The role of Eggs in the diet of New Zealanders

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EXECUTIVE SUMMARY

The objective of this report is to review literature on the major health areas that are relevant to eggs, draw conclusions and provide recommendations for various target audiences. Eggs are a popular food choice amongst the New Zealand population with each New Zealander consuming approximately 237 eggs per year. Over the years there have been mixed messages on potential negative health effects of eggs, in particular the effect of increased consumption on cardiovascular health. This is partly due to earlier epidemiological data that demonstrated a weak, positive association between dietary cholesterol and cardiovascular risk, and the fact that eggs are one of the richest sources of dietary cholesterol. However, public health messaging on egg consumption has evolved over the past years, with many national and international health organizations including regular egg consumption as part of a healthy, balanced diet in their dietary recommendations.

FINDINGS

In total, 68 articles were evaluated, with key topics chosen based on the evidence available. The effect egg consumption has on serum cholesterol levels and cardiovascular disease risk has been the main health area of concern and consequently the one with the most evidence available. In addition, there is a significant amount of evidence available and continuing to emerge on the effect increased egg consumption has on weight management and diabetes, and the nutrient credentials of eggs.

Since the first 2014 edition of this paper was published there have been three key pieces of research that have been released by leading authorities, namely, the American Heart Association, New Zealand Heart Foundation and Australian Heart Foundation.

Research is now suggesting, by the growing number of studies both observational and in controlled trials, that increased egg consumption has little or no association with increased serum cholesterol levels and increased risk of cardiovascular disease.

Research has also confirmed the nutrient credentials of eggs. Alongside the rich source of protein and 11 vitamins and minerals that eggs contain, they are also a rich source of choline, and increased consumption of eggs is shown in research to increase the serum concentrations of two carotenoids Lutein and Zeaxanthin. This is favorable, as Choline, Lutein and Zeaxanthin have been shown to have a protective role with many diseases and health conditions. Evidence has also shown a positive link between egg consumption and satiety, which is beneficial for weight management, although further research is recommended to confirm eggs as a beneficial food choice for long term weight management.

One key health area indicated in research as a potential concern in relation to increased egg consumption is diabetes. There is some evidence demonstrating increased egg consumption in diabetic participants is associated with increased cardiovascular risk versus non-diabetics. Studies have also demonstrated a negative association between egg consumption and the risk of diabetes itself. Additional case controlled and intervention research is recommended to further understand the link between increased egg consumption and diabetes.

The weight of evidence currently available supports eggs as a healthy food choice. This is evident in the current dietary recommendations compared to those from the 1960's and 1970's where eggs were commonly restricted, especially when concerning cardiovascular health. Many leading health organizations have reviewed their dietary guidelines for egg intake, such as the New Zealand Heart Foundation who recommend that New Zealanders who are at increased risk of heart disease can eat up to six eggs per week as part of a heart-healthy diet.

RECOMMENDATIONS

Micro-level

- Individual dietary advice required, with research in this review supporting the consumption up to one-two eggs per day as part of a healthy, balanced diet low in saturated fat for individuals not at risk of diabetes or in need of LDL cholesterol lowering interventions.

Meso-level

- For people with diabetes and people at increased risk of heart disease, healthcare professionals should utilize the latest New Zealand Heart Foundation's recommendations for egg consumption: up to six eggs per week as part of a heart-healthy diet.

Macro-level

- Opportunity for food industry to further research consumers understanding and knowledge on recommendations for egg intake.
- Opportunity for New Zealand government to conduct updated Nutrition Survey and disseminate include more specific guidelines and information on egg consumption to prevent potential confusion.

CONCLUSION

The evidence presented in this literature review supports the inclusion of eggs as part of a healthy, balanced diet. Although additional research is warranted to further understand some potential negative health concerns related to increased egg consumption, the weight of evidence supports eggs as a nutritious food choice for the New Zealand population.

PURPOSE OF THE PROJECT

The purpose of this review is to provide impartial, balanced and evidence-based information and advice to be utilized by a range of audiences including but not limited to, health professionals and health influencers, public health organizations, government agencies and the media. This was achieved through an extensive literature review of both research papers and credible health authorities' recommendations with a New Zealand perspective in mind.

The objectives were to:

- Conduct an extensive literature review to determine up to date research and information available on the issue of eggs
- Develop a balanced and evidence-based position paper
- Provide supportable recommendations for further use within key audiences.

INTRODUCTION

Eggs are a highly nutritious food and play an important part in a healthy balanced diet. They are an affordable source of high-quality protein, contain almost all recognized vitamins and many essential minerals, are high in antioxidants such as lutein and zeaxanthin and the nutrient choline, and are a source of long-chain omega-3 fatty acids. Studies have also shown eggs increase satiety, which is beneficial for weight management.

Due to the flexibility of use, taste and nutritional benefits, eggs are a staple food in the New Zealand (NZ) diet with egg farmers now producing approximately 1 billion eggs per year (Egg Producers Federation New Zealand, 2022) and each New Zealander consuming approximately 237 eggs per year as of June 2021 (Egg Producers Federation New Zealand, 2022). This makes New Zealanders amongst the highest per capita consumers of eggs in the world.

Even so, in previous decades there has been public health messaging that has warning consumers about detrimental health effects of over consumption of eggs, due to their high cholesterol content and its supposed relation to cardiovascular health. These warnings have meant past recommendations for egg intake by health authorities within NZ and around the world have been restrictive.

The concern for egg over-consumption is based on three observations:

- Eggs contain high levels of cholesterol (they are one of the richest sources of dietary cholesterol)
- studies have shown that dietary cholesterol increases serum cholesterol
- high serum cholesterol is a key risk factor for the onset of heart disease

Cholesterol is a waxy molecule that acts as a structural component to animal cell membranes amongst its other functions (Heart Foundation NZ, 2016a). Note, that dietary cholesterol is distinct to serum cholesterol. Dietary cholesterol is cholesterol present within the animal foods that we eat (plant foods do not contain cholesterol). On the other hand, serum cholesterol is the cholesterol found within our blood, such as high-density lipoproteins (HDL) and low-density lipoproteins (LDL) which has been produced endogenously by our body (Heart Foundation NZ, 2016a). Our body can make all the cholesterol that we need.

More recent research shows that while dietary cholesterol may increase serum cholesterol concentrations, the rise in most people is minimal. (National Heart Foundation of Australia, 2019a). Despite some controversy, the body of research suggests that eggs have a neutral relationship with heart health for the general population. This movement in the scientific community has led to health authorities easing their recommendations around eggs, and a shift in the public and professional opinion of eggs. Guidelines are still in place for those at higher risk of cardiovascular disease (CVD) and require LDL-cholesterol lowering interventions and type 2 diabetics.

- Based on current evidence, the NZ Heart Foundation recommends that New Zealanders who are at increased risk of heart disease, including those with Type 2 diabetes, can eat up to six eggs per week as part of a heart-healthy eating pattern (Heart Foundation NZ, 2016b). This amount is unlikely to have any substantive influence on their risk of heart disease (Heart Foundation NZ, 2016b). They have not set a limit for egg intake for the general population (Heart Foundation NZ, 2016a). This in contrast to their 1999 evidence paper, which recommended limiting intake to three eggs a week if at very high risk of heart disease, but did not restrict egg intake for the general population (Heart Foundation NZ, 2016a).

- The American Heart Association (AHA)'s dietary guidelines for 2021 have not set a limit on eggs nor cholesterol but state that adherence to their dietary guidelines would result in relatively low dietary cholesterol intakes (Lichtenstein et al., 2021).

- The Australian Heart Foundation have updated their guidelines in recent years recommending a maximum of seven eggs a week for those with: High LDL cholesterol, type 2 diabetes and existing heart disease (National Heart Foundation of Australia, 2019a). They have not set a limit for healthy individuals.

All aforementioned health authorities recognize eggs as a healthy addition to the diet. They have issued statements encouraging the public to focus on overall diet quality, in particular, one that is plant-rich and based on minimally processed foods and low in saturated fat (Heart Foundation NZ, 2016a)(American Heart Association, 2018)(National Heart Foundation of Australia, 2019a).

METHODOLOGY

In order to develop a position statement on the health credentials of eggs and any issues related to consumption, an extensive literature review was conducted to ensure that the position paper was evidence based and succinct.

Search engines such as 'Medline', 'Google Scholar' and 'Science Direct' were used, utilizing the following key words 'eggs', 'cholesterol', 'cardiovascular disease', 'diabetes', 'weight management', 'satiety', 'lutein', 'zeaxanthin' and 'choline'.

The abstracts were reviewed, and then full copy of the study was sourced if considered suitable. Studies were included in literature review if there was significant strength of evidence, with a preference for position statements, controlled studies and prospective cohorts, only human studies were considered, number of subjects were considered, as well as studies with relevant adjustments made in the data, and majority of studies were from the past 20 years.

For the purposes of the review conducted in 2022, references were checked to ensure that information provided was still valid. Some references were removed if their web links no longer worked. Previously referenced position statements were checked and updated as required.

The search criteria yielded the following articles: 20 reviews, 5 meta-analysis, 13 prospective (observational) studies, 23 controlled trials/interventions and 7 government reports or health authority position papers. A total of 68 articles all together.

HISTORY

The consumption of eggs from a variety of birds, has been traced back to ancient times. However, it was before 7500 BC, that the chicken as we know it today, was domesticated, and is believed to be a descendent of birds from the jungles of Southeast Asia. The inclusion of eggs in the diet has a long history in China, with the Greeks and Romans and throughout Europe, particularly in the Middle Ages. The opening of trade channels between China and England in the early 19th century, lead to major changes in the poultry industry, with major expansion and development of processes (Iannotti et al., 2014).

Eggs from domestic birds (chickens) have been part of the NZ diet, providing an important and cost-effective source of protein and nutrients since Captain Cook brought the first hens here in 1773. The consumer demand for eggs has doubled over the past century, with consumption of eggs increasing from approximately 100 eggs each person per year to now approximately 237 eggs per person per

year (Egg Producers Federation New Zealand, 2022). This has meant farming methods have evolved to meet this demand, moving from mostly individually run coops and small free-range operations to large scale farming via cage, barn or free range to meet the need for 1 billion eggs a year in NZ (Egg Producers Federation New Zealand, 2022).

New Zealand now has around 124 egg farms (Egg Producers Federation New Zealand, n.d.-b). Conventional cages were the source for majority of NZ eggs, however, in 2012 The Animal Welfare (Layer Hens) Code of Welfare came into force. This code aims to phase-out conventional cages, stipulating that from 2018 farmers cannot install new conventional cages and must begin decommissioning existing conventional cages (depending on their age). By 31 December 2022, all conventional cages will be banned (Animal Welfare (Layer Hens) Code of Welfare 2012, 2012)(Egg Producers Federation New Zealand, n.d.-a). Note that larger colony cages are still allowed under this code.

EGG COMPOSITION

Eggs are a highly nutritious food. The table below illustrates the exact nutritional value and how it contributes to the diet (New Zealand Food Composition Database, 2022). The data is based on a single medium egg and all values relate to the edible contents of the egg, excluding the shell.

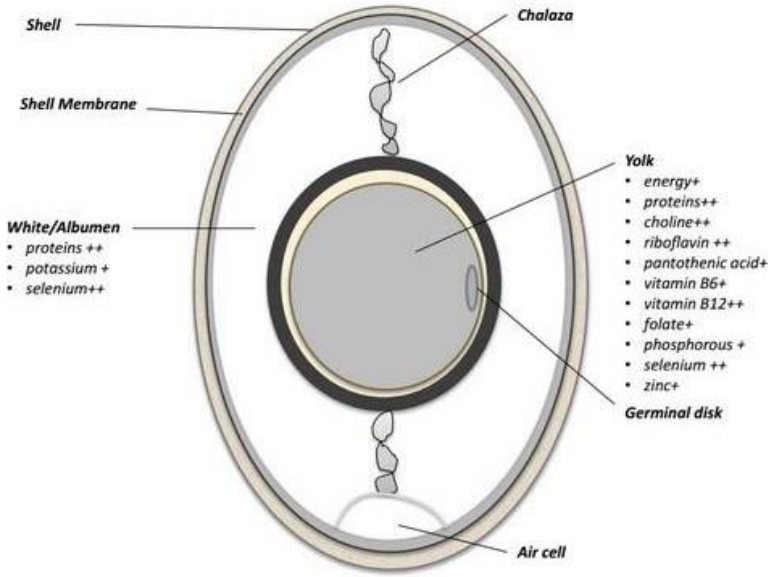

Figure 1 **Illustration of the components of a chicken egg.** The nutrient contents of a whole large egg (60 g) are shown and are indicated by ++ if present at 50% or higher of the adequate intake (AI) or recommended dietary allowance (RDA) level for healthy, breastfed children 7–12 months of age and by + if present at 20–50% of the AI/RDA for healthy, breastfed children 7–12 months of age.[5]

Eggs contain almost all key nutrients, except for vitamin C (Table 1). Eggs are a source of all B vitamins, in particular vitamins B12, riboflavin and folate. They also are a source of fat- soluble vitamins A and D as well as some vitamin E. Eggs are an important source of high quality and easily digestible protein, due to the amino acid profile of eggs.

Table 1. Composition of Eggs

Nutrient	Unit	Quantity per egg (Size 6, 57g)[1]	%DI per serve[2]	Quantity per 100 g
Energy, FSANZ	kJ	268	3%	470.18
Protein	g	6.28	10%	11.02
Fat, total	g	4.28	6%	7.51
Fat, saturated (SFA)	g	1.3	6%	2.28
Monounsaturated Fat (g)	g	2.01	N/A	3.53
Polyunsaturated Fat (g)	g	0.72	N/A	1.26
Fatty acids, total polyunsaturated omega-3 (ALA[3])	g	0.025	N/A	0.04
Fatty acids, total polyunsaturated omega-6	g	0.563	N/A	0.99
Cholesterol (mg)	mg	177	N/A	310.53
Carbohydrate	g	0.15	N/A	0.26
Sugars, total	g	0.15	N/A	0.26
Dietary fibre	g	0	N/A	0.00
Sodium	mg	72	4%	126.32
Folate	µg	49	12%	85.96
Niacin equivalents	mg	1.3	8%	2.28
Riboflavin	mg	0.21	16%	0.37
Thiamin	mg	0.029	2%	0.05
Vitamin B12	µg	1.4	58%	2.46
Vitamin B6	mg	0.034	2%	0.06
Vitamin C	mg	0	0%	0.00
Vitamin A, retinol equivalents	µg	45	5%	78.95
Vitamin D; calculated by summation	µg	0.62	12%	1.09
Vitamin E, alpha-tocopherol equivalents	mg	0.95	10%	1.67

[1]Source: The Concise New Zealand Food Composition Tables, 14th Edition. G1016 Egg, chicken, whole, raw, fresh
[2]Source: Nutrient Reference Values Australia and New Zealand. RDI based on 19–50-year-old Male, 9,300 kJ day.
[3]Alpha-lonoleic acid (ALA)

EGGS AND CHOLESTEROL

NZ intake of dietary cholesterol, saturated fat and trans fat
Eggs are a high cholesterol food, with each egg containing 186 mg. For context, when cholesterol guidelines were in place the AHA (Kritchevsky, 2004) and Dietary Guidelines for Americans (DGA) recommend limiting dietary cholesterol intake to <300mg/day. However, in contrast to other cholesterol containing foods such as red meat and poultry, eggs have a relatively low saturated fat content (New Zealand Food Composition Database, 2022).

According to the 2008/09 Adult Nutrition Survey, the predominant source of dietary cholesterol in the NZ diet is foods of animal origin including meat, eggs, and dairy products. Of those sources, eggs and egg dishes contribute the largest proportion at 13% of the cholesterol in the in NZ adult's diet. Males aged 51 – 70 and females aged 19 – 30 and 71+ had the highest percentage of their cholesterol intake from eggs and egg dishes with 15.7%, 15.8% and 16.0% respectively (University of

Otago and & Ministry of Health, 2011).

Cholesterol intakes were evaluated as part of the NZ Adult Nutrition Survey 2008/2009.

- The usual median daily cholesterol intake for the total adult population was 262mg
- Adult males had a higher median daily cholesterol intake of 316mg
- Adult females' median daily cholesterol intake was 216mg
- The median cholesterol intake per day increased in the Māori population with 410mg for males and 262mg for females
- The Pacific population results were 363mg median daily intake for males and 262mg for females

It is also important to understand New Zealanders' intake of saturated and trans-fat, as these two fats, compared to dietary cholesterol increase serum LDL cholesterol to a greater degree and thus have a more profound impact on CVD risk. Nutrient Reference Values state that saturated and trans fats together should be limited to no more than 10% of energy (Australian Government & NHMRC, n.d.-b), and the WHO recommends that trans-fat should be limited to no more than 1% of total energy (WHO, 2010). New Zealanders consume 15% of dietary energy as saturated fat, thus exceeding the recommended limit (University of Otago and & Ministry of Health, 2011). On a positive note, monitoring of trans-fatty acids in the food supply showed that New Zealanders get only 0.6% of their daily energy intake from trans-fat (Lake et al., 2006) and the level of trans fat in the food supply has continued to decline over the years (Food Standards Australia New Zealand, 2017).

Note that as no other Nutrition Survey has been conducted to date, the statistics presented here regarding cholesterol and saturated are more than ten years old, and thus current intakes might differ. This suggests that an up-to-date survey is warranted.

Serum cholesterol levels

Elevated cholesterol levels in the NZ population remain a concern. According to the 2020/21 NZ Health Survey update 10.3% of the NZ adult population (15 years upwards) had high cholesterol and were on medication. This result is raised significantly in the older adult age group (75 years and older), whereby 28.8% are medicated for high cholesterol (Ministry of Health, 2021).

Relationship between dietary cholesterol and serum cholesterol

It is well documented that high blood cholesterol levels, particularly high LDL cholesterol levels, are a key risk factor for the development of heart disease (Shin et al., 2013). The main concern was that dietary cholesterol found in eggs increase serum cholesterol thus increasing potential CVD risk. Previous nutrition guidelines from the NZHF recommended limiting to no more than three eggs per day if you are at high risk of CVD (Heart Foundation NZ, 2016a) and the AHA previously advised that people with CVD should consume <200mg cholesterol/day and that healthy individuals consume <300 mg cholesterol/day (Krauss et al., 2000).

These intake recommendations have been challenged by research investigating the effects of both dietary cholesterol and egg consumption on serum cholesterol. Research demonstrating the effect dietary cholesterol has on blood cholesterol is inconsistent and limited, ranging from positive associations to no effect at all (Shin et al., 2013). Even with studies demonstrating a positive association of dietary cholesterol with serum LDL- cholesterol, there is a large variability in an individual's response to dietary cholesterol (Djoussé & Gaziano, 2008b), and, they are challenged by the many years of epidemiological research reporting dietary cholesterol has no clinical significant impact on CVD risk (Lee & Griffin, 2006; McNamara, 2002). This shift has been reflected in health authorities easing their recommendations around eggs, with most now suggesting six-seven eggs per

week for those at increased risk of CVD, and no explicit limitation for healthy individuals.

Cohort data demonstrates no strong association between egg consumption and CVD risk. Dawber et al in 1982 utilized the Framingham cohort to further investigate specifically the effects of egg intake on serum cholesterol. 912 males and females were examined, and their diet histories evaluated. This review revealed a lack of association between egg consumption and serum cholesterol levels. This was further demonstrated by the fact that men in the highest third of egg intake had identical cholesterol levels (6.08mmol/L) to the men in the lowest third of intake level. In addition, women with the lowest intake of eggs had slightly higher cholesterol levels than those with a higher intake of eggs, 6.34mmol/L compared to 6.26mmol/L (Dawber et al., 1982). Cohort data however cannot demonstrate cause and effect.

Observational studies, such as cohort studies are influenced by confounding dietary factors, such as saturated fat-containing foods which are commonly consumed alongside eggs (e.g., bacon, butter) or the fact that many cholesterol containing foods are also high in saturated fat. Randomized controlled trials (RCTs), on the other hand, allow us to better isolate the impact of dietary cholesterol. Several RCTs have investigated the impact of adding cholesterol to the diet, majority using egg as the source of dietary cholesterol given its high cholesterol, yet relatively low saturated fat content. A meta-analysis by Griffin & Lichtenstein (2013) of such RCTs showed that within the context of current levels of dietary cholesterol, dietary cholesterol intake produces only modest increases/effects on serum lipid levels (Griffin & Lichtenstein, 2013), especially when compared to the impact that saturated fat and trans fatty acids have on raising LDL-c. Furthermore, dietary cholesterol impacts on serum cholesterol levels are seen in mostly population sub-groups (Lee & Griffin, 2006). Dietary cholesterol increases both LDL and high density lipoprotein (HDL) cholesterol in the plasma thereby having little impact on the LDL: HDL ratio which is a significant indicator of heart disease (McNamara, 2002).

Clinical interventions have reported an increase in cholesterol intake results in an increase in both LDL and HDL cholesterol in those subjects that respond to dietary cholesterol challenges. In addition, there are examples in which dietary cholesterol resulted in an increase in HDL cholesterol only, with no effect on LDL cholesterol observed alongside certain conditions such as weight loss interventions and other factors (Kanter et al., 2012).

A 2001 meta-analysis examining the impact of eggs or dietary cholesterol on serum cholesterol levels indicated an increase of 100mg cholesterol per day increases serum cholesterol by 0.06mmol/L (LDL serum cholesterol by 0.05mmol/L and HDL cholesterol by 0.01mmol/L) (Weggemans et al., 2001). However, subsequent studies have emphasized the importance of taking into the account the background diet. A 100mg increase in dietary cholesterol, alongside a background diet high in saturated fat produced a larger increase in serum LDL cholesterol of 0.061 +/- 0.006mmol/L increase and an increase of only 0.036 +/- 0.004mmol/L with a diet low in saturated fat (Mcnamara, 2002; National Institute of Health, 2002). In addition, it is now recognized we must view dietary effects on serum cholesterol from its impact on the atherogenic LDL cholesterol as well as the anti- atherogenic HDL cholesterol. As already mentioned, it is the ratio of LDL: HDL that is significant to the risk of CVD, and on average the ratio change per 100mg/day increase in dietary cholesterol is from 2.60 to 2.61 which is predicted to have little impact on CVD risk (McNamara, 2002).

There have been further randomized controlled trials (RCT) continuing to demonstrate the lack of significant impact egg intake has on serum cholesterol. An RCT by Katz et al (2005), demonstrated no effect on total serum cholesterol and endothelial function in healthy adults with the addition of two eggs daily to the diet over a six-week period. Goodrow et al RCT in 2006, studied 33 men and women older than 60 years of age. They demonstrated the consumption of one egg per day over a five

week period causes no effect on total, LDL and HDL serum cholesterol levels (Goodrow et al., 2006). Wenzel et al in a study of 24 women aged between 24 – 59 years showed neither mean total serum cholesterol nor total cholesterol (TC): HDL significantly increased following the consumption of six eggs per week over a 12-week period (Wenzel et al., 2006). In a more recent 2012 study, Klangjareonchai et al concluded that in hyperlipidemic adults being treated with lipid-lowering medication, the addition of 3 eggs per day to their regular diet increases the HDL cholesterol but decreases the LDL: HDL ratio (Klangjareonchai et al., 2012).

There are several studies that have demonstrated positive effects on lipid profiles with increased egg consumption alongside other dietary modifications. Mutungi studied 28 overweight/obese males aged 40 – 70 years to examine how egg intake affects serum cholesterol levels within a carbohydrate restricted diet (CRD). Even with the addition of three eggs per day (640mg additional dietary cholesterol per day), there was no change to serum LDL cholesterol and LDL: HDL ratio. However, the HDL serum cholesterol increased (Mutungi et al., 2008). Blesso et al conducted similar studies in adults with metabolic syndrome. The addition of three eggs per day alongside a CRD over a 12-week intervention period compared to egg substitute consumption, lead to improved lipid profiles including increased HDL serum cholesterol (Blesso, Andersen, Barona, et al., 2013). The encouraging results, however, should be treated with caution as they were likely influenced by the background of a CRD.

Subgroup analysis of studies have found that some individuals experience above average increases in serum cholesterol (up to three-fold difference) in response to dietary cholesterol (Heart Foundation NZ, 2016a). They are known as hyper-responders. Until a quick and reliable method for determining hyper-responders is developed, the presence of hyper and hypo-responders will likely continue to result in study outcomes inconsistencies (Griffin & Lichtenstein, 2013; National Heart Foundation of Australia, 2019b). In terms of clinical recommendations, the NZHF recommends that advice for hyper-responders should be based on individual response to egg intake (Heart Foundation NZ, 2016a) and it would appear advisable that they are vigilant about their dietary cholesterol intake.

A more recent meta-regression of 55 RCTs by Vincent et al. (2019), which controlled for dietary fatty acids, found a positive dose-related associated between changes in dietary cholesterol and serum LDL cholesterol along with HDL cholesterol and the LDL to HDL cholesterol ratio. Triglycerides did not increase. The clinical implications of HDL-cholesterol changes associated with dietary cholesterol remain uncertain (Vincent et al., 2019). However, when the AHF conducted another meta-regression of 11 studies in their science advisory, they did not find a significant association between dietary cholesterol and LDL cholesterol nor HDL cholesterol, although the latter was close to significance (0.064), thus like the meta-regression by Vincent et al. (2019) again points towards a connection between dietary cholesterol and HDL cholesterol.

Although there are inconsistencies across the literature, the weight of the evidence suggests eggs can increase LDL cholesterol (Lee & Griffin, 2006) (Weggemans et al., 2001) (Vincent et al., 2019). However, this increase is relatively small and unlikely to be clinically meaningful for most of the population. Some studies show that dietary cholesterol increases the LDL:HDL ratio, however other studies show no or minimal effect with increases observed in HDL cholesterol alongside other dietary modifications (e.g., calorie restriction). Nevertheless, responses to dietary cholesterol are highly variable between individuals, with hyper-responders existing in the population. For these individuals, it would be advisable to be mindful to dietary cholesterol but focus primarily on reducing saturated. Studies consistently show intake of these two fats has more impact on serum cholesterol levels, which is in line with dietary recommendations from leading heart associations around the world.

EGGS AND CARDIOVASCULAR DISEASE

While rates of CVD, including heart, stroke and blood vessel disease have steadily declined over past decade, CVD still a leading cause of death in NZ, responsible for a close to a third of deaths each year (Ministry of Health NZ, 2019).

Increased egg consumption was previously thought to be associated with a higher risk of CVD. As already discussed, this was due to the high amount of cholesterol found in eggs. The strength of evidence available was based on demonstrating a high serum cholesterol level is a key risk factor for the onset of CVD(Lee & Griffin, 2006). But an important question to examine is the direct link of dietary cholesterol to increased CVD risk.

As eggs are considered the richest source of dietary cholesterol in the western diet, with a medium egg containing approximately 200mg cholesterol, they have been commonly chosen as a vehicle of choice to deliver the dietary cholesterol required for human intervention studies, and a marker of dietary cholesterol in prospective cohort studies (Lee & Griffin, 2006). Being low in saturated fat, (which has a stronger effect on raising serum cholesterol), they minimize the confounding effect this nutrient has on CVD risk in intervention trials.

There are several RCT's that have challenged the impact of dietary cholesterol and egg consumption on serum cholesterol levels, and decades of reputable research, despite some controversy, points toward a neutral relationship between egg consumption and CVD risk (National Heart Foundation of Australia, 2019b). However, to date there is no RCT data on the direct link of egg consumption and increased CVD risk, but a growing number of prospective studies (Dawber et al., 1982), (Djoussé & Gaziano, 2008b), (Hu et al., 1999), (Zazpe et al., 2011),(Qureshi et al., 2004) and meta-analysis (Rong et al., 2013).

One of the first of these prospective studies was carried out by Hu et al who did so in response to the lack of epidemiologic studies on egg consumption and increased risk of CVD. Two cohorts were examined – the Health Professionals Follow-up Study (1986 – 1994) and the Nurses' Health Study (1980 – 1994). This included a total of 37,851 men aged 40 – 75 years and 80,082 aged 34 – 59 years, who were CVD, diabetes, hypercholesterolemia, and cancer free. Detailed food frequency questionnaires from both large cohorts were examined to determine egg consumption and adjustments were made for many dietary and lifestyle factors such as smoking, dietary fibre intake and bacon consumption. Data concluded that the inclusion of up to one egg per day in the diet is unlikely to have a substantial effect of the risk of CVD among healthy men and women. Hu et al discussed the equation devised by Keys and Parlin, which, based on the cholesterol intake from an egg of 200mg (with a 7560kJ background diet), results in 4% increase in total serum cholesterol for a normocholesterolemic person. Assuming an increased cholesterol level is the only effect of the egg consumption, this would lead to an 8% increase in CVD risk which is considered too small an effect to be detected in most epidemiologic studies or clinical trials (Hu et al., 1999). One important factor in Hu et al's study was the sheer size made it large enough to examine a variation of background diets, including low dietary cholesterol intake from non-egg sources. This is important as we want to investigate the fact total cholesterol intake may not be different for egg and non-egg eaters due to other dietary sources in their background diet (Kritchevsky & Kritchevsky, 2000).

Zazpe et al investigated the association between egg consumption and the incidence of CVD, utilizing a prospective dynamic free-living Mediterranean cohort consisting of 14,185 university graduates. This observation study concluded the data they collected suggested higher intake of eggs was not associated with increased CVD incidence (Hazard ratio 1.10, 95% confidence interval: 0.46 – 2.63). Adjustments were made for age, sex, total energy intake, adherence to Mediterranean dietary patterns and other cardiovascular risk factors (Zazpe et al., 2011). Zazpe et al, proposed several

mechanisms that could explain the lack of association between egg consumption and increased CVD risk. For example, genes play an important role in regulating cholesterol intake (Lee & Griffin, 2006; McNamara, 2002), (Herron & Fernandez, 2004) although there are some population sub groups such as people with diabetes who may benefit from a low cholesterol intake due to abnormalities in the way cholesterol is transported (Hu et al., 1999), (Qureshi et al., 2004). In addition, it is not only dietary cholesterol from eggs that could affect CVD risk, but the total cholesterol intake from the entire dietary pattern (Herron & Fernandez, 2004) and finally the egg nutrient composition could be protective, being a good source of unsaturated fats and lower saturated than many other protein foods (Herron & Fernandez, 2004).

Djousse and Gaziano in 2008 examined the association between egg consumption and risk of CVD mortality by reviewing the large cohort of 21,327 male participants from the Physicians Health Study. The conclusions were mixed, with consumption of ≤6 eggs per week having no major effect on CVD risk and mortality, whereas the consumption of more than seven eggs per week is associated with a moderately greater risk of total mortality. Participants with diabetes demonstrated greater risk of all-cause mortality with any egg consumption (Djoussé & Gaziano, 2008b). An additional study Djousse and Gaziano carried the same year also utilized the Physicians Health Study cohort, however looked specifically at risk of heart failure in relation to egg consumption (Djoussé & Gaziano, 2008a). This study also had mixed results, with again no associated risks of heart failure of up to six eggs per week, however 7 eggs per week was associated with increased heart failure risk. Adjustments were made for age, body mass index, smoking, alcohol consumption, exercise and history of atrial fibrillation, hypertension, valvular heart disease and hypercholesterolemia. Conclusions drawn from this study are that infrequent egg consumption would not lead to an increase risk of heart failure, however the consumption of ≥1 per day has shown to increase risk of heart failure amongst male physicians in the US (Djoussé & Gaziano, 2008a).

One prospective study examined the association between egg consumption, total cholesterol concentration and the increased risk of CVD, in a population group with high egg consumption. Nakamura et al. (2006) studied the Japan Public Health Center-based prospective study cohort including a total of 90,735 participants (19,856 men and 21,408 women aged 40 – 59 years in cohort 1 and 23,463 men and 26,008 women aged 40 – 69 years in cohort 2). In this study, men and women were combined for the analyses. Four different egg intake groups were examined. It was concluded an intake of eggs almost daily was not associated with any increase in heart disease incidence. In addition, an inverse correlation was found between egg consumption and the occurrence of hypercholesterolemia in both sexes and in both cohorts, most likely due to the fact hypercholesterolaemic participants would avoid eggs due to the cholesterol content (Nakamura et al., 2006).

These conclusions differed slightly from the earlier research carried out by Nakamura et al in 2004. utilizing the NIPPON DATA80 database, which followed a total of 5186 women and 4077 men over a 14 year period, Nakamura et al analyzed the link between egg consumption, serum cholesterol and cause-specific and all-cause mortality (Nakamura et al., 2004). In this study the subjects were categorized into 5 egg consumption groups based off their response to a questionnaire – seldom, 1-2 eggs/week, 1 egg/day, 1-2eggs/day, and ≥2 egg/day. Results showed that among women, there was a tendency for lower mortality due to stroke, ischemic heart disease and cancer in the 1-2 eggs/week group compared to the 1 egg/day group, which may have led to significantly fewer all-cause deaths. This was not seen in any of the men groups. Nakamura et al. (2004) concluded that it's possible that limiting egg consumption can have some health benefits, particularly with women in geographic areas where egg consumption contributes significantly to the total dietary cholesterol intake.

A recent meta-analysis by Rong et al in 2013 investigated and quantified the potential dose-

response association between egg consumption and coronary heart disease and stroke risk (Rong et al., 2013). This meta-analysis reviewed specifically prospective cohort studies, 8 articles and 17 reports in total were eligible. One of the strengths of this meta-analysis was the large sample size and long follow-up periods, which increased the statistical significance and ability to identify possible associations. The results from this meta-analysis demonstrate that higher egg consumption is not associated with increased risk of coronary heart disease and stroke. There is a suggestion in subgroup analyses of a potential positive association between increased egg consumption and risk of coronary heart disease in people with diabetes. It is suggested in the meta-analysis that further research is warranted to confirm the subgroup results, but with larger sample sizes and longer follow-up times (Rong et al., 2013).

The latest science advisory report from the AHA (Carson et al., 2020), concluded that the 17 cohort studies they analyzed, did not support an association between dietary cholesterol and CVD risk. Positive associations typically occurred in when other dietary components such as dietary fat, fibre and energy intake were not adjusted for. Three cohort studies in the AHA's science advisory reported that consumption of >1 egg per day was associated with 20% to 30% higher risk of heart failure compared with infrequent egg intake (Carson et al., 2020). The NZHF and the AHF both also discussed the association between frequent egg consumption and heart failure (Heart Foundation NZ, 2016a; National Heart Foundation of Australia, 2019b) and has led to recommendations that at increased risk of heart disease and those who require LDL-cholesterol lowering interventions consume a maximum of six to seven eggs a week.

Although there is some evidence available showing a positive association between increased egg consumption and CVD risk (Djoussé & Gaziano, 2008a), (Nakamura et al., 2004), the majority of studies reviewed demonstrate the strength of evidence against a relationship between egg consumption and increased CVD risk. An association, however, was observed between frequent egg consumption and increased risk of CVD in individuals with type 2 diabetes (discussed in the following section) and the increased risk of heart failure. There have been numerous hypotheses developed over the years as to why this relationship is not considered clinically significant. It is possibly due to the many other nutrients contained in eggs, which will be discussed further on in the review. In particular, foods rich in dietary cholesterol are most likely also high in saturated fat and trans fatty acids. Therefore the resulting increase in serum cholesterol from these foods is most likely due to the link between saturated fat and trans-fat and increased serum cholesterol levels and CVD risk, which is supported by a wealth of evidence (McNamara, 2002). Eggs in contrast, have a lower saturated fat level relative to other common animal based protein foods for example chicken drumstick legs or sirloin steak, and are good sources of poly and mono unsaturated fats (New Zealand Food Composition Database, 2022).

EGG AND TYPE 2 DIABETES

Diabetes Mellitus (commonly called diabetes) is a disease that continues to be a serious public health problem affecting many New Zealanders. It is estimated that over 270,000 New Zealanders suffer from diabetes mellitus (Ministry of Health NZ, 2021). Type 2 diabetes in particular is associated with many CVD risk factors such as high blood pressure and dyslipidemia (Diabetes New Zealand, n.d.).

Eggs and increased risk of CVD in people living with type 2 diabetes

Studies researching the association between egg consumption and diabetes are limited. Several prospective studies, utilizing epidemiological data have researched the association between egg consumption and increased CVD risk and stroke. They established that increased egg consumption increased the risk of CVD and stroke in study participants with diabetes and concluded increased egg consumption and its effects among people with diabetes warrants further investigation (Djoussé &

Gaziano, 2008b), (Hu et al., 1999; Qureshi et al., 2004). While no mechanism has been confirmed for the association between egg consumption and increased CVD risk for type 2 diabetics, it has been proposed that type 2 diabetics experience molecular and genetic changes that increase intestinal cholesterol absorption (Eckel, 2015).

One such study was Hu et al's prospective study utilizing two large prospective cohort studies of men and women, the Health Professionals Follow-up study, and the Nurse's Health study. The study aimed to look further into any possible positive associations between 12 additional subgroups, including those with diabetes. The diabetes subgroup was the only one of the 12 to show any evidence of a positive association with higher egg consumption (Hu et al., 1999). This association was again demonstrated in Qureshi et al's prospective study of data from the First National Health and Nutrition Examination Survey (NHANES-I), a prospective cohort of 9734 adults aged between 25 – 74 years. In their subgroup analysis, higher egg consumption was observed to be associated with increased risk of coronary artery disease and myocardial infarction among participants with diabetes (Qureshi et al., 2004).

Djousse and Gaziano's prospective study on the cohort from the Physicians' Health Study, also noted a stronger association between increased egg consumption and cardiovascular mortality within the diabetic subjects in the study population. Through stratified analysis of prevalent diabetes at baseline, it was shown physicians with diabetes, who consumed ≥7 eggs per week compared to <one egg per week had a two times greater risk of all-cause mortality. In addition, the data also suggested a greater risk of myocardial infarction amongst male physicians with diabetes (Djoussé & Gaziano, 2008b).

Three meta-analyses (Rong et al., 2013; Shin et al., 2013) reviewed in AHF's summary of evidence, found a link between increased risk of CVD for people living with type 2 diabetes consuming more than 7 eggs/week (National Heart Foundation of Australia, 2019b), which align with the findings above. A forth meta-analysis by Tran et al., (2014) did comment on the limitations of the body of research in this area, which include that they majority of studies are epidemiological in nature, and most fail to adjust for confounders. They also discussed inconsistencies in how outcomes were defined (some studies defined the outcome as CVD, others defined the outcomes as stroke, heart disease, or CVD mortality), however the study by Tran et al., (2014) itself was partly funded by industry.

Eggs and increased type 2 diabetes risk

More recent research, including controlled trials and prospective studies have studied the effect of egg consumption directly on increased risk of diabetes. Most of these studies came to corresponding conclusions that increased egg consumption led to increased risk of diabetes.

The prospective study by Djousse et al in 2008, collected data from two completed randomized trials, 20,703 men from the Physicians' Health Study I and 36,295 women from the Women's Health Study. There was an observed increase in risk of type 2 diabetes of 58% in men and 77% in women with consumption of one or more eggs per day, compared to no egg consumption. This raised concerns of the possibility of undesirable health effects from high egg intakes (Djoussé et al., 2009). The prospective study carried out by Shi et al researched a Chinese population of 2849 adults aged 20 years and older. The results demonstrated after the adjustment of many factors including age and family history of diabetes, that the consumption ≥1 egg per day was positively associated with diabetes risk, particularly in women (Shi et al., 2011).

Radzeviciene et al carried out a case-controlled study to determine whether or not there is an association between egg consumption and the risk of type 2 diabetes. The results demonstrated twice the risk of type 2 diabetes for individual's consuming 3 – 4.9 eggs per week, and three times

the risk of type 2 diabetes with those consuming ≥5 eggs per week, compared to those consuming <one egg per week (Radzeviciene & Ostrauskas, 2012).

One exception to the studies that have supported an association between egg consumption and increased risk of diabetes is a prospective study by Djousse et al in 2010. The objectives of this study were to assess the association between egg intake and incidence of diabetes in older adults. It utilized a prospective study of 3898 men and women from the Cardiovascular Health Study. Egg consumption was assessed via a picture-sorted food questionnaire and adjusted relative risks estimated. The conclusions of this study were in a cohort of older adults with limited egg intake, there is no association between egg intake and increased risk of type 2 diabetes (Djoussé et al., 2010). One possible reason for the difference in results compared to the majority of research available could be due to a limitation in the study that high intakes of eggs could not be specifically evaluated as few people in this cohort consumed such amounts. Therefore, the fact there was no effect on diabetes risk could be due to the limited number of eggs the participants consumed.

While there are several limitations to the research, epidemiological studies, have shown a link between increased between increased egg consumption (>1 egg a/day) and type 2 diabetes. As indicated in majority of the studies reviewed, further research would be beneficial, in particular more clinical research. The latest guidelines for type 2 diabetics recommend a maximum of seven eggs a week, according to the AHF (National Heart Foundation of Australia, 2019a), whereas the NZHF recommends a maximum of six (Heart Foundation NZ, 2016a). In addition, the intake guideline of six eggs a week is also confirmed by Diabetes NZ (Auckland) as their recommendation to diabetic patients (T. Cleary [Diabetes NZ], personal communication, 19th August 2014).

EGGS AND WEIGHT MANAGEMENT

When addressing weight management, satiety is an important tool. The macronutrient dietary protein has been identified with a positive association to satiety (Astrup, 2005; Paddon-Jones et al., 2008; Weigle et al., 2005). As eggs are a rich source of high-quality protein and are also low in energy, contributing only 7% of an individual's daily energy requirements, they therefore have a two-fold benefit as a food choice for weight management. Holt et al developed a satiety index reported in the European Journal of Clinical Nutrition which ranked many popular foods in how they compared to a slice of white bread which carried a rank of 100 (Holt et al., 2001). Eggs were shown to have a satiety index 50% greater than other ready to eat breakfast cereals as well as white bread (Petocz, 1995). Holt et al also demonstrated that eggs have an overall higher satiety index value than popular breakfast foods in non-obese subjects (Holt et al., 2001).

Due to their nutritional composition, research has emerged over the past few years establishing eggs as an effective food choice in weight management. Vander Wal et al first studied the benefit of an egg breakfast in comparison to an isocaloric, equal weight bagel-based breakfast. Their hypothesis was the egg breakfast would produce greater satiety and reduce both perceived cravings as well as subsequent energy intake. Thirty women participated, between the ages of 25 – 60 years with a BMI of at least 25 kg/m2. Participants consumed either an egg or bagel-based breakfast. They would then consume lunch 3.5 hours later. Conclusions from this study demonstrated that the egg based breakfast lead to greater satiety, and energy intake remaining lower for the entire day ($p<0.05$) and the next 36 hours ($p<0.001$)(J. S. Vander Wal et al., 2005). Vander Wal et al's second study established an egg breakfast, again compared to an isocaloric bagel-based breakfast, does enhance weight loss when combined with an energy reduced diet in overweight and obese participants. In this study, otherwise healthy overweight or obese individuals were divided into four groups, an egg and egg diet group, as well as bagel and bagel diet group. The two diet groups were recommended a 1000 kcal energy deficit low fat diet, with the remaining two groups remaining free living (J. S. V. Wal et al., 2008).

Another study researched the hypothesis eating eggs for breakfast would significantly increase subsequent satiety and energy intake for the remainder of the day. In this crossover trial, 21 men aged 20 – 70 years consumed two isocaloric test breakfasts, either egg or bagel based, in a random order separated by a week. Participants then consumed a buffet lunch until satisfied, 180 minutes after breakfast. Visual Analog Scales (VAS), food intake surveys and blood tests were completed. Results concluded that fewer calories are consumed following an egg breakfast compared to the bagel breakfast ($p<0.01$). The VAS established that participants were hungrier and less satisfied 3 hours post bagel breakfast in comparison to egg breakfast ($p<0.01$) (Ratliff et al., 2010). Pombo-Rodrigues et al (2011) carried out similar research, comparing an egg based lunch with other meals in a randomized, three-way crossover study. Thirty-one male and female participants consumed one of the following isocaloric lunches - omelette, jacket potato or chicken sandwich. VAS was used to record satiety, and the energy intake from the following meal was recorded. The egg-based lunch demonstrated increased satiety, particularly compared the jacket potato, however no effect was seen on the subsequent energy intake. Conclusions were drawn that an egg based meal increases satiety compared to a carbohydrate based meal and could help towards reducing the amount of energy consumed between meals (Pombo-Rodrigues et al., 2011).

Finally, a three-way, crossover design study carried out by Fallaize et al (2013) reached the same conclusion of egg based meals increasing satiety and reducing hunger. Thirty men consumed either eggs on toast, cornflakes with milk and toast or a croissant and orange juice, on three separate occasions, separated by one week. Feelings of satiety, hunger, fullness, and desire to eat were rated and recorded at 30-minute intervals utilizing VAS and energy intake at subsequent meals were assessed. Results again demonstrated increased satiety, less hunger, and a lower desire to eat after the egg-based breakfast was consumed, compared to the cornflake breakfast ($p<0.02$), and croissant breakfast ($p<0.0001$). The egg breakfast also leads to significantly less energy intake at subsequent meals. It was noted the breakfast having the most effect on satiety and subsequent energy intake had the highest protein and lowest carbohydrate content compared to the alternative breakfasts (Fallaize et al., 2013).

Further research is warranted on the benefits of eggs as a food choice for weight management. There is still a lack of evidence on the effects eggs have on satiety for long term weight loss and on the role of eggs within the totality of a meal i.e. do they work synergistically or separately to other foods such as bread, and there is a need for further understanding of gastric emptying after an egg based meal and relationship with gut hormones (Layman & Rodriguez, 2009). However, the research that has taken place to date, gives evidence to suggest confidently egg intake should be encouraged during weight loss or management due to its positive effect on satiety and subsequent energy intake. This could be due to the high protein content of eggs, and potentially also due to the specific amino acid composition and digestibility of eggs, as when compared to other protein based foods such as chicken, the satiety effects favored egg based meals (Layman & Rodriguez, 2009; Pombo-Rodrigues et al., 2011).

EGGS AND CHOLINE

Choline is found in a wide variety of foods both plant-based sources and animal-based sources. This includes foods such as soy, wheat germ, broccoli, almonds as well as eggs, meat and milk (Iannotti et al., 2014). Through research it has been shown to have many benefits for various diseases and health conditions, such as neurodevelopment, cognitive function, neural tube defect incidence (Shaw et al., 2004, 2009), CVD, through association with decreased plasma levels of homocysteine and inflammatory factors (Detopoulou et al., 2008), breast cancer (Xu et al., 2009) and has a role in the epigenetic changes via the methylation of DNA (McNamara, 2014).

In 1998 the United States of America (USA) Institute of Medicine (IOM) added choline to the list of

required nutrients and developed Adequate Intakes (AI) for both females and males in a range of age groups (Institute of Medicine, 1998). Adult females 19+ years required 425mg/day, with adult males requiring 550mg/day. Pregnant and lactating women have high AI at 450mg and 550mg respectively (Zeisel & Da Costa, 2009). Data for dietary intakes of choline had been limited, but in the USA has been shown to be inadequate in most adult's diets (Yonemori et al., 2013). Data has been unavailable in NZ. However, in 2013 Mygind et al (2013) utilized the baseline dietary data collection for a folate intervention trial that took place in NZ between July 2008 and May 2009. The objective of this study was to estimate the usual intake and food sources of choline and betaine (metabolite for choline) in NZ women of reproductive age. The study collected data for dietary intake which consisted of a 3-day weighed food record, from a sample of 125 women aged between 18 – 40 years. Women were excluded if they were pregnant, lactating or were planning to be pregnant in the coming 12 months.

Usual choline and betaine intake distributions were then determined. Results showed that the mean total dietary intake for choline was 315mg and daily energy intake was 1843 kilocalories, with 16% of the participants meeting or exceeding the estimated AI for adult women. Eggs were found to be the top contributor to choline intake, providing 13% of the total choline intake in the women's diets. Other top food contributors were red meat at 10%, milk at 8%, and bread at 5.5% and chicken at 4.5% (Mygind et al., 2013).

This study confirms previous reports that suggest choline intakes are suboptimal in a large proportion of the population. It also confirms that eggs are the top contributor to choline intake and a major source of choline, containing 144mg per medium egg and provides more choline per kcal than any other foods (Mygind et al., 2013).

On a seemingly concerning note, research suggests that gut microbes can metabolize choline to trimethylamine-N-oxide (TMAO) production in the gut and subsequently serum TMAO. TMAO has been associated with CVD risk factors such as atherosclerosis or inflammation and oxidation of low-density lipoproteins, however, whether TMAO is simply a marker or whether it plays a role in pathogenesis, is yet to be confirmed. A 2017 RCT which administered 450mg of choline via a supplement to 18 healthy subjects resulted in increased gut microbe-generated levels of TMAO (Zhu et al., 2017). Note that the current AI for men is 550mg/day and women 425/day.

On the other hand, research on choline in food (compared to a supplement) and its impact on TMAO is mixed. Early research by (Zhang et al., 1999) investigated 46 individual foods and found that only fish and other sea-products consumption lead to increases in urinary TMAO levels (Zhang et al., 1999). In contrast research by Miller et al has showed that increased egg consumption (≥2 eggs/day , increased serum TMAO levels (Miller et al., 2014), However this study was preliminary in nature and comprised of only n=6 subjects, which is a significant limitation. A more recent RCT with a larger sample size (n=50) found that daily ingestion for 4 large eggs failed to increase plasma TMAO levels (Wilcox et al., 2021). Overall, given the mixed evidence, more research is required to draw firm conclusions between choline, TMAO and CVD risk.

NZ has now included choline in their RDI/AI charts, with the AI for men at 550mg/day, women 425mg/day, ranging between 415 – 440mg/day for pregnant women and 525 – 550mg/day for women who are lactating (Australian Government & NHMRC, n.d.-a). While research on choline intake in New Zealanders very limited, it suggests low choline intake in the population. Eggs, are a major source of choline, demonstrate the value of including eggs in the diet. Further research is warranted before conclusions are made on TMAO and any potential negative influence it has on CVD risk.

EGGS AND LUTEIN AND ZEAXANTHIN

One of the explanations given by researchers as to why the relationship between egg consumption and increased CVD risk is not as previously supposed seems to be due to the additional nutrients found in eggs. This includes choline discussed above and the antioxidants Lutein and Zeaxanthin.

Lutein and Zeaxanthin are oxygenated carotenoids with antioxidant capabilities that accumulate in the macular region of the retina. These carotenoids have a role in reducing the risk of cataracts and age-related macular degeneration and are possibly protective again some cancers. There is also evidence both experimental and epidemiological, suggesting that lutein and zeaxanthin have a potential role in reducing risk for CVD and stroke (Ribaya-Mercado & Blumberg, 2013).

Eggs are a rich source of lutein and zeaxanthin, they are also found in many vegetables such as spinach, kale, peas, broccoli, onions, and corn.

Table 2. Content of Lutein and Zeaxanthin in Chicken Egg Yolk[1]

	Lutein[2]	Zeaxanthin[2]	Total
μg/yolk	292 ± 117	213 ± 85	505
μg/mg cholesterol	1.19 ± 0.32	0.87 ± 0.23	2.06
μg/100 g yolk	1723 ± 690	1257 ± 502	2980

[1] From Handelman *et al.* [6].

[2] Mean ± SD values.

*Ribaya-Mercado, J.D. & Blumberg, J.B. Lutein and zeaxanthin and their potential roles in disease prevention. Journal of American College of Nutrition **23**, 567S-587S (2004)*

Due to the lipid matrix of egg yolk, lutein and zeaxanthin are more bioavailable from eggs than from plant sources such as spinach (Chung et al., 2004). This was observed by Chung et al in an intervention trial (with crossover design) from 2004. Participants consumed the same total amount of lutein from various sources. The serum lutein levels were highest after the consumption of eggs versus spinach and supplements. This suggests lutein derived from eggs is more bioavailable, even compared to other foods with higher lutein content (Chung et al., 2004).

There are further studies confirming egg consumption will increase serum lutein and zeaxanthin levels. Goodrow et al (2006) investigated the effect of egg consumption on serum concentrations of lutein, zeaxanthin and lipids. The randomized cross-over design trial studied 33 men and women 60 years and above. They consumed one egg per day for five weeks, then no eggs for the following five weeks. There was a significant increase in serum concentrations of lutein and zeaxanthin intervention compared to the no-egg intervention, with the addition of one egg per day increasing lutein and zeaxanthin concentrations by 26% ($p<0.001$) and 38% ($p <0.001$) respectively. This increase took place with no effect on serum lipids and lipoprotein cholesterol concentrations (Goodrow et al., 2006).

The findings of this trial support the findings of Handelman et al (1999). The objective of this trial was to also determine whether supplementation of egg yolk in the diet could increase lutein and zeaxanthin serum concentrations. 1.3 egg yolks per day were supplemented into two different

baseline diets, containing 20% of energy from either beef tallow or corn oil. Results demonstrated that egg yolks are a high bioavailable source of both carotenoids, with an increase in serum lutein and zeaxanthin of 28% ($p < 0.05$) and 142% ($p < 0.001$) respectively in the beef tallow diet and 50% ($p < 0.05$) and 114% ($p < 0.001$) in the corn oil diet. A conclusion from this trial is egg yolks are a beneficial addition to the diet (Handelman et al., 1999).

A trial also confirmed egg yolk as an important source of the two carotenoids lutein and zeaxanthin. It was further observed that egg yolk, due to its high content of these carotenoids, is an important food choice for population groups at higher risk of CVD and type 2 diabetes, due to its positive association to metabolic syndrome (Blesso, Andersen, Barona, et al., 2013). In this study, participants consumed 3 whole eggs per day or an equivalent egg substitute as part of a carbohydrate restricted baseline diet for 12 weeks. During the post intervention period, the egg consuming group had significant increases in serum lutein and zeaxanthin of 21% and 48% respectively, with no significant increases in the egg substitute group (Blesso, Andersen, Bolling, et al., 2013).

Although there is currently no consensus on a daily recommended intake for lutein and zeaxanthin, research that has taken place over the past decade indicates these carotenoids are beneficial for optimal health and have protective role to play in many health conditions and diseases. As eggs are an excellent source of these carotenoids, this is another reason they should be recommended to be a regular inclusion in a healthy diet. However it is noted, that there is research available showing inconsistent results in egg contribution to serum lutein and zeaxanthin concentrations (Surai et al., 2000), therefore, it would be valuable to see further research on this topic.

EGGS AND GUIDELINES FOR RECOMMENDED INTAKES

Dietary recommendations for egg intake over the past decades, have been heavily influenced by the existing guidelines in each country for reducing total fat, saturated fat, cholesterol and increasing polyunsaturated fat intake. If we take the US as an example, in the 1970's the public were advised via dietary guidelines, to avoid foods high in saturated fat and cholesterol, and specifically avoid consumption of eggs. The Inter-Society Commission for Heart Disease Resources stated in 1970 'Ingestion of two eggs a day will seriously hamper dietary programs aimed at reducing serum cholesterol. Consequently, the public should be encouraged to avoid egg yolk consumption'. The AHA also advocated for egg intake restriction, with their 1973 statement 'The association noted that dietary cholesterol be limited to no more than 300mg per day, and recommended that individuals eat no more than 3 egg yolks per week (Lee & Griffin, 2006).

These recommendations were driven by the hypothesis that dietary cholesterol increases heart disease risk, which is based on the observations that dietary cholesterol increases serum cholesterol, and that increased serum cholesterol is a risk factor for heart disease. However, now it is well established that saturated fat and trans-fat have a greater influence in increasing dietary cholesterol. Research specifically studying any direct association between eggs and CVD risk have concluded that there is very little evidence to suggest that eggs, a food rich in dietary cholesterol, but low in saturated fat, will lead to increased risk of CVD (Djoussé & Gaziano, 2008b; Hu et al., 1999; Qureshi et al., 2004; Zazpe et al., 2011).

The lack of evidence demonstrating an association between dietary cholesterol and increased heart disease risk, and the evidence now existing, although limited, concluding increased egg consumption, up to one - two eggs per day does no harm, has driven why most countries now do not recommend restricting cholesterol intake. In particular, dietary guidelines from around

the world have been revised with a more positive view on egg intake.

UK
Leading health organizations in the United Kingdom, National Health Service and the British Heart Foundation, have included eggs as part of a healthy balanced diet and have included no restrictions on the amount of eggs consumed in their dietary recommendations (National Health Service, 2019)(British Heart Foundation, n.d.).

USA
The most recent AHA dietary guidelines (Lichtenstein et al., 2021) revised their recommendations on egg intake, removing any specific restrictions on egg consumption and cholesterol intake instead focusing generally on an overall heart healthy dietary pattern. However, it's interesting to note their latest science advisory does recommend healthy individuals consumer six eggs a week, with more lenient recommendations on those who consume lower amounts of dietary cholesterol (vegetarian diet) and for normocholesterol older individuals who they say can consume two eggs a day within the context of a heart healthy diet pattern (Carson et al., 2020).

Australia
Again, no specific intake recommendations are given for eggs in the Australian Dietary guidelines which were reviewed in 2013, and in fact they state there is no reason eggs cannot be consumed every day as part of a healthy diet (Australian Government, 2013). The AHF's 2019 position statement in 2019 on eggs and cardiovascular health stated that eggs are a food to be included in an overall diet to manage and/or reduce the risk of heart disease, and no specific recommendation made to reduce dietary cholesterol intake for healthy individuals. However, they recommend that those with diabetes or those who require LDL-cholesterol lowering interventions consume a maximum of seven eggs each week alongside a heart healthy diet low in saturated fat, so as to not increase their CVD risk (National Heart Foundation of Australia, 2019a).

NZ
NZ's Food and Nutrition Guidelines for healthy adults, last updated in 2020, applied no limits on egg consumption, and have included eggs as part of an everyday balanced diet (Ministry of Health NZ, 2020). In fact, they list eggs along with legumes, poultry, fish and nuts and seeds as preferable options compared to red meat for which a limit has been placed (500g cooked red meat per week)(Ministry of Health NZ, 2020).

In their 2016 position paper, the NZHF does not recommend restricting egg intake for the general population, but continues to recommend limiting eggs to six per week for people at increased risk of heart disease, including those with type 2 diabetes, for whom eggs may increase CVD risk, and possibly people with heart failure (Heart Foundation NZ, 2016a). They advise hyper-responders to determine that recommendations would be best based on their individual response to egg intake (Heart Foundation NZ, 2016a).

Aside from including people with type 2 diabetes, NZHF did not explicitly define in their position statement nor evidence paper who "individuals who are at an increased risk of heart disease" are. There are many factors from family history, age, smoking status, higher BMI which place an individual at increased risk of heart disease (Ministry of Health NZ, 2018). As the NZHF's approach to CVD risk is to look at combined risk factors, in personal communication (May 16, 2022) they conveyed they "are comfortable that the recommendation of up to 6 eggs a week includes people with diabetes and others who are at an increased risk (whether that is due to their blood pressure/smoking status etc)", keeping in mind the limitations of the evidence base. This in

contrast to AHF's stipulation that those at risk of CVD who require LDL cholesterol lowering intervention follow the recommended limit (National Heart Foundation of Australia, 2019a). Note that the NZHF has a Heart Check Tool which can be used to classify CVD risk (Heart Foundation NZ, n.d.).

Overall
All authorities emphasize the importance of the overall diet, in particular, one that is low in saturated fat (and trans-fat, although the NZ diet is already very low in trans-fat), plant-rich and based on minimally processed foods rather than just focusing on egg intake. The NZHF in their position statement declare that "care should be taken with…the combination of foods often eaten with eggs such as processed meats, like bacon or sausages, refined white bread and/or butter or salt" as these accompanying foods likely play a larger role in increasing risk (Heart Foundation NZ, 2016b, 2016a).

As established, the increased research carried out demonstrating a minimal association between eggs and CVD risk has led to a shift in intake recommendations around the world. As more data becomes available from future controlled trials and interventions, it is predicted that we may see even further shift in recommendation rates for egg consumption in populations.

DISCUSSION

The objective of this position paper is to provide an overview of the research available on eggs, their nutritional benefits and issues related to consumption, in order to form recommendations. A thorough and structured methodology has ensured relevant research to be identified and evaluated to meet this objective.

Public health messaging on eggs, their nutritional credentials and how they fit into the diet has evolved over the past decades. Although an egg is a rich source in many essential nutrients, it is the cholesterol content of the food that has been given the most attention. This is partly due to earlier epidemiological data that demonstrated a weak, positive association between dietary cholesterol and cardiovascular risk, and the fact that eggs are one of the richest sources of dietary cholesterol (Kritchevsky & Kritchevsky, 2000).

As our understanding has progressed on how dietary cholesterol and serum cholesterol relate to our risk of CVD, so too has our understanding of how eggs specifically as a food, can have a positive or negative affect on our diet. Research is now suggesting that although dietary cholesterol can increase the total serum cholesterol, it may not have an impact on cardiovascular risk and mortality. It is suggested in research included in the review, that with foods high in dietary cholesterol that have shown to increase CVD risk, it is actually the saturated fat and trans-fat content commonly found alongside dietary cholesterol in foods, that is actually increasing the risk (Blesso, Andersen, Barona, et al., 2013). This has been supported in the growing number of studies both observational and controlled trials, where the weight of evidence suggests that increased egg consumption has little or no association with increased serum cholesterol levels and increased risk of CVD.

This review also covered additional health benefits of eggs and issues related to increased consumption that have raised concern. Eggs are a highly nutritious food, and alongside the rich source of high quality protein, and over 11 essential vitamins and minerals that eggs contain, research is also showing eggs are a rich source of the nutrient choline (Xu et al., 2009) and that increased consumption of eggs increases the serum concentrations of the two carotenoids Lutein and Zeaxanthin (Goodrow et al., 2006). Choline, Lutein and Zeaxanthin have been shown to have a protective role with many diseases and health conditions such as neural development, cognitive

function, macular degeneration, CVD, and some cancers. It has been suggested that one of the reasons eggs have shown no association with increased CVD risk, despite their high dietary cholesterol content, is the carotenoid content of eggs. The high-quality protein content of eggs has encouraged research on the benefits of eggs for weight management, in particular the influence on satiety. Although findings are positive for the link between egg consumption and increased satiety and resulting weight loss, further research is still warranted to confirm the benefits of eggs as a food choice for long-term weight management.

One disease the literature review has indicated as a potential concern for increased egg consumption is diabetes. Numerous studies looking at the association between increased egg consumption and increased CVD risk, observed that the lack of association was not the case for diabetic participants. Increased egg consumption in diabetic participants, increased CVD risk versus non-diabetics (Djoussé & Gaziano, 2008b; Hu et al., 1999; Qureshi et al., 2004). Studies have also demonstrated a negative association between egg consumption and the risk of diabetes itself. Three observational studies and one case-controlled study were reviewed. Two of the observational studies and the case-controlled study concluded increased egg consumption increased the risk of diabetes (Djoussé et al., 2009; Shi et al., 2011). However, one of the observational studies reviewed concluded there was no association between increased egg consumption and diabetes risk (Djoussé et al., 2010). The difference in results could be explained by one of the limitations of the Djousse et al study, with only limited egg intakes included, due to the data available in the cohort studied. This could suggest that with higher consumptions, similar to that seen in other studies, they may have seen a different result. It is important to note that the AHF have recently updated guidelines on egg consumption for diabetics, and they are recommending up to seven eggs per week can be consumed without any adverse effects on CVD risk, whereas the NZ Heart Foundation recommends a maximum of six. However, it is suggested further case controlled and intervention research is necessary to understand more what it is about increased egg consumption that responds negatively with diabetics and its link to increased CVD.

The more recent research that has taken place on egg consumption has influenced public health messaging on recommendations for egg consumption around the world. Dietary recommendations from the 1960's and 1970's restricted egg intakes, as part of their dietary recommendations for cardiovascular health (Kritchevsky, 2004). However, these have evolved in more recent years with many health organizations reviewing their recommendations for egg intake. The AHA and AHF have reviewed their dietary recommendations for eggs, with the AHA removing any specific restrictions on eggs and cholesterol intake. The AHF only sets limits (7 eggs per week) for type 2 diabetics and individuals who required LDL-cholesterol lowering interventions (National Heart Foundation of Australia, 2019a). The recent the NZ Eating and Activity Guidelines which are targeted toward the general healthy population, do not set any limit on egg consumption (Ministry of Health NZ, 2020). The NZHF does not recommend restricting egg intake for the general population, but continues to recommend limiting eggs to six per week for people with type 2 diabetes, for whom eggs may increase risk, and possibly people with heart failure (Heart Foundation NZ, 2016a).

STRENGTHS AND WEAKNESSES

The review comprised of observational studies from large prospective cohorts, some randomized controlled trials (RCT), meta-analysis and systematic reviews. The main strength of this literature review is the quality of data available. In particular, the observational studies were from extremely large, well-researched cohorts with sample sizes from 912 to 90,735 participants. These large sample sizes increase the authority of a study and the strength of evidence provided from this. The long duration of follow up of these observational studies, significantly increased

the statistical power to detect potential associations.

An additional strength of the observational studies is they considered other influencing factors including, but not limited to high blood pressure and high cholesterol, BMI, age, diabetes, and saturated fat intake. This meant there as a more accurate view on how egg consumption related to specific health issues. Another strength of this review is the amount of RCTs included. In total there were 23 RCTs reviewed which gives the highest level of evidence on egg consumption and possible adverse health outcomes. Lastly, the consistent observations and conclusions made in the observational studies, then supported by the RCTs results is also a strength.

Conversely, there are several limitations identified in this review. Much of our evidence is from observational studies, where the cohorts collected data via food frequency questionnaires, whereby misreporting of intake must be considered and inevitable (Westerterp & Goris, 2002). In addition, the cooking methods used in the consumption of eggs was not always available, which could significantly alter the nutritional composition of the egg meal, depending on the amount of fat and salt used in cooking and the size of the eggs consumed. Another limitation due to the use of observational studies in this review is although the long duration of the following in the cohorts increases the statistical power, it also could mean that participants have an opportunity to change their diets. Lastly, an overall limitation is that the diseases and health conditions we are discussing in this review, such as CVD, diabetes and weight management are incredibly complex and their prevalence and development is highly dependent on a variety of lifestyle and genetic factors, and it would be hard to single out eggs and their effects on these types of diseases. However, this was considered in many of the observational studies where results were stratified against baseline results and various subgroup analyses conducted.

RECOMMENDATIONS

MICRO-LEVEL - DIETARY ADVICE

Due to the strength of evidence now available supporting the nutritional credentials of eggs and demonstrating the lack of association between increased egg consumption and cardiovascular risk, it is recommended that eggs should be considered a healthy food choice as part of balanced diet. As there are currently no restrictions place on egg consumption in otherwise healthy individuals in both the NZ Food and Nutrition Guidelines or by the Heart Foundation, this review of research can support a recommendation of up to one- two eggs per day as part of a heart healthy diet low in saturated fat for individuals not at risk for type 2 diabetes or in need of LDL cholesterol lowering interventions. However, it should be noted that New Zealanders do not typically have a diet low in saturated fat (University of Otago and & Ministry of Health, 2011).

MESO-LEVEL - HEALTHCARE PROFESSIONALS

While the research is limited and inconsistent and observational in nature, the evidence presented in this review suggests healthcare professionals should be utilizing the NZHF's guidance of limiting egg consumption to six eggs a week in individuals with type 2 diabetes and increased risk of CVD. Advice regarding egg consumption for hyper-responders in the population should tailored to the individual. Health professionals must also emphasize having an overall heart healthy diet (rich in vegetables and minimally processed foods and low in saturated fat) has a greater benefit in reducing CVD risk compared to simply limiting egg intake.

MACRO-LEVEL - FOOD INDUSTRY

As a result of this literature review, it is concluded there is a lot of positive messages that could

be communicated to the public on egg consumption and their nutritional credentials. However, it could be that the average consumer's understanding of current recommendations for egg intakes and their nutritional credentials are low. Therefore, there is an opportunity for the food industry to further research their consumer's understanding and knowledge on egg consumption and to increase the awareness of egg as a healthy food choice.

MACRO-LEVEL - GOVERNMENT

The last national nutrition survey was conducted in 2008/09. This research suggests an updated survey, which assess current egg intake would be beneficial. While there is currently no research available to confirm, it is assumed that there is a significant amount of confusion amongst the general public on the nutrition credentials of eggs and exactly how many eggs can be consumed per day. Thus, the government could assist in disseminating the current recommendations.

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