The nutritional properties and health benefits of eggs

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Abstract

Purpose Advice about the role of eggs in the diet has changed several times over the decades. The aim of the current paper is to evaluate published evidence reporting associations between egg consumption, egg nutrients and health.

Approach The scientific literature was searched using Medline and key words relevant to eggs and egg nutrients. In addition, a new secondary analysis of the UK National Diet and Nutrition Survey (NDNS) was undertaken to examine nutritional and health differences between consumers and non-consumers of eggs.

Findings Eggs are a rich source of protein and several essential nutrients, particularly vitamin D, vitamin B12, selenium and choline. Emerging evidence suggests that eating eggs is associated with satiety, weight management and better diet quality. In addition, antioxidants found in egg yolk may help prevent age-related macular degeneration. The secondary analysis showed that regular egg consumers with a low red and processed meat (RPM) intake ate healthier diets and had a better micronutrient status than those who did not eat eggs but who had a high RPM intake. It was concluded that egg consumption, at a range of intakes, was associated with nutrition and health benefits.

Research limitations/implications More research on eggs, and egg nutrients, is needed to confirm the health benefits. Future studies should control for other dietary and lifestyle factors.

Originality/value This paper develops knowledge about egg consumption beyond cholesterol content and provides new evidence from a secondary analysis of a large national dietary database.

Keywords eggs, protein, vitamin D, choline, selenium, lutein, zeaxanthin.

Paper type General review

Introduction

Opinions on the role of eggs in the diet have changed several times over the past few decades. From 1957 the Egg Marketing Board successfully marketed eggs, proposing that an egg for breakfast was a good source of protein and “the best way to start the day” (Guter and Low, 2008). By the 1960s, egg consumption peaked to nearly 5 eggs per person per week (National Food Survey, 2001). However, attention was then drawn to the cholesterol content of eggs, with research studies suggesting that cholesterol-rich foods may elevate blood cholesterol and, hence, increase the risk of coronary heart disease (CHD) (Kannel et al., 1969). More recently, experts have acknowledged that such conclusions are unfounded because previous studies on eggs had not adequately controlled for potential confounders, e.g. saturated fat intake or smoking (Kritchevsky & Kritchevsky, 2000; McNamara, 2000). A recent review reported that public health bodies, such as the Food Standards Agency (FSA) and British Heart Foundation, no longer recommend limits for egg consumption (Gray and Griffin, 2009). Instead, the emphasis for heart health is placed on controlling levels of saturated fat.

Past concerns have also related to food safety. Eggs sales declined by 60% overnight in December 1988 when Junior Health minister, Edwina Currie, announced that “most of Britain’s egg production was affected with salmonella” (MAFF, 1993). Since then, the Lion Quality Code of Practice has significantly reduced the number of *Salmonella enteritiditis* cases in the UK (Lion Quality Code of Practice, 2007). Indeed, in a cross-section of 28,518 eggs from UK stores, no salmonella was found (FSA, 2004).

Consumers who avoid eggs in the belief that this will reduce serum cholesterol may exacerbate other health problems. In an analysis of cost-benefit, Schmier *et al.* (2009) found that eliminating eggs from the diet appeared to increase the risk of age-related macular degeneration (ARMD), leading to higher healthcare costs. Egg yolk contains specific antioxidant nutrients that support eye function. Thus, the overall health benefits of foods must be considered when formulating dietary advice. The present review aims to investigate associations between egg/egg nutrient consumption and health outcomes. Evidence on eggs/egg nutrients was collated from both published literature and a secondary analysis of the National Diet and Nutrition Survey (NDNS; Henderson *et al.,* 2002).

Nutritional benefits

Eggs can make a significant contribution to a healthy diet. A medium-sized egg provides 78 kcals, yet contains 6.5g protein. The fat content is 5.8g, of which 2.3g is monounsaturated fat (Table 1). Eggs contain a variety of important vitamins, minerals and trace elements (Song *et al.,* 2000). According to the European Commission (EC) Nutrition & Health Claims regulation (European Parliament and Council, 2007) a 'source' claim can be made for foodstuffs that meet at least 15% of the Recommended Daily Amount (RDA) per 100g, while a 'rich in' claim applies when nutrient levels exceed 30% RDA. To that end, the average egg is high in protein, 'a source' of vitamin A, folate, choline, phosphorus and selenium, and 'rich in' vitamin D, riboflavin, vitamin B12, biotin and iodine. The lipid matrix within the egg yolk is believed to enhance the bioavailability of nutrients, such as lutein and zeaxanthin (Heron and Fernandez, 2004).

Table 2 compares the nutrient density of eggs with other protein sources. Although eggs are a rich source of cholesterol (391mg/100g) they are relatively low in energy and high in vitamin A, folate, biotin and iodine compared with other protein foods (Table 2). Eggs provide the richest mix of essential amino acids (Layman & Rodriguez, 2009) which is important for children, adolescents and young adults since protein is required to sustain growth and build muscle (Rodriguez, 2005). For older adults, high-quality protein may prevent the degeneration of skeletal muscle (sarcopenia) (Thalacker-Mercer et al., 2007) and protect against some of the health risks associated with ageing (Morais *et al.,* 2006). For those consuming milk-free diets, eggs are an important high-quality protein source (Symons *et al.,* 2007).

Research has shown that regular consumption of eggs is associated with a better diet quality. An analysis of data from the American National Health and Examination Survey (NHANES III) found that egg consumers had higher intakes of all nutrients (except vitamin B_6 and dietary fibre) compared with those who did not eat eggs. Interestingly, cholesterol levels were lower amongst frequent egg consumers (Song *et al.,* 2000).

Secondary analysis of egg consumption among British adults in the NDNS
Seven-day weighed dietary records from the NDNS (for methods, see Henderson *et al.,* 2002) were analysed to explore associations between egg consumption and markers of diet quality and health. Approximately 30% of British adults consumed no eggs in the week of survey, while consumers ate an average of 2-3 eggs per week (women) or 3-4 eggs per week (men). The contribution of eggs to total daily intakes of energy and nutrients was correspondingly modest overall, (approximately 2% of energy, 3% of protein, 3% saturated fatty acids, 5% of monounsaturated fatty acids). However, for high consumers (3+eggs per week), eggs were a substantial source of vitamin D, vitamin B12, biotin, and iodine.

To examine these associations further, egg consumption was stratified into 3 levels: none, less than 3 eggs per week (<150g), and 3 or more eggs per week (150g+). Associations between egg consumption, food and nutrient intakes were examined using Spearman correlation for continuous variables, ANOVA with post-hoc contrasts for categorical data, and ANCOVA (adjusted for age/sex) for selected health measures. Principle components analysis was used to investigate dietary patterns.

Adults who consumed 3 or more eggs per week had higher intakes of vitamins B12, A and D, niacin, iodine, zinc and magnesium, compared with non-consumers (Fig 1). Egg consumption was also positively associated with fat intake and its components, saturated, monounsaturated and polyunsaturated fatty acids. However, principal components analysis identified eggs to be highly correlated with a “traditional” dietary pattern characterised by a high intake of red and processed meat (RPM), e.g. bacon, sausages and meat pies. To disentangle the confounding effect on nutrient intakes of these higher fat foods from any effect due to eggs, 4 groups were compared:

1. Non-consumers of eggs with low RPM (<50g/d) (E-M-)
2. Non- consumers of eggs with high RPM (>50g/d) (E-M+)
3. High consumers of eggs (3 or more per week) with low RPM (<50g/d) (E+M-)
4. High consumers of eggs (3 or more per week) with high RPM (>50g/d) (E+M+)

Adults in the E+M+ group had the highest intakes of fat (as a percentage of energy) and saturated fat, while those in the E-M- group had the lowest fat intakes (Table 3). The two intermediate groups did not differ significantly in regard to fat intake or composition, but the 'health-conscious' egg consumers (E+M-) had a lower mean intake of non-milk extrinsic ('added') sugars and higher intake of fibre compared with the E-M+ group. Micronutrient density was also significantly higher in the 'health conscious' egg consumers (Table 4).

Two thirds of adults in the NDNS provided a blood sample for analysis, thus enabling nutritional status markers to be compared between groups. The 'health conscious' egg consumers (E+M-) had higher plasma levels of lutein and zeaxanthin, carotenoids, vitamin C, selenium and glutathione peroxidise (a marker of selenium status), compared with the E-M+ group (Table 5). Blood lipid results (adjusted for age and sex) were also examined and these showed a weak positive association with total cholesterol. However, no significant difference was seen in the ratio of total to high density lipoprotein (HDL) cholesterol – an established marker of CHD risk (Table 6). Neither were there significant differences in body mass index (BMI) or waist circumference between the 4 groups.

It appears from these data that consumption of 3 or more eggs per week is compatible with a healthy diet and may be especially helpful in enhancing diet quality for those following advice to cut down on fatty meat products.

Eggs and health

In the past, research on eggs focussed on associations with serum cholesterol levels and heart health. However, many of these studies are now considered to be methodologically weak (e.g. Weggemens *et al.,* 2001; Nettleton *et al.,* 2008; D'Avanzo *et al.,* 1995) as they failed to adjust for confounding variables such as other dietary components or pre-existing hypercholesterolemia (Song *et al*., 2000). To date, the most sophisticated analysis has been employed by Hu *et al.* (1999), whose work adjusted for age, smoking and other risk factors. The prospective, observational study, which was based on two large US cohorts, concluded that egg consumption was not significantly associated with the risk of CHD or stroke in healthy adults or those with pre-existing hypercholesterolaemia. However, those with diabetes were twice as likely to develop CHD if they ate more than 7 eggs per week. Another study on two long-term prospective cohorts investigated whether egg consumption was related to diabetes risk (Djousse *et al.,* 2009), estimating egg consumption using questionnaires. There appeared to be a greater risk of developing diabetes when diets included eggs, although the study was observational. Other studies have reported similar findings but as secondary outcomes (Djousse *et al.,* 2008; Qureshi *et al.,* 2007 & Hu *et al.,* 1999), while Trichopoulou *et al.* (2006) reported that higher intakes of eggs and saturated fats were associated with diabetic mortality. However, all of these studies are observational and cannot determine whether the association between eggs and diabetes risk is causal or related to other dietary factors, such as the intake of processed meats (found to correlate with egg consumption in the NDNS and US cohorts). Controlled, intervention trials are now needed to determine whether people with diabetes should limit egg consumption.

More recent research on eggs, CVD and cholesterol has been better controlled. Within the last 15 years, 11 key studies have been published (Table 7). Of these, the majority do not support the contention that egg consumption is a risk factor for heart disease (Barraj *et al.,* 2009; Nakamura *et al.,* 2006; Hu *et al.,* 1999) or stroke (Djousse and Gaziano, 2008; Qureshi *et al.,* 2007 & Nakamura *et al.,* 2004). Using a risk apportionment model, Barraj *et al.* (2009) calculated that eating one egg per day accounted for <1% of CHD risk. In contrast, 40% of risk was attributed to lifestyle factors (smoking, poor diet, minimal exercise, alcohol intake). Katz *et al.* (2005) demonstrated that eating 2 eggs per day for 6 weeks had no effect on endothelial function, a marker of cardiovascular disease (CVD) risk. In another study, HDL cholesterol (i.e. ‘good’ cholesterol) increased, and markers of metabolic syndrome decreased when 28 overweight/obese males ate a carbohydrate-restricted diet and 3 eggs daily for 13 weeks (Mutungi *et al*., 2008). The previously mentioned study by Harman *et al.* (2008) found no significant impact on low density lipoprotein (LDL) cholesterol (i.e. ‘bad’ cholesterol) levels when two eggs were eaten daily for 12 weeks.

Scientists are now investigating new areas of egg research. There is emerging evidence that the high protein content of eggs may contribute to greater satiety (Ratliff *et al.,* 2009 & Vander Wal *et al.,* 2005) and weight loss (Vander Wal *et al.,* 2008), although the amount needed for an effect requires clarification (Benelam, 2009). Ratliff and colleagues (2009) studied whether appetite hormone levels altered when participants were randomised to an egg/day, or control whilst eating a carbohydrate-restricted diet for 12 weeks. Although the egg group reported that they felt "full", "satisfied" and "wanted to eat less", levels of appetite hormones were similar to those seen in the control group. Vander Wal *et al.* (2005) provided more conclusive findings, reporting that an egg-breakfast induced both greater feelings of satiety while reducing energy intake throughout the day and over the following 36 hours. In terms of body weight, Vander Wal *et al*. (2008) identified that body weight reduced by 65% (BMI reduced by 61%) when 152 adults ate 2 eggs daily for breakfast as part of an energy deficit diet over an 8-week period. Interestingly, cholesterol levels remained unchanged in this study. A similar finding was reported by Harman *et al.* (2009) who conducted a randomised, parallel study over 12 weeks. The intervention group (n=24) ate 2 eggs per day as part of an energy deficit diet, while the 21 controls followed the same diet minus the eggs. A similar weight loss of around 4 kg was seen in both groups. LDL cholesterol levels remained unchanged despite a doubling of cholesterol intake in the egg group to 582 mg per day. In contrast, an observational study (Cho *et al*., 2003) reported that higher daily energy intakes and a higher BMI were associated with inclusion of eggs at breakfast. However, as in the NDNS, egg consumption was strongly correlated with meat consumption, thus it is not possible to establish cause and effect from this study. Controlled trials should now examine if eggs really can aid weight management.

As mentioned previously, only one US epidemiological study investigated the nutritional contribution of eggs to overall diet quality (Song *et al*., 2000). Data analysed from 27,378 participants taking part in NHANES III showed that micronutrient intakes were higher amongst adults eating more than 4 eggs per week (Song et al., 2000). Micronutrients found in significant amounts in eggs may contribute to health, i.e. vitamin D, vitamin B12, choline, folate, selenium, lutein and zeaxanthin. Vitamin D seems to slow cell ageing and may help prevent CVD, diabetes, autoimmune diseases and certain cancers (Ruxton and Derbyshire, 2009), while vitamin B_{12} may delay cognitive decline and protect against Alzheimer's disease (Malouf and Areosa Sastre, 2003), although further research is warranted.

The health benefits of choline, another key egg nutrient, are not fully understood. An adequate choline intake appears to be important during reproduction (Zeisel, 2009). Choline donates methyl groups to fetal DNA, causing hypermethylation, which is believed to silence genes that may be detrimental to health (Maloney and Rees, 2005). Studies have identified that a diet adequate in choline (>456mg/day) may help to protect against breast cancer (Xu *et al.,* 2008) and DNA damage (Da Costa *et al.,* 2006). Evidence is still emerging and requires further investigation.

The positive impact of folate on the prevention of neural tube defects is well known (Tamura and Picciano, 2006) but there may also be a role for folate in CVD prevention. Several meta-analyses have reported that folic acid improves endothelial function (De Bree *et al.,* 2007) and reduces the risk of stroke (Wang *et al.,* 2007). In addition, there is emerging evidence that a low folate intake is a risk factor for depression (Gilbody *et al.,* 2007).

For selenium, two recent meta-analyses are relevant. Flores-Mateo *et al.* (2006) found that a 50% increase in blood selenium concentration decreased the risk of developing CHD by 24%. Selenium also appeared to exert protective effects in both the early and latter stages of cancer development (Zeng and Combs, 2008). Selenium has been found to protect against lung cancer in areas where average intakes are low (Zhuo *et al.,* 2004) and may attenuate the risk of prostate and colonic cancer (Brinkman *et al.*, 2006; Connelly-Frost *et al.*, 2006). The US Food and Drug Administration (FDA) recently acknowledged that sufficient evidence now exists to permit a health claim for selenium in relation to cancer (Duntas, 2006).

The antioxidants, lutein and zeaxanthin, are both found in egg yolk and accumulate, post consumption, within the macular region of the human retina (Burke *et al.,* 2005). One study found that eating 1.3 eggs yolks daily for 4.5 weeks increased plasma lutein and zeaxanthin levels by 50% and 114% respectively (Handelman *et al.,* 1999). Goodrow *et al.* (2006) also found that lutein and zeaxanthin concentrations increased when older adults (>60yrs) ate one egg daily for 5 weeks. Wenzel *et al.*

(2006) developed this research further and identified that eating 6 eggs weekly for 12 weeks raised serum zeaxanthin levels and increased macular pigment optical density. Overall, the findings from these studies indicate that egg consumption may be important in helping to prevent ARMD.

Discussion

Eggs are a nutrient-dense food, rich in essential vitamins and minerals, as well as antioxidants (Fernandez, 2006; Song *et al.,* 2000). New evidence now suggests that, although eggs provide dietary cholesterol, other factors are stronger risk factors for heart disease (Barraj *et al.,* 2009). Dietary cholesterol can raise serum LDL levels but the overall effects are negligible compared with the LDL-raising effects of saturated fatty acids (Gray and Griffin, 2009). Consequently, the potential of eggs to increase cholesterol has little clinical importance when considered relative to other dietary and lifestyle factors (McNamara, 2002).

Although it is clear that eggs are a healthy food when eaten as part of a balanced diet, further clarification is needed on the level of egg consumption that is consistent with optimal health (Gilbert, 2000). The research suggests that 1-2 eggs daily can be consumed with no effect on endothelial function or total cholesterol (Katz *et al.,* 2005). Public health bodies, such as the FSA, do not place any limits on egg consumption for the general population. However, according to observational studies, individuals diagnosed with diabetes or hypercholesterolaemia may be at increased risk of CVD when egg intakes exceed 7 per week (Hu *et al.,* 1999; Qureshi *et al.,* 2007). Heart UK advises that people with familial hypercholesterolaemia, a genetic condition where there is increased sensitivity to dietary cholesterol, should restrict their egg intake to 2-3 per week (Heart UK, 2008).

While the above ‘at risk’ individuals may benefit from restricting egg consumption to fewer than 7 eggs per week, for the healthy majority, regular egg consumption could impact positively on diet quality (Song *et al.,* 2000). Eggs are a rich source of protein and essential micronutrients that may offer health benefits (Layman and Rodriguez, 2009). One interesting finding is the link between consuming an egg-based breakfast and feelings of satiety (Ratliff *et al.,* 2009) which could have an impact on body weight (Vander Wal *et al.,* 2008), although further research is warranted.

The role of other egg nutrients in relation to health outcomes looks promising. It is well documented that vitamin D intakes are inadequate in most Westernised countries (Ruxton and Derbyshire, 2009). Eggs are an important dietary source of vitamin D and could help to boost daily intakes as they provide more than 20% RDA per egg (Table 1). For selenium, evidence is now sufficient to warrant a US health claim (Duntas, 2006), although scientific evidence is still emerging (Ziesel, 2009; da Costa *et al.,* 2006). It is worth noting that selenium intakes in the UK are significantly below recommended levels (Jackson *et al.*, 2004). The role of choline in eye health is becoming more apparent, while further research is needed to investigate how other egg nutrients, such as biotin and iodine, may contribute to the maintenance of health.

Conclusions

This review has identified that eggs are a low energy, nutrient-dense food source that contribute to diet quality, particularly intakes of selenium and vitamin D. For most individuals, egg consumption will have little or no influence on cholesterol levels (Fernandez, 2006) or CHD risk (Hu *et al.*, 1999). For the general population, there are clear nutritional benefits to eating eggs on a regular basis. Emerging evidence suggests that eggs may be beneficial for satiety, weight control and eye health.

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Table 1: Nutritional composition of eggs (chicken egg, raw)

Nutrient	**Nutrient content per 100g**	**Per medium egg (52g)** *[a]*	**Cut-off for 'source' claim (15% RDA)**	***RDA***
Energy (kcal)	151	78	--	--
Protein (g)	**12.5**	6.5		--
Carbohydrate (g)	Trace	Trace	--	--
Fat (g)	11.2	5.8	--	--
Cholesterol (mg)	391	225	--	--
Retinol equiv. (μg)	**190**	98	120	*800*
Vitamin D (μg)	**1.6**	0.9	0.75	*5*
Riboflavin (mg)	**0.47**	0.24	0.21	*1.4*
Folate (μg)	**50**	26	30	*200*
Vitamin B_{12} (μg)	**2.5**	1.3	0.38	*2.5*
Choline (mg)	**160**	83.2	82.5	*550*[b]
Biotin (μg)	**20**	10	7.5	*50*
Phosphorus (mg)	**200**	104	105	*700*
Iron (mg)	1.9	0.99	2.1	*14*
Zinc (mg)	1.3	0.68	1.5	*10*
Iodine (μg)	**53**	28	22.5	*150*
Selenium (μg)	**11**	5.7	8.25	*55*

Key: RDA, recommended daily allowance; [a] refers to edible portion of an average 56g egg

Sources: Nutritional composition data, FSA (2006); RDA data, European Commission (2008) except [b]Zeisel *et al.* (2003). Values in **bold** meet the minimum requirement to be labelled as 'a source' according to EU regulations (European Parliament and Council, 2006; European Commission, 2008), except for protein which can be labelled 'high' because more than 20% of the energy value is protein (European Parliament and Council, 2006).

Table 2: Nutrient density of different protein sources (per 100g)

	Chicken (grilled)	Beef (roasted)	Eggs (boiled)	Fish (steamed salmon)	Tofu (steamed)
Energy (kcal)	148	202	147	194	73
Protein (g)	32	36.2	12.5	21.8	8.1
Total fat (g)	2.2	6.3	10.8	11.9	4.2
SFA (g)	0.6	2.6	3.1	2	0.5
MUFA (g)	1.0	2.8	4.7	4.7	0.8
PUFA (g)	0.4	0.3	1.2	3.3	2.0
Cholesterol (mg)	94	88	385	54	0
Sodium (mg)	55	62	140	49	4
Vitamin A (μg)	Tr	Tr	190	14	0
Vitamin D(μg)	0.3	0.8	1.8	8.7	0
Folate (μg)	6	21	39	17	15
Biotin (mg)	2	2	16	7	N
Phosphorous (mg)	310	230	200	270	95
Selenium (μg)	16	12	11	28	N
Iodine (μg)	7	13	53	4	N

Source: Data extracted from FSA (2006).

Key: NSP, non-starch polysaccharide (Englyst fibre), NMES, non-milk extrinsic sugars, SFA, saturated fatty acids; PUFA, polyunsaturated fatty acids; MUFA, monounsaturated fatty acids; Tr, Trace

Table 3: Energy and macronutrient intake by weekly egg consumption

	Weekly egg consumption			ANOVA linear
	none	<3	3 or more	P value
n	553	584	587	
Energy (MJ)	7.6	7.9	8.8	0.000
Protein (g)	69	73	81	0.000
Fat (g)	65	70	82	0.000
Carbohydrate (g)	229	229	244	0.001
NSP (g)	13.5	13.5	14.3	0.032
NMES g	62	61	66	0.045
% Energy from fat	32.0	33.3	35.1	0.000
% Energy from SFA	12.0	12.6	13.2	0.000
% Energy from MUFA	10.5	11.0	11.7	0.000
% Energy from PUFA	5.9	5.9	6.1	0.036
% Energy from protein	15.5	15.8	15.7	0.33
% energy from NMES	12.4	11.8	11.6	0.017

Key: NSP, non-starch polysaccharide (Englyst fibre), NMES, non-milk extrinsic sugars, SFA, saturated fatty acids; PUFA, polyunsaturated fatty acids; MUFA, monounsaturated fatty acids

Table 4: Micronutrient density according to dietary habit

	No eggs Low RPM	No eggs >50g RPM	3+eggs low RPM	3+eggs >50g RPM	P value for contrast*
Sample size=	*183*	*370*	*149*	*438*	
Sodium (mg/MJ)	343	344	334	345	0.15
Potassium (mg/MJ)	405	374	399	361	0.001
Calcium (mg/MJ)	123	111	126	105	0.000
Magnesium (mg/MJ)	38	33	37	32	0.000
Phosphorus (mg/MJ)	167	159	170	157	0.002
Iron (mg/MJ)	2.2	1.5	1.7	1.5	0.019
Copper (mg/MJ)	0.2	0.2	0.2	0.2	0.016
Zinc (mg/MJ)	1.1	1.2	1.1	1.2	0.86
Iodine (µg/MJ)	26.0	22.6	28.6	23.7	<0.0001
Retinol (µg/MJ)	56	69	77	87	0.424
Carotene (µg/MJ)	306	239	301	235	0.002
Retinol Equivalents (µg/MJ)	107	109	127	126	0.081
Vitamin D (µg/MJ)	0.5	0.4	0.6	0.5	<0.0001
Thiamin (mg/MJ)	0.4	0.2	0.5	0.2	0.059
Riboflavin (mg/MJ)	0.4	0.2	0.5	0.2	0.069
Niacin Equiv (mg/MJ)	5.0	4.9	5.0	4.7	0.632
Vitamin C (mg/MJ)	15.5	12.8	16.7	12.2	0.024
Vitamin E (mg/MJ)	2.6	1.8	1.7	1.6	0.729
Vitamin B6 (mg/MJ)	0.5	0.3	0.7	0.3	0.046
Vitamin B12 (µg/MJ)	0.7	0.7	0.8	0.8	0.491
Folate (µg/MJ)	44	38	45	37	<0.0001
Pantothenic Acid (mg/MJ)	1.0	0.8	1.3	0.8	0.042
Biotin (µg/MJ)	5.0	4.1	6.1	4.9	<0.0001

*contrast between (E-M+) and (E+M-)

Table 5: Blood markers of antioxidant status according to dietary habit

	No eggs Low RPM	No eggs >50g RPM	3+eggs low RPM	3+eggs >50g RPM	P value for contrast*
N=	*129*	*252*	*106*	*308*	
Red cell selenium (µmol/l)	1.9	1.7	1.8	1.6	0.001
Plasma alpha-carotene (µmol/l)	0.09	0.07	0.1	0.07	0.014
Plasma beta-carotene (µmol/l)	0.34	0.24	0.37	0.24	0.001
Plasma vitamin C (µmol/l)	57	55	66	55	0.001
Plasma lutein + zeaxanthin (µmol/l)	0.29	0.26	0.33	0.29	<0.0001
Glutathione peroxidase (nmol/min/mgHb)	131	122	129	122	0.047

*contrast between (E-M+) and (E+M-)

Table 6: Blood lipids according to dietary habit (means adjusted for age and sex)

	No eggs Low RPM	No eggs >50g RPM	3+eggs low RPM	3+eggs >50g RPM	P value for contrast*
N=	132	252	103	308	
Plasma total cholesterol (mmol/l)	5.1	5.2	5.5	5.3	0.034
Plasma HDL-C (mmol/l)	1.2	1.2	1.2	1.2	0.23
Plasma LDL-C (mmol/l)	3.9	4.1	4.3	4.1	0.09
TC:HDL ratio	4.5	4.8	4.8	4.8	0.9

*contrast between (E-M+) and (E+M-)

Table 7: Egg consumption and health

Study	Health outcomes	Subjects	Study details	Findings (No. eggs recommended)
Heart disease/serum cholesterol				
Barraj *et al.* (2009)	CVD	Not applicable	Used weighted models to determine overall risk of egg consumption.	Consuming 1 egg/d accounted for <1% CHD risk. Other lifestyle factors were stronger determinants.
Djousse and Gaziano (2008)	CVD, mortality	n=21,327 M.	20y cohort. Participants completed SQ-FFQs every 2 yrs. Medical questionnaires were sent out annually to monitor health status.	MI or stoke incidence was not related to egg consumption. Eating 7 eggs+/wk increased risk of death by 23%, particularly in diabetics.
Mutungi *et al.* (2008)	HDL-C, markers of metabolic syndrome	n=28 overweight/obese M, 40-70y.	12 wk RCT. Subjects ate a carbohydrate-restricted diet and 3 eggs/d or an egg substitute.	Carbohydrate restriction combined with eating 3 eggs/d significantly increased HDL and decreased markers of metabolic syndrome.
Nettleton *et al.* (2008)	Heart failure	n=14,153, 45-64y.	13y cohort. FFQ at baseline and when followed-up (over a 6y period).	Heart failure risk was higher with a greater intake of eggs and high-fat dairy.
Qureshi *et al.* (2007)	Stroke	n=9734 M & F, 25-74y.	20y cohort. Data reanalysed from NHANES I.	Weekly consumption of >6 eggs/wk did not increase stroke risk in healthy individuals (only in diabetics).
Nakamura *et al.* (2006)	Serum cholesterol, CHD	n=90,735 M & F, 40-59y.	7-11y cohort. Self-reported FFQ, serum cholesterol measured.	Eating eggs frequently (almost daily) did not increase CHD risk.
Katz *et al.* (2005)	Endothelial function	n=41 M and F, 56y.	Randomised crossover trial. Eggs or oat daily for breakfast (4-wk washout between crossovers).	Eating 2 eggs/d had no effect on total cholesterol or endothelial function.

Nakamura *et al.* (2004)	Serum cholesterol, mortality	n=9263 M and F, >30y+.	14y cohort. Lifestyle and FFQ, serum cholesterol measured.	In women, mortality due to stroke, IHD and cancer was lower in the 1-2 eggs/wk group than the 1 egg/d group.
Weggemans *et al.* (2001)	Ratio of total:HDL cholesterol	n=556 subjects	Data from 17 experimental studies analysed.	An additional 100mg dietary cholesterol/d increased the ratio of total:HDL cholesterol by 0.020 units.
Hu *et al.* (1999)	CVD	n=37,851 M, 40-75y. n=80,082 F, 34-59y.	8-14 y cohort. Dietary questionnaire data merged from the Health Professional and Nurses' Health Study.	Egg consumption was not related to CHD or stroke in men or women (only in diabetic patients).
D'Avanzo *et al.* (1995)	Serum cholesterol	n=792	Retrospective cohort. Serum cholesterol levels and diet history were recorded.	Higher intakes of meat, ham, eggs, fruit, carrots and green vegetables were associated with higher cholesterol levels.
Diabetes				
Djousse *et al.* (2009)	Type II diabetes	n=56,998 M & F.	11-20y cohort. Dietary questionnaire data merged from the Physicians' Health Study I and Women's Health Study.	Risk of type 2 diabetes increased with levels of egg consumption (>/= 7 eggs/wk), particularly in women.
Trichopoulou *et al.* (2006)	Mortality	n=28,572 M & F	Cohort (4579 person yrs). Diet assessed at baseline using a questionnaire.	Higher intakes of eggs and saturated lipids with associated with higher rates of diabetic mortality.
Satiety/body weight				
Ratliff *et al.* (2009)	Satiety/appetite hormones	Not specified	12-wk parallel RCT. Consumed an egg or placebo daily whilst following a carbohydrate-restricted diet.	Both groups felt more satiated (*P*<0.05) but egg consumption did not influence ghrelin levels (hormone associated with weight loss).

Vander Wal *et al.* (2008)	Weight loss	n=152, 25-60y.	8-wk intervention. Participants assigned to an egg, bagel or egg/bagel diet breakfast + energy restriction for 5 days/wk.	When combined with energy restriction, BMI reduced by 61% in the egg compared to the bagel diet group. (P<0.05)
Vander Wal *et al.* (2005)	Satiety	n=30 F, BMI>25kg/m^2.	2-wk RCS. Participants ate an egg or bagel-based breakfast. Dietary intake and satiety measured.	Energy intake was lower at lunchtime and up to 36hrs later in after eating the egg breakfast (2 scrambled eggs) (P<0.001).
Cho *et al.* (2003)	BMI	n=16,452 M & F.	Observational study. Breakfast habits were analysed using data from NHANES III.	Meat and/or egg eaters had higher energy intakes and BMI.
Antioxidants/ARMD				
Goodrow *et al.* (2006)	Serum lutein & zeaxanthin concentrations	n=33 M & F, >60y.	18-wk randomised crossover study. Two 5-wk interventions eating 1 egg/d or a substitute, separated by a washout period.	Serum lutein and zeaxanthin levels increased (P<0.001) without affecting LDL, HDL or triglyceride levels.
Wenzel *et al.* (2006)	Macular pigment optical density	n=24 M & F, 24-59y.	12-wk intervention. 6 eggs/wk consumed containing 331µg or 964µg lutein/zeaxanthin, or a pill taken daily.	Serum zeaxanthin was associated with increased macular pigment optical density.
Handelman *et al.* (1999)	Plasma lutein & zeaxanthin concentrations	n=11 M with mild hypercholesterolemia	4.5-wk intervention. Baseline diets supplemented with 1.3 egg yolks/d.	Lutein and zeaxanthin levels increased in both groups. LDL concentration increased by 8-11%.

Key: ARMD, age-related macular degeneration; BMI, body mass index; CVD, cardiovascular disease; CHD, coronary heart disease; F, female; HDL, high-density lipoprotein; ICH, ischaemic heart disease; M, male; MI, myocardial infarction; NHANES, National Health and Nutrition Examination Survey; RCS, randomised crossover study; RCT, randomised controlled trial; y, year/s; SQ-FFQ, semi-quantitative food frequency questionnaire, wk, week.

Figure 1: Micronutrient intakes among adults by egg consumption