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Association between egg intake and blood pressure in the USA: the INTERnational study on MAcro/micronutrients and blood Pressure (INTERMAP)

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Abstract
Objectives: To investigate associations of egg intake with blood pressure (BP) and the role of dietary variables and other macro- and micro-nutrients in the association.
Design: We used cross-sectional data for the USA as part of the INTERnational study on MAcro/micronutrients and blood Pressure (INTERMAP). INTERMAP was surveyed between 1996 and 1999, including four 24-h dietary recalls, two 24-h urine collections and eight measurements of systolic BP and diastolic BP (SBP, DBP). Average egg intake (g/d) was calculated. Multivariable linear regression models were used to estimate the association between egg intake (per each 50 g/d or per quintile) and BP. The roles of dietary variables and other macro- and micro-nutrients in this association were also investigated.
Setting: In the USA.
Participants: In total, 2195 US INTERMAP men and women aged 40–59 years.
Results: Participants were 50 % female, 54 % non-Hispanic White and 16 % non-Hispanic Black. Mean egg intake (SD) in men and women was 30·4(29·8) and 21·6(20·5) g/d, respectively. Adjusting for demographics, socio-economics, lifestyle and urinary Na:K excretion ratios, we found non-linear associations with BP in non-obese women (*P*-quadratic terms: 0·004 for SBP and 0·035 for DBP).The associations remained after adjusting for dietary variables, macro/micro nutrients or minerals. Dietary cholesterol was highly correlated with egg intake and may factor in the association. No association was found in obese women and in obese or non-obese men.
Conclusion: Egg intake was non-linearly associated with SBP and DBP in non-obese women, but not in obese women or men. Underlying mechanisms require additional study regarding the role of obesity and sex.

Keywords
Blood pressure
Egg intake
Diet
Hypertension

Hypertension is a well-established risk factor for CVD[1]. The population attributable risk resulting from hypertension at levels of systolic blood pressure (SBP)/ diastolic blood pressure (DBP) ≥140/90 mmHg has been estimated at about 50 % for CVD events worldwide[2]. The 2017 ACC/AHA guideline defined hypertension as a SBP ≥ 130 mmHg and DBP ≥ 80 mmHg[3], with nearly 50 % of US adults (>100 million) now classified as hypertensive[4].

Diet is an important modifiable factor for preventing hypertension[5]. Eggs are a commonly consumed nutrient-dense food, containing high-quality protein, essential fatty acids, choline, various minerals and vitamins A, D, B_{12}[6]. But there are also some nutritional drawbacks to eating eggs. For example, egg yolks are the single richest source of dietary cholesterol among commonly consumed foods[7,8]. The benefits of egg consumption on hypertension are controversial. Some studies show that egg consumption is

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associated with a reduced risk of hypertension, while others show no association, or a U-shaped association[9–13]. Moreover, there is a lack of modulating roles of multiple macro/micronutrients on the association of egg consumption with blood pressure (BP). The primary objective of this study is to examine the associations between egg intake and BP using data from the INTERMAP Study (International Study on Macro/Micronutrients and Blood Pressure). The modulating roles of dietary cholesterol, the dietary approaches to stop hypertension (DASH) scores, as well as multiple macro/micronutrients on the association of interest were also investigated.

Methods

Population samples

Information on the INTERMAP study has been published[14,15]. Briefly, between 1996 and 1999, INTERMAP surveyed 4680 men and women 40 to 59 years of age from seventeen population samples in total: United States (eight samples), Japan (four), People's Republic of China (three) and United Kingdom (two). Participants were selected randomly from community or workplace population lists and arrayed into four age/sex strata. Each participant attended four clinic visits – initially two on consecutive days and two more visits on consecutive days on average 3 weeks later. The INTERMAP study excluded individuals who did not attend all four visits or have two 24-h urine collections and four 24-h dietary recalls (110 people). Participants with extreme values of energy intake from any 24-h dietary recall (<500 kcal/d or >5000 kcal/d for women or 8000 kcal/d for men), or with missing values for any study covariates (105 people), were also excluded. When a participant was excluded, a supplementary participant was recruited from the sample age/sex group[14].

The current analysis focused on the US participants (the largest sample in the INTERMAP Study), including 2195 men and women. The study was approved by the Northwestern University Institutional Review Board, and written informed consent was obtained from all participants.

Diet data assessment

Dietary intake data were collected by trained, certified interviewers using the in-depth multipass 24-h recall method; all foods, drinks and supplements consumed in the previous 24 h were recorded at each of the four visits[14]. Dietary data were converted into nutrients by the Nutrition Coordinating Center, University of Minnesota, and the measurements per person were averaged across the four visits. The DASH scores based on eight food and nutrient components (fruits, vegetables, whole grains, nuts and legumes, low-fat dairy, red and processed meats, sweetened beverages and Na) were calculated as described by Fung *et al.*[16] The DASH score ranges from 8 to 40, with a higher score representing a healthier diet.

Egg intake was expressed as g/d, calculated from the number of servings consumed per day using the Nutrient Data Software for Research (University of Minnesota, USA)[14].

Blood pressure ascertainment

As previously reported[15], seated SBP and DBP were measured two times at each study visit, for a total of eight measurements made by trained staff using a random zero sphygmomanometer. A standard set of three cuff sizes was available (standard adult, large adult and small adult). Measurements were performed on the right arm with participants seated for at least 5 min in a quiet room, with bladder emptied and no physical activity, eating, drinking or smoking in the preceding 30 min. The eight measurements of SBP or DBP were averaged[14].

Covariate assessment

Demographic, medical and behavioural health data, obtained by an interviewer-administered questionnaire, included age, sex, race and ethnicity, attained educational level, daily alcohol intake over the preceding 7 d, cigarette smoking status, physical activity, antihypertensive and lipid-lowering medications and participant and family history of CVD and diabetes mellitus. BMI was calculated based on average height and weight measures[14], and obesity was defined as BMI $\geq$ 30 kg/m^2.

Participants provided two borate-preserved timed 24-h urine collections, one at each of two clinical visits, 3 weeks apart. Aliquots were air-freighted frozen to the Central Laboratory (Leuven, Belgium) for biochemical analyses by using emission flame photometry. Because urinary data provide objective measures of Na, K and Na:K excretion ratios that are significantly associated with BP[15], urinary excretions including Na and K per person were measured and averaged across the two collections[14]. Na:K excretion ratios were calculated.

Statistical analyses

Descriptive characteristics of the study sample were calculated for all participants and by sex and compared across the five quintiles of egg intake, using *F* tests for continuous variables and χ^2 tests for binary variables. Associations of egg intake with other nutrients were explored by a partial correlation procedure. Coefficient/partial Rho was calculated with adjustment for age, sex, race/ethnicity, total energy intake and population samples.

Multivariable linear regression models were used to examine the association of egg intake with SBP and DBP. Because 50 g approximately being equivalent to one large egg[17], we used 50 g/d increments of egg intake as a continuous variable to test for trends and egg intake quintile as a categorical variable to test for differences by quintiles. Interactions between egg intake and sex, race/ethnicity, CVD/diabetes status and BP medication use were assessed to determine if stratified analyses were needed; and we found significant interaction terms between sex and egg intake ($P = 0{\cdot}037$). Moreover, we also found significant interaction terms between obesity status and egg intake in females ($P = 0{\cdot}023$). Therefore, the analyses were performed for males and females separately and by obesity status. Non-linear association between egg intake and BP was also tested by adding a quadratic egg term into the model as well as by employing restricted cubic spline models. We found the quadratic egg term was significant. Therefore, when sex-specific quintiles of egg intake were used for the analyses, we used the third quintile as the reference group for comparisons with other quintiles to demonstrate a non-linear association between egg intake and BP.

The main model employed was presented with adjustment for age, race/ethnicity, population sample (eight samples for the USA), education (years in school), family history of high BP, smoking status (current, former and never), moderate/heavy physical activity (h/d), alcohol consumption (g/d), history of CVD (heart attack, other heart disease and stroke) or diabetes, use of antihypertensive medication, total dietary energy intake (kcal/d) and Na:K excretion ratios. BP differences were estimated between egg quintiles or per each 50 g/d increment. Adjusted mean BP by quintiles of egg intake and obesity status were also calculated.

Potential impacts of DASH score, non-egg dietary cholesterol intake and selected macro- and micronutrients that are rich in eggs[6] on the egg intake and BP relations were explored by adding those variables individually into the main model.

We also conducted sensitivity analyses by simulating BP treatment in treated hypertensive participants by adding 10 mmHg for systolic and 5 mmHg for diastolic BP[18]. Analyses were conducted using SAS statistical software version 9.4 (SAS Institute Inc.). Statistical tests were two-sided; two-tailed probability values <0·05 were considered statistically significant.

Results

Descriptive analysis

Of the 2195 US INTERMAP participants, 50 % were women, 54·2 % were non-Hispanic White, 16·8 % were African American, 7 % were non egg consumers, mean age was 49·1 years, the mean total egg intake was 26·0 g/d and the average SBP/DBP was 118·6/73·4 mmHg. In general, compared with men, women were less likely to be current smokers and had lower mean education levels, alcohol consumption, physical activity, urinary Na and K, dietary egg intake, total energy intake, dietary cholesterol intake, dietary protein intake and SBP level. In contrast, a higher proportion of women reported having family with history of high BP. More than one-third of both men and women were obese (see online Supplemental Table S1).

Characteristics of the study sample by sex and sex-specific quintile of total egg consumption are shown in Table 1. The highest (the fifth) quintile of egg intake (51–190 g or about 1–4 eggs/d for men and 36–114 g or 0·7–2·3 eggs/d for women) included the highest proportion of Hispanic and obese, the highest level of physical activity (in men), highest levels of dietary energy, dietary cholesterol (with or without egg source), dietary protein, urinary Na and SBP and the highest proportion of diabetics. The fifth quintile group was further characterised by the lowest mean education level, lowest urinary K level (in men only) and lowest DASH score. We observed that the relations of smoking status, obesity status, family history of hypertension and BP medication use with egg intake were different for men and women. For example, the proportion of women with obesity was significantly different across quintiles of egg intake (49 % were in the fifth quintile and 28 % were in the first quintile, with *P*-value <0·001), while in men they were 42 % in the fifth quintile and 32 % in the first quintile, and there was no significant difference on this binary relation.

Pearson partial correlations (adjusted for age, race/ethnicity, population sample and energy intake) between egg intake and other heath behaviours, urinary excretion and selected dietary nutrients were shown in the Supplemental Table S2. The correlation of egg intake with dietary cholesterol was strong and positive (adjusted Pearson correlation coefficients *r*/*P*-values were 0·828/ <·001 in women and 0·849/<·001 in men), while it was weak with non-egg dietary cholesterol, DASH score, animal protein, total protein, MUFA and total SFA (absolute values of r were between 0·2 and 0·3 and *P*-values<·001) – and very weak (absolute values of $r < 0{\cdot}2$ with *P*-values <0·05) or no correlations with other macro/micro nutrients or minerals.

Multivariable analysis

Table 2 shows the adjusted association of egg intake (assessed by quintiles as well as by a continuous variable) with SBP and DBP for men and women separately and by their obesity status. Models were adjusted for age, race/ethnicity, population sample, education levels, family history of BP, physical activity, alcohol consumption, smoking status, hypertensive medication use, history of CVD or diabetes, total energy intake and the ratio of urinary Na/K. In non-obese women, compared with the third egg intake quintile, those who were at the second and the fifth quintiles of egg intake had about 4–5 mmHg higher SBP (the difference in SBP (mmHg) compared with the third quintile, 3·55 (95 % CI (0·69, 6·41)) and 4·63 (95 % CI (1·42, 7·83)), respectively); SBP was also higher in those at the first quintile, but this difference was not statistically significant, and SBP or DBP was similar in those who were at the fourth quintile. There was no association between

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Table 1 Descriptive characteristics of the study sample in US INTERMAP by quintile of total egg consumption and sex

	Total egg consumption (g/d§) by sex-specific quintile																			
	Women (*n* 1092)										Men (*n* 1103)									
	Q1	0–<4·4 g	Q2	4·4–<11·4 g	Q3	11·4–<20·9 g	Q4	20·9–<36·0 g	Q5	36·0–114·4 g	Q1	0–<5·0 g	Q2	5·0–<15·4 g	Q3	15·4–<29·5 g	Q4	29·5–<50·6 g	Q5	50·6–190·14 g
Characteristic*	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Number of person	218		218		219		218		219		219		222		220		221		221	
Age (years)	49·1	5·4	49·0	5·6	49·4	5·4	49·3	5·5	49·3	5·3	48·2	5·2	49·4	5·3	48·5	5·5	49·5	5·1	49·6	5·5†
Race/ethnicity									†										†	
Non-Hispanic White	63·3		54·1		56·2		46·8		40·6		58·5		67·6		55·9		54·8		44·3	
Non-Hispanic Black	16·1		17·4		17·4		24·3		18·3		13·7		10·4		18·2		16·7		15·8	
Hispanic	7·3		8·7		11·4		11·9		27·9		6·4		8·6		7·3		12·2		29·4	
Others	13·3		19·7		15·1		17·0		13·2		21·5		13·5		18·6		16·3		10·4	
Education (years)	15·1	2·8	15·3	2·8	14·6	2·9	14·2	2·7	13·5	2·9†	16·0	3·0	16·0	3·2	15·5	2·8	15·2	3·2	14·1	3·1†
Smoking status																			†	
Current	16·1		11·5		11·0		14·7		19·2		18·3		10·8		20·0		19·5		27·2	
Former	23·9		27·1		24·2		24·3		26·9		35·6		39·6		34·6		36·7		35·3	
Never	60·1		61·5		64·8		61·0		53·9		46·1		49·6		45·5		43·9		37·6	
BMI (kg/m^2)	27·9	6·7	27·8	6·7	28·3	6·4	28·6	6·1	30·8	6·9†	28·5	5·1	28·6	4·5	29·3	5·7	29·1	4·5	30·0	5·6†
Obesity	28·0		27·1		32·4		36·2		48·9†		32·4		31·1		37·7		37·1		42·1	
Alcohol consumption (g/d)	4·4	9·5	2·6	5·0	3·4	6·7	3·1	6·8	3·2	7·8	10·0	18·7	9·2	15·8	10·8	15·1	9·7	16·1	13·0	19·5
Moderate/heavy physical activity (h/d)	2·9	2·9	2·8	2·7	3·1	3·1	3·0	3·1	3·1	3·1	3·0	3·0	3·1	3·1	3·2	3·1	3·8	3·5	4·4	3·5†
On BP medication,%	23·9		16·5		20·6		22·5		28·8†		20·1		21·6		20·0		21·3		25·3	
Family history with hypertension,%	68·8		76·2		74·4		74·3		74·0		63·5		61·3		61·4		61·1		64·7	
History of diabetes, %	5·1		5·5		8·2		8·3		15·5†		9·1		3·2		7·7		7·2		11·8†	
History of CVD, %	11·0		6·4		8·2		7·3		7·8		7·8		10·4		10·0		11·8		7·2	
SBP, mmHg	115·4	14·3	116·4	14·7	115·5	14·5	116·2	14·1	120·3	15·9†	119·1	12·5	119·5	11·2	120·6	14·1	120·1	12·5	122·5	12·8†
DBP, mmHg	70·6	8·6	71·1	9·8	71·2	9·4	71·2	8·9	71·4	9·4	75·3	9·8	75·7	8·8	76·3	9·5	75·2	10·7	75·9	9·1
Urinary Na (mmol/d)	131·0	43·7	137·3	46·6	137·4	40·7	144·6	48·0	160·9	55·8†	173·5	59·4	175·3	57·8	182·6	67·0	184·0	58·3	198·0	66·6†
Urinary K (mmol/d)	52·4	18·5	52·9	18·8	50·5	17·2	49·8	17·3	48·5	17·4	68·1	23·0	67·8	22·0	62·9	21·4	61·4	19·8	61·8	20·4†
Ratio, urinary Na to K	2·8	1·20	2·9	1·3	3·0	1·1	3·2	1·3	3·6	1·4†	2·8	1·1	2·8	1·0	3·1	1·2	3·2	1·1	3·5	1·3†
Dietary energy (kcal/d)	1659·5	436·9	1814·3	454·2	1869·5	438·3	1964·9	463·8	2070·2	474·2†	2335·4	639·2	2492·2	608·9	2570·4	673·8	2736·2	659·8	2908·0	745·0†
Dietary cholesterol (mg/d)	140·5	63·5	175·5	60·6	220·8	69·6	277·9	76·0	403·3	110·5†	198·9	87·7	242·7	85·9	314·8	92·0	392·0	101·8	592·5	157·9†
Non-egg dietary cholesterol (mg/d)	132·4	61·7	142·3	58·6	153·8	66·0	161·9	68·4	175·4†	65·2	191·3	85·7	199·6	83·3	220·0	83·2	226·9	97·3	257·0†	109·3
DASH score‡	24·8	5·3	25·3	4·9	24·5	4·8	23·8	5·2	21·6	4·9†	24·7	5·0	25·0	4·9	24·3	4·7	23·5	4·6	22·2	4·5†
Dietary animal protein (g/d)	40·3	15·3	42·7	15·2	44·8	16·4	48·8	18·2	55·5	17·9†	58·4	24·0	59·3	21·8	64·6	22·6	66·1	25·1	78·3	26·8†
Dietary total protein (g/d)	63·9	18·5	69·0	18·3	69·1	18·2	73·4	20·8	80·7	20·1†	91·7	28·6	92·9	24·5	96·1	26·4	99·7	29·2	112·0	31·4†

BP, blood pressure; DASH, dietary approaches to stop hypertension.
*Numbers are mean (SD) unless otherwise indicated.
†*P*-value <0·05 for group comparisons across quintiles of total egg intake per day using χ^2 test or *F*-test.
‡DASH score was calculated based on eight food and nutrient components (fruits, vegetables, whole grains, nuts and legumes, low-fat dairy, red and processed meats, sweetened beverages and Na); the score ranges from 8 to 40, with a higher score corresponds to a healthier diet pattern.
§50 g is approximately equivalent to one large egg.

Table 2 Adjusted* association of egg intake with SBP and DBP in US INTERMAP by sex and obesity status

	ΔBP† (95 % CI)							
	SPB				DBP			
	Non-obese		Obese		Non-obese		Obese	
Egg intake	OR	95 % CI	OR	95 % CI	OR	95 % CI	OR	95 % CI
Female								
Number of person	715		377		715		377	
Egg intake quintile (g/d)								
Quintile 1 (0–<4·4 g)	1·98	−0·93, 4·88	−0·20	−4·89, 4·49	0·53	−1·42, 2·48	−1·70	−4·62, 1·22
Quintile 2 (4·4–<11·4 g)	3·55	0·69, 6·41	−1·07	−5·70, 3·56	1·06	−0·87, 2·98	−0·99	−3·87, 1·90
Quintile 3 (11·4–<20·9 g) (Ref)	0·0		0·0		0·0		0·0	
Quintile 4 (20·9–<36·0 g)	−0·60	−3·54, 2·34	0·00	−4·32, 4·31	−0·53	−2·50, 1·45	−0·63	−3·32, 2·06
Quintile 5 (36·0–114·4 g)	4·63	1·42, 7·83	−1·11	−5·28, 3·07	1·93	−0·23, 4·09	−2·49	−5·10, 0·11
Egg intake continuous‡								
Linear trend	2·35	−0·44, 5·14	−0·54	−3·74, 2·65	1·70	−0·16, 3·57	−1·16	−3·16, 0·85
Quadratic trend	6·52	2·07, 10·96	−1·28	−6·12, 3·56	3·17	0·19, 6·14	−1·66	−4·68, 1·36
Male								
Number of person	705		398		705		398	
Egg intake quintile (g/d)								
Quintile 1 (0–<5·0 g)	0·56	−2·18, 3·29	−2·69	−6·51, 1·12	0·31	−1·69, 2·30	−1·66	−4·62, 1·29
Quintile 2 (5·0–<15·4 g)	0·67	−2·04, 3·38	−3·00	−6·76, 0·77	0·48	−1·50, 2·46	−2·54	−5·45, 0·38
Quintile 3 (15·4–<29·5 g) (Ref)	0·0		0·0		0·0		0·0	
Quintile 4 (29·5–<50·6 g)	−0·39	−3·16, 2·38	−2·28	−5·88, 1·32	0·21	−1·82, 2·23	−2·73	−5·52, 0·06
Quintile 5 (50·6–190·14 g)	0·71	−2·23, 3·65	−0·38	−4·10, 3·35	0·08	−2·06, 2·23	−0·16	−3·04, 2·73
Egg intake continuous‡								
Linear trend	−0·45	−2·16, 1·26	0·91	−1·11, 2·94	−0·66	−1·91, 0·59	0·67	−0·91, 2·25
Quadratic trend	0·13	−1·97, 2·22	−0·60	−2·50, 1·30	−0·51	−2·04, 1·01	−0·06	−1·54, 1·41

SBP, systolic blood pressure; DBP, diastolic blood pressure; BP, blood pressure.
*Model adjusted for age, race/ethnicity (non-Hispanic Black *v.* otherwise), population sample (eight samples for the US), education attainment, family history of high BP, physical activity, alcohol consumption, current smoking status, hypertensive medication use, history of CVD or diabetes, total energy intake and Na/K excretion ratios.
†Δ, the difference in BP compared with the third quintile of egg intake.
‡Continuous variable per 50 g/d increment of egg intake (50 g is approximately equivalent to one large egg), with ‘egg’ was included in the model for the linear trend and ‘egg’ and ‘egg^2’ for the quadratic trend.

egg intake and SBP or DBP in obese women. There was also no association between egg intake and SBP or DBP in men, regardless of their obesity status. Results were consistent when egg intake was assessed as a continuous variable, with a significant non-linear association of egg intake with SBP in non-obese women (*P*-value for the quadratic egg term was 0·004). We also observed a non-linear association of egg intake with DBP in non-obese women (*P*-value for the quadratic egg term was 0·035), but no association was found in obese women for DBP. Using the restricted cubic spline model (best fitted with three knots) also confirmed a non-linear association between egg intake and BP. Similarly, results as adjusted mean SBP and DBP by egg intake quintiles were presented in Fig. 1, with pronounced non-linear associations in non-obese women.

Table 3 shows the results from the egg intake and BP relations in non-obese women, with adjustment separately for DASH score, non-egg dietary cholesterol intake and selected macro- and micronutrients that are rich in eggs. The association between egg intake and SBP was only slightly changed/attenuated (especially when comparing the fifth egg intake quintile with the third quintile) after accounting for non-egg cholesterol intake, DASH score, animal protein or total MUFA, but the association remained significant. Adjustment for other micronutrients or minerals did not alter the association.

Sensitivity analyses

When the analyses were repeated after simulating the BP treatment in treated hypertensive participants by adding 10 mmHg for systolic and 5 mmHg for diastolic BP, similar results were observed when compared with the results from the main analysis (results not tabulated). For example, compared with the third egg intake quintile, those who were at the second and the fifth quintiles of egg intake significantly had about 4–5 mmHg higher SBP (the difference in SBP (mmHg) compared with the third quintile, 3·34 (95 % CI (0·41, 6·31)) and 4·71 (95 % CI (1·41, 8·01)), respectively). We also observed a significant non-linear association of egg intake with SBP and DBP (*P*-values for the quadratic egg term were 0·002 and 0·010, respectively), and these non-linear associations were also confirmed by using the restricted cubic spline model with three internal knots. There was also no association with both SBP and DBP for men in the sensitivity analyses.

Discussion

In 2195 INTERMAP US men and women aged 40–59 years in 1996–1999, we observed a non-linear association between dietary egg intake and mean SBP and DBP in non-obese women. This association was independent of

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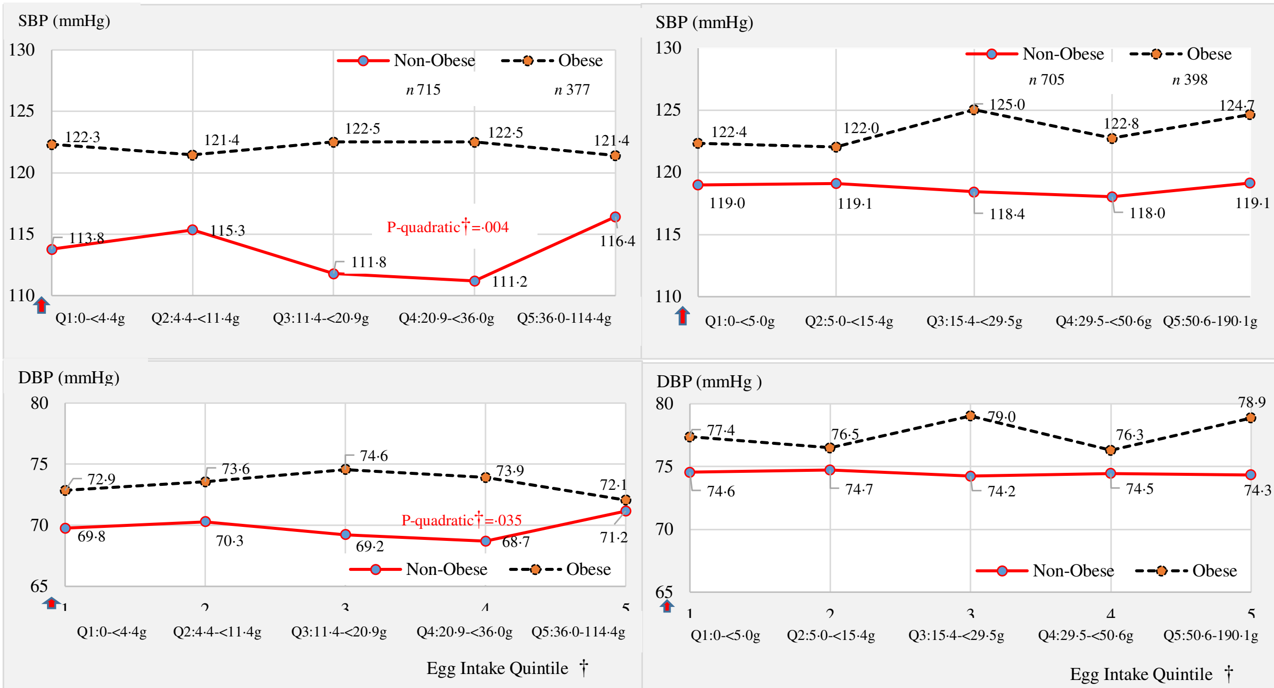

Fig. 1 (colour online) Adjusted* Mean SBP (mmHg) by egg intake quintile, sex and obesity status in US INTERMAP. *Model adjusted for age, race/ethnicity (non-Hispanic Black vs. otherwise), population sample (eight samples for the US), education attainment, family history of high BP, physical activity, alcohol consumption, current smoking status, hypertensive medication use, history of CVD or diabetes, total energy intake and Na/K excretion ratios. †50 g is approximately equivalent to one large egg. Y-axis omitted values from 0 to 110 mmHg for SBP and 0 to 65 mmHg for DBP. †$P_{\text{quadratic trend}}$ used 50 g/d increments of egg intake as a continuous variable with models included egg and egg^2

socio-demographic characteristics, health behaviours, family history of hypertension, health status, ratio of urinary Na/K excretion, non-egg dietary cholesterol intake, as well as selected dietary macro/micro nutrients and minerals. The association may be explained by the relation of egg intake with dietary cholesterol intake. We observed no association of egg intake with SBP/DBP in obese women. Egg intake also had no association with both SBP and DBP in men, regardless of the obesity status.

Some studies have focused on egg consumption and BP or hypertension, but their findings are inconsistent[9–13]. A meta-analysis, searching 2010 potentially relevant articles identified from PubMed, Web of Science, and Embase through August 2017, found three prospective studies examining the association of egg consumption with risk of hypertension[11]. Those prospective studies suggested that egg consumption is associated with a lower risk of hypertension or the association may be U-shaped. For example, the Coronary Artery Risk Development in Young Adults (CARDIA) Study with 15 years of follow-up reported that the hazard ratio for incident elevated BP (SBP/DBP >= 130/85 mmHg or use of antihypertensive medication) of the highest quintile of egg consumption (the fifth quintile, about 3+ times/week) was lower by 21 % compared with the first quintile, <0·7 time/week, and no linear association was found between egg consumption and incident elevated BP[19]. The KoGES Yangpyeong study in South Korea with 3·2 years of follow-up further suggested a U-shaped association between egg consumption (measured by the number of eggs/week) and the risk of high BP. The current study also suggested a moderated role of BMI levels on the association of egg consumption and high BP although the interaction term of egg consumption and the BMI groups was not statistically significant[9].

Another meta-analysis identifying and quantifying the results of fifteen randomised controlled trials (RCT) concluded that egg consumption has no significant effects (both linear and non-linear) on SBP and DBP in adults overall, or in subgroups based on obesity and hypertension status[10]. Some cross-sectional studies, such as the Korean National and Nutrition Examination Survey (KNHANES) 2007–2011, reported that higher egg intake was associated with lower SBP and DBP among 23 993 Korean adults. The association, however, was found only in unadjusted analyses, not in multivariable regression models[12].

Existing studies on the relation of egg consumption and hypertension or BP, however, had limitations. One limitation is with respect to egg consumption measurements, e.g. measured egg intake by eating-frequency (times/week) rather than quantity and thus the inference is not clearly established[19]. Another limitation involved the possible lack of power to detect the association (BP was not a primary objective of RCT, so with small sample sizes, those

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Table 3 Adjusted association of egg intake with SBP in non-obese women in US INTERMAP – role of dietary nutrients

	ΔBP† (95 % CI) compared with the third quintile (Q3)								
	Q1 (0–<4·4 g/d§)		Q2 (4·4–<11·4 g/d)			Q4 (20·9–<36·0 g/d)		Q5 (36·0–114·4 g/d)	
Variable added to the main model	OR	95 % CI	OR	95 % CI	Q3 (11·4–<20·9 g/d) (Ref)	OR	95 % CI	OR	95 % CI
Number of person	157		159		148	139		112	
Main model*	1·98	−0·93, 4·88	3·55	0·69, 6·41	0·0	−0·60	−3·54, 2·34	4·63	1·42, 7·83
Added dietary intake									
DASH‡ score	2·02	−0·88, 4·91	3·62	0·76, 6·48	0·0	−0·61	−3·54, 2·33	4·48	1·28, 7·69
Non-egg cholesterol intake (mg/d)	2·05	−0·85, 4·95	3·68	0·82, 6·55	0·0	−0·54	−3·47, 2·40	4·64	1·43, 7·84
Added macronutrients									
Total protein (g/d)	1·95	−0·95, 4·85	3·54	0·68, 6·41	0·0	−0·59	−3·53, 2·35	4·44	1·22, 7·66
Animal protein (g/d)	2·11	−0·79, 5·00	3·70	0·84, 6·56	0·0	−0·64	−3·57, 2·29	4·34	1·12, 7·55
MUFA (g/d)	2·05	−0·86, 4·95	3·61	0·74, 6·47	0·0	−0·62	−3·55, 2·32	4·47	1·24, 7·70
SFA (g/d)	2·21	−0·71, 5·12	3·73	0·86, 6·60	0·0	−0·55	−3·49, 2·38	4·56	1·36, 7·77
Trans-fatty acids (g/d)	2·02	−0·89, 4·93	3·59	0·72, 6·47	0·0	−0·58	−3·52, 2·36	4·60	1·39, 7·81
Added micronutrients									
Vitamin A (mg/d)	2·05	−0·85, 4·96	3·65	0·78, 6·51	0·0	−0·54	−3·48, 2·40	4·68	1·48, 7·89
β-carotene (mcg/d)	2·05	−0·86, 4·95	3·62	0·76, 6·49	0·0	−0·54	−3·48, 2·40	4·65	1·44, 7·85
Vitamin E (mg/d)	1·97	−0·93, 4·88	3·65	0·78, 6·52	0·0	−0·60	−3·54, 2·33	4·66	1·45, 7·87
Riboflavin (mg)	2·03	−0·87, 4·93	3·62	0·76, 6·48	0·0	−0·62	−3·55, 2·31	4·96	1·74, 8·18
Vitamin B_6 (mg)	2·07	−0·84, 4·98	3·65	0·78, 6·52	0·0	−0·62	−3·56, 2·32	4·70	1·49, 7·91
Vitamin B_{12} (mg)	1·98	−0·92, 4·89	3·55	0·69, 6·42	0·0	−0·58	−3·52, 2·36	4·66	1·44, 7·87
Added minerals									
Dietary Ca (mg/d)	2·12	−0·79, 5·02	3·65	0·79, 6·52	0·0	−0·50	−3·44, 2·44	4·69	1·48, 7·90
P (mg/d)	1·99	−0·92, 4·90	3·56	0·69, 6·43	0·0	−0·60	−3·54, 2·34	4·64	1·42, 7·86
Se (mcg/d)	1·97	−0·93, 4·88	3·54	0·68, 6·41	0·0	−0·61	−3·55, 2·33	4·56	1·33, 7·79
Fe (mg/d)	1·97	−0·93, 4·86	3·73	0·87, 6·59	0·0	−0·77	−3·70, 2·16	4·68	1·48, 7·88

SBP, systolic blood pressure; DBP, diastolic blood pressure; BP, blood pressure; Q, quintile ; BP, blood pressure; DASH, dietary approaches to stop hypertension.

*Main model was adjusted for age, race/ethnicity (non-Hispanic Black *v.* otherwise), population sample (eight samples for the US), education attainment, family history of high BP, physical activity, alcohol consumption, current smoking status, hypertensive medication use, history of CVD or diabetes, total energy intake and Na/K excretion ratios.

†Δ, the difference in BP compared with the third quintile (Q3) of egg intake.

‡DASH score was calculated based on eight food and nutrient components (fruits, vegetables, whole grains, nuts and legumes, low-fat dairy, red and processed meats, sweetened beverages and Na); the score ranges from 8 to 40, with a higher score corresponds to a healthier diet pattern.

§50 g is approximately equivalent to one large egg.

RCT may not have sufficient power to detect significant relationships[10]). Moreover, existing studies did not fully examine the role of macro-/micronutrients on the association between egg intake and hypertension[9,19–22]. In our study, we extensively applied standardised methods in dietary collection and repeated BP measurements. We also evaluated whether consumption of multiple macro/ micronutrients explained these egg – BP relations.

It is well documented that men and women differ in prevalence of hypertension[23], but the underlying mechanisms responsible for these differences are not well understood. We also observed the sex differences in the association of egg intake with BP. The differences in the pathophysiology and the dietary patterns between men and women may contribute in part to the sex differences in the association between egg intake and BP.

Although previous studies have suggested that egg consumption was commonly correlated with unhealthy behaviours such as low physical activity, current smoking and unhealthy dietary patterns[24,25], we were still able to detect the association of interest after taking into account the effect of those factors on the association. Our findings on the non-linear association of egg intake with SBP and DBP and the difference in the association by obesity status were in line with the findings of the KoGES Yangpyeong study in South Korea[9]. The lack of relationship between egg intake and BP in obese women may be due to the direct association of obesity and BP[26,27]; therefore, the association cannot be seen among obese women when they are more likely to have high BP.

Regarding the role of dietary cholesterol on the association of egg intake and SBP, eggs contribute 25 % of total dietary cholesterol in the US population[28], and in our study, egg intake and dietary cholesterol were highly correlated, with egg intake contributing about 31 % of total dietary cholesterol (results not shown). The role of dietary cholesterol on BP was also reported in previous publications[29,30]. We found that the association between egg intake and SBP in non-obese women was independent from non-egg dietary cholesterol intake, and there was no association between non-egg dietary cholesterol intake and SBP. This may reflect the role of egg as the main source of dietary cholesterol.

The current study also has several key limitations. This is a cross-sectional analysis and reverse causation is possible. Also, causal inferences cannot be established. There was also a possibility of residual confounding (e.g. cooking method, added salt, egg preparation and accompanying food items) although a number of covariates were taken into account. Also, these data do not permit the study of egg yolk and egg white separately since few participants reported consuming only egg whites without the yolk and < 20 % of participants consumed one or more large eggs/d (≥50 g[17]). Thus, we could not examine the impact of very high egg intake on BP. Further, because our data were collected since 1996–1999, the average SBP/DBP in our study (118·6/73·4 mmHg) would be lower than the more recent average BP level in the USA[31]. However, our focus was on the effects of dietary egg consumption on BP level, and we observed that non-obese women at middle to older ages who consume eggs at the highest 20 % of their group or consume eggs at a low level (i.e. at the first or second quintiles) may have higher BP than those who consume eggs at a moderate level (at the third or fourth quintiles). Moreover, the non-linear association between egg intake and SBP may be due to the effects of other dietary/lifestyle factors on BP such as body composition, stress and sleep, but we were not fully able to capture these factors in our study.

In summary, our findings expand the sparse literature on the relationship between egg intake and BP. Our findings suggest that egg intake may relate to risk of hypertension in certain individuals, and this may depend on the level of egg intake and the obesity status of the individual. Further longitudinal research is needed to elaborate the association and underlying mechanisms associated with egg intake and BP, as well as the role of gender and obesity on these associations.

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Supplementary material

For supplementary material accompanying this paper visit https://doi.org/10.1017/S1368980021002949

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