1 and Day 2 intake data. Abbreviations: LCL, lower confidence level; SE, standard error; UCL, upper confidence level.

to blindness with advancing age, typically known as age-related macular degeneration (16, 32). Lutein and zeaxanthin intakes were not related to reduced risks of early age-related macular degeneration, but rather, elevated intake of both carotenoids may offer protection against late-onset age-related macular degeneration, based on conclusions from a meta-analysis (33). Findings from a US prospective cohort analysis using data from 2 large epidemiological follow-up studies supported increased intakes of bioavailable lutein and zeaxanthin and linked the carotenoids to a reduced risk of macular degeneration (34). When considering egg consumption, a recent, population-based cohort found that adults who included 2 to 4 eggs per week in their diet, compared to less than or equal to 1 egg per week, had a significantly reduced risk for macular degeneration. A subset analysis of adults whose age-related macular degeneration onset was at or prior to a 10-year follow-up revealed that consuming 2–4 and 5–6 eggs per week was linked with 54% and 65% risk reductions, respectively, of incident late age-related macular degeneration (35). While limited eye health data are available for children and infants pertaining to lutein and zeaxanthin intakes, the antioxidant potential of lutein and zeaxanthin has previously been reported to be particularly significant in infancy, since downregulation of blood flow in the vasculature of the eye does not occur in infants as it does in adults; thus, vessels in the eye deliver an abundance of oxygen to the retina and promote the generation of damaging free radicals (36).

While the importance of lutein + zeaxanthin has been documented (31–34), a previous survey in optometrists showed a moderate to well-established understanding of the association between lutein + zeaxanthin and vision health (37). Nonetheless, the same study indicated that

optometrists routinely recommend a lutein + zeaxanthin supplement and spinach or dark green vegetables to increase lutein + zeaxanthin intakes in patients who are at risk of age-related macular degeneration (37). While cooked spinach and kale contain high amounts of lutein, poultry egg yolks are a superior source of lutein + zeaxanthin relative to other foods due to a higher bioavailability, which is attributed to the fat content of the yolk (16, 17). A survey of registered dietitians and physicians reported limited education on the nutritional relevance of dietary choline and lacked background on dietary sources of choline. With documented evidence to support the nutritional contribution of eggs in all Americans, health professionals were least likely to recommend choline in the diet, with only 10% of physicians and dietitians surveyed likely to recommend choline-containing foods (33). Thus, health professional education on the nutritional value of eggs, emphasizing lutein, zeaxanthin, and choline, is warranted to optimize public health nutrition strategies, in particular when considering the promotion of eye health (38–40).

Observational studies analogous to the present analysis have documented limitations intrinsic to epidemiological studies (41–44). The use of a large, cross-sectional survey like NHANES contributes a distinct advantage in allowing researchers access to a large, cross-sectional database that combines refined personal and individual assessments with biochemical, clinical, and anthropometric examinations for various age groups, ethnicities, and socioeconomic statuses. Shortcomings of the modeling approach when using NHANES include recollection bias, which includes the over- or under-reporting of foods and beverages consumed. Nonetheless, NHANES has employed

protocols to limit the introduction of errors in data gathering and research protocols.

In conclusion, to our knowledge, our analysis provides the first evidence of usual intakes of choline and lutein + zeaxanthin in American children of various age groups. The current modeling analysis demonstrates that younger and older American children are falling short of attaining intake recommendations for dietary choline. The present analysis is also the first to model the role eggs play in helping younger Americans meet recommendations for choline intake, such that removal of eggs from the diet reduced choline intakes in all age groups examined, resulting in significantly fewer subjects being above the AI for choline. In comparison, the addition of eggs to the daily dietary pattern can have meaningful outcomes on choline intakes in childhood. Likewise, the current modeling analysis shows that eggs play a substantial role in delivering lutein + zeaxanthin to children and adolescents. Public health initiatives, school feeding programs, and authoritative dietary guidance should further consider the nutritional importance of eggs within healthy dietary patterns when developing recommendations to help children increase choline and lutein + zeaxanthin intakes.

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Data Availability

Data presented in the manuscript are derived from the National Health and Nutrition Examination Survey, which is collected by the National Center for Health Statistics, a division of the Centers for Disease Control and Prevention. All data, including food codes used in the analysis, are documented and can be made available upon request.

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