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The Impact of Dietary Egg Intake on Metabolic Health in Food Insecure Households

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The Impact of Dietary Egg Intake on Metabolic Health in Food Insecure Households

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ABSTRACT

Food Insecurity (FI) is defined as a condition in which individuals lack access to adequate food due to limited financial resources. FI is estimated to impact 12% of households in United States. Adults and children who experience FI are an increased risk for developing metabolic disease such as type 2 diabetes, obesity, hypertension, and cardiovascular disease. The negative health outcomes associated with FI are multifactorial, however, many of them may be caused by limited nutritional intake and poor diet quality. Efforts to better understand the obstacles food insecure populations face is critical in order to improve nutrient intake and minimize the negative health outcomes involved. Dietary intake of eggs may serve as applicable solution for FI families who are challenged by limited nutritional intake. Eggs contain a variety of nutrients that support metabolic health. For instance, eggs are a complete source of high quality protein. Diets abundant in high quality protein are shown to improve body composition, nutrient intake, and markers of cardiometabolic health. In addition, eggs contain sixteen vitamins and minerals, and are one of the few sources of naturally occurring vitamin D. Furthermore, eggs are cost-efficient. When comparing the relationship between foods based on calories and unit cost, the energy cost of eggs is significantly less when compared to other animal protein foods such as meat, poultry and fish. However, dietary intake of eggs is controversial in-regards to cardiovascular health and it is unclear whether or not regular and long-term consumption is appropriate. Therefore, the **objective** of this thesis was to determine if habitual egg intake improves body composition, cardiometabolic markers, and nutrient status is adults and children from food insecure households.

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DEDICATION

This thesis is dedicated to my lovely wife, Kayley, and my two dogs Von and Blue.

TABLE OF CONTENTS

FIGURES

Chapter 1

Chapter 2

TABLES

Chapter 1

Chapter 2

INTRODUCTION

Food insecurity (FI) affects millions of people both globally and nationally [1]. FI is defined as a state of being in which individuals lack access to adequate food due to limited financial or other resources [2]. Currently FI is estimated to impact 12% of households in United States [3]. Adults and children who experience FI are an increased risk for developing metabolic disease such as type 2 diabetes, obesity, hypertension, and cardiovascular disease [4-6]. In addition, exposure to persistent bouts of FI is associated with poor mental health [7,8]. Altogether, episodic household FI diminishes quality of life in both adults and children [9,10]. Efforts to better understand the obstacles food insecure populations face is critical in order to improve nutrient status and minimize the negative outcomes involved.

Food insecurity is dynamic and multifactorial. Individuals may experience FI 365 days of the year while others may only experience FI for one month [1]. One of the strongest predictors of FI is low income status, followed by limited educational background, disability, and unhealthy lifestyle patterns such as skipping meals and physical inactivity [11]. In addition, having children is considered a predictor for FI. For instance, households with children are twice as likely to identify as FI [5].

Household FI impacts the entire family and is correlated with many adverse outcomes [5,7,12-15]. In general, the majority of the adverse outcomes associated with FI are related to metabolic health [5,16]. For this reason, dietary intake of FI individuals has become an area of increased interest. For instance, numerous publications have shown irregular eating patterns and reduced dietary quality when comparing FI individuals to their food secure counterparts [17-20]. Multiple indices have been devised to determine diet quality [21]. Collectively, dietary quality is a reflection of the amount of nutrient dense foods in one's diet compared to the amount of energy consumed [22]. A cross-sectional analysis of dietary recalls belonging to nearly 4,000 adults, showed that living below the poverty level was associated with reductions in dietary quality as evidenced by increased consumption of fruit juices, processed meats, sugary

beverages, and decreased consumption of vegetables and fruits [23]. A recent systematic review analyzing data from 16 studies measuring diet quality in FI and FS adults found numerous associations with FI which include: lower fruit, vegetable, and dairy intake, lower intakes of vitamin A, B-6, calcium, magnesium, and zinc [24]. Generally, reductions in dietary quality for adults often coincide with the dietary quality of children residing in the same household. Survey data obtained from a group of 3790 households found significant differences in fruit, vegetable, and dairy intake between FI and FS children [25].

The disparities in food quality between FI and FS individuals may be explained by the multitude of challenges FI families endure, specifically, limited access to food due to financial constraints [26,27]. In most cases, low-energy and nutrient dense foods tend to be more expensive than high-energy nutrient light foods [28]. As a result, FI families may opt to partition food choices based on cost instead of nutrient quality, thus sacrificing nutrient dense foods containing vitamins and minerals for more affordable energy dense foods which are high in calories and low in vitamins and minerals [29,30]. In fact, FI families are shown to spend significantly less on monthly groceries when compared to FS families [31]. Therefore, nutrient interventions aimed at improving the associated symptoms of FI must place an emphasis on food sources that are both nutrient dense and affordable.

Eggs may be a viable solution for FI families who face nutritional intake challenges. Eggs are considered a functional food because of they contain a variety of nutrients that support human nutrition and an array of biological processes [32]. For instance, eggs are a complete protein source. Two eggs (100g) contains roughly 12 grams of high quality protein [33,34]. Diets abundant in high protein quality foods can lead to positive outcomes such as improved body composition, increased satiety, better mood and sleep, and greater diet quality. In addition, eggs contain 16 vitamins and minerals, and antioxidants and carotenoids. Eggs are one of the few sources of naturally occurring vitamin D and daily intake of eggs is shown to protect serum 25OHD3 concentrations during winter months [35,36]. When comparing the relationship

between foods based on calories and unit cost, the energy cost of eggs is considered one of the lowest and is significantly less when compared to other animal protein foods such as meat, poultry and fish [37,38].

As stated previously, FI families face barriers in consuming higher cost foods which include lean meats [39]. As a result, overall protein intake in terms of quantity and quality may be negatively impacted. Lower protein intake has been observed in young and older adults experiencing FI [40]. Protein intake is associated with improved dietary quality and metabolic health [41-44]. Therefore, an emphasis on attaining high quality protein foods may fill some of the nutrient gaps associated with FI and improve markers of cardiometabolic health. Altogether, eggs represent a feasible food choice for combating the nutritional challenges and disparities associated with food insecure populations. Therefore, the **objective** of this thesis was to determine if habitual egg intake improves body composition, cardiometabolic markers, and nutrient status is adults and children from food insecure households.

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LITERATURE REVIEW

Food Insecurity

Food insecurity (FI) is a condition in which individuals lack access to adequate food due to limited financial or other resources [1]. Currently, FI is estimated to impact nearly 11% of U.S households, which accounts for about 41 million individuals [2]. The US alone spends an estimated $103.6 billion dollars annually to help support individuals who experience FI [1]. FI is commonly associated with multiple chronic diseases which include; cardiovascular disease, obesity, type 2 diabetes, hyperlipidemia, and hypertension [3-7]. There are multiple factors that pre-dispose individuals to FI which include; income, race, disability, and education [8-10]. The United States Department of Agriculture (USDA) categorizes levels of FI into different ranges [11]. These conditions are not static and individuals may meet the criteria for either classification at any given time [12]. There are multiple strategies to combat the progression and onset of FI [13], and throughout the past decade, there has been minor improvements in the national prevalence rate [14]. Since 2011, the national severity rate has declined from 14.9% to 11.1% [14]. However, the issue still remains at large, especially in the wake of the recent global pandemic which threatens our national food supply [15]. Therefore, in addition to combatting financial disparities among the population, it is paramount for nutritional research to explore potential interventions aimed at improving nutrient intake and health status among individuals at risk.

Defining Food Insecurity

Food insecurity was first measured in the U.S in 1995 by the U.S. Census Bureau [16]. Data were collected from the use of a national level statistical inquiry of food consuming behaviors called the Current Population Survey [16]. Each year the USDA uses the obtained results for monitoring the annual magnitude and severity of FS. The 18-question survey includes questions such as; “We worried whether our food would run out before we got money to buy more” and

"We couldn't afford to eat balanced meals" [17]. The USDA's Core Food Security Module (CFSM) is used to categorize a household's level of food security into four distinctive subgroups: high, marginal, low and very low FS [18]. The two-food security sub-categories are divided into high and marginal FS. Individuals who report no food access problems or limitations are classified as having high FS, and individuals who experience no significant changes in dietary intake or quality, but have anxiety toward food supply are classified as having marginal FS. On the contrary, FI is further divided into low food security and very low food security. Both FI subcategories are described as having reduced intake of nutrient quality and variation, however, very low FI is indicated by reports of reduced food intake and disrupted eating patterns [19].

Food Insecurity Prevalence

National prevalence rates of FI have fluctuated throughout the past 20 years [20]. At the beginning of the 21st century, FI was shown to impact 10.5% of U.S households [20]. In 2011, the prevalence rate of FI reached its highest point at 14.9% and has since declined to 11.1% in 2018 [20]. Although the overall FI rate has significantly declined over the past years, the rate for very low food security has not. In addition, recent threats to national employment may exacerbate FI to an unprecedented level [21,22].

The prevalence of FI is not universal across the entire population. Specific demographics and household characteristics are shown to increase the risk for experiencing FI [1]. For example, economic hardship is shown to be one of the greatest predictors of FI [23]. According to the USDA, 35.3% of households with incomes below the federal poverty line are classified as food insecure. Furthermore, rates were higher than the national average for households with children, headed by single mothers or ethnic minorities, and in metropolitan areas and southern states [20].

Food Insecurity and Adverse Health Outcomes

Numerous health consequences exist for individuals living with FI [24]. The root causes for these adverse health outcomes are multifactorial. Lower socioeconomic areas and neighborhoods which disproportionally house FI families are more likely to have fewer grocery stores, fewer parks, and poorer air and water quality when compared to higher socioeconomic areas [25-27]. Altogether, this creates a harmful impact on the health and wellbeing of FI families. Many of the adverse health outcomes that children face will follow them through adolescence and into their adult years [28].

Adults

One of the first investigations into the relationship between FI and overall wellbeing in adults identified a relationship between self-reported health status and FI [29]. In a sample of 724 welfare recipients, FI was significantly associated with poor self-rated physical and mental health [29]. Over the past 20 years, multiple findings have emerged to support these associations [30-33]. In addition, studies have demonstrated specific health interactions and concerns. For example, FI is a key predictor for cardiovascular disease risk [34]. Survey data from a sample of 5870 Mississippians was analyzed and over half of the population with high blood pressure and 30% of diabetics identified as FI. A recent comprehensive analysis of NHANES data between the years of 2007-2014 found differences in cardiometabolic markers between and within FI and FS adults [7]. For instance, adult males identifying as FI were more likely to have higher total cholesterol, females had lower HDL and higher triglycerides and fasting glucose. As a whole, individuals from the FI population were shown to have higher body mass index (BMI) and waist circumference. Collectively, this places FI populations at a greater risk for developing CVD.

Children

Similar to adults, chronic health disparities are observed among FI children. In an analysis of survey data belonging to children aged 2-17 between the years of 2013 and 2016 and concluded significant differences in health outcomes between FI and FS populations [35]. In the study, an array of health outcomes were measured and separated into specific domains which included: general, chronic, and acute health and health care access. The authors concluded that children from FI households had significantly worse health outcomes for all four of the categories measured. Overall, poor childhood health status due to FI can manifest into the following abnormalities: anemia, low bone mass, generalized anxiety, asthma, and behavioral problems [36-40].

In agreement with the outcomes observed in FI adults, children from FI households may be at an increased risk for abnormal cardiometabolic markers of health [41,42]. There is evidence to support differences in body composition between FI and FS children, specifically obesity. However, data obtained from over 16,000 children participating in SNAP was not shown to be associated with higher BMI percentile [43]. Furthermore, the risk for developing childhood obesity may be exacerbated among different sub-populations. For instance, FI was strongly associated with obesity in a sample of Hispanic children [44] .Therefore, the relationship between the two is unclear.

Food Insecurity and Nutritional Status

The underlying reason behind the relationship between FI and poor metabolic health may be due to irregular dietary habits and behaviors [45-48]. Multiple studies have identified barriers to food access, which not only affects total food intake but also of foods considered healthy. Limited access to nutritionally adequate foods may manifest into what is referred to as a “dual nutrition burden” in which individuals experience over- and under-nutrition due to chronic consumption of energy dense and nutrient scarce foods [49]. Moreover, dietary intake is closely

linked to development and progression of metabolic diseases such as obesity, type 2 diabetes, hypertension, and heart disease. Therefore, in order to investigate whether or not this assumption is supported, special interest should be placed on analyzing dietary intake between the FI and FS populations.

Adults

In one of the largest systematic reviews of dietary intake records between FI and FS adults, researchers observed numerous associations between the two groups [50]. Based off of the data obtained from 13 studies, multiple correlations between FI and dietary intake were confirmed including: lower vegetable, fruit, and dairy intake, and lower intake of vitamins and minerals such as vitamin A, B6, calcium, magnesium, and zinc. Similar results were found in a study comparing dietary records from SNAP participants between the years of 2003-2010. The study identified reduced healthy eating index scores and a significantly higher intakes of empty calories and added sugars in adults experiencing FI [51]. In addition, differences in micronutrient intake between FI and FS adults have been observed. These differences include lower intakes of vitamin A, thiamin, riboflavin, B6, folate, B12, magnesium, phosphorus, and zinc [52]. In addition to these findings, differences in macronutrient were reported as evidence by lower protein intake among FI adults [52]. Although total grams of protein were not measured, it has been reported that food insecure women consume significantly lower amounts of meat [53]. Aside from the fact protein foods are the most expensive per mass [54], there is limited information as to why FI or low-income adults would consume less. Therefore, additional research is needed.

Children

Similar to adults, there is evidence to suggest that children from FI homes are at an increased risk for deficient nutrient intake when compared to their counterparts. A recent study

identified multiple barriers to nutrition among FI youth [55]. These barriers include: “lack of time/no one making healthy foods”, “healthy foods are expensive”, and “no availability of healthy foods at home”. When comparing Healthy Eating Index (HEI) scores from food recalls belonging to a sample of nearly 600 children, those who identified as FS had lower overall HEI scores when compared to FS children [56]. Similar results were shown from a large sample of FI and FS fourth and fifth graders [57]. The authors of the study confirmed poor dietary quality among FI children as evidence by lower intake of vegetables and greater intake of total energy, sugar, and fat. In contrast, data obtained from 5540 children showed no differences between HEI between FI and FS children [58]. Furthermore, discrepancies in nutrient intake of FI adults and children within the same household have been observed [50]. A recent systematic review identified numerous nutrient inadequacies among FI adults; however, they were less pronounced in children within the same household [50]. In order to explain the findings, the authors of the review speculated that FI parents may sacrifice their own dietary intake to help offset the risks of their child. However, these findings may be explained by inaccuracies in food reporting by the parents of the children. Perceived childhood FI by the parent is shown to be under reported when compared to the child [59]. Unfortunately, this may mask the severity of nutrient inadequacies amid children living in FI households, therefore additional inquiry is needed.

Egg Consumption

Eggs are a nutrient dense conventional food and have been a large component in diets throughout out the world. In the U.S alone, eggs are consumed by about 20% of the population on a given day [60]. Packed within the calcium carbonate shell exist both water and fat-soluble vitamins and essential minerals. In addition, eggs represent one of the best food sources available for dietary protein while at the same time being relatively low in calories [61,62]. Perhaps one of more novel aspects regarding egg consumption is the price point per serving

[63]. Eggs are an affordable dietary and culinary option for individuals experiencing FI. However, incorporation of eggs into the diet must be met with caution, as eggs have received both praise and scrutiny within scientific literature [61,64,65]. Therefore, additional research involving egg consumption, specifically, in the target population of low-income and food insecure adults and children is needed.

Over the past 50 years, the association between egg consumption and overall health has been closely monitored due to the potential risks of developing cardiovascular disease (CVD). Throughout the 1930s and 40s, CVD had become the leading cause of mortality in the U.S. and became a major health concern after claiming the life of President Roosevelt [66,67]. In 1968, The American Heart Association (AHA) began to introduce dietary recommendations aimed at flattening the cardiovascular disease curve [68]. Due to the saturated fat and cholesterol content commonly found in eggs, the AHA recommended that consumption of eggs should be less than three a week [61]. Per recommendation, individuals began to scale back on egg consumption, which continued throughout the tail end of the twentieth century [69].

Egg Nutrients

Eggs are described as a nutrient dense food [62]. They have 14 different vitamins and minerals, and are one the greatest sources for vitamin A, folate, biotin, iodine, and vitamin D among commonly consumed protein sources [70]. As for macronutrients, a single egg contains roughly 78kcal, 7g of protein, less than 1g of carbohydrate, and 4g of total fat (1.6g saturated, 2g mono-saturated, and 0.7g polyunsaturated).

Dietary Protein

Eggs are made up about 12.6% of protein and one egg alone contains nearly six grams of complete protein containing all essential amino acids [61,71]. The protein in eggs are considered of high biological value (BV). This means that the protein within the egg can be

readily utilized via the body to support various biological processes in an efficient manner [72]. For example, the BV would consider the total nitrogen content of a digested food source in ratio to its incorporation into body proteins via protein synthesis. There are different factors that can influence a protein sources BV, however, the essential amino acid content of the protein source of interest is typically the greatest deciding factor [73,74]. For eggs, this number is relatively high, in fact, eggs have maximal BV score of 100 [75].

Dietary protein is an essential nutrient for supporting life. Protein is composed of 20 amino acids; however, not every protein source contains the same amount. Currently, there are three different dietary recommendations for protein consumption [76]. First, the Estimated Average Requirement (EAR) is 0.66 g/kg^{-1}/d^{-1}. Second, the Recommended Dietary Allowance (RDA) recommends daily dietary intake of protein of 0.8 g/kg/d. Lastly, the Acceptable Macronutrient Distribution Range (AMDR) recommends 10-35% of calories consumed should come from dietary protein [77]. Collectively, these protein recommendations were established based on efforts to avoid muscle wasting in response to nitrogen imbalance. However, the benefits of protein intake are not only exclusive for preventing nitrogen imbalance as protein intake near the higher end of current recommendations may support body composition and metabolic health [78-81].

Dietary protein intake may support lean mass and prevent the accretion of fat mass by impacting energy balance via dietary induced thermogenesis and hormonal regulation of appetite [82]. The thermic effect of feeding (TEF) describes the increase in post-prandial energy expenditure following a meal [83]. As the process of digestion begins, the laws of thermodynamics respond accordingly [84]. However, the rise in energy expenditure is not equal among macronutrients [85]. Of the three major macronutrients, protein has the highest impact on increasing post-prandial energy expenditure (25-40%), followed by carbohydrates (6-8%) and fat (3%) [83]. Dietary protein intake influences energy intake by acting on members of endocrine

system that regulate appetite and hunger [86]. Protein feeding is shown to activate satiety signals located in gut and brain [87]. In addition, dietary protein intake may also reduce feelings of hunger by attenuating secretion of the hormone ghrelin [82]. Ghrelin acts as an orexigenic hormone [88]. When compared to a breakfast meal high in carbohydrates, a higher protein meal resulted in a significantly stronger reduction in plasma ghrelin concentration [82]. Therefore, protein intake may act as a therapeutic strategy in attenuating or preventing obesity in populations at risk, such as FI.

Vitamin D

One of the greatest dietary sources of naturally occurring vitamin D is fish and fish products [89]. However, seafood products are one of the highest costing foods per gram of energy. Therefore, it may be unrealistic to expect FI households to habitually consume seafood, thus leaving them at risk for inadequate vitamin D intake. Egg yolks are one the highest vitamin D concentrated foods available and two eggs alone can provide nearly 20% of the RDA for the vitamin [90]. Furthermore, the vitamin D content of the yolk can be enhanced via the dietary fortification of the laying hen [91].

It is estimated that vitamin D deficiency impacts 50% of the global population [92]. As noted earlier, vitamin D deficiency is a common characteristic of FI individuals due to lower nutrient intake and limited sun exposure [93,94]. Although not yet conclusive, there is evidence to suggest vitamin D status in adults may act as a predictor for cancer, heart disease, T2D, and depression. In addition, low vitamin D status in children is correlated with behavioral problems such as anxiety and depression [95,96].

One of the more researched interactions of vitamin D is its relationship to bone health. Vitamin D intake coupled with calcium is shown to have a significant and positive impact on bone mineral density (BMD) [97]. The presence of vitamin D within the small intestine promotes calcium absorption into enterocytes, thus assisting in the maintenance of serum concentrations

of calcium and phosphorus for incorporation into bone matrix [98]. At the cellular level, vitamin D acts as a transcription factor for stimulating osteoblast and bone reabsorption activity [99]. In the absence of vitamin D, intestinal absorption of calcium is limited, thus causing parathyroid hormone (PTH) excretion and bone de-mineralization [100] . Therefore, prolonged inadequacies of vitamin D intake may adversely affect calcium metabolism, thus increasing risk of osteoporotic events later in life [101].

Data obtained from over 20,000 food records show that egg consumers aged 2-18 self-report higher daily intake of vitamin D than their non-egg eating peers [102]. Importantly, higher intake of vitamin D translates to higher serum levels [103]. In a recent study, differences in serum vitamin D levels were shown following an 8-week dietary intervention of either a minimal egg intake (<2 eggs/week) diet or habitual egg intake (7 eggs/week) diet during winter months [104]. The participants who habitually consumed eggs had higher levels of serum vitamin D than individuals who minimally consumed eggs, thus protecting from the risk seasonal vitamin D deficiency due to winter months. Furthermore, a study examining egg intake and serum vitamin D levels divided 564 children aged 9-12 into two groups based on self-reported daily egg intake. The authors concluded that egg intake was associated with higher serum vitamin D [105]. Although performed in rats, research comparing serum 25OHD levels following an 8-week experimental diet of either whole egg, or supplemental cholecalciferol concluded that the whole egg diet was more successful at maintaining serum 25(OH)D when compared to supplementation [106]. Although additional research is needed, these data support the notion that natural food sources such as eggs may be a more effective strategy in improving or maintaining serum 25(OH)D levels, specifically, in individuals at risk such as FI populations.

Impact on Markers of Cardiometabolic Health

Poor cardiometabolic health in the form of high fasting blood glucose, high triglycerides and low high-density lipoprotein (HDL) can have a negative impact on overall health and

increase the risk for mortality [107,108]. Altogether, dysregulation of these markers increases the risk of mortality by acting as precursors for the development of type 2 diabetes, cardiovascular disease, and stroke [109]. Currently, there are mixed results throughout the literature regarding egg intake and cardiometabolic health. In a meta-analysis analyzing the results from 16 clinical trials on the association between CVD, diabetes, and egg consumption, researchers reported no significant associated risk for the development of CVD, however, increased incidences of type 2 diabetes was observed among the general public [110]. On the contrary, another study examining a large pool of subjects belonging to six different cohorts found opposing results [65]. The study concluded that cholesterol and egg consumption significantly increases the risk for developing CVD in a dose-response manner [65]. As described earlier, FI populations in particular are at an increased risk for the development of metabolic abnormalities which include CVD. With this in mind, it is important to consider how egg consumption may influence markers of cardiometabolic health.

Glucose Homeostasis

The studies cited in the previous section highlight a possible association between egg intake and type 2 diabetes. A study examining egg intake and fasting glucose levels [111] confirmed these findings, however, when adjusted with dietary patterns, the associations became insignificant. Moreover, a randomized control trial of participants consuming a carbohydrate-restricted diet with eggs showed no significantly changes in plasma glucose levels [112]. In addition, significant reductions in fasting glucose levels were observed following daily egg consumption in 12 in adults with pre and type 2 diabetes [113]. Altogether, this suggests that eggs do not independently raise fasting glucose levels, thus manifesting type 2 diabetes, and that the risk associated with eggs must come from outside influencers.

Cholesterol Profile

According to NHANES data, eggs represent the highest cholesterol containing food consumed in the United States [114]. Two eggs alone have over 300mg of cholesterol, the former daily recommended amount prior to the publication of the 2015-2020 Dietary Guidelines for Americans [115]. Plasma cholesterol originates from both endogenously secreted cholesterol and exogenously absorbed cholesterol from the diet. The absorption of dietary cholesterol is shown to reduce the rate limiting enzyme involved in the biosynthesis of cholesterol, HMG CoA reductase, thus allowing feedback inhibition in the presence of increased exogenously absorbed cholesterol [116].

Indeed, eggs contain cholesterol. However, an acute dose response study examining the effect of eggs on plasma cholesterol concluded no differences in plasma cholesterol levels following ingestion of meals containing eggs or no eggs [117]. This observation is consistent with findings showing no changes in total cholesterol following a high egg diet of >12 eggs a week. Furthermore, an analysis of a cohort of 28,000 participants showed no association between daily egg consumption and all-cause mortality [118]. In contrast, an increase in plasma concentrations of total cholesterol was observed during an acute dose response study following the intake of 0,1,2 and 4 eggs [119].

The risk between cholesterol and CVD from eggs may be reduced due to an increase in HDL [120]. A recent meta-analysis examining 28 randomized control trials concluded that egg consumption is associated with an increase in total cholesterol in tandem with increased HDL [121]. An intake of 2-3 eggs a day for 14 weeks reduces LDL and promotes an increase in HDL in healthy adults [122]. Additionally, consumption of eggs has been shown to improve HDL levels in adults with metabolic syndrome when supplemented with moderate carbohydrate restriction [123]. However, in a review examining the relationship between egg consumption and cholesterol profile in 17 studies, the authors showed the addition of dietary cholesterol was associated with an adverse change in the total to HDL cholesterol ratio [124]. Given that acute

and long-terms studies both show contrasting evidence for egg consumption and cholesterol profile, additional research is warranted.

Triglycerides

Triglycerides (TG) represent an important biomarker for assessing cardiometabolic health. For instance, independent of cholesterol levels, elevated TGs are shown to be a risk factor for the development of atherosclerosis [125]. In a meta-analysis examining the association between egg intake and lipid values in 28 studies concluded there was no observable change in triglycerides when compared to low egg consumption [121]. In a longitudinal study following a large cohort, an inverse association between egg intake and increased triglycerides was observed following a 6 – 8 yr. follow up [126]. Overall, it appears that eggs may have a protective impact on TG levels in humans.

Conclusion

In conclusion, FI poses numerous threats to both children and adults [1,14,18,19]. Chronic imbalances in nutrient intake can increase the risk for developing metabolic disease throughout life. Therefore, it is paramount to develop nutritional strategies and identify food sources that improve nutrient intake and minimize risk for chronic disease. A potential food source to be considered is dietary eggs. Eggs are complete protein source and contain a plethora of vitamins and minerals [61,127]. In addition, eggs are an affordable food. However, concerns regarding their long-term intake is controversial, therefore additional research is needed to better clarify their role within a food insecure population.

Therefore, the **objectives** of this thesis were:

(1) To identify barriers to protein consumption in low-income, food insecure adults.

(2) To determine if habitual egg intake influences markers of cardiometabolic health, body composition and nutrient status in food insecure adults and children.

We **hypothesized:**

(1) Food insecurity is associated with barriers to protein consumption

(2) Dietary consumption of two eggs a day, five days per week for twelve weeks would improve markers of cardio-metabolic health in adults and children living in a food insecure environment.

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CHAPTER 1

Habitual Egg Consumption for Twelve Weeks Does Not Alter Cardiometabolic Parameters in Food Insecure Adults

Abstract

Objective: The objectives of this study were to 1) identify barriers to protein consumption in low-income, food insecure adults and, 2) determine if increasing protein intake through habitual egg consumption influences markers of cardiometabolic health.

Methods: In the first study, participants were recruited during a one day medical outreach event (HOPE) for homeless and low-income adults. A total of ninety-six adults (62 male and 33 female; 50.3 ± 13.3 y) completed the survey. Participants were asked to verbally respond to questions regarding their sociodemographic and family background, dietary habits, current housing, and food security status. Cardiometabolic risk factors (BMI, plasma glucose, and blood pressure) were also measured. In a separate study, twenty adults were recruited to participate in a 12-week dietary intervention. Each participant was required to consume two eggs per day, five days per week without altering current dietary habits. Participants were either assigned to a food insecure (FI; n=10; 8 female, 2 male; 38.0 ± 5.2 y; 74.2 ± 23.4 kg; BMI 28.5 ± 9.6 kg/m^2) or food secure (FS; n=10; 9 female, 1 male; 38.4 ± 4.1 y; 79.3 ± 17.1 kg; BMI 28.1 ± 5.4 kg/m^2) group. FI was determined using the USDA's six item Short Form Food Security Survey or enrolled in SNAP. Anthropometrics (height, weight, and waist-to-hip ratio) and food intake were collected at baseline, 4-, 8-, and 12-weeks. Fasting plasma and serum samples were collected at each visit and markers of cardiometabolic health were analyzed (glucose, triglycerides, total cholesterol, HDL, and Vitamin D).

Results: Study 1: The vast majority of survey participants reported some degree of FI (75%). Over 70 percent reported at least one barrier to protein consumption. The highest reported barrier was cost (58%), followed by convenience (25%) and time available to prepare food (22%). In addition, more than one-third of survey respondents reported consuming protein

fewer than five times per week. The majority of participants had elevated blood pressure (88%) and either overweight or obese (76%), with nearly 40 percent having glucose values above 100 mg/dL. **Study 2**: Throughout the 12-week dietary intervention, there were no significant changes in body weight, BMI, or waist-to-hip ratio in either FI or FS participants. In addition, there was no effect of egg supplementation on plasma lipids, glucose, or Vitamin 25(OH)D in either group. Compared to FI adults, FS adults consumed higher amounts of fiber throughout the intervention ($P<0.05$). Both groups increased their cholesterol intake throughout the intervention ($P<0.05$).

Conclusions: The results of the survey indicate that barriers to consuming dietary protein exist among low-income and homeless adults. The two greatest barriers within this population were cost and convenience. In addition. FI and homelessness may increase the risk for irregular cardiometabolic markers. Additional research on how to overcome perceived barriers to protein intake is needed. The results of this dietary intervention study indicate that regular consumption of eggs for twelve weeks does not impact body composition, cardiometabolic markers, or Vitamin D status in either FI or FS adults. However, a larger study population and longer intervention period are needed (NCT 03412825).

Introduction

Food insecurity is estimated to affect up to 50 million people in the United States [1]. The USDA defines food insecurity as a condition in which individuals lack access to food due to limited financial or other resources [2]. The severity of food insecurity is a dynamic condition which can fluctuate at various months of the year and days of the month and is most heavily influenced by low income status [3, 4]. Food insecurity can negatively impact a person's quality of life by increasing the risk for developing metabolic disorders such as obesity, diabetes, cardiovascular disease, hypertension, and stroke [5-7].

Decreased food quality is a hallmark characteristic of food insecure adults, as shown by lower healthy eating index scores when compared to food insecure adults [8], this is called the

“substitution effect [3].” For instance, food insecure adults are more likely to replace nutrient dense foods for more affordable energy dense foods [3]. Thus, sacrificing lean meats and vegetables for simple carbohydrates and added sugars [9]. Partitioning food choices based on food cost may be the ultimate driver behind this dietary behavior [10]. In general, low-energy foods tend to be more expensive than high-energy foods [11], for example, a one-standard deviation increase in food price is associated with up to a 12.4% increase in food insecurity among SNAP recipients [12]. High biological value protein in the form of meats, poultry, and fish are shown to have the highest price per serving when compared to other foods [13]. Additionally, these types of protein sources require proper storage, handling, and preparation for consumption. Collectively, these factors may be responsible for barriers to protein consumption among food insecure adults.

Eggs represent a potential food choice for combating nutritional disparities among food insecure adults. For instance, eggs are an affordable food choice and can be prepared in many different ways [15]. When comparing the price per 100g, other protein sources such as beef, poultry and fish are about 3 times the cost of eggs [14]. In addition, eggs are a source of dietary protein [15,16]. One egg contains 6 grams of high biological value protein as indicated by a Protein Digestibility Corrected Amino Acid Score value of 100 [17]. Furthermore, eggs are rich in micronutrients and contain up to 17 different vitamins and minerals [18]. For these reasons, daily egg consumption may an effective dietary strategy for protecting food insecure adults from the negative health outcomes associated with food insecurity. Therefore, the objectives of this study were to 1) identify barriers to protein consumption in low-income, food insecure adults and 2) to determine if increasing protein intake (via increased egg consumption) influences markers of cardiometabolic health. We hypothesize that food insecurity and homelessness are associated with barriers to protein consumption and that increasing protein intake through consumption of two eggs a day, five days per week for twelve weeks would improve markers of cardio-metabolic health in adults living in a food insecure environment.

Methods

Study 1: HOPE Medical Outreach Survey

Study Design. Participants were recruited during a one-day medical outreach event for homeless and low-income adults living in Northwest Arkansas. The services provided at the event included: access to medical, dental, and podiatry screening, hygienic care, legal advice, and food distribution. Prior to checking in for services, individuals were interviewed using a 5-minute survey administered by trained personnel. Participation was completely voluntary and participants had the ability to opt out at any time. Choosing not to participate did not interfere with access to medical care. Subjects were asked to verbally respond to questions regarding their current housing and food security status, dietary habits, and general access to medical care. Food insecurity was measured using USDA Six-Item Short Form of the Food Security Survey Module [19]. Following the survey, participants had their BMI, blood glucose, and blood pressure were recorded. This study was approved by the University of Arkansas' Institutional Review Board (IRB; IRB Protocol #1709049334).

Statistical Analysis. Percentages and mean and standard deviation values obtained from data collection were analyzed via GraphPad version 8.0 and Statistical Package for the Social Science v25. Differences of means tests are performed ($P < 0.05$) between cardiometabolic and sociodemographic variables.

Study 2: Dietary Intervention

Study Design. A total of twenty adults from food insecure (FI; n=10; 8 female, 2 male; 38.0 ± 5.2 y; 74.2 ± 23.4 kg; BMI 28.5 ± 9.6) or food secure (FS; n=10; 9 female, 1 male; 38.4 ± 4.1 y; 79.3 ± 17.1 kg; BMI 28.1 ± 5.4) households were recruited on a rolling basis to participate in a randomized, controlled dietary intervention. Participants were recruited throughout Northwest Arkansas via the daily University of Arkansas Newswire, word of mouth, social media, and the community through the distribution of fliers. In order to participate in the

intervention, potential participants underwent an initial phone screening to determine eligibility. During the phone screening, food security status was determined using the USDA Six-Item Short Form of the Food Security Survey Module [19], or if they were currently participating in the Supplemental Nutrition Assistance Program (SNAP) [20]. Participants with diet-related metabolic conditions, dietary restrictions, food allergies, or requiring medication were not able to participate in the study. In addition, participants were required to have access to a stovetop, hot plate, or microwave in order to safely prepare eggs. Written consent was obtained prior to beginning the study. Ethical approval for the study design was approved by the IRB at the University of Arkansas (IRB Protocol #1709049334). This study was registered on clincicaltrials.gov (NCT 03412825).

Dietary Intervention. Both FI and FS adults participated in this intervention. All participants within each group received the same dietary intervention. Participants were required to consume 10 eggs per week (2 eggs a day for a total of 5 days a week) for 12 weeks. Participants reported to the Center for Human Nutrition at the University of Arkansas at baseline, 4, 8, and 12 weeks for sample collection. At each laboratory visit, participants underwent a fasted blood draw and height, weight, and waist-tip-hip ratio were measured. To ensure compliance, participants were required to complete a weighed 3-day food record for each month of the intervention which were reviewed by a registered dietitian, all eggs (Great Value Large White Eggs) were provided for each family member in the household, and participants were provided with monthly gift cards to assist with groceries. Participants were also required to turn in receipts to ensure that the money was spent on groceries. Educational materials and dietary counseling on how to prepare, handle and store eggs were provided prior to beginning the intervention and upon request throughout the 12-week intervention period.

Anthropometric Assessment. Body height was measured using a stadiometer (Detecto, St. Louis, MO) with subjects barefoot, in the free-standing position. Body weight was measured in the fasted state using a calibrated balance scale (Detecto, St. Louis, MO). BMI was

calculated as weight (kg) divided by height (m) squared. Waist-to-hip ratio (WHR) as measured using the WHO and calculated by dividing waist circumference (at the naval) by hip circumference (widest part of the buttocks) [21].

Cardiometabolic Biomarkers. Plasma and serum samples were collected following a 10-12 hr fast at baseline, 4, 8, and 12 weeks. Following collection, samples were immediately centrifuged at 4° C for 15 minutes at 1800 x g and stored at -80°C. Plasma glucose (Cayman Chemical Company item #10009582), triglycerides (Cayman Chemical Company item #10010303), total cholesterol (Cayman Chemical Company item #10007640), and high-density lipoproteins (HDL; Abcam item #ab125961), concentrations were determined using commercially available colorimetric and fluorometric kits using a Biotek Synergy HTX multi-mode plate reader (BioTek Instruments Inc. Winooski,VT USA). Serum 25-OH-Vitamin D was measured and analyzed via Liquid chromatography-mass spectrometry (Heartland Assays, Ames, IW, USA).

Dietary Assessment. Prior to beginning the study, participants were assisted in a 24-hour dietary recall [22]. Food scales and measuring devices were provided at the beginning of the study. Participants were required to maintain a 3-day (2 week days and 1 weekend day) food record for each month of the study. Dietary records were monitored each month for compliance by a Registered Dietitian. Dietary intake data were analyzed using the Nutrition Data System for Research software (NDSR; NDS version 2018, Nutrition Coordinating Center, University of Minnesota, Minneapolis, MN) to determine average energy and macronutrient intake.

Statistical Analysis. Results are reported as means ± standard deviations (SD). Summary statistics were conducted using Prism GraphPad Software Version 6.0 (La Jolla, CA). One-way ANOVA was used to analyze differences in nutrient intake within each group at different collection times throughout the intervention. Two-way ANOVA was used to compare differences in dietary intake between both groups at different collection times throughout the

intervention. Data were analyzed using analysis of covariance with group as the factor, time as a repeated measure, and BMI as the covariate. Response variables were assumed to follow a gamma distribution. Where appropriate, differences among least square means were determined using a protected least significant difference (LSD) at the five percent level ($P<0.05$).

Results

Study 1

Participant Characteristics. A total of 96 adults (62 male and 33 female; 50.3±13.3 y) completed the HOPE survey. Of the participants screened, 74.8 percent reported some degree of FI. FI participants reported high- (32.6%) followed by moderate- (31.5%) and low-severity (16.3%). There were no significant differences between sex for glucose and blood pressure, however, a significant difference between BMI was observed between sex (male; 34.0 BMI, female; 30.0, kg/m^2 $p < 0.05$). Participant demographics and characteristics of who completed the HOPE survey are presented in **Table 1**.

Barriers to Protein Consumption and Eating Behaviors. Barriers to protein consumption were positively correlated with FI ($r=0.36$; $p < 0.001$). Over 70% of participants reported at least one barrier that prevented them from consuming protein. The largest reported barrier to accessing protein was cost (58%), followed by convenience (25%) and time available to prepare it (22%). More than one-third of respondents reported consuming protein fewer than 5 times per week. The majority of participants reported having access to essential kitchen appliances such as refrigerator and a stovetop. In addition, participants reported consuming the majority of their meals at home. **Table 2** presents the participant responses to questions regarding protein consumption and eating behaviors.

Cardiometabolic Risk Factors. The majority of participants screened (88%) had blood pressure above 120/80 mmHg and had blood glucose values above 100 mg/dL (39.7%) and over

75 percent were either overweight or obese. **Table 3** presents data obtained from individuals who participated in cardiometabolic measurements.

Study 2

Participant Characteristics. There were no significant differences in age between FI and FS groups. In addition, there were no significant differences in weight, BMI, and WHR between both groups at baseline. In addition, no changes throughout the 12 weeks were observed in weight and WHR in the FI group and the FS group. Participant characteristics and anthropometrics from baseline and week 12 are presented in **Table 4 and 5.**

Dietary Intake. Energy, macronutrient composition, and nutrient intake were obtained from 24-h and 3-d food logs are shown in **Tables 7, 8, and 9**. No significant differences were observed in energy intake prior to beginning the study and throughout the intervention between both groups. In addition, no significant differences were observed in macronutrient intake. Although no differences at baseline, FS adults consumed more fiber throughout the intervention, which was significantly higher at week 12 compared to intake at week 8 in FI adults ($P<0.05$). Both groups had a significant increase in dietary cholesterol intake throughout the intervention ($P<0.05$).

Plasma Biomarkers. Fasting plasma biomarkers obtained throughout the dietary intervention are shown in **Table 6**. No significant changes were observed in plasma glucose levels in the FI group and in the FS group. No significant changes were observed in pre-and post-intervention cholesterol and pre- and post-intervention HDL in both groups. In addition, there was no significant changes in pre- and post-intervention triglycerides in both groups There were no significant differences at baseline vitamin D among both groups and no changes in were observed throughout the 12-week intervention.

Discussion

The connection between food insecurity and dietary intake has been well established [23]. For example, the overall macronutrient composition of diets consumed by food insecure individuals provides less protein and more carbohydrates than diets consumed by food secure individuals [24]. In the present study, food insecurity and homelessness were positively associated with self-reported reductions of protein intake. Similar findings were reported following the analysis of over 15,000 community health surveys from adults identifying as FI [25]. Multiple barriers were identified that may explain circumstantial reductions of protein intake, which include the cost and ability to prepare protein foods. One of the highest and most complete protein sources is dietary meat. However, per mass, meat is considered one of the highest costing foods [53]. For this reason, FI adults may end consuming less meat than FS adults, as observed in dietary records belonging to FI woman residing in metropolitan areas [53]. However, no significant differences in protein and overall dietary intake existed between the FI and FS individuals who participated in the nutrition intervention study.

In addition to dietary disparities, food insecure adults are also shown to be at a greater risk for developing symptoms of metabolic diseases which results in an increased risk of mortality. For example, FI is shown to be an independent risk factor for the development of type 2 diabetes [26] and dyslipidemia. Collectively, compared to FS adults, FI adults are shown to have 20% higher odds in developing CVD within the next 10 years of their life [27]. These findings are in line with cardiometabolic measurements we obtained during medical outreach screening. Commonly, these conditions require dietary strategies for managing and preventing progression. This creates a continuous dilemma for FI adults as many find it difficult in adhere to dietary recommendations due to food cost and access, thus, increasing the risk of exacerbating their metabolic symptoms.

Although eggs contain a large body of cholesterol, plasma cholesterol levels do not appear to change in humans immediately following a meal containing either two eggs or no

eggs [28]. However, A recent publication analyzing the associations between dietary cholesterol from eggs and the risk of cardiovascular disease in 6 US cohorts involving over 29,000 participants concluded those consuming higher amounts of eggs were at an increased risk for all-cause mortality [29]. Conversely, following an analysis of a cohort of 28,000 participants, researchers denied an association between daily egg consumption and all-cause mortality [30]. In the present study, 12 weeks of habitual egg consumption did not lead to changes in fasting plasma cholesterol in both groups. This observation is consistent with findings showing no changes in total cholesterol following a high egg diet of >12 eggs a week [31]. In contrast, total cholesterol was elevated in healthy adults consuming 3 eggs a day for 6 weeks when compared to controls [32].

The association between CVD and dietary cholesterol from eggs may be blunted due to an increase in HDL fractions. A recent meta-analysis examining 28 randomized control trials concluded that egg consumption is associated with an increase in total cholesterol in tandem with increased HDL [33]. An intake of 2-3 eggs a day for fourteen weeks was shown to reduce LDL and promote an increase in HDL in healthy adults [34]. Additionally, consumption of eggs has been shown to improve HDL levels in adults with metabolic syndrome when supplemental with moderate carbohydrate restriction [35]. In the present study, HDL values remained unchanged in both groups.

Triglycerides (TG) represent an important biomarker for assessing cardiometabolic health. For instance, independent of cholesterol levels, elevated TGs are shown to be a risk factor for the development of atherosclerosis[36]. As cited earlier, a meta-analysis examining the relationship between egg consumption and lipid profiles in 28 RCTs concluded there was no observable change in triglycerides when compared to low egg consumption [33]. These observations resemble the findings in the present study showing no change within both groups.

Eggs are natural source of vitamin D. The majority of vitamin D exists inside of the yolk and the total amount can be further increased via feed supplementation [37]. Eggs are shown to

contain about 41 IU of vitamin D. Two eggs alone would provide about 20% of the recommended daily allowance for vitamin D, thus, eggs represent a potential candidate for improving serum vitamin d status. Low socioeconomic status has been linked to poor vitamin D status among adults, thus, those experience food insecurity may be potentially vulnerable [38]. In the present study, there was no difference in baseline serum vitamin D (25OH) values between FI and FS adults. In addition, no significant change was observed in either group following the intervention.

Reports on poor diet quality and lower intake of micronutrients such as folate, iron, are consistent throughout the literature [23, 25, 39, 40]. However, the present study did not find any difference in baseline value between both FI and FS populations. The only differences in dietary intake observed throughout the intervention was in cholesterol and fiber. Both groups had an increase in total cholesterol intake that was significantly higher when compared to baseline values. This finding was expected due to the large amount cholesterol found within eggs [41]. FI and low-income adults are reported to consume less fiber when compared to FS adults [42]. Although not significant at baseline, FS adults ended the study with a higher consumption of fiber when compared to FI adults. However, a recent review examining the associations between FI and nutrient intake failed to find any associations between FI and fiber intake [40]. Therefore, additional research is needed to clarify whether or not FI populations are at risk of lower fiber intake.

There are multiple limitations in the present study. First, we relied on self-reported food recalls and diaries to measure dietary intake, which may lead to inaccuracies in intake reporting [45]. In addition, we did not control for energy intake, however, there was no significant differences in energy intake between both groups. Second, we did not control for seasonal components, which may lead to misleading findings regarding serum vitamin D levels. Lastly, the findings of this observational study may not translate to the entire food secure/insecure population, especially in urban environments. For instance, we did not control for age or gender,

all of the research participants were residents of one region of the country, and our overall sample size was low.

The results of this study indicate that barriers to consuming dietary protein exist among homeless and low-income adults. Cost and convenience are the two most important barriers among this population subgroup; persons reporting barriers to protein access also reported higher levels of FI. In addition, regular consumption of eggs for twelve weeks does not impact body weight, plasma glucose, lipids, or vitamin D in either FI or FS adults. However, a larger study population and longer intervention period are needed.

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FIGURES

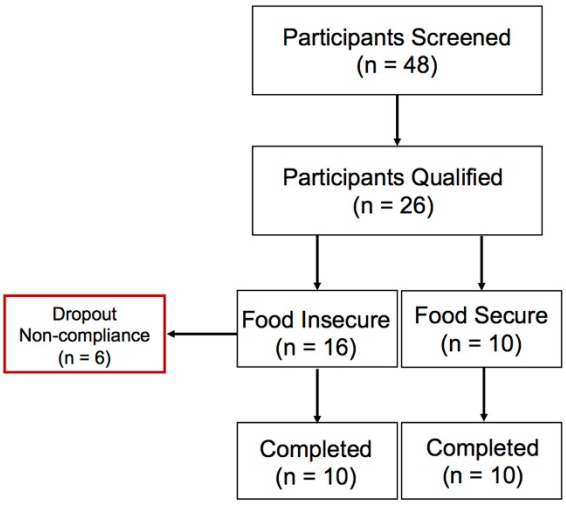

Figure 1. Flowchart visualizing screening and enrollment process of the nutrition intervention study.

TABLES

Table 1:

Study 1 survey results: Participant characteristics (n = 94)

Characteristics	
Age, (years)	50.3 ± 13.3
Sex, (male:female)	63:33
Ethnicity, n	
Caucasian	76
African American	16
Other	6
American Indian	1
Food Insecurity Severity, %	
No Insecurity	20
Low Insecurity	16
Moderate Insecurity	32
High Insecurity	33
Current Living Situation, %	
Home/apartment	76
Transitional Housing	16
Homeless	6
Family & Marital Status, %	
Single	49
Couple without Children	14
Single with Children	11
Couple with Children	14
Other	4
Health Insurance, %	
Yes	71
No	25
Military Service, %	
Yes	41
No	59

Table 2:

Study 1 survey results: Barriers to protein consumption and eating behaviors.

How often per week do you consume protein? (%)	
1-2 times	16
3-4 times	18
5 or more times	67
Do you think overall that protein is good for you? (%)	
No	1
Yes	99
Do you think eggs are a good source of protein? (%)	
No	4
Yes	96
Do you have barriers that prevent you from consuming protein? (%)	
No	26
Yes	74
Barriers to consuming protein: Total (%)	
Cost	58
Convenience	25
Dislike	3
Unsure how to prepare	7
No means to cook/prepare	16
Too busy	21
Other	11
Do you have access to a refrigerator or freezer? (%)	
No	19
Yes	78
Do you have access to a stove, oven, or microwave? (%)	
No	17
Yes	83
Where do you consume the majority of your meals? (%)	
At home	56
In car	4
At fast food restaurant	3
At community meals/shelters	28
Sit down restaurant	6
At convenience store	2
At other	20

Table 3:

Study 1 survey results: Cardiometabolic risk factors.

Characteristic	
BMI (n=84), kg/m^2	31.6 ± 9.1
Blood pressure category (n=84), %	
Normal (≤120/80)	12
Prehypertension (>121-139/80-90)	56
Hypertension (>140/90)	32
Blood glucose category (n=73), %	
Normal (≤99 mg/dL)	60
High (≥100 mg/dL)	40

Values are presented as means ± SD. BMI, body mass index.

Table 4:

Study 2: Participant characteristics

Characteristic	FI (n=10)	FS (n=10)	p-value
Total			
Female, n	8	9	
Male, n	2	1	
Age, years	38.0 ± 5.2	38.4 ± 4.1	0.77
Ethnicity			
Caucasian	5	9	
African American	3	1	
Hispanic	1	-	
Asian	1	-	

Values are presented as means ± SD. FI, food insecure group; FS, food secure group

Table 5:

Study 2: Participant anthropometrics

	FI		FS	
	Baseline	Week 12	Baseline	Week 12
Weight, kg	73.9 ± 21.1	73.3 ± 20.5	79.3 ± 16.2	78.3 ± 14.8
BMI, kg/m^2	28.0 ± 8.8	27.8 ± 8.6	28.1 ± 5.1	27.6 ± 4.2
WHR	0.90 ± 0.05	0.90 ± 0.07	0.84 ± 0.08	0.84 ± 0.08

Values are presented as means ± SD. FI, food insecure group; FS, food secure group; BMI, body mass index; WHR, waist to hip ratio.

Table 6:

Study 2: Cardiometabolic markers and Vitamin D

	FI		FS	
	Baseline	Week 12	Baseline	Week 12
Glucose, mg/dL	88.0 ± 12.2	88.1 ± 11.5	82.6 ± 10.3	95.3 ± 10.3
Cholesterol, mg/dL	136.7 ± 44.6	139.3 ± 52.3	158.6 ± 48.3	140.4 ± 29.2
HDL, mg/dL	102.9 ± 27.2	101.9 ± 24.2	83.5 ± 12.7	84.6 ± 18.6
Triglycerides, mg/dL	50.2 ± 50.6	43.8 ± 20.8	40.9 ± 57.9	43.8 ± 46.8
Vitamin D (25OH), ng/dL	25.9 ± 9.5	32.4 ± 11.9	30.3 ± 11.2	30.1 ± 6.7

Values are presented as means ± SD. FI, food insecure group; FS, food secure group; HDL, high density lipoprotein.

Table 7:

Study 2: Energy and macronutrient intake

	FI				FS		
	Baseline	Week 0-4	Week 4-8	Week 8-12	Baseline	Week 0-4	
Energy, Kcal	2056.7 ± 996.1	1807.0 ± 363.0	1696.0 ± 459.9	1984.1 ± 871.0	1780.3 ± 447.8	1800.3 ± 389.5	1
Carbohydrate, g	222.6 ± 128.5	177.8 ± 54.2	174.0 ± 65.4	171.8 ± 53.4	182.7 ± 47.0	197.2 ± 48.4	
Fat, g	86.2 ± 41.4	80.3 ± 18.4	76.1 ± 21.4	106.7 ± 80.7	77.9 ± 21.3	78.6 ± 23.1	
Protein, g	91.4 ± 35.6	89.6 ± 20.6	77.5 ± 24.8	85.7 ± 25.3	86.1 ± 29.5	78.4 ± 17.5	
Kcal from CHO, %	41.9 ± 8.1	38.4 ± 6.9	39.7 ± 6.9	35.9 ± 7.3	40.7 ± 6.5	42.3 ± 6.6	
Kcal from Fat, %	37.4 ± 8.0	39.7 ± 5.6	40.5 ± 6.7	44.3 ± 8.1	38.7 ± 4.8	38.8 ± 5.5	
Kcal from Protein, %	19.2 ± 4.1	20.8 ± 3.5	18.8 ± 2.9	19.3 ± 4.0	19.5 ± 3.8	17.6 ± 1.6	
Animal Protein, g	67.0 ± 21.3	77.9 ± 148.6	57.9 ± 19.5	63.9 ± 18.6	61.2 ± 25.6	78.1 ± 29.0	
Vegetable protein, g	24.5 ± 16.8	18.8 ± 6.2	19.5 ± 7.7	21.8 ± 10.0	25.0 ± 10.6	24.4 ± 9.2	
Total sugar, g	87.7 ± 71.4	64.7 ± 26.5	66.7 ± 33.8	57.1 ± 27.0	55.8 ± 31.2	69.9 ± 33.9	
Total fiber, g	16.0 ± 8.5	11.1 ± 5.5*	13.6 ± 5.9	12.5 ± 5.0	17.5 ± 6.	19.2 ± 5.2	
Omega 3 FA, g	2.0 ± 1.6	1.6 ± 0.7	1.6 ± 0.8	3.1 ± 3.2	1.9 ± 1.1	1.8 ± 0.5	
Cholesterol, mg	389.1 ± 203.5^{a}	648.8 ± 178.7^{bc}	570.4 ± 108.8^{abc}	624.7 ± 161.8^{c}	355.8 ± 221.3^{a}	453.6 ± 117.0^{ab}	5

Values are presented as means ± SD. FI, food insecure group; FS, food secure group. Lower case letters indicate differences within groups.

Table 8:

Study 2: Micronutrient intake

	FI				FS		
	Baseline	Week 0-4	Week 4-8	Week 8-12	Baseline	Week 0-4	Week 4-
Vitamin D, µg	3.5 ± 0.8	6.5 ± 4.2	5.9 ± 3.2	4.9 ± 1.8	7.6 ± 12.5	5.3 ± 4.0	5.7 ± 3.3
Retinol, µg	365.8 ± 113.7	506.0 ± 176.2	435.6 ± 91.2	510.8 ±228.9	357.3 ± 156.8	505.9 ± 221.5	528.8 ± 22
Vitamin K, µg	108.2 ± 114.9	117.8 ± 111.2	84.5 ± 55.7	125.2 ± 94.2	144.8 ± 132.5	116.9 ± 60.7	124.5 ± 63
Cobalamin, µg	4.0 ± 1.7	4.8 ± 1.3	4.9 ± 1.9	4.0 ± 1.2	3.5 ± 1.9	4.0 ± 0.7	4.5 ± 1.3
Total Folate, g	315.6 ± 139.2	327.8 ± 98.0	299.8 ± 86.6	335.5 ± 90.7	357.5 ± 147.1	396.3 ± 122.5	372.0 ± 12
Thiamin, mg	1.5 ± 0.7	1.3 ± 0.3	1.5 ± 0.7	1.5 ± 0.5	1.5 ± 0.5	1.6 ± 0.6	1.3 ± 0.5
Riboflavin, mg	1.8 ± 0.6	1.9 ± 0.4	3.3 ± 4.5	1.9 ± 0.4	1.9 ± 0.9	2.1 ± 0.5	2.0 ± 0.6
Niacin, mg	28.3 ± 20.9	19.8 ± 3.0	17.7 ± 7.6	21.4 ± 8.8	26.9 ± 12.3	22.0 ± 6.4	21.6 ± 8.
Vitamin B-6, mg	2.1 ± 1.0	1.5 ± 0.2	1.5 ± 0.6	1.5 ± 0.6	1.9 ± 0.6	1.7 ± 0.4	1.8 ± 0.6
Ascorbic Acid, mg	63.2 ± 49.6	36.3 ± 20.5	64.7 ± 45.9	45.5 ± 29.0	51.4 ± 33.8	76.0 ± 43.3	55.8 ± 33
Calcium, mg	745.2 ± 286.9	789 ± 284. 7	718.6 ± 160.8	698.5 ± 181.8	849.0 ± 445.1	853.2 ± 257.2	755.4 ± 25
Magnesium, mg	247.7 ± 106.1	196.7 ± 65.3	186.3 ± 82.0	211.8 ± 84.4	237.2 ± 77.9[a]	253.2 ± 56.8[ab]	257.1 ± 93.
Iron, mg	12.5 ± 5.3	11.5 ± 2.4	11.3 ± 4.2	11.9 ± 2.9	11.6 ± 4.4	13.4 ± 4.3	13.2 ± 5.
Zinc, mg	11.0 ± 4.4	11.2 ± 2.8	10.0 ± 3.3	10.2 ± 3.4	8.1 ± 3.3[a]	10.4 ± 2.0[ab]	10.8 ± 3.8
Sodium, mg	3404.6 ± 1590.2	3696.4 ± 855.7	3514.0 ± 645.8	3738.9 ± 1266.7	3384.8 ± 1268.1	3406.2 ± 926.2	3167.5 ± 85

Values are presented as means ± SD. FI, food insecure group; FS, food secure group. Lower case letters indicate differences with groups.

Table 9:

Study 2: Food groups serving intake

	FI				FS			
	Baseline	4 weeks	8 weeks	12 weeks	Baseline	4 weeks	8 weeks	12 weeks
Fruits, Total serving,	1.7 ± 1.8	1.3 ± 1.1	1.6 ± 1.2	1.5 ± 0.7	0.9 ± 1.1	1.2 ± 1.2	1.6 ± 1.3	1.5 ± 1.3
Vegetables, Total serving,	2.0 ± 1.5	1.7 ± 1.0	1.4 ± 0.9	1.6 ± 0.8	1.4 ± 1.4	1.3 ± 0.9	1.5 ± 1.1	1.0 ± 0.9
Meat, Eggs, Nuts, and Seeds, per serving	5.6 ± 5.7	6.9 ± 3.3	7.1 ± 3.5	4.7 ± 2.0	3.6 ± 3.0	5.5 ± 1.5	5.6 ± 1.6	5.6 ± 3.3
Grains, Total serving,	4.8 ± 2.4	5.8 ± 2.8	5.6 ± 2.1	5.8 ± 1.6	6.5 ± 2.1	7.4 ± 3.8	7.3 ± 2.9	6.5 ± 2.3
Dairy, Total serving,	1.7 ± 1.2	1.4 ± 0.7	1.5 ± 0.9	1.9 ± 1.0	2.2 ± 1.2	1.8 ± 1.0	1.9 ± 1.2	1.9 ± 1.6
Sweets, Total serving	1.7 ± 1.2	1.4 ± 0.7	1.5 ± 0.9	1.9 ± 1.0	2.2 ± 1.2	1.8 ± 1.0	1.9 ± 1.2	1.9 ± 1.6
Fats, Total serving	1.7 ± 2.7	5.2 ± 5.2	4.5 ± 2.7	5.5 ± 5.7	2.2 ± 1.8	4.0 ± 2.7	3.6 ± 2.0	3.1 ± 1.9

Values are presented as means ± SD. FI, food insecure group; FS, food secure group.

CHAPTER 2

Impact of Daily Egg Consumption on Food Insecure and Secure Children: A Pilot Study

Abstract

Objective: The objectives of this study were to 1) define the nutritional impact of habitual egg consumption in food insecure children and 2) determine if habitual egg consumption influences markers of cardiometabolic health and body composition.

Methods: Twenty children were recruited to participate in a 12-week dietary intervention. Each participant was required to consume two eggs per day, five days per week. Participates were either assigned to a food insecure: (FI; n=10; 7 male, 3 female; 10.1 ± 2.0 y; 38.0 ± 16.2 kg; 144.0 ± 16.8 cm) or food secure (FS; n=10; 8 female, 2 male; 9.8 ± 2.2 y; 38.6 ± 12.0 kg; 145.6 ± 14.0 cm) group. FI was determined using the USDA's six item Short Form Food Security Survey. Data was collected at baseline, 4-, 8-, and 12-weeks. Fasting plasma and serum samples were collected at each visit and glucose and lipids were analyzed using commercially available kits. Height and weight were recorded at each time point and a dual-energy x-ray absorptiometry (DXA) was performed at baseline and week 12. Dietary intake was also collected via food recalls at 4-, 8-, and 12-weeks. Data were also analyzed using analysis of covariance with group and gender as the factors, time as the repeated measure, and BMI percentile as the covariate. All statistical analyses were carried out using PROC GLIMMIX in SAS® (version 14.1) and Prism GraphPad Software (version 6.0 La Jolla, CA).

Results: After controlling for sex, habitual egg consumption had no effect on plasma glucose, cholesterol, HDL, triglycerides, or serum Vitamin D in either FI or FS children. Differences in baseline serum 25(OH)D were observed between FI and FS males (FI, 20.8 ± 2.9; FS, 42.4 ± 10.7 ng/dL) ($P<0.05$). In addition, significant increases were observed in both groups for weight, height, BMC, and BMD.

Conclusions: The results of this study indicate that habitual intake of eggs has no impact on cardiometabolic outcomes. The habitual intake of eggs for twelve weeks may be associated with improvements in growth parameters as evidenced by increased bone mineral density, bone mineral content, and height in both groups. In addition, egg consumption may increase dietary intake of vitamin D and retinol in FI children. However, a larger study population and longer intervention period are needed. NCT03412825.

Introduction

In the United States, about 12.3% households are considered food insecure [1], which impacts 1 in 5 children [2]. Food insecure children are at an increased risk for developing obesity and the associated metabolic complications due to irregular dietary and behaviors including high energy intake, disrupted eating patterns, and reduced physical activity [3-6]. Additionally, food insecure children are at greater risk for depression, anxiety, substandard academic performance, and suicidal tendencies [7-10]. Coping strategies for food insecure households include sacrificing dietary quality for quantity [11]. An example of this behavior includes the substitution of protein, fruits, and vegetables for grains and starches [11]. Two of the most well-known scales for measuring dietary quality include the Healthy Eating Index and The Nutrient Rich Foods Index [12,13]. Both scores are shown to be reduced in children belonging to low socioeconomic homes [14]. According to the latest Food Acquisition and Purchase Survey report published by the USDA, children from FS households are more likely to consume total protein and fruit when compared to children from FI households [15].

Childhood dietary habits impact eating preferences, behaviors, and BMI into adulthood [16]. Establishing dietary interventions that improve dietary quality and protect from the negative health outcomes associated with childhood food insecurity are critical for maintaining health throughout the lifecycle. Eggs may be an effective food choice for combating the nutritional disparities observed among food insecure children. For example, eggs are affordable and can

be prepared in variety of ways. In addition, eggs are a complete source of dietary protein. One egg contains 6 grams of high biological value protein as indicated by a Protein Digestibility Corrected Amino Acid Score value of 100 [17]. Furthermore, eggs are rich in micronutrients and contain up to 17 different vitamins and minerals such as vitamin D, A, folate, B12, magnesium, and iron [18]. For these reasons, daily egg consumption may be an appropriate dietary strategy for protecting food insecure children from the negative health outcomes associated with food insecurity.

Therefore, the overall objective of this study was to explore the nutritional benefits of egg consumption in food insecure children. We hypothesize that dietary consumption of two eggs a day for twelve weeks will improve cardio-metabolic measurements, vitamin D status, and growth parameters in children living in a food insecure environment.

Methods

Participants. A total of twenty children from food insecure (FI; n=10; 7 male, 3 female; 10.1 ± 2.0 y; 38.0 ± 16.2 kg; 144.0 ± 16.8 cm) and food secure (FS; n=10; 7 female, 3 male; 9.8 ± 2.2 y; 38.6 ± 12.0 kg; 145.7 ± 14.0 cm) households 7-13 years of age were recruited to participate in the study. Participant characteristics are presented in (**Tables 1 and 2)**. Participants were recruited on a rolling basis to participate in this randomized, controlled dietary intervention. Participants were recruited throughout Northwest Arkansas via the daily University of Arkansas Newswire, word of mouth, social media, and the community through the distribution of fliers. The parents underwent an initial phone screening to determine eligibility of their child(ren). During the phone screening, food security status was determined using the USDA Six-Item Short Form of the Food Security Survey Module or if they were currently participating in the Supplemental Nutrition Assistance Program (SNAP). Participants with diet-related metabolic conditions, dietary restrictions, food allergies, or requiring medication were not able to participate in the study. In addition, participants were required to have access to a stovetop, hot

plate, or microwave in order to safely prepare eggs. Written consent was obtained from parents/guardians and written assent was obtained from participants prior to beginning the study. Ethical approval for the study design was approved by the Office of Research Compliance Institution Review Board of the University of Arkansas (Fayetteville, AR; IRB Protocol #1709049334; NCT03412825)

Dietary Intervention. Participants were required to follow a dietary intervention which included the consumption of 10 eggs per week (2 eggs a day for a total of 5 days a week) for twelve weeks. Participants were required to report the Center for Human Nutrition at the University of Arkansas at baseline, 4, 8, and 12 weeks of data collection. Participants were required to fast overnight (10-12 hours) prior to each data collection points. Height and weight were recorded and a fasting plasma and serum sample were collected at baseline, 4, 8, and 12 weeks. Body composition was measured at baseline and 12 weeks using dual x-ray absorptiometry (DXA). Participants were required to maintain one, 3-day food record for every four weeks for twelve weeks, which were thoroughly reviewed by a registered dietitian. To ensure compliance, all eggs were provided, and participants and their families were provided with monthly gift cards to assist with groceries. Parents/guardians were also required to turn in receipts to ensure that the money was spent on groceries. Educational materials and regular dietary counseling on how to prepare, handle and store eggs were provided to the parent/guardian of the child prior to beginning the intervention and upon request throughout the 12-week intervention period.

Anthropometric Assessment. Body height and body weight were measured in the fasted state at baseline using a calibrated balance scale and stadiometer (Detecto, St. Louis, MO). BMI was calculated as weight (kg) divided by height (m) squared. Body composition, including fat-free mass (FFM), was assessed by dual energy x-ray absorptiometry (DXA; Lunar Prodigy, GE Healthcare).

Cardiometabolic biomarkers. Fasting plasma and serum samples were collected following a 10-12 hour fast by a licensed phlebotomist. Following collection, samples were immediately centrifuged at 4° C for 15 minutes at 1800 x g and stored at -80°C. Plasma glucose (Cayman Chemical Company, item #10009582), triglycerides (Cayman Chemical Company, item #10010303), total cholesterol (Cayman Chemical Company, 10007640), and high-density lipoproteins (Abcam item #ab125961) concentrations were determined using commercially available colorimetric and fluorometric kits using a Biotek Synergy HTX multi-mode plate reader (BioTek Instruments Inc. Winooski, VT USA). Serum 25-OH-Vitamin D was measured and analyzed via liquid chromatography-mass spectrometry (Heartland Assays, Ames, IA, USA).

Dietary assessment. Prior to beginning the study, participants were assisted in a 24-hour dietary recall [19]. Food scales and measuring devices were provided at the beginning of the study. Participants were required to maintain a 3-day (2 week days and 1 weekend day) food record for each month of the study. Dietary records were monitored each month for compliance by a registered dietitian. Dietary intake data were analyzed using the Nutrition Data System for Research software (NDSR; NDS version 2018, Nutrition Coordinating Center, University of Minnesota, Minneapolis, MN) to determine average energy and macronutrient intake.

Statistical analysis. Results are reported as means ± SD $P < 0.05$ was considered statistically significant. One-way ANOVA was used to analyze values collected at time-points within diet groups and two-way ANOVA was used to compare values collected at time-points between groups. Data were also analyzed using analysis of covariance with group and gender as the factors, time as the repeated measure, and BMI percentile as the covariate. Except for fat tissue percentage all response variables were assumed to follow a gamma distribution. Fat tissue percentage was converted to a proportion and was assumed to follow a beta distribution. Where appropriate, differences among least square means were determined using a protected

least significant difference at the five percent level. All statistical analyses were carried out using PROC GLIMMIX in SAS® (version 14.1) and Prism GraphPad Software (version 6.0 La Jolla, CA).

Results

Anthropometrics. There were significant changes in body composition in both groups from pre- and post-dietary intervention. Participant anthropometrics are presented in **Table 2.** Body weight and height significantly increased between baseline and week 12 in both groups ($P < 0.05$). No significant changes were observed in body fat percentage, fat free mass (FFM), and lean mass (LM) between both groups at baseline and week 12. Significant increases in bone mineral content (BMC) and bone mineral density (BMD) were observed in both groups (0.05).

Cardiometabolic Markers. Fasting plasma cardiometabolic markers are shown in **Table 3**. No significant changes were observed in plasma glucose values at baseline and week 12 between both groups. However, a significant increase was observed in the subject population as a whole ($P < 0.05$). There were no significant group differences in plasma cholesterol, HDL, triglycerides and serum 25(OH)D values at baseline or throughout the 12-week intervention. However, there were significant differences in triglycerides between sex of both groups at baseline and week 12 (P value < 0.05).

Dietary Intake. Energy and macronutrient composition obtained from 24-h and 3-d food logs are displayed in **Table 4**. No significant differences were observed in energy intake prior to beginning the study and throughout the intervention. Changes in micronutrient intake were observed throughout the twelve weeks of the study as shown in **Table 5**. Intake of vitamin D significantly increased from baseline in the FI group ($P < 0.05$), however, no change was observed in the FS group. In addition, increased retinol intake from baseline was observed in the FI group, however, no change was observed in the FS group. Dietary intake of zinc increased in the FS group, however, no change was observed in the FI group. No significant

differences were observed in the intake of food group servings at baseline or throughout the length of the study in both groups as shown in **Table 6**.

Discussion.

This study aimed to compare outcomes related to cardiometabolic health and growth parameters in FI and FS children following a 12-week dietary intervention of 2 eggs a day for 5 days a week. Positive outcomes in growth parameters such as height, BMD, BMC were observed in both groups following the intervention. There were no differences in weight or BMI between both groups of FI and FS children at baseline and week-16. These results are similar to the findings in school aged children following 6 months of consuming multiple eggs a day [20,21]. The increase in BMD and BMC are of significance due to their potential impact on bone health into adulthood [22]. These findings are of importance given that FI children may be at an increased risk for lower BMD values when compared to FS children. In a cross-sectional study examining DXA results from children aged 8-19 years old, FI boys were shown to have lower BMC scores when compared to their FS counterparts [23].

Poor glycemic control throughout childhood and adolescence is shown to be a risk factor for the onset and progression of metabolic disease throughout adulthood [24,25]. In a longitudinal study involving over 300 participants, researchers identified irregular fasting glucose values during childhood as a key predictor for cardiovascular risk and atherosclerosis later on in life [26]. In another retrospective cohort study, researchers identified irregular glucose homeostasis during childhood as a predictor for the symptoms of the metabolic syndrome later on in life [27]. Although data is limited, children from FI and low-income homes may be at a greater risk for irregular glucose metabolism when compared to children from food secure homes. In a study examining NHANES data from 2003-2014, researchers identified both SNAP enrollment and irregular glucose metabolism as common characteristic of FI [28]. Furthermore, in a sample of over 300 children, identified disproportional glucose and insulin values between

FI and FS children [29]. Although insulin was not measured in the present study, we did observe changes in fasting glucose values. Interestingly, we observed a significant increase in fasting glucose values between baseline and week 12 in both FI and FS children, however, when using BMI percentile as a covariant, the values are within levels considered normal [30]. Epidemiological studies have identified potential associations between egg intake and the risk for type 2 diabetes [31] however, randomized clinical trials show that risk factors associated with egg consumption and diabetes may be explained by reductions in overall dietary quality and macronutrient content [31-33]. In addition, a recent longitudinal study concluded that long term egg intake showed no adverse on effect on glucose levels in children throughout adolescence [34]. Collectively, this warrants further investigation into the relationship between fasting glucose levels and childhood FI.

Eggs represent one of the highest dietary cholesterol containing foods [35]. In fact, eggs are estimated to be responsible for about 25% of daily cholesterol intake in children [18]. Two eggs alone have over 300mg of cholesterol, the former daily recommended amount which was removed in the 2015-2020 Dietary Guidelines for Americans. The impact of dietary eggs on cholesterol levels is debatable [36,37]. The majority of observational studies on cholesterol and egg consumption has been performed in adults and little is known on the impact involving children. In a study examining the cardiometabolic impact of 2 eggs a day for 30 days in children aged 8-12 showed an increase in total cholesterol, however, the LDL:HDL ratio remained consistent. The parallel increase of HDL with total cholesterol led the researchers to conclude there was no additional risk for coronary artery disease [38]. In the present study, 12 weeks of habitual egg intake did not lead to any significant changes in plasma cholesterol in both groups of children. Levels of HDL were reduced in FI children following the conclusion of the study, however, their values remained within the normal reference value. According to NHANES data collected from over 7000 children aged 12 through 18, FI was associated with reduced HDL and plasma triglycerides when compared to FS children [39]. Collectively, this

placed FI children at a greater risk for developing symptoms related to metabolic syndrome. However, no significant findings were found regarding baseline and week 12 triglyceride levels between the two groups.

Reduced healthy eating index scores and dietary diversity can leave FI children ask risk for suboptimal micronutrient intake. Additionally, FI children are shown to spend more time inside than compared to FS children [40,41]. Low dietary diversity coupled with minimal sun exposure may leave FI children at risk for vitamin D deficiency. Not only is low plasma vitamin D detrimental to bone health, it also shown to be associated with behavioral problems such as anxiety and depression throughout childhood [42,43]. Eggs represent an excellent source for consuming Vitamin D [44]. Two eggs a day contains about 20% of RDA for vitamin D. In a recent analysis comparing diet records from over 3000 egg consumers aged 2-18 with non-egg consumers concluded that egg consumers had higher daily intakes of vitamin d than their non-egg eating counterparts [45]. In the present study, there was no difference between serum 25(OH)D levels in FI and FS children. However, when separated by gender, FI males were shown to have lower baseline and week-12 values when compared to FS males. It should be noted that the FI male group had the highest African American population within the study. Compared to Caucasian children, African American children are shown to be at a greater risk for low serum 25(OH)D [46]. This observation warrants further attention for food insecure families, especially during the winter months and for those living north of the 37^{th} latitude [47].

Children from food insecure households may experience irregular eating patterns and behaviors when compared to food secure children [48]. Data obtained from dietary recalls in children aged 9-11 showed findings that food insecurity was associated with elevated caloric intake in female children when compared to food secure female children [4]. Furthermore, researchers examining the dietary intake of fourth and fifth graders identified elevated energy intake among FI children when compared to their counterparts [6]. Over time, elevated energy intake may lead to energy imbalance, thus, causing weight gain and ultimately leading to

obesity. Based off of findings when comparing feeding behaviors between FI and FS children, researchers concluded that children are 5 times more likely to become obese if FI [49]. However, the present study did not find any differences in energy intake between FI and FS children. Our lab has identified FI adults as an at-risk population for lower protein intake due to perceived barriers for consumption. However, we did not observe any differences in protein intake or any other macronutrient between both groups of children.

There are multiple factors that are shown to influence dietary quality in children. One of those being low income [50,51]. Compared to children from FS households, FI children are shown to consume fewer servings vegetables and fruits [52]. However, in the present study, there was no difference in fruit and vegetable intake or any other food group between FI and FS children. In addition, FI children are shown to be more at risk for inadequate micronutrient intake [53], however, our findings indicate no difference between the groups at baseline.

There are multiple limitations in the present study. For dietary analysis, we used self-reported food recalls and diaries, which may lead to inaccurate findings [54]. Second, we did not control for seasonal components, which may lead to misleading findings regarding serum vitamin D levels [55]. We did not have a control population to compare our findings to, thus making it difficult to draw any conclusions in regard to the effect of habitual egg intake on growth parameters or cardiometabolic markers in children. In addition, the small sample size of both groups acts as a limitation for acquiring statistical significance. In most cases, the children may have lacked the ability to prepare meals on their own, therefore strict parental collaboration was required in order for children to maintain the studies' dietary protocol. Lastly, we did not control for sex, therefore, the findings of this observational study may not translate to the entire food secure/insecure population.

6. Conclusion

In conclusion, the results of the present study indicate that regular intake of eggs has no impact on cardiometabolic outcomes. The habitual intake of eggs for twelve weeks may be associated with improvements in growth parameters as evidenced by increased bone mineral density, bone mineral content, and height in both groups. In addition, egg consumption may improve dietary intake of vitamin d and retinol in FI children.

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FIGURES

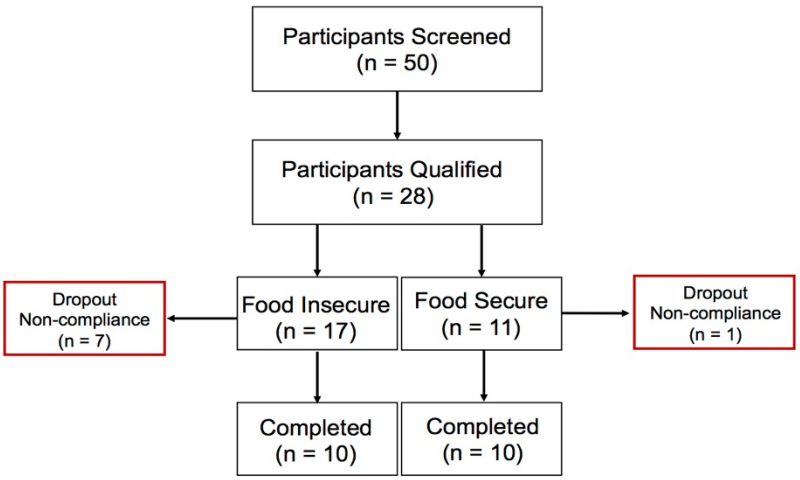

Figure 1. Flowchart visualizing screening and enrollment process of the nutrition intervention study.

TABLES

Table 1:
Participant characteristics

	FI (n=10)		FS (n=10)	
Characteristic	Male (n=7)	Female (n=3)	Male (n=2)	Female (n=7)
Age, years	10.0 ± 2.4	10.3 ± 1.0	7.0 ± 0.0	10.5 ± 2.0
Ethnicity				
Caucasian	3	2	2	6
African American	3	-	-	1
Hispanic	1	-	-	-
Asian	-	1	-	-

Values are presented as means ± SD. FI, food insecure group; FS, food secure group.

Table 2:

Participant characteristics: DEXA Results

	FI				FS			
	Male		Female		Male		Female	
	Baseline	Week 12	Baseline	Week 12	Baseline	Week 12	Baseline	Week 12
Weight, kg	43.4 ± 15.3	44.0 ± 15.5	25.6 ± 5.0	26.5 ± 4.9	29.0 ± 8.1	30.4 ± 8.2	41.0 ± 10.8	42.4 ± 11.6
Height, cm	149.1 ± 15.3	150.3 ± 15.3	132.0 ± 9.9	133.2 ± 10.0	133.5 ± 12.0	135.0 ± 12.0	148.6 ± 11.8	150.5 ± 12.4
Body Mass Index, kg/m^2	18.8 ± 3.6	18.8 ± 3.4	14.5 ± 0.8	14.7 ± 0.7	15.8 ± 1.7	16.3 ± 1.6	18.4 ± 3.5	18.5 ± 3.6
Body Mass Index, percentile	60.4 ± 30.7	59.6 ± 31.4	6.0 ± 3.4	6.8 ± 2.8	43.3 ± 30.7	50.4 ± 26.6	50.2 ± 32.7	48.5 ± 33.1
Tissue Fat, %	19.4 ± 10.1	19.5 ± 10.4	18.3 ± 2.1	19.3 ± 0.8	12.7 ± 3.0	13.5 ± 3.2	24.9 ± 7.9	25.9 ± 8.8
Fat Free Mass, kg	34.2 ± 11.6	35.4 ± 12.8	25.7 ± 3.5	20.8 ± 3.9	25.6 ± 5.8	25.4 ± 6.1	30.3 ± 7.0	31.3 ± 7.6
Lean Mass, kg	32.4 ± 10.8	27.7 ± 15.2	19.7 ± 3.6	19.9 ± 3.7	24.4 ± 5.4	24.1 ± 5.7	28.8 ± 7.0	29.7 ± 7.1
Bone Mineral Content, kg	1.78 ± 0.78	1.84 ± 0.79	0.93 ± 0.14	0.95 ± 0.15	1.22 ± 0.35	1.26 ± 0.35	1.52 ± 0.47	1.58 ± 0.48
Bone Mineral Density, g/cm	1.02 ± 0.15	1.03 ± 0.16	0.83 ± 0.01	0.84 ± 0.01	0.95 ± 0.05	0.95 ± 0.05	0.92 ± 0.06	0.96 ± 0.08

Values are presented as means ± SD. FI, food insecure group; FS, food secure group.

Table 3:

Cardiometabolic markers and Vitamin D

	FI						FS
	Male		Female		Male		
	Baseline	Week 12	Baseline	Week 12	Baseline	Week 12	
Glucose, mg/dL	87.2 ± 13.5	103.3 ± 8.5	93.5 ± 7.0	97.3 ± 7.1	83.6 ±11.7	95.1 ± 5.1	9
Cholesterol, mg/dL	122.3 ± 42.5	137.4 ± 54.9	170.1 ± 13.2	143.7 ± 33.6	131.3 ± 41.2	145.5 ± 30.5	16
HDL, mg/mL	105.7 ± 30.3	87.3 ± 16.0	113.1 ± 2.7	110.1 ± 6.7	83.7 ± 6.2	83.9 ± 3.4	10
Triglycerides, mg/dL	22.6 ± 9.5	29.8 ± 13.3	25.9 ± 10.5	38.3 ± 3.8	73.4 ± 50.7	31.2 ± 16.0	1
Vitamin D (25OH), ng/dL	20.9 ± 6.3*	20.0 ± 8.5*	21.4 ± 9.4	26.2 ± 7.6	44.0 ± 10.3**	44.6 ± 13.7**	3

Values are presented as means ± SD. FI, food insecure group; FS, food secure group. HDL, high density lipoprotein. * indicates sign
and FS groups at baseline and week 12 time-points, $P < 0.05$

Table 4:

Energy and macronutrient intake

	FI				FS		
	Baseline	4 weeks	8 weeks	12 weeks	Baseline	4 weeks	8
Energy, kcal	1655 ± 495	1896 ± 517	1762 ± 435	1735 ± 79	1710 ± 346	2080 ± 525	18
Carbohydrate, g	194.1 ± 62.4	199.0 ± 47.8	192.5 ± 59.4	197.1 ± 30.0	223.1 ± 51.7	247.1 ± 68.4	224
Fat, g	70.3 ± 40.4	89.4 ± 32.1	76.6 ± 24.9	77.8 ± 22.1	67.7 ± 16.4[a]	89.6 ± 24.3[ab]	82.
Protein, g	67.5 ± 35.4	77.1 ± 25.7	78.1 ± 26.9	65.8 ± 18.5	57.9 ± 20.4	74.5 ± 16.4	69
Kcal from CHO, %	36.0 ± 10.0	42.2 ± 7.1	43.9 ± 9.2	45.5 ± 7.0	51.3 ± 7.0	45.5 ± 5.2	46
Kcal from Fat, %	35.6 ± 10.2	40.9 ± 5.7	38.0 ± 7.1	39.0 ± 5.7	35.3 ± 5.1	39.4 ± 4.5	38
Kcal from Protein, %	15.8 ± 5.7	16.9 ± 2.2	18.1 ± 3.1	15.5 ± 3.0	13.3 ± 3.3	15.1 ± 1.4	15
Animal Protein, g	46.9 ± 29.9	57.4 ± 24.8	60.7 ± 24.9	47.3 ± 18.7	36.6 ± 18.8	46.4 ± 12.5	47
Vegetable protein, g	20.6 ± 13.0	19.7 ± 8.0	17.4 ± 7.3	18.5 ± 4.3	21.3 ± 7.7	28.2 ± 9.5	21
Total sugar, g	80.0 ± 42.7[ab]	45.8 ± 20.6[a]	84.5 ± 35.4[b]	40.4 ± 20.3[a]	92.0 ± 31.4[ab]	52.7 ± 31.5[a]	93.
Total fiber, g	14.8 ± 6.6	12.9 ± 4.4	10.5 ± 4.6	12.5 ± 3.4	13.7 ± 6.5	16.4 ± 6.2	15
Omega 3 FA, g	1.4 ± 0.8	2.0 ± 0.8	1.3 ± 0.6	1.9 ± 1.0	1.7 ± 0.7	1.9 ± 0.3	1
Cholesterol, mg	226.2 ± 214.9[a]	563.0 ± 156.1[bcd]	566.7 ± 130.1[bcd]	510.2 ± 113.6[bcd]	175.2 ± 109.3[a]	481.2 ± 144.0[b]	447.

Values are presented as means ± SD. FI, food insecure group; FS, food secure group; CHO, carbohydrate; FA, fatty acid. Letters ind
within FI and FS groups at baseline and week 12 time-points, $P < 0.05$

Table 5:

Micronutrient intake

	FI				FS		
	Baseline	4 weeks	8 weeks	12 weeks	Baseline	4 weeks	8
Vitamin D, µg	3.9 ± 3.0[a]	7.5 ± 4.1[ab]	6.5 ± 2.0[b]	6.5 ± 1.9[b]	4.4 ± 4.0	5.7 ± 4.4	6
Retinol, µg	328.5 ± 231.7[a]	616.9 ± 126.1[abc]	580.2 ± 150.0[bc]	647.3 ± 202.4[bc]	417.7 ± 359.6	481.5 ± 178.1	563
Cobalamin, µg	3.0 ± 2.5	4.9 ± 1.5	5.8 ± 2.2	4.4 ± 0.9	2.5 ± 1.7	3.9 ± 1.5	4
Total Folate, g	238.4 ± 131.9	348.8 ± 105.5	325.5 ± 127.3	355.2 ± 102.3	213.6 ± 128.0[a]	378.6 ± 126.2[b]	332
Thiamin, mg	1.3 ± 0.6	1.6 ± 0.5	1.4 ± 0.5	1.4 ± 0.3	1.5 ± 0.5	1.9 ± 0.5	1
Riboflavin, mg	1.4 ± 0.8	2.1 ± 0.5	1.9 ± 0.6	2.0 ± 0.3	1.5 ± 0.7	1.9 ± 0.5	1
Niacin, mg	18.7 ± 12.3	21.0 ± 8.6	18.8 ± 6.6	15.7 ± 3.3	16.9 ± 7.2	20.2 ± 4.1	18
Vitamin B-6, mg	1.5 ± 0.8	1.7 ± 0.6	1.5 ± 0.5	1.3 ± 0.3	1.4 ± 0.6	1.4 ± 0.5	1
Ascorbic Acid, mg	52.3 ± 46.9	55.5 ± 35.4	44.2 ± 32.7	47.9 ± 26.9	40.7 ± 42.1	50.7 ± 21.0	61
Calcium, mg	672.2 ± 472.3	817.5 ± 222.1	811.3 ± 287.2	859.7 ± 302.1	890.6 ± 621.9	861.6 ± 464.8	947
Magnesium, mg	203.0 ± 115.2	203.3 ± 49.8	186.7 ± 57.8	192.2 ± 44.7	183.6 ± 77.6	214.5 ± 68.6	206
Iron, mg	10.0 ± 5.2	13.5 ± 5.3	12.0 ± 3.9	13.6 ± 6.0	10.2 ± 3.4	14.2 ± 4.7	15
Zinc, mg	8.8 ± 5.7	10.5 ± 4.0	10.0 ± 3.6	8.6 ± 1.8	6.4 ± 3.0[a]	9.4 ± 3.3[b]	9.
Sodium, mg	2388 ± 1348.0	3609 ± 1086.0	3266 ± 1051.0	2919 ± 648.3	2932 ± 981.1	3502 ± 977.0	333

Values are presented as means ± SD. FI, food insecure group; FS, food secure group. Letters indicate significant difference within FI and FS gro
time-points, $P < 0.05$

Table 5:

Food groups serving intake

	FI				FS			
	Baseline	4 weeks	8 weeks	12 weeks	Baseline	4 weeks	8 weeks	12 weeks
Fruits, Total serving,	1.7 ± 1.8	1.3 ± 1.1	1.6 ± 1.2	1.5 ± 0.7	0.9 ± 1.1	1.2 ± 1.2	1.6 ± 1.3	1.5 ± 1.3
Vegetables, Total serving,	2.0 ± 1.5	1.7 ± 1.0	1.4 ± 0.9	1.6 ± 0.8	1.4 ± 1.4	1.3 ± 0.9	1.5 ± 1.1	1.0 ± 0.9
Meat, Eggs, Nuts, and Seeds, per serving	5.6 ± 5.7	6.9 ± 3.3	7.1 ± 3.5	4.7 ± 2.0	3.6 ± 3.0	5.5 ± 1.5	5.6 ± 1.6	5.6 ± 3.3
Grains, Total serving,	4.8 ± 2.4	5.8 ± 2.8	5.6 ± 2.1	5.8 ± 1.6	6.5 ± 2.1	7.4 ± 3.8	7.3 ± 2.9	6.5 ± 2.3
Dairy, Total serving,	1.7 ± 1.2	1.4 ± 0.7	1.5 ± 0.9	1.9 ± 1.0	2.2 ± 1.2	1.8 ± 1.0	1.9 ± 1.2	1.9 ± 1.6
Sweets, Total serving	1.7 ± 1.2	1.4 ± 0.7	1.5 ± 0.9	1.9 ± 1.0	2.2 ± 1.2	1.8 ± 1.0	1.9 ± 1.2	1.9 ± 1.6
Fats, Total serving	1.7 ± 2.7	5.2 ± 5.2	4.5 ± 2.7	5.5 ± 5.7	2.2 ± 1.8	4.0 ± 2.7	3.6 ± 2.0	3.1 ± 1.9

Values are presented as means ± SD. FI, food insecure group; FS, food secure group.

CONCLUSION

In conclusion, consumption of two eggs a day for twelve weeks had no impact on cadiometabolic outcomes in adults and children living in a food insecure environment. For adults, body composition did not change, however, growth parameters in children did increase. The daily addition of eggs had no impact on nutrient intake in adults, however, there was an increase in vitamin D and retinol intake in children. Daily incorporation of eggs into the diet of food insecure individuals appears to be well tolerated and did not lead to any adverse outcomes. Additional research is required to identify appropriate food sources to improve metabolic health in food insecure households. Future research may require longer intervention times and larger study populations.

APPENDIX

UNIVERSITY OF ARKANSAS

To:	Jamie I Baum FDSC N2216
From:	Douglas James Adams, Chair IRB Committee
Date:	10/08/2018
Action:	**Approval**
Action Date:	10/08/2018
Protocol #:	1708023122R002
Study Title:	The Effect of Dietary Supplementation on Nutrient Status in Families Living in a Food Insecure Environment
Expiration Date:	10/13/2019
Last Approval Date:	10/14/2018
Risk Level:	

The above-referenced protocol has been approved following Full Board Review by the IRB Committee that oversees research with human subjects.

If the research involves collaboration with another institution then the research cannot commence until the Committee receives written notification of approval from the collaborating institution's IRB.

It is the Principal Investigator's responsibility to obtain review and continued approval before the expiration date.

Protocols are approved for a maximum period of one year. You may not continue any research activity beyond the expiration date without Committee approval. Please submit continuation requests early enough to allow sufficient time for review. Failure to receive approval for continuation before the expiration date will result in the automatic suspension of the approval of this protocol. Information collected following suspension is unapproved research and cannot be reported or published as research data. If you do not wish continued approval, please notify the Committee of the study closure.

Adverse Events: Any serious or unexpected adverse event must be reported to the IRB Committee within 48 hours. All other adverse events should be reported within 10 working days.

Amendments: If you wish to change any aspect of this study, such as the procedures, the consent forms, study personnel, or number of participants, please submit an amendment to the IRB. All changes must be approved by the IRB Committee before they can be initiated.

You must maintain a research file for at least 3 years after completion of the study. This file should include all correspondence with the IRB Committee, original signed consent forms, and study data.

cc: Hexirui Wu, Key Personnel
Aubree L Worden, Key Personnel
Regan Kahleah Burgess, Key Personnel
Katie D. Cloud, Key Personnel
Jamie Lauren McDermott, Key Personnel
Samuel Preston Belt Walker, Key Personnel
Samuel Alexander Davis, Key Personnel