The Health Implications of Periodic Dietary Restrictions on Animal Products among Orthodox Christians in the United States

Hilary Bethancourt

A dissertation
submitted in partial fulfillment of the
requirements for the degree of

Doctor of Philosophy

University of Washington
2018

Reading Committee:
Kathleen O’Connor, Chair
Mario Kratz
Bettina Shell-Duncan

Program Authorized to Offer Degree:
Anthropology

University of Washington

Abstract

The Health Implications of Periodic Dietary Restrictions on Animal Products among Orthodox Christians in the United States

Hilary Bethancourt

Chair of the Supervisory Committee:
Kathleen O'Connor
Department of Anthropology

Despite increasing recognition that dietary factors are major contributors to cardiovascular and metabolic (cardiometabolic) related disability and mortality in the United States and worldwide, the optimal diet for reducing the burden of these nutrition-related conditions has yet to be clearly identified. While anthropological and demographic data on pre-industrialized populations suggest that humans are well-adapted omnivores, some epidemiological data from industrialized populations suggest a potential health and longevity benefit associated with the omission of animal products. Nonetheless, plant-based diets, broadly defined, do not always provide an observable health advantage over equally broadly-defined omnivorous diets, and there is reason to believe that any health effects of omitting animal products from the diet may depend on whether they are replaced with "healthy" plant-sourced foods (e.g., whole grains, legumes, nuts, seeds, fruits, and vegetables) or “unhealthy” plant-sourced foods (e.g., refined grains and added sugars). However, few studies have tested the degree to which different choices of plant-based replacement foods may modify any potential health benefits of reduced consumption of animal products. This study aimed to address this gap by examining if any observable changes in cardiometabolic health biomarkers that result from a temporary, religious fast from meat, dairy, and egg (MDE) products are more pronounced when accompanied by increases in “healthy” plant-sourced foods but less pronounced when accompanied by increases in “unhealthy” plant-sourced foods. To do this, the Lenten Season Study followed a sample of 95 self-identified Orthodox Christians (OCs) and four non-OCs from the United States before and during the OC period of “Lent,” the 48 days prior to Easter during which many OCs fast from MDE products as part of a spiritual discipline. Food frequency questionnaires (FFQs) and 7-day undocumented food records (FRs) were used to measure dietary changes and accompanying shifts in nutritional composition. This study then investigated A) whether MDE restriction was associated with shifts in measures of body fat, blood lipids, glucose metabolism, and inflammation, and B) whether the degree of change in those health measures was dependent on concurrent reductions in calories or shifts in intake of different “healthy” or “unhealthy” non-MDE foods.

Among the study sample, both FFQ and FR data provided evidence that consumption of legumes, soy products/meat alternatives, nuts and seeds, and discretionary oils increased in relation to MDE restrictions. There was no strong evidence, however, that average consumption of other “healthy” plant-based foods, such as fruits and vegetables, increased during the Lenten MDE fast; in fact, among a substantial portion of the study sample, fruit and vegetable consumption remained below the levels recommended by national guidelines. Consumption of less healthy refined grains and added sugars were unchanged, on average, during the MDE fast but also remained above recommended thresholds in a large segment of the study sample. MDE restriction was associated with significant reductions in total and LDL cholesterol but not with changes in other blood lipids, glucose, insulin, or C-reactive protein. There was no evidence that relationships between MDE restrictions and cardiometabolic health biomarkers were modified by concurrent changes in calories or intake of different "healthy" and "unhealthy" non-MDE foods.

This study suggests that the temporary MDE fasts of OCs in the United States may result in some short-term improvements in diet and health markers, though the clinical relevance and long-term effects of this practice remain unknown. The consistently high consumption of refined grains and added sugars and consistently low consumption of fruits and vegetables during the OC Lenten MDE fast exemplify the ways in which animal product restriction or omission may not uniformly lead to an optimal, health-promoting diet. This study also demonstrates some of the ways in which cross-disciplinary frameworks are valuable for moving beyond overly simplified and incomplete perspectives on diet and health toward theoretical and statistical models that account for more of the interactive relationships among biological, dietary, and lifestyle components that shape diet-disease relationships across different life history stages and ecological contexts.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 2 TABLES

CHAPTER 3 TABLES

CHAPTER 4 TABLES

LIST OF FIGURES

CHAPTER 2 FIGURES

CHAPTER 3 FIGURES

CHAPTER 4 FIGURES

ACKNOWLEDGEMENTS

This dissertation project was made possible with tremendous support from more individuals than can be named, but I would like to acknowledge some of the key contributors.

First and foremost, I want to acknowledge and thank my parents and two older brothers for their unwavering love, support, advice, sympathy, and encouragement throughout my degree program and pursuit of this project. It is also with their help that I was connected with and welcomed graciously into a variety of Orthodox Christian communities for both my initial qualitative exploration of Orthodox Christian fasting practices and the quantitative data collection on which this dissertation is focused.

I owe much of my success in this doctoral program and dissertation project to my graduate advisor and dissertation committee chair, Dr. Kathleen O’Connor, who has invested countless hours reviewing and thoroughly commenting on research proposals, fellowship and grant applications, human subjects materials, annual reports, and papers. Her careful attention to detail and high scholarly standards have pushed me to work hard and to learn and grow as a researcher. Yet beyond being an incredibly dedicated mentor, I am also grateful that she has also been someone with whom I can laugh and commiserate and who understands and respects my need for intermittent playtime and adventure.

I owe a great deal of thanks to Dr. Mario Kratz for not only investing the time to serve on two of my graduate reading committees, but also welcoming me into the Kratz Lab; being a valuable source of intellectual inspiration; and exemplifying the thoughtfulness, healthy skepticism, and collaborative leadership that make a phenomenal researcher. I am also thankful for all of the moral support and encouragement from everyone in the Kratz lab.

I am grateful for all of the advice and feedback Dr. Bettina Shell-Duncan has offered throughout this project, particularly in the early stages of project development, qualitative pilot research, and logistical planning. She was the voice of reason, encouraging me to keep things simple and manageable (even though I was often too stubborn to listen).

Many thanks to Dr. Daniel Eisenberg, who has been another valuable source of academic and professional advice and who also welcomed me into his lab group and provided me with opportunities to expand my areas of research.

I would like to acknowledge the members of the Center for Studies in Demography and Ecology for their computer, laboratory, and statistical support and help with the submission and processing of grant proposals. I am particularly fortunate to have received training, advice, and support from Eleanor Brindle throughout the process of planning and carrying out the biomarker collection and sample assaying procedures for this project. I would also like to offer thanks to Cori Mar for helping me think through some of my complex and messy data quandaries.

Of course, this project would not have been possible if it were not for the participation of everyone who generously volunteered a substantial portion of their time to complete arduous food records and surveys and were willing to undergo multiple finger pricks. I am forever indebted to my study participants, as well as to the parish priests and other church members who helped in the recruitment process and even offered space in their churches or homes to conduct the health assessments. I am also deeply touched by and sincerely appreciative of the donations and housing accommodations offered by family, friends, and my extended network in order to help cover the unforeseen or unbudgeted costs of this project.

I am grateful beyond words for all of the friends and colleagues who helped keep me from becoming a (complete) hermit, served as a sounding board during times of stress, and/or

offered companionship on outdoor adventures that helped balance out the hours spent in front of a computer. I especially want to thank Tiffany Pan for being a constant source of cheer, optimism, and inspiration and for sharing with me the article that first triggered my idea to pursue this project. I also want to thank Brad Wagenaar and Mark Hensley for frequently engaging me in thought-provoking philosophical discussions and encouraging me to push my limits in the outdoors to the same degree that I push them academically. I am so thankful for the friendship and love of Anne Weiss and for her willingness to challenge my perception of reality. Many thanks to Anna Boiko-Weyrauch and the Boiko-Weyrauch family for their consistent love and support and for welcoming me into their home for annual holidays. Many thanks to Susan Clapsaddle for her moral support and advice on personal development throughout my graduate program and, importantly, for introducing me to aerial dance – another activity that became a key source of stress relief. I am grateful for everyone in the Versatile Arts community who has fostered a safe, welcoming, supportive environment in which to play and temporarily escape real life each week. Finally, tremendous thanks to Steve and Judy Gossett, who let me make their home my home, were always there to celebrate my triumphs or offer sympathy in moments of disappointment, and became part of my Seattle family.

This project was funding in part by a National Science Foundation Graduate Research Fellowship (DGE-0718145 and DGE-1256082); the University of Washington Department of Anthropology Pilot Fund; a National Science Foundation Doctoral Dissertation Research Improvement Grant (Award Number 1540282); a Shanahan Endowment Fellowship and a Eunice Kennedy Shriver National Institute of Child Health and Human Development training grant (T32 HD007543) awarded to the Center for Studies in Demography and Ecology at the University of Washington; and the generosity of private donors through Experiment.com.

DEDICATION

I dedicate this dissertation to my grandmother, Martha Flandro Bethancourt, who I believe passed on to me the tenacity and strong will to persevere through the many stages and challenges of this project. It is also Martha's independent, adventurous, courageous, curious, and forever young-at-heart spirit that inspires me as I embark on the next stage of my life's journey.

CHAPTER 1: INTRODUCTION TO THE LENTEN SEASON STUDY

OVERVIEW

Despite the growing recognition that suboptimal diets and nutrition are among the leading contributors to the cardiovascular and metabolic diseases that account for a large proportion of death, disability, and health care expenditures in the US (Mokdad et al. 2004; The US Burden of Disease Collaborators 2018; US Burden of Disease Collaborators 2013) and worldwide (Forouzanfar et al. 2015; Lim et al. 2013), scholars and policy makers have yet to agree on an effective dietary intervention that may help curb the rising global nutrition-related chronic disease burden. One challenge to developing feasible and effective dietary interventions is the fact that there is considerable intra- and inter-disciplinary disagreement about what components do and do not constitute an optimally healthy diet. Of particular interest among both academic and popular nutrition circles is the question about whether animal products deserve a place in a healthy human diet. Perspectives often advanced in the field of epidemiology suggest that, relative to omnivorous diets, vegetarian and vegan diets are protective against cardiometabolic morbidity and mortality (Craig 2009; Craig 2010; Craig et al. 2009; Kahleova et al. 2017; Melina et al. 2016; Satija and Hu 2018). Such perspectives contrast with anthropological theories that meat and animal fat played critical roles in human evolution and continue to be an important source of calories and nutrients for subsistence populations that, if still living more traditional lifestyles, remain relatively free of cardiometabolic disease (Cordain et al. 2002a; Cordain et al. 2000; Eaton and Konner 1985; Eaton et al. 1988; Kaplan et al. 2000; Lindeberg 2010). At the same time, scholars within the fields of anthropology, bioarcheology, and paleodemography disagree about whether transitions to more grain- and legume-based agricultural diets resulted in a deterioration of health and longevity (Cohen 1997; DeWitte and Stojanowski 2015; Gage 2005; Wood et al. 1992). In contrast, whole grains and legumes are regularly touted as "health foods" in contemporary settings.

Meanwhile, most scholars do tend to agree that the calorie-, sodium-, fat-, and/or sugar-laden processed and refined foods of either animal or plant origin that have arisen only since the industrial revolution are not doing our health any favors (Grotto and Zied 2010; Micha et al. 2017; Mozaffarian 2016; Yang et al. 2014). Yet until recently, the existing research did not adequately consider how varying degrees of inclusion of “unhealthy” processed and refined foods, in either omnivorous or plant-based diets, might influence the degree to which such diets are relatively health-promoting or detrimental. This oversight can bias comparative associations between omnivorous versus plant-based diets on health if, as is commonly reported (Bedford and Barr 2005; Dyett et al. 2013; Fogelholm et al. 2015; Haddad and Tanzman 2003; Kappeler et al. 2013; Sinha et al. 2009), inclusion of meat in the diet tends to be accompanied by higher consumption of refined grains, added sugars, and fried potato products, which may be detrimental to health independent of meat consumption (Mozaffarian 2016; Satija et al. 2016; Satija et al. 2017). At the same time, these “unhealthy” plant-based foods may easily account for a substantial portion of calories in the diets of vegetarians and vegans, particularly those who elect such diets for ecological, ethical, or religious rather than health reasons. Varying proportions of “unhealthy” and “healthy” plant-sourced foods could explain why restrictions on animal products do not always seem to confer a health advantage (Kwok et al. 2014; Satija et al. 2016; Satija et al. 2017). Yet few studies attempt to investigate the degree to which variation in the quality of plant-sourced foods may modify the relative health-promoting potential of plant-based diets. Until further investigation of these nuances is carried out, the pervasive notion that removal of animal products from the diet will unequivocally improve health remains unsubstantiated. It is on investigating the potential interactions between animal- and plant-sourced foods of varying nutritional quality and exploring some of methodological sources of conflicting research findings that this dissertation is focused.

The objective of this dissertation project was to A) explore how the nutritional quality of a diet that restricts animal products varies when such dietary restrictions are primarily undertaken for reasons other than health and B) investigate if and how variation in the intake of "healthy" (e.g., whole grains, legumes, nuts, fruits and vegetables) versus "unhealthy" (e.g., refined grains and added sugars) plant-sourced foods modifies the degree to which animal product restriction results in improvements in biomarkers of cardiometabolic health. Specifically, the Lenten Season Study described in this dissertation focuses on the periodic dietary shifts of Orthodox Christians (OCs), who are encouraged to give up meat, dairy, and egg (MDE) products for 48 days prior to Easter (a period referred to as "Lent") but are not directed on which plant-sourced products should be consumed as MDE replacements. Although vertebrate fish is allowed occasionally and shellfish is unrestricted during this period, this practice leads to a diet that is primarily plant-based. This study was able to measure intra-individual shifts in dietary and nutritional composition and concurrent shifts in health biomarkers but did so in a context that may produce more generalizable data than that produced from controlled trials, where participants may be asked to regulate their food choices more stringently than the average person who elects to follow a plant-based diet. The measures of concurrent intra-individual level dietary changes also allowed for the exploration of the potential interactions between MDE restrictions and MDE replacements in a way that no cross-sectional study comparing different omnivorous versus vegetarian/vegan populations can accomplish. Importantly, as described further below, this study unites theory and methods from the fields of anthropology, biodemography, and epidemiology to provide a comprehensive, cross-disciplinary, and nuanced perspective on the role of different animal- and plant-based foods in the development and progression of cardiometabolic diseases.

THEORETICAL AND EMPIRICAL BACKGROUND

A case for omnivory in the pre-industrial era

A more comprehensive picture of the potential links between diet and disease in modern contexts requires understanding the ecological niches in which humans evolved. Though our early hominin ancestors likely consumed mostly fruit- and plant-based diets, as do our closest extant primate-relatives (Kaplan et al. 2000; Milton 2003), subsequent *Homo* species inhabited more seasonal, arid woodland and grassland environments (deMenocal 2004; Reed 1997), in which access to fruit and other plant foods likely become increasingly variable (Milton 2003; O'Connell et al. 2002). Yet the *Homo* lineage also experienced gradual increases in body mass (Aiello and Wells 2002), marked increases in cranial capacity (Leonard et al. 2007), and reductions in the gastrointestinal tract and large colon (Aiello and Wheeler 1995), suggesting a shift toward a more easily-digestible, energy- and nutrient-dense diet (Aiello and Wheeler 1995; Leonard et al. 2007; Milton 2003; Snodgrass et al. 2009). As the timing of these morphological changes coincide with archaeological evidence of increasingly sophisticated stone tools and growing concentrations of cut-marked bones (Bunn 2007; Ungar et al. 2006), many scholars suggest that animal tissues were fundamental to these hallmark morphological changes (Aiello and Wheeler 1995; Bunn 2007; Kaplan et al. 2000; Leonard et al. 2007; Snodgrass et al. 2009).

By the time *Homo sapiens* appear in the fossil record, cranial capacity was three times that of other great apes (Leonard et al. 2007). Beyond the archeological evidence for increased hunting and consumption of animal tissues, there are good reasons from a nutritional standpoint to believe that animal muscle, marrow, and brain tissue provided the necessary bioavailable calories, essential fatty acids, and micronutrients to support encephalization. Brains are energetically expensive, accounting for 20-25% of the resting metabolic rate of adult humans and substantially more than that in infancy and childhood (Aiello and Wells 2002; Aiello and Wheeler 1995; Leonard et al. 2007; Snodgrass et al. 2009). This compares to 8-10% in other primates and 3-5% in other mammals (Leonard et al. 2007). Animal-sourced foods, particularly brain tissue and aquatic animal-based foods, and to a lesser degree muscle and organ meats, are a primary source of adequate, bioavailable forms of the essential long-chain polyunsaturated fatty acids, docosahexaenoic acid (DHA) and arachidonic acid, needed for brain development (Cordain et al. 2001; Leonard et al. 2007). There are only trace amounts of these fatty acids in plants, and the synthesis of these polyunsaturated fatty acids from their plant-sourced precursors, alpha-linolenic acid and linoleic acid, is inefficient (Cordain et al. 2001). Inadequate supplies of essential fatty acids from plants is thought to be one reason why an increase in body mass often occurs at the expense of cranial capacity across most herbivorous species but not across carnivorous species and, apparently, not among *Homo* species (Cordain et al. 2001). Insects, which are often consumed by other primates, may have been one source of these fatty acids prior to more consistent consumption of animal-sourced foods. Likely, however, it was the DHA-rich brain tissue and energy-dense bone marrow to which scavenging hominins would have had access (Cordain et al. 2001) and, eventually, muscle and organ meat from hunting and fishing (Braun et al. 2010), that would have been superior to prior dietary components for supporting concurrent increases in cranial capacity and body mass over evolutionary time (Cordain et al. 2001). Animal-sourced tissues are also an easy-to-digest form of protein, fat, and calories that would have been ideal weaning foods to support the development of infant brains (Leonard et al.

2007; Snodgrass et al. 2009), and they provide a rich source of bioavailable vitamins that are important for early cognitive development (Murphy and Allen 2003; Neumann et al. 2007). Further evidence of the importance of animal-based foods in traditional human diets is provided by ethnographic research indicating that no known contemporary hunter-gatherer or hunter-horticulturalist population subsists exclusively on plant-based foods (Cordain et al. 2000).

Notwithstanding, plant-based foods never lost their value in the human diet (Melamed et al. 2016), and populations living at lower latitudes, in particular, likely continued to obtain a large proportion of calories from plants (Cordain et al. 2002a). Even with food-sharing strategies (Hawkes et al. 2001; Kaplan et al. 2000), access to meat would have been unpredictable across days and seasons (Hawkes et al. 2001; O'Connell et al. 1999; Wrangham et al. 1999), leaving plants as essential backup sources for energy. Additionally, consuming more plants, as well as choosing fattier meat sources, can help avoid protein toxicity (Cordain et al. 2000; Speth and Spielmann 1983). Plants also would have remained vital for preventing deficiencies in certain nutrients (e.g., vitamin C) that are not provided by animal tissues (Milton 2000). Moreover, some plants, such as roots, tubers, and ribosomes, can provide a rich and more dependable source of calories and carbohydrates, particularly if cooked to remove their toxins and increase the digestibility of their starches (Wrangham 2017; Wrangham and Conklin-Brittain 2003; Wrangham et al. 1999).

Together, the evidence points to the notion that humans are by default neither carnivores nor herbivores but omnivores. Humans' dietary breadth and flexibility would have not only helped them ensure adequate nutrition and avoid toxicity from any single food or nutrient, it was also likely what allowed them to, unlike any other primate, expand to most regions of the globe long before the advent of agriculture. Foods acquired from hunting and fishing were able to sustain human populations that migrated to arctic climates and had limited and seasonally variable access to plant-based foods, while cooking and other acquired food processing methods allowed humans to extract calories from starchy tubers and a variety of other plants encountered in different regions. It was also their adaptability and flexibility that allowed humans to relatively quickly and easily adopt diets containing more cereal grains, legumes, and, in some regions, dairy following the advent of agriculture.

Though grains and legumes were encountered and consumed long before they were cultivated (Henry et al. 2011; Mercader 2009; Piperno et al. 2004), it is generally thought that they were not consumed as staples in the diet until after the advent of agriculture, when large amounts could be grown, harvested, and stored. Neither the causes nor the health-related outcomes of the transition from hunter-gatherer subsistence to farming are entirely clear from the available data (DeWitte and Stojanowski 2015; Gage and DeWitte 2009; Price and Bar-Yosef 2011). It appears that farming practices arose independently in different regions of the world around the same timeframe (5,000-12,000 years ago) and gradually took over as the main source of subsistence in most regions of the world (Pluciennik and Zvelebil 2009; Price and Gebauer 1995). The rapid spread of lactase persistence alleles in Europe and Africa (Ingram et al. 2009; Tishkoff et al. 2006) suggest that, in addition to grains and legumes, dairy also became an important source of calories for some populations. The effects of this shift in subsistence patterns on physiological health is disputable. More frequent evidence of poor dental health (e.g., dental caries and tooth loss), disrupted growth (e.g., linear enamel hypoplasia, reduced tooth size, and shorter long bones), anemia (e.g., porotic hyperostosis), and infection (e.g., periosteal bone lesions) are found in the osteological data from farming compared with pre-farming cemetery populations (Cohen and Crane-Kramer 2007; Lambert 2009). However, it is unclear to what degree this evidence represents a deterioration in health (Cohen 1989; Cohen and Armelagos 1984; Cohen and Crane-Kramer 2007; Larsen 1995; Larsen 2006) or an enhanced ability to survive malnutrition, injury, and infection for long enough to develop visible bone lesions (DeWitte and Stojanowski 2015; Gage and DeWitte 2009; Wood et al. 1992). The latter interpretation is challenged by data showing evidence of osteoarthritis (also an indicator of longevity) among pre-farming populations (Cohen and Crane-Kramer 2007), evidence that those with bone pathologies were more likely to succumb to plagues (DeWitte and Wood 2008); and data from contemporary populations demonstrating associations between enamel hypoplasia and poorer health (DeWitte and Stojanowski 2015). Still, the osteological data should be interpreted with caution; as some scholars have pointed out (Boldsen and Milner 2012 cited in DeWitte and Stojanowski 2015), using data from cemetery populations to estimate disease prevalence is akin to estimating the health status of a population by sampling only from patients admitted to the hospital.

Moreover, even if health did decline as a result of the transition to farming, it remains unclear to what degree such declines would have resulted from the change in diet as opposed to an increased exposure to infectious and zoonotic diseases that often accompany living in more crowded settlements with domesticated animals (Cohen 1989). Diet would have been the most likely factor contributing to the purported increase in dental caries in farming populations. Also, because the cereal grains and legumes that began to dominate the diet are not optimal sources of protein, fat, and vitamins, and because they contain phytates and lectins that may interfere with mineral absorption, there is at least a theoretical basis for the speculation that the dominance of these foods in agricultural diets could contribute to disrupted growth and a decline in health (Cohen 1989; Cordain 1999). Any effects of malnutrition could be compounded by the effects of infection, which can cause further energy and nutrient depletion (Schaible and Kaufmann 2007). Nonetheless, despite any suggestive or theoretical reductions in the nutritional adequacy of farming diets, the paleodemographic data suggest that the shift in subsistence patterns may have been accompanied by an increase in fertility and at least a slight increase in population growth (Bocquet-Appel 2011a; Bocquet-Appel 2011b; Bocquet-Appel and Naji 2006; Gage and DeWitte 2009). Moreover, whatever effect the transition had on longevity in the pre-industrial era, life expectancy while sustaining agricultural diets increased dramatically across the 20th century once hygiene, sanitation, and health care improved (Gage 2005; Oeppen and Vaupel 2002; Omran 1998; Vaupel 2010). In fact, today it is populations that follow a traditional agricultural-based diet (e.g., Mediterranean or Okinawan diets) that are often cited as having the greatest longevity in contemporary settings (Poulain et al. 2013; Willcox et al. 2014; Willcox et al. 2009).

Competing perspectives on the health effects of animal-product consumption in an industrialized era

While the archeological, paleontological, and ethnographic evidence suggests that humans are by default omnivores, large cross-sectional and prospective epidemiological studies suggest that vegetarian and vegan segments of the world's industrialized populations tend to experience lower rates of obesity, hypertension, dyslipidemia, type 2 diabetes, cardiovascular disease, and overall mortality (Crowe et al. 2013; Fraser 1999; Huang et al. 2012; Orlich et al. 2013; Pettersen et al. 2012; Rizzo et al. 2011; Spencer et al. 2003a; Tonstad et al. 2013). Yet data also indicate that extant hunter-gatherer, hunter-horticulturalist, and pastoralist populations exhibit remarkably low prevalence of cardiometabolic risk factors, despite regularly relying on animal-sourced foods for a nontrivial portion of their calories (Bang et al. 1971; Bang et al. 1980; Cordain et al. 2002a; Cordain et al. 2000; Dyerberg et al. 1975; Eaton et al. 1988; Kaplan et al. 2000; Kaplan et al. 2017; Leonard et al. 1994; Lindeberg 2010; Mann et al. 1964). How do we reconcile with these conflicting evidence-based perspectives? Is the best strategy for preventing, managing, or reversing disease a return to a diet that resembles that of hunter-gatherers, or should we abandon omnivory and adopt a diet that more closely resembles the diets of our more distantly related primate relatives?[1]

Any theory of diet-disease relationships that does not account for the broader ecological context, lifestyle, and concurrent dietary factors that might modify the degree to which any given food or dietary pattern has a protective or harmful impact on health is incomplete and may be misleading. For example, hunter-gatherer, hunter-horticulturalist, and pastoralist populations may experience little to no increase in cardiometabolic disease risk factors from consuming large amounts of animal protein and fat in part because consumption of those foods is often sporadic across days and seasons (Benefice et al. 1984; Hawkes et al. 2001; Shell-Duncan 1995; Speth and Davis 1976) and their otherwise high-fiber diets (Cordain et al. 2005), physically active levels (Mann et al. 1965; O'Keefe et al. 2011), and frequent exposure to pathogens (Gurven et al. 2016; Vasunilashorn et al. 2010) might support the need for more protein and fat than may be required by a well-fed, sedentary population living in a low pathogen environment. Moreover, the meat consumed by many non-industrialized populations is unprocessed, tends to have a different fatty acid profile than grain-fed meats (Bang et al. 1980; Cordain et al. 2002a; Cordain et al. 2005; Pereira and Vicente 2012), and is often consumed in the context of a diet that is otherwise minimally processed and high in fiber- and antioxidant rich plant-based foods

---

[1] Acknowledging that even our closest extant primate relatives, chimpanzees, include meat in their diets.

(Cordain et al. 2005; Cordain et al. 2000; Eaton and Konner 1985). Thus, evidence of humans' long history of hunting and consuming animal products is not sufficient to justify eating copious amounts of any or all animal products on a daily basis in the context of the otherwise low-fiber and high-caloric diets, sedentary lifestyles, and low infectious disease burden experienced among many industrialized populations today. Furthermore, it is important to recognize that the low blood lipid levels observed among high meat- and dairy-eating populations may not always translate into protection from atherosclerosis (Mann et al. 1972) or coronary artery disease (Fodor et al. 2014). Hence, we cannot presume that all meat- or dairy-eating hunter-gatherers, hunter-horticulturalists, or pastoralists would necessarily live longer than industrialized populations if following their same diet but living a modern lifestyle. Nor can we presume that the foods that supported the evolution of humans' expensive brains during the Paleolithic era and that are arguably still important for cognitive development early in life (Murphy and Allen 2003; Neumann et al. 2007) are the same foods that are going to promote longevity beyond the reproductive years in the industrialized era.

Likewise, the ecological context of a study needs to be considered when interpreting the data on health measures and outcomes of vegetarians or vegans relative to omnivores in industrialized settings. For example, individuals inclined to voluntarily omit meat or all animal products from their diet tend to be more health conscious in general, often reporting higher physical activity; a greater tendency to refrain from tobacco and alcohol consumption; higher consumption of fruits, vegetables, and fiber; and lower caloric intake overall (Bedford and Barr 2005; Dyett et al. 2013; Fogelholm et al. 2015; Haddad and Tanzman 2003; Kappeler et al. 2013; Sinha et al. 2009). Calorie restriction (Fontana et al. 2004; Fontana et al. 2007) or greater consumption of whole, minimally processed, "healthy" plant-based foods, such as whole grains

(Aune et al. 2016b; Aune et al. 2013b; Hollænder et al. 2015; Pereira et al. 2002), nuts (Aune et al. 2016a; Luo et al. 2014; Sabaté et al. 2010; Souza et al. 2015), legumes (Afshin et al. 2014; Bazzano et al. 2011; Becerra-Tomás et al. 2017; Messina 2014), and vegetables (Cooper et al. 2012; Gan et al. 2015; Leenders et al. 2014; Li et al. 2014; Wang et al. 2014b; Zhang et al. 2011) could each have beneficial impacts on cardiometabolic disease biomarkers independent of intentional restriction on animal products. Hence, it is difficult to isolate the potential benefits of animal product restriction from the benefits of co-varying dietary and lifestyle patterns that are common in vegan and vegetarian segments of the population. Even randomized controlled trials, which attempt to reduce these sources of bias, have not been substantially better at isolating the health effects of eliminating animal foods from the health effects of concurrent changes in consumption of different plant-based foods. This is because participants in such studies do not generally start with an otherwise healthy diet, and they typically receive extensive nutritional advice on which plant-based foods to prioritize and which to avoid while on the intervention. Most randomized controlled trials, therefore, essentially test for the health effects of the combination of reducing MDE products, increasing “healthy” plant-based foods (e.g., whole grains, legumes, fruits, vegetables), and even potentially decreasing “unhealthy” plant-based foods (e.g., refined grains, foods and beverages with added sugars and fried foods).

It is also important to consider the standard “omnivorous” dietary pattern to which most vegetarian and vegan diets are compared. Theoretically, comparing a vegetarian diet to an omnivorous diet that is high in the whole, minimally processed lean meats, dairy, whole grains, legumes, nuts, fruits, and vegetables would produce different risk estimates than comparing it to an omnivorous diet that is high in the processed meats, refined grains, added sugars, dairy-based desserts, and fried potato products. After all, poultry, dairy, and eggs are not generally associated with increased morbidity or mortality (Abete et al. 2014; Guo et al. 2017; Mozaffarian 2016; Rong et al. 2013; Shin et al. 2013; Sinha et al. 2009), and fish consumption is generally considered protective against cardiovascular disease (He et al. 2004; Mozaffarian 2016). Unprocessed red meat is only inconsistently (potentially because of differences in co-varying dietary and lifestyle factors) associated with increased cardiometabolic disease risk and mortality (Abete et al. 2014; Micha et al. 2010; Mozaffarian 2016; Schwingshackl et al. 2017). Interestingly, even intake of processed meat, the only animal product consistently associated with increased risk of cardiometabolic morbidity and mortality in observational studies (Micha et al. 2012; Micha et al. 2010; Mozaffarian 2016), may be less strongly associated with all-cause mortality among those with higher fruit and vegetable consumption (Rohrmann et al. 2013). Yet studies do not generally differentiate between different reference omnivorous diets, and more often than not, the average omnivorous diet to which vegetarian or vegan diets are compared is one that is higher in the less healthy, processed, sodium- and sugar-rich animal- and plant-sourced foods. Additionally, few studies test for interactive effects with co-varying dietary factors; so many study analyses inherently assume that the relationship between MDE products and cardiometabolic disease is the same at all levels of intake of other foods.

Consequently, the existing data do not yet confirm that the omission of MDE products in an otherwise healthy, nutritious omnivorous diet offers substantial added health benefit; nor do they confirm that omitting MDE products will improve health in the absence of concurrent increases in high-quality, “healthy” plant-sourced foods consumed as replacements. There is reason to believe, however, that reduction or omission of MDE products may not result in a meaningful health advantage if the diet otherwise remains high in calorically-dense but nutrient-poor plant-sourced foods. For example, evidence suggests that high intake of “unhealthy,” heavily processed/refined, sodium- and sugar-laden plant-based foods, like refined grain products, fried potatoes, and sugar-sweetened beverages and desserts, may adversely affect cardiometabolic health (Aeberli et al. 2011; Mozaffarian 2016; Te Morenga et al. 2014; Yang et al. 2014), even in the context of low meat consumption (Satija et al. 2016; Satija et al. 2017). One 21-day randomized controlled trial even demonstrated that relative to omnivorous and vegan diets that restricted processed foods, an "unrestricted" vegan diet had no beneficial impact on cholesterol levels (Bloomer et al. 2015). Variation in the proportion of "healthy" and "unhealthy" plant-based foods in vegetarian and vegan diets may help explain why some vegans and vegetarians remain susceptible to weight gain (Rosell et al. 2006), overweight and obesity (Jaacks et al. 2016; Singh et al. 2014; Zhang et al. 2010), metabolic syndrome (Rizzo et al. 2011; Shang et al. 2011), diabetes (Tonstad et al. 2009; Tonstad et al. 2013; Zhang et al. 2010), hypertension (Berkow and Barnard 2005; Zhang et al. 2010), dyslipidemia (Zhang et al. 2010), or cardiovascular-related mortality (Appleby et al. 2016; Kwok et al. 2014).[2]

Piecing apart the different health effects of reducing MDE products versus increasing "healthy" plant-sourced foods or decreasing "unhealthy" plant-sourced foods is important for understanding which nutritional and public health messages will most effectively address the current nutrition-related chronic disease burden. In other words, is it enough to advise the public to reduce or omit MDE products, or do they also need more direction on which plant-sourced foods to avoid and which to consume as MDE replacements? Is it necessary to reduce or omit all MDE products, or would the greatest benefit be obtained from simply omitting the processed meats and other processed, preserved, or sodium- or sugar-enriched MDE products? Is it

---

[2] Admittedly, reverse causation could also contribute to the observations of poor health markers among vegetarians and vegans (i.e., individuals choosing to omit animal products in attempt to manage existing health conditions).

necessary for intake of MDE products to be reduced or omitted at all if they are otherwise consumed with plenty of whole, fiber- and antioxidant-rich plant-sourced foods?

No single study can answer all of these questions, and a fair amount of research has already tried to differentiate between the health effects of processed versus unprocessed meats (Abete et al. 2014; Larsson and Orsini 2014; Micha et al. 2012; Micha et al. 2010; Pan et al. 2012b; Pan et al. 2011; Schwingshackl et al. 2017; Wang et al. 2016) and different kinds of dairy (Aune et al. 2013a; Chen et al. 2014; de Goede et al. 2015; Guo et al. 2017; St-Onge et al. 2000) or test the health effects of omitting processed foods from an omnivorous diet (Boers et al. 2014; Frassetto et al. 2009; Genoni et al. 2016; Jönsson et al. 2009b; Lindeberg et al. 2007; Manheimer et al. 2015; Mellberg et al. 2014; Otten et al. 2017; Pastore et al. 2015). The major gap in the research exists in our understanding of the degree to which variation in the quality of plant-sourced foods that comprise MDE-restricted diets may modify the health effects of MDE restriction. This is a particularly relevant question in today's industrialized food environment, where concerns for the environmental impacts of meat production and ethical concerns about the ways in which meat and dairy animals are raised and slaughtered are motivating a growing number of individuals to omit MDE products from the diets for reasons other than health. Modern food manufacturers have responded to these trends by producing vegan MDE substitutes and vegan versions of many snacks and desserts that make it easier than ever before to reduce MDE products while maintaining a highly palatable and satiating diet. Consequently, so-called "ethical" vegetarians/vegans, as well as individuals that give up MDE products for religious purposes, may be able to reduce MDE products without reducing their caloric intake or increasing their intake of healthy, whole, nutrient-rich plant-based foods. Whether variation in the quality of plant-based foods chosen as MDE replacements impacts the health effects of such dietary decisions remains understudied. This dissertation project, thus, looks at this question in detail by exploring the dietary shifts and related changes in cardiometabolic health biomarkers of Orthodox Christians (OCs) when temporarily restricting MDE products for spiritual purposes.

A case for studying the Lenten dietary restrictions of Orthodox Christians in the United States

For over 1,500 years, OCs around the world have been encouraged to abstain from meat, dairy, eggs, and vertebrate fish (and sometimes olive oil and alcohol) most Wednesdays and Fridays and for the 40 days before Christmas, the 48 days before Easter, and for 15 days in August (Sarri et al. 2004; Ware 1977). This practice is known among the OC community as “fasting,” though it may or may not lead to a reduction in caloric intake. Previous studies have demonstrated that 40-48 days on the OC restricted, “fasting” diet may lead to acute decreases in body mass index (BMI) and total blood cholesterol levels among Greek (Papadaki et al. 2008; Sarri et al. 2003) and Egyptian (Elshorbagy et al. 2017; Morcos et al. 2013) OCs.

Interestingly, this intentional restriction on MDE products during certain days and seasons may instill a frequency of MDE consumption that more closely resembles that of both our traditional farming and hunter-gatherer ancestors. Some investigators have even suggested that the regular intermittent periods of MDE restriction among many Greek OCs could, in addition to healthy baseline diets, contribute to the superior health of Greek populations relative to US and other European populations (Sarri et al. 2004). Yet, this conclusion may be premature, as the direction and degree of acute cardiometabolic responses to OC dietary restrictions appear to be variable within populations (Morcos et al. 2013) and inconsistent across the few OC populations studied. Moreover, as existing studies did not analyze the effects of specific dietary changes on the degree of change in physiological health markers, it is not clear whether it was the reported reductions of animal products, the reductions in calories, or the increases in cereal fiber, fruits, and vegetables (Papadaki et al. 2008; Sarri et al. 2004) - or an interaction among all three factors - that contributed to the observed short-term improvements in weight and blood lipids among OCs. Researchers have not taken the next step of exploring how variations in the realization of this practice might contribute to distinct cardiometabolic responses.

Importantly, no study of OCs has yet been conducted in the US, where diverse culinary traditions and food environments may lead to distinct realizations of the OC fasting diet. In fact, a mixed-methods pilot study on the dietary restrictions of OCs in the US offered insight on the variability in how this practice is followed (Bethancourt unpublished). This preliminary pilot work was pursued in the Antiochian OC jurisdiction, which is particularly open to converts (Krindatch 2011) and is represented by a mix “cradle-born” OCs of Arab and US-descent and convert OCs of US descent. Qualitative interviews and focus group discussions with adult parishioners (n=50) and priests (n=4) from four Antiochian OC churches in three states highlighted the fact that this practice is not about physiological health but rather about spiritual growth through exercising self-discipline and willpower and reducing the time and attention spent trying to satisfy bodily appetites and cravings. Accordingly, the emphasis is on what foods to give up, and little to no instruction is provided on what to consume during restricted periods. Of particular relevance is the fact that the specific rules on what foods should be avoided reflect what were considered in early Christian history to be “feasting” or celebratory foods. There are, therefore, no restrictions on sugars or processed foods that at the time did not exist or were not easily accessible. Nor is there a concrete guideline on how much to eat during OC fasting periods but rather general advice to consume less food or avoid overeating. Consequently, while some OC parishioners felt they typically consume healthier diets during the fasting periods, others confessed to eating decadent vegan chocolate cakes or unlimited amounts of fried potato products, bread, and pasta during those periods. Thus, the perceived physical health benefits of the OC fasting practice varied considerably. However, as most individuals do not closely track their diet or monitor changes in cardiometabolic health markers, interview data was not sufficient to objectively assess the health implications of OC dietary practices in the US.

Hence, guided by the insights provided by the qualitative research, a series of quantitative instruments were designed for collecting objective measures of changes in cardiometabolic health during an OC fasting period in addition to information on dietary patterns, health status, demographics, and lifestyle. These instruments (described in the methods section of each chapter) were first piloted in a small sample (n=11) of Antiochian OCs and then revised for use in the Lenten Season Study, the primary results of which are described in this dissertation. In short, this dissertation aims to answer four main questions:

> **Aim 1**: What concurrent changes in dietary quality and composition occur in relation to spiritually-motivated MDE restrictions among OCs in the US?
>
> **Aim 2:** Do OCs in the US experience the same kinds of short-term changes in well-established cardiometabolic health biomarkers during the Lenten period that are observed in other non-US OC populations during periods of MDE restriction?
>
> **Aim 3:** Does the direction and degree of change in cardiometabolic health biomarkers experienced by OCs in the US depend on the degree of concurrent change in caloric intake or the degree of concurrent change in specific “healthy’ or “unhealthy” non-MDE foods?

Chapter 2 of this dissertation addresses Aim 1 by using data from standard food frequency questionnaires (FFQs) to A) describe the nutritional and food composition of the pre-Lenten and Lenten diets of a sample of US-based OCs and B) explore whether restricting MDE products necessarily results in consumption of more "healthy" plant-based foods and a greater likelihood of meeting national dietary guidelines.

To address aims 2 and 3, Chapter 3 uses data from FFQs and health assessments to test the following hypotheses:

> **Hypothesis 1:** A 48-day restriction on MDE products will result in an overall improvement in cardiometabolic risk, as measured by decreases in BMI, body fat percentage, blood lipids, glucose, insulin, and C-reactive protein.
>
> **Hypothesis 2:** Any observed reductions in cardiometabolic health biomarkers will be more pronounced when MDE reduction is accompanied by decreases in calories or increases in consumption of "healthy" non-MDE foods (e.g., fish, whole grains, legumes, nuts and seeds, fruits and vegetables, or unsaturated discretionary oils) but less pronounced or null when MDE reduction is accompanied by increases in "unhealthy" plant-sourced foods (e.g., refined grains or added sugars).

Because errors in measurement of diet may be a major factor contributing to null diet-disease relationships (Bingham et al. 2003; Dahm et al. 2010; Freedman et al. 2006), Chapter 4 focuses on the following supplementary aim:

> **Aim 4:** Do relatively detailed but burdensome multiple-day food records provide different information than widely used retrospective food frequency questionnaires when investigating the relationships between dietary changes and

shifts in health biomarkers?

To answer this question, Chapter 4 reexamines aims 1-3 using 7-day food record data and compares the results to those obtained from the FFQ data in Chapters 2 and 3. In so doing, it addresses some of the reasons why the epidemiological literature often produces inconsistent results, and it outlines the limitations and strengths of nutritional assessment tools for providing dependable evidence on diet-disease relationships.

Finally, Chapter 5 summarizes the findings of the Lenten Season Study, highlights the theoretical significance and broader implications of this project, discusses some of the caveats and unanswered questions of the study, and proposes future directions for further investigating the potential factors that may modify the degree to which exclusion of animal products from the diet might influence short or long-term health measures and outcomes.

CHAPTER 2: THE EFFECTS OF A SPIRITUALLY-MOTIVATED MEAT, DAIRY, AND EGG FAST ON THE DIETARY COMPOSITION OF ORTHODOX CHRISTIANS IN THE UNITED STATES

CHAPTER 2 ABSTRACT

Vegetarian and vegan diets have been touted in both popular and academic nutritional spheres as being among the most effective strategy for meeting dietary guidelines, preventing and managing chronic disease, and promoting longevity. While such diets may be, in many aspects, healthier than the average industrialized omnivorous diet, it is important to explore how plant-based diets, like the omnivorous diets to which they are compared, can vary in the foods they include and in their nutritional composition. This study challenges the notion that the omission of animal products from the diet is, on its own, necessarily associated with improved dietary quality and increased likelihood of meeting dietary recommendations on plant-based foods. The data for this study come from a sample of 95 self-identified Orthodox Christians (OCs) and four non-OCs in the US who reported on their diet and relevant lifestyle factors before and during Lent, a 48-day period when OCs are encouraged to abstain from meat, dairy, and egg (MDE) products. Using data from food frequency questionnaires, a detailed examination of food and nutrient composition during Lent as compared to participants' pre-Lenten diet reveals that greater degrees of MDE restriction are significantly associated with increased consumption of legumes, soy products, nuts and seeds, and discretionary oils. These shifts translated into a reduction in total and animal-sourced protein and fat, vitamins B-12 and D, calcium, and zinc, along with increases in carbohydrates, dietary fiber, and magnesium. Greater degrees of MDE restriction were not, however, associated with greater odds of meeting recommendations on fruit and vegetable intake or staying below recommended cutoffs on refined grains and added sugars. Thus, while some improvements in dietary composition were observed as a result of the temporary spiritually-motivated MDE fast, recommended levels of several key dietary components remained outside of what are currently considered healthy ranges. Consumption

levels of any given non-MDE food during Lent were more strongly related to the amounts of that food consumed prior to Lent than to the reduction in MDE products. It is important, therefore, to consider how the potential health implications of shifting to a plant-based diet may depend both on the quality of the diet prior to the restriction of MDE products and on the interactions among the suite of food and nutrient changes that can occur in relation to restriction or omission of MDE products.

INTRODUCTION

A small but increasing minority of Americans chooses to abstain from some or all animal products in response to concerns regarding the purported detrimental health effects of meat and animal fat consumption and/or the ethical and environmental impacts of industrialized meat production (Radnitz et al. 2015). From a historical context, the idea of a meatless diet can be traced back to the teachings of early Greek philosophers and early leaders of Buddhist and Christian spiritual traditions (Leitzmann 2014; Spencer 1996), but the composition of a meatless diet today is substantially different than the meatless diets of pre-industrialized populations. Similarly, the meatless diets of vegetarians and vegans in the United States (US) might differ in meaningful ways from those living in regions with a longer history of consuming diets containing little or no meat. The increased popularity and availability of meat and dairy analogues (Melina et al. 2016), for example, may allow individuals to more easily transition from an omnivorous “standard American” or industrialized diet (Grotto and Zied 2010) to a vegan diet that is neither less calorically dense nor more fiber-, nutrient-, or antioxidant-rich (Leitzmann 2014; Satija et al. 2016; Satija et al. 2017). Thus, while the variability of meatless sources of protein, fat, and micronutrients now make it easier than ever to obtain a nutritionally adequate meatless diet if pursued with care (Craig et al. 2009; Melina et al. 2016), such diets may not necessarily be considerably healthier than omnivorous ones if they include the same or even greater amounts of added sugars, refined grains, and other highly processed foods that are thought to contribute to weight gain and cardiometabolic disease risk in omnivorous populations (Leitzmann 2014; Mozaffarian 2016; Mozaffarian et al. 2011; Satija et al. 2016; Satija et al. 2017; Yang et al. 2014).

Vegetarian and vegan diets, relative to omnivorous diets, tend to be praised for containing higher amounts, on average, of "healthy" plant-based foods and their components, such as fruits and vegetables, whole grains, legumes, fiber, antioxidants, and unsaturated fats (Craig et al. 2009; Fraser 2009; Melina et al. 2016). Yet, just as there is no single "omnivorous" diet, the dietary composition of vegetarian or vegan diets is not uniform within or across populations and may contain varying proportions of both healthy plant-based foods and less healthy (e.g., refined grain products and added sugars) plant-based foods. (Satija et al. 2016; Satija et al. 2017). Vegetarian and vegan Seventh Day Adventists (SDAs) in the US and Canada, for example, appear to consume more fruits and vegetables than non-SDA vegetarians and vegans in the UK (Orlich et al. 2014). The vegetarian diets of South Asians have also been shown to vary from those of American vegetarians in their relative amounts of vegetables, whole grains, nuts, desserts and fried foods (Jaacks et al. 2016). Food choices among vegetarians and vegans may differ in relation to distinct motivations for adopting a meatless diet (i.e., health, ethical, or religious reasons), length of adherence to a meatless diet, food access, and the local food and culinary environment (Dyett et al. 2013; Fraser 2009; Radnitz et al. 2015). Such dietary variations could explain the variability in cardiometabolic risk markers within and across US and South Asian vegetarian populations (Jaacks et al. 2016) and the inconsistent relationships observed between vegetarian or vegan diets and mortality risk across populations in the US, Europe, and Australia (Fraser et al. 2015b; Kwok et al. 2015; Kwok et al. 2014; Mihrshahi et al. 2017). However, few studies have attempted to explore the extent to which inclusion of unhealthy plant-based foods in broadly defined plant-based diets actually poses a public health concern.

Understanding what individuals choose in place of animal products is important when considering the potential implications of advice to omit or decrease intake of animal products. It is not clear that restriction of animal products from the diet will necessarily result in higher consumption of whole grains, legumes, and fruits and vegetables among individuals who are not already accustomed to consuming such foods or who refrain from animal product consumption for reasons other than to improve health (e.g., ethical or religious reasons). Orthodox Christians (OCs), for example, are encouraged as part of their spiritual practice to periodically “fast” (abstain) from meat, dairy, egg (MDE) products for up to 48 consecutive days at a time, but there are no church guidelines on what foods should be consumed in place of MDE products. Though this particular form of “fasting” has been part of the OC tradition for over a millennia and appears to be associated with some purportedly healthful nutritional shifts among Greek OCs in Crete (e.g., decreases in saturated fat and increases in fruits, vegetables, and dietary fiber) (Papadaki et al. 2008; Sarri et al. 2004), it is unclear if similarly beneficial nutritional shifts are experienced by OCs in the US, where culinary traditions and food environments differ substantially from those in Greece. To date no known studies have attempted to quantify changes in the diet that occur among any OC groups in the US when restricting MDE products as a spiritual rather than health-motivated discipline. An investigation into the dietary and nutritional shifts that occur during Lent among OCs in the US may offer valuable insight on the degree to which their periodic MDE fasts result in a “healthier” dietary profile.

The objective of this study, therefore, is to learn how US-based OCs modify their diets during periods of spiritually-motivated restrictions on animal products and to explore if those modifications lead to the same kinds of improvements in diet quality seen in other OC populations or other study populations that restrict MDE products from their diet. This study focuses on the fasting period known in the OC church as “Lent” (the 48 consecutive days prior to OC Easter, known as “Pascha”), as it is the longest and strictest period of guided dietary restrictions in the OC calendar. Specifically, this study aims to 1) describe the variation in the pre-Lenten and Lenten diets of OCs in the US; 2) test whether Lenten MDE restriction is associated with a greater likelihood of meeting national dietary recommendations on plant-based foods; 3) test the degree to which intake of fish and major plant-based foods changes in relation to MDE product restriction during Lent; and 4) assess what kinds of shifts in energy and nutrient composition result from reductions in MDE products.

METHODS

Study sample population

Study volunteers were recruited through oral and written announcements from nine OC churches in the southern region of the US. As the study aimed to recruit individuals with a range of adherence to OC Lenten dietary restrictions, non-OC individuals were also invited to join the study. Eligibility was limited to men and non-pregnant, non-lactating women between the ages of 18 and 75 who were born or raised in the US or Canada; no other exclusion criteria was in place.

At the end of a 5-month study recruitment period, 141 eligible adults signed up and consented to participate in the study, but only 120 actually initiated any of the study protocols. Of those who signed up and began taking part in the study protocols, 114 completed the first two surveys, first food questionnaire, and first health assessment. Of those, 108 participants completed the final survey and second health assessment, and 107 participants completed the second food questionnaire. All study protocols were approved by the University of Washington's Human Subjects Division.

Study design and covariate measurement

This was a short prospective study that followed participants during a 5- to 6-week unrestricted dietary period prior to the OC 2016 Lenten period through the subsequent 5- to 6-week Lenten period of dietary restrictions. Across the course of the study, participants were asked to complete three surveys to collect information about demographics; self-rated health status, existing health conditions; medication and supplement usage; tobacco, alcohol, and caffeine consumption; usual dietary preferences, food preparation, and patterns of eating at fast food and non-fast food restaurants. As most questions were categorical, assessments of change in time spent preparing food and frequency of eating out were based on whether participants chose a different frequency category in the follow-up (Lenten) survey compared with the prior (pre-Lenten) survey.

In addition to being asked to rate their daily occupations as either mostly sedentary, mostly standing or walking, moderate physical exertion, or hard physical labor, participants' physical activity prior to and during Lent were estimated using a modified version of the questionnaire developed for and used in the Aerobics Center Longitudinal Study (Kohl et al.

1997; Kohl et al. 1988). To obtain a measure of energy expenditure, participants were asked about their average weekly frequency, duration, and speed (if relevant) of engagement in 15 specific activities (walking, hiking, stair climbing, jogging, treadmill use, bicycling, swimming, aerobics, moderate activity sport, vigorous racquet sports, other vigorous sports, weight training, household chores, yard work, and manual labor) and any additional moderate and vigorous physical activities in the previous month. Activity-specific metabolic equivalent values (METs), which represent the ratio of the metabolic cost of performing the activity to a standardized resting metabolic rate (Ainsworth et al. 2011), were multiplied by the minutes per week of reported engagement in each activity. METs for each activity were summed and divided by 60 to obtain a measure of weekly MET hours in each data collection period.

Diet and Nutrition Assessment

Diet was measured before and during Lent using retrospective self-administered food frequency questionnaires (FFQs) available through the Nutrition Assessment Shared Resource of the Fred Hutchinson Cancer Research Center. The specific FFQ used was previously validated against the average of four 24-hour recalls and a 4-day FR for the measurement of energy intake and major nutrients among participants of the Women's Health Initiative (Patterson et al. 1999). The FFQs asked participants about the frequency (never, once per month, two to three times per month, once per week, twice per week, three to four times per week, five to six times per week, once a day, or twice or more a day) and usual serving size (small, medium, or large, with reference sizes for medium servings provided) of 106 food items and 18 beverage items consumed over the previous 4-5 weeks. An additional 13 adjustment questions asked participants about the kinds of added fats used regularly and the typical fat content of meat and dairy products consumed. Because the FFQs did not cover a comprehensive range of meat and dairy substitutes, participants received additional written instructions from the researcher to count rice, almond, or coconut milk as “soy milk;” coconut oil as “other oils;” almond cheese as “tofu cheese;” and veggie burgers as “tofu and tempeh.”

FFQs were reviewed for errors by the researcher and processed by the Nutrition Assessment Shared Resource of the Fred Hutchinson Cancer Research Center, which used the 2015 version of the University of Minnesota Nutrition Data Systems for Research (NDSR) software (Nutrition Coordinating Center: University of Minnesota 2015) to obtain measures of average daily consumption of major food groups, macro- and micronutrients, and calories. The food variables that were generated by this software utilized the MyPyramid Equivalent Database (Bowman et al. 2008), which measures meat in ounces (oz); eggs, grains, nuts, and soy products in ounce equivalents (oz-eq); fruit, vegetables, dairy, and legumes (not including soy products) in cup equivalents (cup-eq); discretionary oils in grams (g), and added sugar as grams and teaspoon equivalents (tsp-eq). Estimates of macro- and micronutrients were measured by their mass (e.g., grams), and energy intake was measured in kilocalories (kcal).

In addition to the individual food and nutrient variables, the NDSR software provided scores for the 2010 Healthy Eating Index, a measure of conformance to target consumption levels of the major food sources laid out in the 2010 Dietary Guidelines of Americans (Guenther et al. 2013; Guenther et al. 2014). The total 2010 HEI score system ranges from 0 to 100 and is based on twelve components: total fruit (maximum 5 points for ≥ 0.8 cup equivalent per 1000 kcal), whole fruit (maximum 5 points for ≥ 0.4 cup equivalent per 1000 kcal); total vegetables (maximum 5 points for ≥ 1.1 cup equivalents per 1000 kcal); greens and beans, including any legumes not included in total protein foods (maximum 5 points for ≥ 0.2 cup equivalent per 1000 kcal); whole grains (maximum 10 points for ≥ 1.5 oz equivalents per 1000 kcal); dairy (maximum 10 points for ≥ 1.3 cup equivalents per 1000 kcal); total protein foods (maximum 5 points for ≥ 2.5 oz equivalents per 1000 kcal); seafood and plant proteins (maximum 5 points for ≥ 0.8 oz equivalent per 1000 kcal); fatty acids (maximum 10 points for ≥ (PUFA+MUFAs/SFAs>2.5); refined grains (maximum 10 points for ≤1.8 oz equivalent per 1000 kcal); sodium (maximum 10 points for ≤1.1 per 1000 kcal); and empty calories, including solid fats, alcohol, and added sugars (maximum 10 points for ≤19% of energy).

Statistical analyses

After data on caloric intake were reviewed for implausibly low or high estimates of energy intake in either time period (<500 kcal or >4500 kcal for females and <800 kcal or >5000 kcal for males), one male was excluded because of an estimated energy intake >5000 before Lent and one female was excluded for an estimated energy intake <500 during Lent. Another six participants with complete data were excluded from the analyses for being on a strict weight loss regime during the study period (n=2), following the earlier Catholic Lenten calendar (n=1), already restricting all MDE products at baseline (n=2), or reporting a change in cholesterol- or diabetes-related medications during the study period (n=1). These exclusions resulted in a sample of 99 participants.

Standardized food and nutrient density variables (intake per 2000 kcal) were used in all analyses to reduce some of the correlated measurement error between nutrient/food and total energy estimates (Willett 2001b; Willett 2013). Nutrient and food densities also offer a better representation of dietary change, as a decrease or increase in one food inevitably shifts the dietary proportions. Standardization was achieved by dividing the average daily amount of each food or nutrient in each collection period by the respective caloric intake and multiplying that number by 2000. Following standard protocol, estimates of the percent of energy obtained from total, animal, and plant proteins; carbohydrates; and total and added sugars were obtained by multiplying estimated amounts of those macronutrients in grams by the standard ratio of 4/kcal intake, while estimates of percent of energy obtained from total and specific fats were obtained by multiplying estimated amounts of those nutrients by a ratio of 9/kcal intake.

Composite measures of participants' consumption of MDE products at time 1 (MDE1 score) and time 2 (MDE2 score) were created by adding the number of servings/2000 kcal of MDE products consumed in each period. For the purposes of this composite score, a MDE "serving" was defined as 3 oz of unprocessed meat, 2 oz of processed meat, 1 cup-eq of dairy, or a 2 oz-eq of eggs. The difference between the MDE1 and MDE2 scores was used to create a composite measure of the estimated change in MDE servings (MDEΔ score) between the two time periods.

For the purpose of describing the pre-Lenten and Lenten diets of the study population (Aim 1), food densities are presented across tertiles of MDEΔ score, with tertile 1 representing the least amount of change in MDE consumption and tertile 3 representing the greatest degree of MDE reduction. One-way Anova tests with Bonferroni-corrected pairwise comparisons were used to test for differences in consumption of prominent animal- and plant-based foods across the MDEΔ score tertiles at baseline and again during Lent.

To assess whether MDE restriction is associated with a greater likelihood of meeting national dietary recommendations (Aim 2), binary variables were created to indicate whether each individual met 2015-2020 Dietary Guidelines for Americans (US Department of Health Human Services; US Department of Agriculture 2015) on total vegetables, green vegetables, red and orange vegetables, starchy and other vegetables, legumes, total fruit, whole grains, dairy and dairy alternatives, total protein foods, meat and eggs, seafood, and nuts and soy products or staying below recommended thresholds for refined grains and added sugars. Multiple logistic regression models with robust standard errors were used to test whether MDEΔ score was associated with the odds of meeting recommendations on intake for the seafood and plant-sourced food categories. Logistic regression models controlled for the baseline consumption of the given food being tested, MDE1 score, baseline calories, change in calories, average weekly METs, change in weekly METs, baseline BMI, age, and sex. P-values were considered significant if below 0.05/11=0.0045. Additionally, HEI 2010 scores were compared across tertiles before and during Lent, and multiple linear regression analyses tested the change in the total score relative to the MDEΔ score, adjusting for the baseline HEI 2010 score, MDE1 score, baseline calories, change in calories, age, sex, BMI, average MET hours, and change in MET hours.

To test how food and nutrient composition changes in relation to reductions in MDE products during Lent (Aims 3 and 4), multiple linear regression models with robust standard errors were used to regress the Lenten density of 11 major food groups (fish, whole grains, refined grains, legumes, meat alternatives, nuts and seeds, fruit, vegetables, white potatoes, discretionary oils, and added sugars) on the MDEΔ score while controlling for MDE1 score, baseline intake of the respective food being tested, baseline calories, change in calories, average weekly METs, change in weekly METs, baseline BMI, age, and sex. A Bonferroni-adjusted α-level of 0.05/11=0.0045 was used to assess statistical significance in these food models. The same multiple linear regression models were then run with total calories, energy density, and 28 macro- and micronutrients with a Bonferroni-adjusted α-level of 0.05/30=0.0017. Regression analyses on percentage differences in non-MDE foods explained the models poorly (all $R^2<0.2$) as those variables were highly skewed; hence, regression results for foods are presented as additive differences, but regression results on calories and nutrients are presented as percent differences. These analyses were all conducted using StataSE 14 or RStudio.

RESULTS

Sample demographics, health characteristics, and dietary behaviors

The adults in this study sample were 19-73 years old (mean=46.7); 42% were male, and 94% reported their race as "white or Caucasian" (Table 2.1a). Overall, this was a highly educated, high-earning group of individuals, with 92% having received a minimum of a 4-year college degree and 45% reporting an annual household income ≥$100,000. There were no differences across MDEΔ score tertiles in age, sex distribution, education level, or income. Four individuals in the sample did not self-identify as OCs and were in the first MDEΔ score tertile (the tertile with the least amount of change in MDE consumption during the Lenten period). Among those who identified as OC, 77% were converts to the practice (i.e., did not grow up with the tradition of OC fasting practices), and the proportion of converts did not differ across MDEΔ score tertiles.

Most individuals (90%) rated their health status as "good," "very good," or "excellent" at the start of the study. The average BMI of 27.3 kg/m^2 would, by standard cutoff levels (Flegal et al. 2012), categorize this group as slightly overweight, on average, and 14% of individuals reported regularly taking medication for blood pressure (n=10), cholesterol (n=6), or diabetes (n=3). Only 8% of the sample reported that they currently consume some form of tobacco products, and 24% consumed more than an average of one alcoholic drink per day. These characteristics did not differ significantly across MDEΔ score tertiles.

Five individuals reported regularly following a vegetarian (n=3) or pesco-vegetarian diet (n=2) (Table 2.1b). Two of the vegetarians still changed their dairy and egg consumption enough to end up in tertile 2. As expected, tertile 3 had the greatest proportion of individuals consuming one or more servings/2000 kcal of meat and the equivalent of at least one egg/2000 kcal prior to Lent. Yet even in that third tertile, about 9% were still not eating a full serving/2000 kcal of meat on a daily basis. There was no difference across tertiles in the proportion of individuals consuming one or more cup-equivalent serving of dairy at baseline.

The majority (77%) of individuals reported that they were the ones primarily responsible in their household for preparing meals. The proportion of the sample reporting an increase versus decrease in time spent engaged in food preparation during Lent was not significantly different within or across the MDEΔ score tertiles. Likewise, there was no significant difference in the proportion of individuals reporting increased versus decreased frequencies of eating out at non-fast food restaurants during Lent. There was, however, a greater proportion of individuals in the second and third tertiles that reported a lower frequency of eating out at fast-food restaurants during Lent.

Aims 1 and 2: The pre-Lenten and Lenten diets and adherence to dietary guidelines among OCs in the US

Pre-Lenten (baseline) MDE consumption varied from <1 serving/2000 kcal to 6.4 servings/2000 kcal (Figure 2.1) and was most variable among the first MDEΔ score tertile, in which those who were consistently low MDE eaters were grouped with those that ate more MDE products but did not follow the OC Lenten fast or did so less strictly. Average baseline meat consumption was estimated to be at least one serving (>3 oz/2000 kcal) across the MDEΔ tertiles, though consumption ranged from zero to more than three servings/day on average (Table 2.2). Consumption of red meat was more variable and tended to be higher than average poultry intake. Consumption of processed meat was, on average, <1 oz/2000 kcal, though some consumed close to a 2 oz serving/2000 kcal. Fish consumption was close to 1 oz/2000 kcal in this sample. Dairy consumption was low at baseline; participants consumed, on average, only about one serving of dairy/2000 kcal at baseline, and this did not differ by MDEΔ tertiles. The equivalent of one egg/2000 kcal was consumed, on average, among the third MDEΔ; about half this amount was consumed by the other two tertiles.

During Lent, individuals in MDEΔ tertile 1 either did not reduce MDE consumption by more than one serving or were estimated to have slightly increased MDE consumption during Lent. MDE servings in tertile 1 ranged from <1 serving to 5.5 servings/2000 kcal in both time points, and the average drop in MDE servings was only 0.3 servings/2000 kcal. Individuals in MDEΔ tertile 2 decreased their MDE consumption by 1.3 to 2.1 servings (mean=1.8); all but one individual in this tertile was consuming <2.5 MDE servings/2000 kcal during Lent. MDEΔ tertile 3 comprised individuals who reduced their MDE consumption by 2.2 to 4.9 servings (mean=3.1); most were consuming <1.5 MDE servings during Lent. Fish was the only animal product that was consumed to similar degrees across all MDEΔ tertiles during Lent.

Intake of many plant-based foods were variable both before and during Lent (Table 2.2; Figure 2.2). Whole grain consumption ranged from 0 to >7 oz-eq servings/2000 kcal (mean <2 oz-eq/2000 kcal) in both periods. However, <15% of the sample was meeting dietary guidelines to consume ≥3 oz-eq/day of whole grains at baseline, and the odds of meeting this recommendation did not increase in relation to MDE restriction during Lent (Table 2.3). Refined grain consumption, on the other hand, was higher on average and more variable than whole grain consumption both before and during Lent; over half of the sample was surpassing the recommended cutoff of ≤3 oz-eq/2000 kcal of refined grains before Lent, and there was no evidence that the odds of meeting this guideline changed with MDE restriction.

Legume intake was low prior to Lent; few individuals consumed more than 0.25 cup-eq/2000 kcal (Table 2.2; Figure 2.2). However, each serving reduction in MDE products was associated with a 2.4-fold (95%CI: 1.3-4.1, p=0.003) increase in the odds of meeting the recommended 1.5 cup-eq/week intake of legumes (Table 2.3). Nut and seed consumption, on the other hand, started off high; median and average consumption prior to Lent was >1 oz-eq serving/2000 kcal. The majority of the sample was meeting recommendations to consume ≥5 oz-eq/week of any combination of nuts, seeds, and soy products at baseline, yet MDE product restriction still increased the odds of meeting this recommendation by 3-fold (95%CI: 1.5-5.9, p=0.002). In fact, some individuals in the second and third tertiles were consuming >5 oz-eq/2000 kcal of nuts and seeds during Lent.

Fruit consumption was low prior to Lent; less than 10% of the total sample was meeting dietary guidelines to consume ≥2 cup-eq servings/2000 kcal of whole fruit, and the odds of meeting these recommendations did not increase with MDE restriction (Table 2.3). Median and average vegetable intake neared 2 cup-eq servings/2000 kcal but ranged from nearly no consumption to >5 cup-eq/2000 kcal. Individuals in this sample seemed to be better at meeting recommendations for intake of dark green and other vegetables than they were at meeting recommendations on starchy or red/orange vegetables. However, there was no indication that MDE restriction increased the odds of meeting recommendations on any non-legume vegetable.

Potato consumption was below 1 cup-eq/2000 kcal for all but a few individuals prior to Lent, and it did not increase, on average, during Lent. A meaningful coefficient for the odds of meeting the 5 cup-eq/week recommendation for starchy vegetables was unobtainable for MDEΔ, as all of the other covariates in the model predicted consumption perfectly (i.e., MDEΔ was unrelated to starchy vegetable consumption during Lent after accounting for baseline consumption and other covariates).

Consumption of discretionary oils ranged from <15 g/2000 kcal to >40 g/2000 kcal; average consumption was approximately 30 g/2000 kcal – or approximately 6.7 tsp/2000 kcal (Table 2.2). During Lent, discretionary oil consumption had increased in the third MDEΔ tertile to 38 g/2000 kcal or approximately 8.4 tsp/2000 kcal.

Added sugars ranged from <2 tsp/2000 kcal to >25 tsp/2000 kcal, and median and average intake was approximately 12 tsp/2000 kcal (Table 2.2). Less than half of the total sample was meeting guidelines to keep calories from added sugars below 10%, and there was no evidence that the odds of meeting these guidelines changed in relation to MDE restriction (Table 2.3).

Overall, this sample had an average HEI 2010 score of 66 out of 100 (ranging from 39 to 88) (Table 2.3). The multiple linear regression analysis estimated that each serving reduction in MDE products during Lent was associated with an average 2-point increase in the HEI 2010 score (95% CI: 0.6 to 3.3, p=0.005).

Aim 3: Shifts in non-MDE foods in relation to the Lenten MDE fast

Each serving decrease of MDE products during Lent was associated with a statistically significant increase in consumption of legumes, soy products, nuts and seeds, and discretionary oils (Table 2.4; Figure 2.3), after controlling for differences in baseline consumption patterns, changes in calories, age, sex, baseline BMI, and activity patterns. Specifically, each unit-change in the MDEΔ score was associated with an average 0.09 (95% CI: 0.05-0.13, p<0.0001) cup-eq/2000 kcal increase in legumes; 0.19 (95% CI: 0.11-0.27, p<0.0001) oz-eq/2000 kcal increase in soy products; and 0.54 (95% CI: 0.31-0.77, p<0.0001) oz-eq/2000 kcal increase in nuts and seeds. Discretionary oils increased by an average 3.34 (95% CI: 1.60-5.09, p=0.0003) g/2000 kcal for each serving reduction in MDE products. There was no evidence of a change in consumption of fish, whole grains, refined grains, fruit, vegetables, white potatoes, or added sugar in relation to shifts in MDE consumption.[1] The greatest predictor of Lenten consumption of all plant-based foods was baseline consumption levels of those same foods (all p-values for baseline intake of individual plant-based foods ≤0.0003).

Aim 4: Shifts in energy and nutrient intake related to MDE restriction

Baseline caloric and nutrient intake varied substantially in this sample (Table 2.5a and Table 2.5b). Caloric intake among the males in the sample ranged from approximately 1100 to 4200 kcal with an average of approximately 2300 kcal; caloric intake among the females ranged from approximately 650 to 4200 kcal with an average of approximately 2000. Prior to Lent, individuals in this sample obtained approximately 17%, 37%, and 45% of their energy from protein, fat, and carbohydrates, respectively. A greater proportion of their protein prior to Lent was obtained from animal sources than plant sources, particularly in the third MDEΔ tertile.

---

[1] Whole grains and refined grains increased by an average 0.26 (95% CI: 0.06-0.46, p=0.01) and 0.28 (95% CI: 0.03-0.52, p=0.03) oz-eq/2000 kcal, respectively, for each serving decrease in MDE products, but these changes were only significant at the standard, non-adjusted α-level of 0.05. Similarly, the average 0.17 (95% CI: 0-0.34, p=0.04) cup-eq/2000 kcal increase in vegetables was only significant at the standard α-level.

Saturated fat supplied approximately 12% of total energy among the entire sample. Carbohydrate intake was both higher and more variable in the first MDEΔ tertile; total sugars, on the other hand, did not differ across MDEΔ tertiles and were estimated to supply approximately 19% of total energy prior to Lent. Baseline fiber intake was approximately 23 g/2000 kcal, on average, but ranged from 9 to 42 g/2000 kcal. Most nutrients and fatty acids did not differ substantially across MDEΔ tertiles prior to Lent, with the exception of arachidonic acid, vitamin B-12, and vitamin D, which were all higher in the third MDEΔ tertile.

During Lent, average calorie intake of males and females in the third MDEΔ tertile was approximately 1600 and 1300, respectively, with ranges from approximately 800 to 2800 in males and 700 to 2400 in females. There was no indication that average caloric intake was different across the MDEΔ tertiles during Lent. The average 5.2% (95% CI: 2.0-8.5%, p=0.002) kcal decrease and a 4.9% (95% CI 1.5-8.4%, p=0.005) decrease in energy density associated with each serving decrease in MDE products were not significant at the Bonferroni-adjusted α-level of 0.0017 (Table 2.6). However, the average 8.0% (95% CI: 6.1-9.9%, p<0.0001) decrease in total protein density, 24.9% (95% CI: 21.4-28.5%, p<0.0001) decrease in animal protein density, and 24.9% (95% CI: 20.5-29.2%, p<0.0001) increase in plant protein density associated with each unit change in MDEΔ score were highly significant. As a result, protein was supplying 13% of energy in the third MDEΔ tertile during Lent, compared with the 18% in that tertile prior to Lent.

Each serving reduction in MDE products was also significantly associated with an average 5.8% (95% CI: 3.3-8.3%, p<0.0001) decrease in total fat, 14.5% (95% CI: 12.1-16.9%, p<0.0001) decrease in saturated fat density, 17.1% (95% CI: 13-21.2%, p<0.0001) decrease in trans fat density, and 22.4% (95% CI: 17.6-27.2%, p<0.0001) decrease in arachidonic acid density. The average proportion of energy supplied by saturated fat in the third MDEΔ tertile was reduced from 13% prior to Lent to 7% during Lent, though it ranged from 3-13%. There was no indication, however, that mono- and polyunsaturated fats changed in relation to the Lenten MDE restrictions.

Carbohydrate intake was higher in the third MDEΔ tertile than in the first MDEΔ tertile during Lent but varied widely, contributing 30% to 73% of calories. Carbohydrate density increased by an average of 9.4% (95% CI: 6.3-12.5%, p<0.0001) in relation to each serving decrease in MDE products. Total sugars contributed 13% to 29% of calories in the third MDEΔ tertile during Lent, but there was no indication that total sugar consumption changed in relation to MDE restriction. Dietary fiber density increased by an average of 16.9% (95% CI: 11.6-22.2%, p<0.0001) for each unit change in MDEΔ score, but it varied substantially in the third MDEΔ tertile, ranging from 16 to 82 g/2000 kcal.

The micronutrient changes that were significantly associated with MDE reductions included the average 17.3% (95% CI: 12.2—24.4%, p<0.0001) reduction in Vitamin B-12, 26.4% (95% CI: 18.4-34.4%, p<0.0001) reduction in Vitamin D, and 12.1% (95% CI: 7.5-16.7%, p<0.0001) reduction in calcium. The only micronutrient to significantly increase in relation to the MDE changes was magnesium, which was estimated to increase by an average of 7.2% (95% CI: 3.9-10.4%, p<0.0001). There were no significant associations between MDEΔ score and shifts in sodium, potassium, folate, vitamin B6, vitamin K, iron, selenium, or zinc.[2]

---

[2] Though only significant at an unadjusted α-level, there was some suggestion that iron increased by an average of 6.1% (95% CI: 1.9-10.4%, p=0.005) and zinc decreased by an average of 4.9% (95% CI: 1.8-8.1%, p=0.002) for each serving decrease in MDE products. The estimated 5.9% (95% CI: 1.1-10.7%, p=0.016) increase in folate and 3.4% (95% CI: 0.4-6.3%, p=0.026) increase in selenium were not statistically significant at the adjusted α-level.

DISCUSSION

This is the first known study to attempt to describe and quantify the pre-Lenten and Lenten diets of a sample of OCs in the US. It uniquely assesses the change in fish, plant-based foods, calories, and nutrients in relation to reductions in MDE products and evaluates whether temporary, spiritually-motivated dietary restrictions on MDE products increases adherents' odds of meeting dietary recommendations on plant-based foods.

The major findings of this study are that Lenten restrictions on MDE products were strongly associated with increases in legumes, soy products, nuts and seeds, and discretionary oils after accounting for multiple comparisons. However, these dietary shifts did not necessarily translate into a greater odds of meeting target or threshold levels of all plant-based foods set by the 2015-2020 Dietary Guidelines for Americans. No significant associations were observed between MDE reductions and changes in consumption of fish, fruit, white potatoes, or added sugars, whole grains, refined grains, and vegetables.

Importantly, though the average 0.09 cup-eq/2000 kcal increase in legumes for each unit decrease in MDE products would seem insignificant from a nutritional standpoint, this was enough of an increase above baseline consumption levels to more than double the odds of meeting USDA recommendations on consumption of legumes during Lent. Similarly, the average 0.19 oz-eq/2000 increase in soy products and 0.54 oz-eq/2000 increase in nuts and seeds nearly tripled the odds of meeting recommended intakes of that composite group of plant-based protein sources. On the other hand, even among those who made the greatest change in MDE consumption, $\geq$30% still were not meeting recommendations on total, dark green, or red and orange vegetables, and barely one-fifth were meeting recommended fruit intake during Lent. Moreover, though not statistically significant at the adjusted α-level, there was a trend toward increasing refined grains that was at least on par with the trend toward increased whole grain consumption, and over 70% of those in the third MDEΔ tertile were consuming more refined grains than is advised. Likewise, over half of those in the third MDEΔ tertile were estimated to have obtained more than 10% of their calories from added sugars during Lent.

Though few individual plant-sourced foods increased to a statistically significant degree, the combination of MDE reductions and increases in multiple plant-sourced foods unsurprisingly resulted in decreases in total and animal protein, total and saturated fat, and arachidonic acid, along with increases in vegetable protein, total carbohydrates, dietary fiber, and magnesium. Likewise, given that animal-sourced foods tend to be one of the predominant sources of vitamins B-12 and D and calcium, it is not surprising that those micronutrients were estimated to have decreased during Lent in relation to MDE restriction. The implications of these observed changes in dietary and nutritional composition are discussed below.

Comparisons with other OC populations

The findings in this study are comparable to reports of dietary changes among a sample of 10 Cretan OC monks (Papadaki et al. 2008) and a sample of 60 Cretan OC clergy, monastics, and laypersons (Sarri et al. 2004) but contrast with findings reported for a sample of 70 Greek OC monks in Mount Athos (Karras et al. 2017). Average energy intake during Lent in the third MDEΔ score tertile was similar to that of the mixed group of Cretan OCs (Sarri et al. 2004), lower than that of Cretan monks (Papadaki et al. 2008), and higher than that of Athonian monks (Karras et al. 2017). Like the US OC sample, both of the Cretan OC study populations also experienced significant decreases in the average percent of energy consumed from protein and total, saturated, and trans fatty acids along with increases in the average percent of calories obtained from carbohydrates and dietary fiber intake during prolonged periods of restricting animal products. Conversely, the sample of Athonian monks, who already abstain from meat year-round and only omit dairy, eggs, vertebrate fish, and olive oil during the period of dietary restriction, experienced an average decrease in carbohydrates and fiber and increase in total fat and protein (Karras et al. 2017). Similar to the present study, the Cretan populations similarly experienced drops in calcium and increases in folate, iron, and magnesium intake. Among the Athonian monks, however, iron decreased, as did vitamin E and vitamin K. In all Greek OC samples and at both time periods, calcium was lower than in this US OC sample.

Other than the description of changes in nutrient intake, there were no detailed reports of shifts in food consumption patterns among the Athonian monks. However, among Cretan OCs, consumption of bread, cereal, and sugar products did not differ significantly between the restricted and unrestricted diet periods. Nonetheless, the modest increases in each of these food groups may have been interpreted differently had estimates of those foods been standardized to energy consumption, since estimated caloric intake did drop in both samples. There was, however, a more notable increase in vegetable intake among the sample of Greek monks relative to this study (Papadaki et al. 2008). Again, the increase in fruits and vegetables in the larger Greek sample (Sarri et al. 2004) may have been more meaningful if standardized to caloric intake. Legume intake did not increase among the larger Cretan OC sample, perhaps because of an already high baseline intake of legumes, but it did increase significantly among the Cretan monks (Papadaki et al. 2008). Overall, although direct comparisons are difficult given differences in how food groups were categorized and lack of standardization of non-macronutrient variables, it appears that Cretan OCs that adhere to Lenten fasting guidelines experience shifts in consumption of plant-based foods and nutritional composition that are similar to those observed in this US OC population, whereas the Athonian OCs who consistently consume meatless diets, experience distinct and unexpected nutritional shifts when they omit fish, dairy, and eggs. No previous studies explored whether the periodic MDE fasts are associated with a change in the odds of meeting dietary recommendations, so it remains unclear to what degree the Lenten MDE restrictions are associated with an overall "healthier" dietary pattern in other OC populations.

Comparisons with other non-OC study populations

US-based clinical trials that involve vegetarian or vegan dietary interventions frequently report changes in protein, total fat, saturated fat, and carbohydrate that are comparable to those observed in this OC study sample during the MDE Lenten fast (Barnard et al. 2009a; Barnard et al. 2009b; Bloomer et al. 2015; Bloomer et al. 2010; Mishra et al. 2013; Turner-McGrievy et al. 2004; Turner-McGrievy et al. 2015). For example, the drops in the percent of energy from total protein, total fat, and saturated fat and increases in percent of energy from carbohydrates experienced among OCs in the third MDEΔ tertile were more similar to the degree of change in those macronutrients experienced by study participants randomized to a strict vegan or vegetarian diet than by those randomized to semi- or pesco-vegetarian diets (Turner-McGrievy et al. 2015). This may be due to the fact that many OCs were also giving up most dairy products and eggs, making their diets more similar to a vegan diet than to a standard vegetarian diet. In fact, the change in protein, saturated fat, and carbohydrates among OCs were comparable to or greater than the changes observed in one intervention study in which some participants were randomized to a low-fat vegan diet (Mishra et al. 2013). Other low-fat vegan dietary interventions have been more extreme, however, resulting in more dramatic decreases in total fat, saturated fat, and protein and more substantial increases in fiber than observed in the present OC study (Barnard et al. 2009a; Barnard et al. 2009b; Bloomer et al. 2015; Bloomer et al. 2010; Turner-McGrievy et al. 2004). Notably, one study reported an average 1.6 servings/day increase in fruit and 2.2 servings/day increase in vegetable intake among a free-living study population randomized to a low-fat vegan diet (Barnard et al. 2009a). Though some individuals in the OC sample reported here increased their intake of fruits and vegetables by that much or more during Lent, the average increase of fruit and vegetables in the third MDEΔ tertile was 0.6 and 1.0 serving/2000 kcal, respectively.

An important difference between randomized controlled trials and Lenten OC dietary restrictions is that participants of intervention studies generally receive more guidance on what foods to avoid and what foods to consume in place of MDE products. Therefore, it is worth comparing the characteristics of the OC Lenten diet to the dietary characteristics of other free-living, self-selected vegetarian and vegan populations. For example, nutrient profiles of OCs in the second and third MDEΔ score tertiles were on par with those of lacto-ovo-vegetarians and pesco-vegetarians in a large sample of Seventh Day Adventists from the US and Canada (Rizzo et al. 2013) and a large sample of non-meat-eaters in the UK (Bradbury et al. 2014; Sobiecki et al. 2016; Spencer et al. 2003b). However, total energy intake among those aforementioned study populations appears slightly higher than the total energy intake estimated for those in the upper two MDEΔ score tertiles of this sample of OCs. Lower energy intake in this sample could be related to the tendency of some OCs to reduce total meal consumption on certain days during Lent. Interestingly, the present OC population appeared to have slightly lower percentages of energy coming from total sugar compared to both meat-eating and non-meat-eating European populations (Sobiecki et al. 2016; Spencer et al. 2003b). However, the OCs in the present sample appear to consume fewer fruits and vegetables, soy products, legumes, and whole grains and may be less likely to meet national dietary guidelines than vegetarian and vegan groups in the large North American Seventh Day Adventist sample (Orlich et al. 2014).

Implications of study findings

It is worth considering that even the moderate decrease in calories observed in this OC study sample, particularly when coupled with a reduction in protein, may by itself be health-promoting, regardless of other shifts in food and nutrient composition. Even just five days of a low-protein, low-calorie (700-1100 kcal) diet practiced periodically has been shown to lower body fat, blood pressure, and insulin-like growth factor, implicated in the pathogenesis of cancer and diabetes (Wei et al. 2017). Two days/week of more substantial calorie reduction, as may be practiced by some OCs during Lent, may also reduce body fat and increase insulin sensitivity, thus potentially helping to prevent the development and progression of metabolic diseases (Mattson et al. 2017). Nonetheless, as specific foods and dietary patterns do tend to be associated with differential health markers and outcomes after controlling for caloric intake, the implications of the Lenten shifts in specific sources of calories are worth considering. Yet, as none of the dietary changes observed in this study occurred in isolation but rather as a part of a multifaceted dietary shift, the potential health implications of these findings are far from straightforward.

On the one hand, observational data suggest that risk of cardiometabolic-related morbidity and mortality may increase in relation to higher meat, particularly red and/or processed meat consumption (Abete et al. 2014; Aune et al. 2009; Ley et al. ; Micha et al. 2012; Micha et al. 2017; Micha et al. 2010; Pan et al. 2012a; Pan et al. 2011; Rohrmann et al. 2013;

Sinha et al. 2009) and decrease in relation to higher intake of nuts and seeds, legumes, and soy products (Aune et al. 2016a; Micha et al. 2017; Souza et al. 2015). Randomized controlled trials also demonstrate that vegan diets, particularly low-fat versions, can promote weight loss, improve glycemic control, and lower total and LDL cholesterol, though with mixed effect sizes across studies (Wang et al. 2015; Yokoyama et al. 2014; Yokoyama et al. 2017). These apparent health benefits may be contributed, at least in part, to the blood lipid lowering effects of reducing intake saturated fat (Dinu et al. 2017; Sacks et al. 2017; Yokoyama et al. 2017), particularly when replaced with polyunsaturated fats (Hooper et al. 2015; Mozaffarian et al. 2010; Sacks et al. 2017) and high-fiber plant-based foods (Gardner et al. 2005; Jenkins et al. 2003). Nuts, seeds, and legumes, perhaps because of their high fiber content (Messina 2014; Salas-Salvadó et al. 2006), appear to help improve blood lipid profiles (Banel and Hu 2009; Bazzano et al. 2011; Ha et al. 2014; Reynolds et al. 2006; Sabaté et al. 2010; Souza et al. 2015) and glycemic control (Ramdath et al. 2016; Salas-Salvadó et al. 2006; Sievenpiper et al. 2009). From this perspective, even the temporary reduction in meat and saturated fat combined with increases in nuts, seeds, legumes, soy products, and overall dietary fiber observed in this sample of OCs restricting MDE products could have benefits on cardiometabolic risk markers. Even though the Lenten restrictions are only temporary, it is conceivable that similar restrictions practiced periodically throughout the year, as is the case for many OCs, could confer long-term health benefits also.

On the other hand, the present study demonstrated how easy it is in the US to make substantial reductions in consumption of MDE products and still not consume recommended amounts of whole plant-based foods while overconsuming refined plant-based foods. Suboptimal intake of whole grains relative to refined grains (Aune et al. 2016b; Aune et al. 2013b; Hollænder et al. 2015; Micha et al. 2017), low fruits and vegetable consumption (Carter et al.

2010; Dauchet et al. 2009; Dauchet et al. 2006; Gan et al. 2015; He et al. 2007; Leenders et al. 2014; Lock et al. 2005; Micha et al. 2017; Zhang et al. 2011), and excess intake of added sugars (Malik et al. 2010; Micha et al. 2017; Stanhope et al. 2015; Te Morenga et al. 2014; Yang et al. 2014) tend to be associated with increased risk of weight gain, metabolic diseases, dyslipidemia, and disease-related mortality. Some evidence suggests that low-meat or meatless diets containing high amounts of highly refined or processed plant-based foods may confer no health benefit or may even be unhealthy relative to an omnivorous diet combing meat with ample whole grains, fruits and vegetables (Bloomer et al. 2015; Satija et al. 2016; Satija et al. 2017). Replacing saturated fats with refined grains and added sugars, for example, could worsen rather than improve blood lipid profiles (Jakobsen et al. 2009; Li et al. 2015; Mozaffarian et al. 2010; Willett 2012). This variation in plant-based diets may explain why vegetarian and vegan diets are not consistently associated with reduced risk of cardiovascular disease and premature mortality (Dinu et al. 2017; Fraser et al. 2015b; Huang et al. 2012; Kwok et al. 2015; Kwok et al. 2014; Mihrshahi et al. 2017; Orlich et al. 2013; Sobiecki et al. 2016). The ease with which refined plant-based foods can be chosen as MDE replacements may also help explain why, despite having better health markers on average, neither vegetarian nor vegan populations are immune to weight gain (Rosell et al. 2006), overweight and obesity (Jaacks et al. 2016; Singh et al. 2014; Zhang et al. 2010), metabolic syndrome (Rizzo et al. 2011; Shang et al. 2011), diabetes (Tonstad et al. 2009; Tonstad et al. 2013; Zhang et al. 2010), hypertension (Berkow and Barnard 2005; Zhang et al. 2010), or dyslipidemia (Zhang et al. 2010). In fact, many OC monks on Mount Athos have body fat and insulin measures that are outside of optimal ranges, despite omitting meat year-round, fasting from dairy and eggs for 180-200 days out of the year, and consuming relatively low calorie diets (Karras et al. 2017).

Of course, this sample of OCs is not alone in falling short on recommended targets for daily servings of whole plant-based food or exceeding the threshold for intake of empty calorie foods. The majority of Americans fail to meet guidelines on fruit, vegetable, whole grain, and legume consumption and consume excess added sugar (Krebs-Smith et al. 2010; Moore and Thompson 2015; Yang et al. 2014). However, an important observation that is not apparent when looking at averages and proportions is that few individuals in this sample fell short on every key recommendation simultaneously. In other words, though a substantial portion of OCs in this sample were, according to 2015-2020 Dietary Guidelines for Americans, consuming inadequate servings of whole grains, fruits, and vegetables or undue amounts of refined grains and added sugars, only three participants (one individual per tertile) neglected all of these recommendations at the same time. Thus, the average HEI scores for this sample still managed to be higher in both time periods than the average scores calculated for other US adults from similar demographic categories using data from the National Health and Nutrition Examination Survey (Wang et al. 2014a). During Lent in particular, though some individuals in each tertile had low HEI scores, the average HEI scores in this sample were within the ranges found in the NIH AARP cohort to be protective against CVD- and cancer-related mortality (Reedy et al. 2014).

Apart from the shifts in food densities, it is important to consider the implications of the micronutrient changes associated with restriction of MDE products. Relative to omnivorous populations, vegetarians and vegans tend to be more vulnerable to deficiencies in vitamins B-12 and D, zinc, iron, calcium, and omega-3 fatty acids (Craig 2010; Gilsing et al. 2010; McEvoy et al. 2012). The inclusion of shellfish in the OC Lenten diet may be a valuable source of some of these nutrients that are less bioavailable in plant-based foods (Holden et al. 2008; Nieves 2013). Nonetheless, <50% of this sample was meeting USDA recommendations on seafood intake during Lent, and average intake of the essential omega-3 fatty acids, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), were in both periods below recommended levels of 500 mg/day (Gebauer et al. 2006). Low intake of omega-3 fatty acids may be associated with increased risk of cardiovascular disease (Calder 2017), though perhaps the decreased intake of the pro-inflammatory omega-6 fatty acid, arachidonic acid (Calder 2011), can help to bring the fatty acid ratios into a more health-promoting balance overall.

Fish intake in this sample was also apparently not substantial enough to keep vitamin B-12 and zinc from dropping during Lent. While mean intake of vitamin B-12 remained above the RDA of 2.4 mcg/day in both time periods and similar to that of other vegetarian and vegan populations (Pawlak 2014; Rizzo et al. 2016; Sobiecki et al. 2016), over two thirds of individuals in the second and third tertiles were consuming <2.4 mcg/day during Lent. This is potentially problematic, as low vitamin B-12 is associated with elevated homocysteine, an independent risk factor for cardiovascular disease (Pawlak 2015). Additionally, though the observed decreases in vitamin D and calcium may not be a major concern among OCs who are only eliminating animal products for a limited period of time, these changes are an important consideration for older adults or others at risk for low bone density.

Hence, it remains unclear to what degree the benefit of periodically reducing MDE products and increasing nuts/seeds and legumes outweighs the potential health costs of consistently consuming too many refined carbohydrates and too few fruits and vegetables. After all, a variety of intervention studies testing the cardiometabolic health effects of low-carbohydrate or Atkins-type diets (Dansinger et al. 2005; Foster et al. 2010; Gardner et al. 2007) and so-called Paleolithic diets (Genoni et al. 2016; Jönsson et al. 2009b; Lindeberg et al. 2007; Mellberg et al. 2014) have demonstrated that improvements in measures of body fat, glycemic control, triglycerides, and blood lipid ratios are possible without restricting meat if processed foods are eliminated from the diet. Thus, it is not clear that the periodic restriction on MDE products practiced by this group of OCs would on its own lead to health benefits, even if it contributes to an overall reduction in red and processed meats and saturated fats. This practice could theoretically have differential effects on health depending on whether adherents increase their intake of whole grains, legumes, nuts/seeds, fruits, and vegetables or refined grains and added sugars.

Study Limitations

The findings of this study, as well as the comparisons made with other study populations, must be interpreted with caution given a number of methodological limitations. One of the largest sources of bias in this study can be attributed to the reliance on FFQs for measuring pre-Lenten and Lenten diets. FFQs are notoriously fraught with measurement error, due in large part to the retrospective nature of the questionnaire, recall bias, and a tendency of individuals to report ideal consumption patterns rather than actual consumption patterns (Kristal et al. 2005; Willett 2013). The use of nutrient densities rather than absolute values should have helped reduce some degree of the correlated measurement errors that arise when measuring diet retrospectively (Willett 2013), but the use of two FFQs to measure change in diet essentially double the amount of measurement error in the estimates of dietary change (Willett 2013). There could also be sequencing effects (i.e., the effect of simply being more familiar with the FFQ at the second administration) that could bias study results in unmeasurable ways. This noise in the data may have made it difficult to detect changes or may have led to spurious associations.

Beyond the potential errors in reporting, FFQs are limited in the kinds of foods they capture and may be even more limited in capturing a diet that deviates in any way from the standard American diet. Because FFQs have been designed to reduce participant burden by focusing only on food groups that are thought to make the largest contribution to estimates of major nutrient categories of interest (Willett 2013), they are not comprehensive in the number of foods about which they ask, nor do that capture the degree of nutritional variability that exists within either simple food categories (e.g., bread) or complex mixed dishes (e.g., casseroles, stews, etc.) (Kristal and Potter 2006). This latter point is particularly relevant in this study when trying to measure changes in consumption of animal products, as the FFQ does not distinguish between vegan and non-vegan forms of the mixed dishes, such as the pizzas, burritos, enchiladas, tacos, and tostadas. Some participants expressed uncertainty about how to report consumption of fish tacos or vegan pizza, for example, and it is not clear that all participants dealt with these foods in a uniform manner. Similarly, the FFQ is not comprehensive in asking about the array of meat and dairy alternatives, such as non-soy milk and cheese alternatives and meat analogues. Though additional instructions were on how to categorize alternative forms of milk and meat substitutes, it is unclear if participants were consistent in how they reported those foods.

Admittedly, the creation of the MDE scores that gave equal weight to a serving decrease in meat, dairy, and eggs does not capture the potentially distinct effects each of those food categories (or sub-categories of meat and dairy products) may have on nutritional shifts. This method also meant that individuals with consistently high MDE consumption and no/low change Pre-Lent to Lent were ranked similarly to those with consistently low MDE consumption and no/low change from Pre-Lent to Lent. Control of the MDE1 score in the regression analyses should have accounted for this discrepancy, but the comparisons of baseline and Lenten diets across MDE∆ tertiles come with the caveat that the first tertile was highly heterogeneous.

A major factor that may limit the generalizability of this study's results to other meat-restricting populations is the uniqueness of the OC spiritual dietary tradition. In addition to being encouraged to omit MDE products, OCs also sometimes limit vertebrate fish, olive oil, and alcohol during Lent. These are not foods that are typically given up by the average vegetarian or vegan. Likewise, some individuals in this sample reported trying to limit sugars, sodas, and processed foods during Lent, which again may not be typical of the average person choosing to avoid animal products. Moreover, part of the spiritual Lenten discipline of OCs is to eat more simply and potentially even consume fewer meals, particularly on Wednesdays and Fridays. In fact, many OCs restrict animal products most Wednesdays and Fridays throughout the year. Thus, any reduction in meals during Lent may lead to a sharper drop in calories than might be observed among the general population of vegetarians or vegans and would contribute to the challenge of distinguishing changes in consumption of foods and nutrients that are due to restricting MDE products from changes that are due to a drop in caloric intake. On the other hand, a tendency to avoid animal products on Wednesdays and Fridays outside of the Lenten period could lead to less dramatic shifts in diet and nutritional composition than might be expected for a more typical omnivore switching to a quasi-vegan diet.

Finally, the fact that this sample was relatively well-educated and part of a higher socioeconomic stratum could influence food preferences and choices due to differences in access to healthier plant-based foods and/or differences in nutritional knowledge. The fact that this study was conducted in the southern part of the US could further lead to nutritional profiles of pre-Lenten and Lenten diets that may be somewhat different than might be observed among populations residing in other regions of the country. Restricting the study sample to individuals who were born and/or raised in the US or Canada limits the degree to which this study's findings can be generalized to the many foreign born OCs living in the US. Furthermore, there may be something about the individuals who were willing to invest time in tracking their diet and completing other study tasks that might also be related to dietary choices and the tendency to be stricter or more regimented with their diet in general.

What this study does have to offer, however, is the first quantitative examination of the range of dietary and nutritional changes experienced by a sample of OCs in the US during the unique MDE fast practiced by OCs during Lent. Moreover, it offers a more thorough and comprehensive dissection of the composition of plant-based diets in the US than offered in most other studies detailing the nutritional aspects of vegetarians' and vegans' diets. It is also among the few studies to highlight the fact that protein and micronutrient deficiencies are not the only health concern of plant-based diets practiced in modern industrialized settings, where reduction of animal products does not necessarily compel greater consumption of fruits, vegetables, and whole grains.

CONCLUSIONS

It would be easy to follow the trend set by prior studies and point to the increases in legumes, soy products, nut and seeds, discretionary oils, fiber, and magnesium and the reductions in animal protein, saturated fat, and arachidonic acid observed in this sample and conclude that restrictions on MDE products, such as those practiced by OCs in the US, lead to improvements in diet quality and nutritional composition. While that would be a correct conclusion from the data, it would also be an incomplete one. Just as notable as the changes in the aforementioned foods and nutrients are the lack of consistent changes in other foods (e.g. fruits and vegetables), the decrease in important micronutrients (e.g., vitamins B-12 and D and calcium), and the persistent failure to meet many dietary guidelines even following relatively large drops in MDE products. This study demonstrates, therefore, that encouraging Americans to reduce or eliminate MDE products from their diets has the potential to, but may not necessarily, produce an improvement in overall dietary and nutritional quality. Moreover, taking into consideration the nuances and caveats surrounding the existing data on the health effects of meat, saturated fat, and overall vegetarian or vegan dietary patterns relative to other well-rounded omnivorous diets, it would be premature to suggest that the reduction in animal products on their own would be health-promoting without considering the foods consumed as caloric replacements. Further research is needed to evaluate the health-related costs and benefits of exchanging any given food or nutrient for another during either temporary MDE fasts, as practiced by OCs, or long-term MDE restriction practiced by committed vegetarians and vegans.

Notwithstanding, these results in no way suggest that the OC tradition of encouraging omission of MDE products during Lent is harmful or that it should be changed. Rather, it provides some data to A) support the notion that this practice has the potential to be health-promoting, as others have asserted (Sarri et al. 2004), and B) encourage adherents to be mindful of their nutritional needs and the tradeoffs associated with their potential food choices during Lent and other prolonged periods of spiritually-guided dietary restrictions. Overall, any degree of increased mindfulness about diet is likely to have some benefits, as observed in this sample, where even those who made little change in MDE consumption still showed some suggestive improvements in diet quality. Thus, the OC Lenten tradition and other forms of promotion of plant-based diets, whether for health, environmental, ethical, religious, or other reasons, can all be considered at least somewhat beneficial in that they encourage individuals to pay more attention to what they put into their bodies and try to incorporate more plant-based foods. It cannot, however, be assumed that even mindful choices of what to eat in place of animal products will have a uniform effect on short- or long-term health.

CHAPTER 2 TABLES

Table 2.1a. Baseline demographic and lifestyle characteristics of study participants by MDEΔ tertiles (n=99).

	Entire Sample (n=99)	Tertile 1 (n=33) (Mean MDEΔ Score: -0.3)	Tertile 2 (n=33) (Mean MDEΔ Score: -1.8)	Tertile 3 (n=33) (Mean MDEΔ Score: -3.1)
	Mean (Range)	Mean (Range)	Mean (Range)	Mean (Range)
Age (years)	46.7 (19.1-73.2)	48.1 (26.2-73.2)	45.5 (19.1-67.8)	46.6 (24.2-67.6)
Baseline BMI (kg/m^2)	27.3 (18.1-43.8)	28.3 (19.7-42.3)	27.3 (18.7-43.8)	26.4 (18.1-40.9)
Average weekly MET hours [a]	20.1 (0-128.4)	22.7 (1.1-128.4)	16.7 (0-54)	20.7 (1.2-52.3)
Average change in weekly MET hours [a]	-2.8 (-57.5-30.5)	-2.2 (-50-18.2)	-3.3 (-57.5-29.8)	-2.8 (-47-30.5)
	%	%	%	%
% Male	42.4%	39.4%	39.4%	48.5%
% Self-reported race as "White or Caucasian"	93.9%	97.0%	90.9%	93.9%
% 4-year college degree or higher	91.8%	97.0%	87.9%	90.6%
% Annual income ≥ $100,000 [b]	44.7%	40.6%	46.9%	46.7%
% Orthodox Christian	96.0%	87.9% [2,3]	100.0% [1]	100.0% [1]
% Convert	76.8%	69.0%	87.9%	72.7%
% Self-rated health "Good" to "Excellent"	89.9%	90.9%	87.9%	90.9%
% Reporting mostly sedentary occupations	52.5%	57.6%	54.5%	45.5%
% Current Smokers	8.1%	9.1%	3.0%	12.1%
% Reporting >7 alcohol drinks/week	24.2%	24.2%	18.2%	30.3%
% Taking medications for dyslipidemia or diabetes	14.1%	18.2%	6.1%	18.2%

[a] Metabolic equivalent values for moderate to vigorous physical activities
[b] Estimated from the 32 in tertile 1, 32 in tertile 2, and 30 in tertile 3 who responded to the question on household income.
[1] Significantly different proportion in Tertile 1 at alpha level of 0.05
[2] Significantly different proportion in Tertile 2 at alpha level of 0.05
[3] Significantly different proportion in Tertile 3 at alpha level of 0.05

Table 2.1b. Baseline dietary characteristics of study participants MDEΔ tertiles (n=99).

	Entire Sample (n=99) %	Tertile 1 (n=33) (Mean MDEΔ Score: -0.3) %	Tertile 2 (n=33) (Mean MDEΔ Score: -1.8) %	Tertile 3 (n=33) (Mean MDEΔ Score: -3.1) %
% Vegan, Ovo-Lacto-Vegetarian, or Pesco-Vegetarian	5.1%	9.1%	6.1%	0.0%
% Consuming 1+ serving of meat/2,000 kcal	67.7%	51.5% [3]	60.6% [3]	90.9% [1,2]
% Consuming 1+ serving of dairy/2,000 kcal	52.5%	51.5%	42.4%	63.6%
% Consuming 1+ egg/2,000 kcal	20.2%	12.1% [3]	12.1% [3]	36.4% [1,2]
% Prepare own meals	76.8%	72.7%	78.8%	78.8%
% Reporting increase in food prep hours during Lent	19.2%	27.3%	15.2%	15.2%
% Reporting decrease in food prep hours during Lent	23.2%	21.2%	15.2%	33.3%
% Reporting increase in eating out during Lent [c]	20.2%	30.3%	15.2%	15.2%
% Reporting decrease in eating out during Lent [c]	26.3%	24.2%	27.3%	27.3%
% Reporting increase in fast food consumption during Lent	11.1%	15.2%	12.1%	6.1%
% Reporting decrease in fast food consumption during Lent	34.3%	12.1% [3]	36.4% [*]	54.5% [1*]

[c] Eating out at non-fast food restaurants

[1] Significantly different proportion in Tertile 1 at alpha level of 0.05

[2] Significantly different proportion in Tertile 2 at alpha level of 0.05

[3] Significantly different proportion in Tertile 3 at alpha level of 0.05

* Significantly greater within-tertile decrease than increase at alpha level of 0.05

Table 2.2. Animal- and plant-based food intake before and during Lent (standardized to 2000 kcal/day) by MDEΔ tertiles.

	Pre-Lent			Lent		
	Tertile 1	Tertile 2	Tertile 3	Tertile 1	Tertile 2	Tertile 3
Animal-Based Foods	Mean (5th-95th%)	Mean (5th-95th%)	Mean (5th-95th%)	Mean (5th-95th%)	Mean (5th-95th%)	Mean (5th-95th%)
All Meat (oz)	3.7 (0.2-8.1)	3.6 (0.3-7.6)[3]	5.1 (2.3-9.7)[2]	2.4 (0.1-8.1)[2,3]	0.5 (0.05-1.5)[1]	0.3 (0-0.6)[1]
Red Meat (oz)	1.9 (0.1-4.7)	1.9 (0.1-6.0)	2.6 (0.6-7.7)	1.0 (0-3.2)[2,3]	0.3 (0.02-0.7)[1]	0.2 (0-0.4)[1]
Poultry (oz)	1.3 (0.0-4.7)	1.2 (0.1-2.7)	1.6 (0.5-3.4)	1.1 (0.0-3.2)[2,3]	0.1 (0-0.6)[1]	0.1 (0-0.3)[1]
Processed Meat (oz)	0.5 (0-2.1)	0.5 (0.04-1.4)	0.8 (0.05-2.0)	0.3 (0-2.2)[2,3]	0.03 (0-0.2)[1]	0.01 (0-0.1)[1]
Fish & Shellfish (oz)	0.9 (0-2.7)	0.8 (0.02-2.2)	1.0 (0.1-2.1)	1.0 (0-3.7)	1.2 (0-4.7)	1.6 (0.3-4.3)
All Dairy (cup eq)	1.2 (0.2-2.4)	1.0 (0.5-1.6)	1.3 (0.4-2.5)	1.4 (0.1-4.4)[2,3]	0.5 (0.04-1.4)[1]	0.3 (0.1-0.7)[1]
Milk (cup eq)	0.5 (0.03-2.0)	0.4 (0.1-0.6)	0.6 (0.1-1.4)	0.7 (0.03-2.2)[2,3]	0.2 (0.02-0.5)[1]	0.1 (0-0.3)[1]
Yogurt (cup eq)	0.2 (0-0.9)	0.1 (0-0.5)	0.2 (0-0.8)	0.2 (0-1.4)[2,3]	0.04 (0-0.3)[1]	0.02 (0-0.2)[1]
Cheese (cup eq)	0.5 (0.03-1.1)	0.5 (0.1-0.9)	0.6 (0.2-1.2)	0.5 (0.06-1.1)[2,3]	0.3 (0-0.9)[1]	0.2 (0-0.5)[1]
Eggs (oz eq)	0.5 (0.03-1.5)[3]	0.6 (0.1-1.6)[3]	1.0 (0.1-4.0)[1,2]	0.4 (0.02-1.7)	0.4 (0.01-1.8)	0.3 (0-1.7)
Plant-Based Foods						
Whole Grain (oz eq)	1.4 (0.1-3.2)	1.9 (0.3-5.6)	1.3 (0-3.4)	1.6 (0-5.5)	2.1 (0.3-5.3)	2.3 (0.1-5.9)
Refined Grain (oz eq)	3.6 (0.7-6.9)	4.3 (1.9-6.8)	3.4 (1.0-6.4)	4.1 (0.9-6.8)	5.1 (2.6-8.6)	4.8 (1.9-8.7)
Legumes (cup eq)	0.1 (0-0.5)	0.2 (0-0.3)	0.1 (0.02-0.5)	0.2 (0-0.6)[2,3]	0.3 (0.02-0.7)[1]	0.4 (0.02-1.1)[1]
Soy Products (oz eq)	0.3 (0-1.7)	0.3 (0-1.1)	0.2 (0-0.6)	0.4 (0-2.0)	0.7 (0-2.1)	0.6 (0-2.1)
Nuts & Seeds (oz eq)	1.9 (0-4.9)[3]	1.3 (0.2-4.6)	0.9 (0.02-2.1)[1]	1.9 (0.02-4.9)	2.4 (0.3-7.4)	2.3 (0.1-6.3)
Fruit (cup eq) [a]	1.2 (0.1-3.7)	0.8 (0.2-1.6)	0.7 (0.1-2.0)	1.2 (0.1-3.4)	1.0 (0.2-2.3)	1.3 (0.04-3.4)
Vegetables (cup eq) [b]	2.0 (0.7-4.3)	1.7 (0.3-3.9)	2.1 (0.8-5.9)	2.4 (0.7-5.3)	2.4 (0.5-5.9)	3.0 (1.2-6.6)
White Potatoes (cup eq)	0.4 (0.02-0.9)	0.4 (0.1-1.1)	0.4 (0.1-0.7)	0.4 (0.03-0.8)	0.5 (0.1-1.1)	0.5 (0.1-1.4)
Discretionary Oil (g)	30.5 (14.9-44.1)	29.0 (21.0-43.0)	27.0 (14.2-46.4)	32.4 (16.4-50.2)	35.8 (23.0-63.2)	38.0 (19.0-61.8)
Added Sugar (tsp eq)	12.5 (3.0-28.1)	11.6 (4.6-21.4)	11.0 (1.6-19.9)	11.6 (4.5-23.0)	12.2 (4.2-19.9)	11.0 (3.8-20.5)

[a] Excluding fruit juice; [b] Excluding white potatoes; [1] Significantly different than mean in Tertile 1 at α-level of 0.017; [2] Significantly different than mean in Tertile 2 at α-level of 0.017; [3] Significantly different than mean in Tertile 3 at α-level of 0.017.

Table 2.3. Proportion of sample meeting USDA dietary recommendations and change in Healthy Eating Index (HEI) 2010 score relative to MDEΔ score. [a]

Food Group	Recommended Amount per 2,000 kcal	% Meeting Guidelines, Pre-Lent			% Meeting Guidelines, Lent				
		MDEΔ Tertile 1	MDEΔ Tertile 2	MDEΔ Tertile 3	MDEΔ Tertile 1	MDEΔ Tertile 2	MDEΔ Tertile 3	OR [a] (95% CI)	p-value
All Vegetables [b]	2½ cup-eq/day	45%	30%	33%	61%	67%	67%	1.31 (0.81 to 2.10)	0.27
Dark Green Vegetables	1½ cup-eq/wk	64%	42%	61%	61%	58%	70%	1.31 (0.74 to 2.31)	0.35
Red & Orange Vegetables	5½ cup-eq/wk	42%	24%	33%	64%	58%	61%	1.47 (1.00 to 2.17)	0.05
Legumes (Beans & Peas)	1½ cup-eq/wk	24%	30%	12%	33%	67%	61%	2.35 (1.34 to 4.11)	0.003
Starchy Vegetables [c]	5 cup-eq/wk	6%	21%	15%	21%	33%	36%		
Other Vegetables	4 cup-eq/wk	61%	55%	55%	70%	67%	85%	1.36 (0.84 to 2.20)	0.21
Fruits [d]	2 cup-eq/day	15%	3%	6%	18%	9%	21%	1.06 (0.51 to 2.19)	0.87
Grains	6 oz-eq/day	30%	39%	18%	42%	73%	70%		
Whole Grains	≥ 3 oz-eq/day	9%	12%	12%	15%	21%	27%	2.37 (0.84 to 6.74)	0.11
Refined Grains	≤ 3 oz-eq/day	45%	24%	39%	18%	12%	27%	1.31 (0.61 to 2.82)	0.49
Dairy & dairy alternatives	3 cup-eq/day	6%	0%	0%	9%	0%	3%		
Protein Foods [e]	5½ oz-eq/day	70%	64%	94%	58%	33%	27%		
Seafood	8 oz-eq/wk	27%	24%	21%	30%	45%	48%	1.15 (0.79 to 1.68)	0.47
Meats, Poultry, Eggs	26 oz-eq/wk	45%	36%	70%	30%	3%	0%		
Nuts, Seeds, Soy Products	5 oz-eq/wk	82%	70%	70%	82%	97%	94%	2.96 (1.48 to 5.90)	0.002
Saturated Fat	<10% of total calories	24%	21%	9%	45%	85%	88%		
Added Sugars	<10% of total calories	36%	33%	55%	45%	24%	42%	0.80 (0.53 to 1.22)	0.30
								β [f] (95% CI)	p-value
HEI 2010 Score (out of 100)	Mean (Range)	68 (44-88)^3	66 (45-81)	63 (39-80)^1	71 (42-91)	70 (48-87)	73 (56-86)	2.0 (0.6 to 3.3)	0.005

[a] Odds ratios represent the ratio of the odds of meeting recommended intake during Lent for the given category relative to a serving decrease in MDE products, controlling for MDE1 score, baseline intake of each food/food group of interest, baseline caloric intake, change in calories, average METs, change in METs, age, sex, and baseline BMI; [b] Includes legumes; [c] Includes white potatoes; [d] Excluding fruit juices; [e] Combination of meats, poultry, eggs, seafood, nuts and seeds, and soy products; [f] Beta coefficient represents the change in HEI 2010 score in relation to each serving decrease in MDE products, controlling for MDE1 score, baseline HEI 2010 score, baseline caloric intake, the change in calories, average METs, change in METs, age, sex, and baseline BMI.

Table 2.4. Multiple linear regression results for additive change in major non-MDE foods in relation to MDEΔ Score (n=99). [a]

	β[b] ± SE[c]	(95% CI)	p-value	R^2
Fish (oz/2,000 kcal)				
MDEΔ Score	0.04 ± 0.09	(-0.13 to 0.22)	0.61	0.17
Baseline Fish	0.85 ± 0.23	(0.38 to 1.31)	0.04	
Whole Grain (oz eq/2,000 kcal)				
MDEΔ Score	0.26 ± 0.10	(0.06 to 0.46)	0.01	0.36
Baseline Whole Grains	0.38 ± 0.18	(0.02 to 0.75)	<0.0001	
Refined Grain (oz eq/2,000 kcal)				
MDEΔ Score	0.28 ± 0.12	(0.03 to 0.52)	0.03	0.45
Baseline Refined Grains	0.67 ± 0.15	(0.38 to 0.97)	<0.0001	
Legumes (cup eq/2,000 kcal)				
MDEΔ Score	0.09 ± 0.02	(0.05 to 0.13)	<0.0001*	0.34
Baseline Legumes	0.89 ± 0.10	(0.69 to 1.09)	0.0003	
Soy Products (oz eq/2,000 kcal)				
MDEΔ Score	0.19 ± 0.04	(0.11 to 0.27)	<0.0001*	0.44
Baseline Soy Products	0.67 ± 0.18	(0.32 to 1.01)	0.0002	
Nuts & Seeds (oz eq/2,000 kcal)				
MDEΔ Score	0.54 ± 0.12	(0.31 to 0.77)	<0.0001*	0.44
Baseline Nuts and Seeds	0.55 ± 0.15	(0.24 to 0.86)	<0.0001	
Fruit (cup eq/2,000 kcal) [d]				
MDEΔ Score	0.08 ± 0.07	(-0.06 to 0.22)	0.25	0.42
Baseline Fruit	0.95 ± 0.15	(0.66 to 1.24)	0.0002	
Vegetables (cup eq/2,000 kcal) [e]				
MDEΔ Score	0.17 ± 0.09	(0 to 0.34)	0.04	0.61
Baseline Vegetables	0.67 ± 0.17	(0.32 to 1.01)	<0.0001	
White Potatoes (cup eq/2,000 kcal)				
MDEΔ Score	0.02 ± 0.02	(-0.02 to 0.06)	0.35	0.39
Baseline White Potatoes	1.00 ± 0.19	(0.62 to 1.38)	<0.0001	
Discretionary Oil (g/2,000 kcal)				
MDEΔ Score	3.34 ± 0.88	(1.60 to 5.09)	0.0003*	0.29
Baseline Discretionary Oil	0.81 ± 0.16	(0.50 to 1.13)	<0.0001	
Added Sugar (tsp eq/2,000 kcal)				
MDEΔ Score	0.12 ± 0.34	(-0.56 to 0.80)	0.72	0.37
Baseline Added Sugar	0.64 ± 0.12	(0.39 to 0.88)	<0.0001	

[a] Controlling for MDE1 score, baseline consumption of the dependent variable of interest, baseline caloric intake, the change in calories, average METs, change in METs, age, sex, and baseline BMI; [b] Beta coefficients for MDEΔ score represent the additive difference in each variable of interest during Lent relative to a one serving decrease in MDE products; Beta coefficients for baseline food categories represent the additive difference in each variable of interest during Lent relative to a unit difference in baseline intake of that same variable; [c] Robust standard errors; [d] Excluding fruit juice; [e] Excluding white potatoes; * Significant at the Bonferroni-adjusted α-level of 0.0045.

Table 2.5a. Caloric and macronutrient intake before and during Lent (standardized to 2000 kcal/day or % energy) by MDEΔ tertiles.

	Pre-Lent			Lent		
	Tertile 1 Mean (5th-95th%)	Tertile 2 Mean (5th-95th%)	Tertile 3 Mean (5th-95th%)	Tertile 1 Mean (5th-95th%)	Tertile 2 Mean (5th-95th%)	Tertile 3 Mean (5th-95th%)
Energy Intake (♂, kcal/day)	2528 (1358-4170)	2329 (1153-4237)	2170 (1147-3875)	1964 (1313-3137)	1715 (1125-2446)	1594 (818-2823)
Energy Intake (♀, kcal/day)	1942 (960-3490)	2083 (910-3478)	1895 (1223-2966)	1699 (774-2719)	1578 (678-2958)	1325 (672-2396)
Energy Density (kcal/kg)	27 (12-60)	28 (13-45)	28 (12-54)	23 (11-40)	21 (10-31)	20 (10-37)
Protein (g)	83 (60-109)	80 (59-100)[3]	92 (68-126)[2]	79 (54-121)[2,3]	66 (47-99)[1]	67 (52-83)[1]
Protein (%E)	17% (12%-22%)	16% (12%-20%)[3]	18% (14%-25%)[2]	16% (11%-24%)[2,3]	13% (9%-20%)[1]	13% (10%-17%)[1]
Animal Protein (g)	51 (15-92)[3]	48 (21-73)[3]	66 (48-94)[1,2]	43 (5-102)[2,3]	19 (4-45)[1]	18 (5-44)[1]
Animal Protein (%E)	10% (3%-18%)[3]	10% (4%-15%)[3]	13% (10%-19%)[1,2]	9% (1%-20%)[2,3]	4% (1%-9%)[1]	4% (1%-9%)[1]
Vegetable Protein (g)	32 (17-52)[3]	32 (19-42)[3]	26 (16-35)[1,2]	36 (20-60)[2,3]	47 (27-62)[1]	49 (29-65)[1]
Vegetable Protein (%E)	6% (3%-10%)[3]	7% (4%-8%)[3]	5% (3%-7%)[1,2]	7% (4%-12%)[2,3]	9% (5%-12%)[1]	10% (6%-13%)[1]
Total Fat (g)	80 (55-103)	80 (63-115)	88 (58-111)	79 (56-109)	72 (51-106)	69 (42-104)
Total Fat (%E)	36% (25%-47%)	36% (28%-52%)	39% (26%-50%)	36% (25%-49%)	33% (23%-48%)	31% (19%-47%)
Saturated Fat (g)	24 (14-33)[3]	25 (18-34)[3]	29 (18-38)[1,2]	23 (12-33)[2,3]	17 (10-29)[1]	15 (7-24)[1]
Saturated Fat (%E)	11% (6%-15%)[3]	11% (8%-15%)[3]	13% (8%-17%)[1,2]	10% (6%-15%)[2,3]	8% (4%-13%)[1]	7% (3%-11%)[1]
Trans Fat (g)	2.0 (1-3)[3]	2.4 (1.3-3.9)	2.7 (1.4-4.4)[1]	2.0 (0.6-3.7)[3]	1.8 (0.6-3.8)	1.4 (0.4-2.1)[1]
Trans Fat (%E)	1% (0.4%-1.4%)[3]	1% (0.6%-1.8%)	1% (0.6%-2%)[1]	1% (0.3%-1.7%)[3]	1% (0.3%-1.7%)	1% (0.2%-1%)[1]
Monounsaturated Fat (g)	30 (20-40)	29 (22-41)	32 (19-42)	29 (18-47)	29 (19-45)	27 (14-40)
Monounsaturated Fat (%E)	13% (9%-18%)	13% (10%-18%)	14% (9%-19%)	13% (8%-21%)	13% (8%-20%)	12% (7%-18%)
Polyunsaturated Fat (g)	19 (12-25)	19 (14-27)	19 (12-27)	20 (11-28)	21 (15-30)	21 (14-31)
Polyunsaturated Fat (%E)	8% (5%-11%)	9% (6%-12%)	9% (5%-12%)	9% (5%-13%)	10% (7%-13%)	9% (6%-14%)
Carbohydrates (g)	233 (146-326)[3]	236 (140-281)[3]	202 (104-260)[1,2]	250 (182-333)[3]	278 (199-339)	282 (194-359)[1]
Carbohydrate (%E)	47% (29%-65%)[3]	47% (28%-56%)[3]	40% (21%-52%)[1,2]	50% (36%-67%)[3]	56% (40%-68%)	56% (39%-72%)[1]
Total Sugar (g)	104 (34-156)	93 (40-143)	87 (22-133)	104 (52-157)	101 (47-144)	98 (63-145)
Total Sugar (%E)	21% (7%-31%)	19% (8%-29%)	17% (4%-27%)	21% (10%-31%)	20% (9%-29%)	20% (13%-29%)
Fiber (g)	24 (14-41)	23 (13-33)	21 (12-34)	28 (12-46)[3]	32 (20-53)	36 (20-58)[1]

E=energy; [a] Measured as available carbohydrates [1] Significantly different than mean in Tertile 1 at α-level of 0.017; [2] Significantly different than mean in Tertile 2 at α-level of 0.017; [3] Significantly different than mean in Tertile 3 at α-level of 0.017.

Table 2.5b. Micronutrient intake before and during Lent (standardized to 2000 kcal/day) by MDEΔ tertiles.

	Pre-Lent			Lent		
	Tertile 1 Mean (5th-95th %)	Tertile 2 Mean (5th-95th %)	Tertile 3 Mean (5th-95th %)	Tertile 1 Mean (5th-95th %)	Tertile 2 Mean (5th-95th %)	Tertile 3 Mean (5th-95th %)
Linoleic Acid (g)	16 (11-22)	17 (12-23)	16 (10-24)	18 (10-24)	19 (13-26)	19 (12-28)
Arachidonic Acid (mg)	138 (37-307)[3]	138 (69-198)[3]	204 (91-369)[1,2]	112 (22-235)[3]	68 (16-212)	63 (17-205)[1]
Alpha-linolenic acid (g)	1.6 (0.8-2.4)	1.7 (1.1.0-3)	1.8 (1.1-2.5)	1.7 (1.1-2.3)	1.8 (0.9-3)	1.9 (0.9-2.9)
Eicosapentaenoic acid (mg)	73 (6-221)	62 (10-169)	74 (11-183)	64 (4-179)	63 (2-227)	87 (18-227)
Docosahexaenoic acid (mg)	143 (5-461)	124 (15-312)	152 (19-437)	116 (3-351)	103 (2-267)	122 (19-444)
Sodium (mg)	3222 (2272-4520)	3371 (2539-4225)	3562 (2851-5092)	3388 (2538-4874)	3678 (2471-5122)	3752 (2939-6075)
Potassium (mg)	3139 (2066-4818)	2862 (1912-4319)	3066 (1985-4051)	3371 (2469-4736)	3196 (2259-4577)	3650 (2386-5153)
Folate (mcg)	499 (301-688)	487 (340-642)	463 (302-654)	584 (354-833)	674 (447-1207)	658 (434-1016)
Vitamin B-6 (mg)	2.0 (1.4-2.8)	1.9 (1.4-2.7)	2.1 (1.4-2.9)	2.1 (1.5-3)	2.1 (1.3-4.2)	2.1 (1.4-3.4)
Vitamin B-12 (mcg)	5.2 (2.2-9.4)	4.6 (1.9-8.3.0)[3]	6.1 (3.6-10.7)[2]	5.4 (2.6-9.8.0)	4.2 (0.8-10.1)	4.2 (1.4-10)
Vitamin D (IU)	220 (93-489)	187 (93-365)[3]	253 (112-459)[2]	222 (65-422)[2,3]	128 (21-389)[1]	121 (13-449)[1]
Vitamin K (mcg)	210 (80-471)	143 (57-292)	226 (53-756)	229 (70-544)	240 (63-1098)	245 (95-846)
Calcium (mg)	905 (530-1498)	877 (595-1197)	950 (543-1351)	1019 (522-1687)[2,3]	842 (529-1267)[1]	804 (503-1166)[1]
Iron (mg)	14 (10-20)	14 (11-17)	13 (10-17)	15 (9-25)	18 (11-33)	17 (11-26)
Magnesium (mg)	361 (252-488)	336 (218-446)	328 (243-459)	392 (286-493)[3]	415 (305-550)	444 (304-643)[1]
Selenium (mcg)	123 (91-170)	126 (95-162)	131 (89-182)	125 (92-158)	121 (88-168)	124 (89-184)
Zinc (mg)	12 (9-19)	11 (9-14)[3]	13 (9-18)[2]	12 (9-18)	12 (8-25)	12 (8-16)

[1] Significantly different than mean in Tertile 1 at α-level of 0.017; [2] Significantly different than mean in Tertile 2 at α-level of 0.017; [3] Significantly different than mean in Tertile 3 at α-level of 0.017.

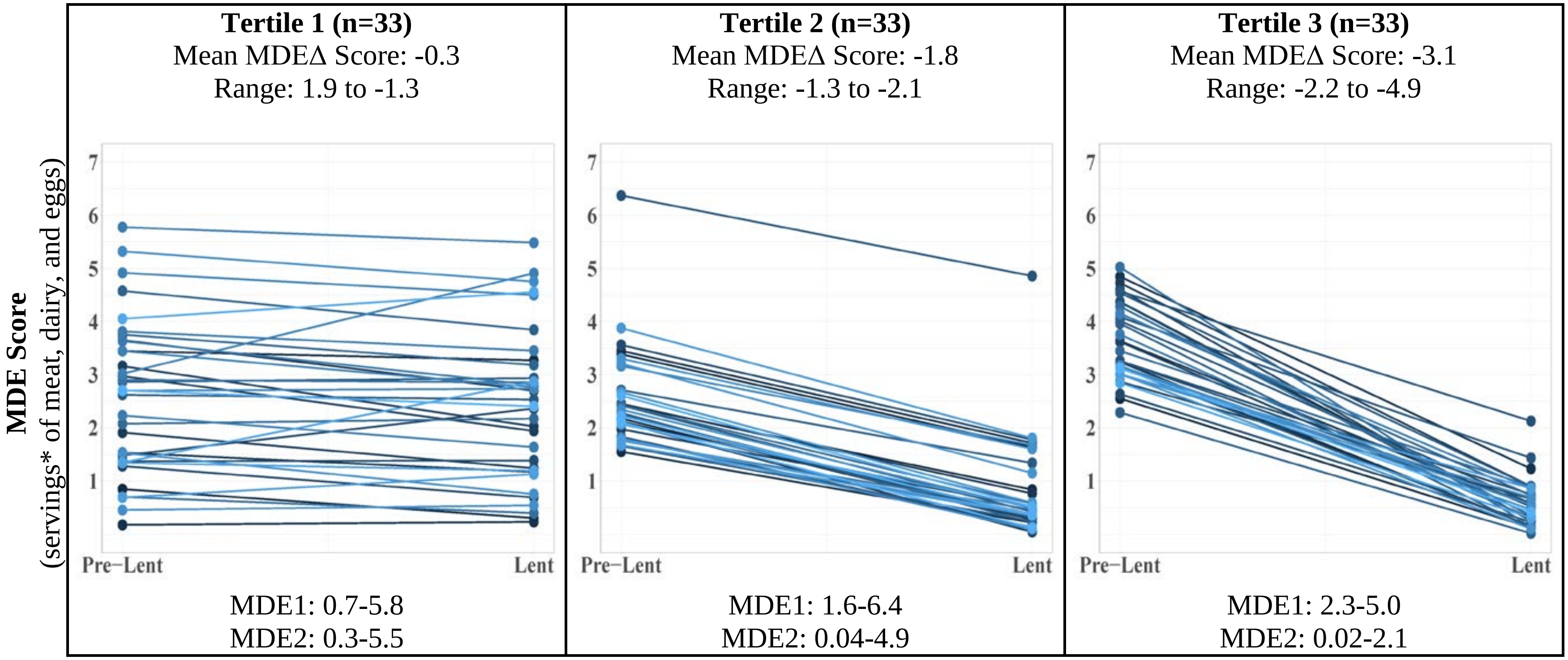
Table 2.6. Multiple linear regression results for percentage change in macro- and micronutrients in relation to MDEΔ Score (n=99). [a]

	β[b] ± SE[c]	(95% CI)	p-value	R^2
Kilocalories [d]	-5.2% ± 1.7%	(-8.5% to -2.0%)	0.002	0.21
Energy Density (kcal/kg) [d]	-4.9% ± 1.7%	(-8.4% to -1.5%)	0.005	0.15
Protein (g/2000 kcal)	-8.0% ± 1.0%	(-9.9% to -6.1%)	<0.0001*	0.55
Animal Protein (g/2000 kcal)	-24.9% ± 1.8%	(-28.5% to -21.4%)	<0.0001*	0.71
Vegetable Protein (g/2000 kcal)	24.9% ± 2.2%	(20.5% to 29.2%)	<0.0001*	0.71
Total Fat (g/2000 kcal)	-5.8% ± 1.2%	(-8.3% to -3.3%)	<0.0001*	0.26
Saturated Fat (g/2000 kcal)	-14.5% ± 1.2%	(-16.9% to -12.1%)	<0.0001*	0.68
Trans Fat (g/2000 kcal)	-17.1% ± 2.1%	(-21.2% to -13.0%)	<0.0001*	0.47
Monounsaturated Fat (g/2000 kcal)	-1.7% ± 1.8%	(-5.3% to 1.9%)	0.35	0.04
Polyunsaturated Fat (g/2000 kcal)	3.6% ± 2.6%	(-1.5% to 8.7%)	0.17	0.15
Linoleic Acid (g/2000 kcal)	4.3% ± 2.6%	(-0.9% to 9.5%)	0.11	0.15
Arachidonic Acid (mg/2000 kcal)	-22.4% ± 2.4%	(-27.2% to -17.6%)	<0.0001*	0.55
Alpha-linolenic acid (g/2000 kcal)	0.9% ± 2.8%	(-4.6% to 6.3%)	0.75	0.13
Eicosapentaenoic acid (mg/2000 kcal)	-2.7% ± 19.5%	(-41.4% to 36.0%)	0.89	0.11
Docosahexaenoic acid (mg/20000 kcal	-11.2% ± 19.1%	(-49.3% to 26.8%)	0.56	0.10
Carbohydrates (g/2000 kcal)	9.4% ± 1.5%	(6.3% to 12.5%)	<0.0001*	0.56
Total sugar (g/2000 kcal)	2.5% ± 3.2%	(-3.9% to 8.9%)	0.44	0.22
Fiber (g/2000 kcal)	16.9% ± 2.7%	(11.6% to 22.2%)	<0.0001*	0.49
Sodium (mg/2000 kcal)	1.1% ± 1.6%	(-2.1% to 4.3%)	0.51	0.15
Potassium (mg/2000 kcal)	2.2% ± 1.5%	(-0.8% to 5.2%)	0.16	0.32
Folate (mcg/2000 kcal)	5.9% ± 2.4%	(1.1% to 10.7%)	0.016	0.13
Vitamin B-6 (mg/2000 kcal)	-1.4% ± 2.2%	(-5.7% to 3.0%)	0.54	0.24
Vitamin B-12 (mcg/2000 kcal)	-17.3% ± 2.6%	(-22.4% to -12.2%)	<0.0001*	0.15
Vitamin D (IU/2000 kcal)	-26.4% ± 4.0%	(-34.4% to -18.4%)	<0.0001*	0.28
Vitamin K (mcg/2000 kcal)	5.1% ± 7.3%	(-9.5% to 19.6%)	0.49	-0.01
Calcium (mg/3000 kcal)	-12.1% ± 2.3%	(-16.7% to -7.5%)	<0.0001*	0.34
Iron (mg/3000 kcal)	6.1% ± 2.1%	(1.9% to 10.4%)	0.005	0.12
Magnesium (mg/3000 kcal)	7.2% ± 1.6%	(3.9% to 10.4%)	<0.0001*	0.52
Selenium (mcg/3000 kcal)	-3.4% ± 1.5%	(-6.3% to -0.4%)	0.026	0.22
Zinc (mg/3100 kcal)	-4.9% ± 1.6%	(-8.1% to -1.8%)	0.002	0.19

[a] Controlling for MDE1 score, baseline consumption of the dependent variable of interest, baseline caloric intake, the change in calories, average METs, change in METs, age, sex, and baseline BMI; [b] Beta coefficients represent the percent difference in each macro- and micronutrient density relative to a one serving decrease in MDE products; [c] Robust standard errors; [d] Controlling for same covariates with the exception of change in calories; * Significant at the Bonferroni-adjusted α-level of 0.0017.

CHAPTER 2 FIGURES

Figure 2.1. Baseline and Lenten meat, dairy, and egg servings by MDEΔ tertile.



Tertile 1 (n=33)
Mean MDEΔ Score: -0.3
Range: 1.9 to -1.3

MDE1: 0.7-5.8
MDE2: 0.3-5.5

Tertile 2 (n=33)
Mean MDEΔ Score: -1.8
Range: -1.3 to -2.1

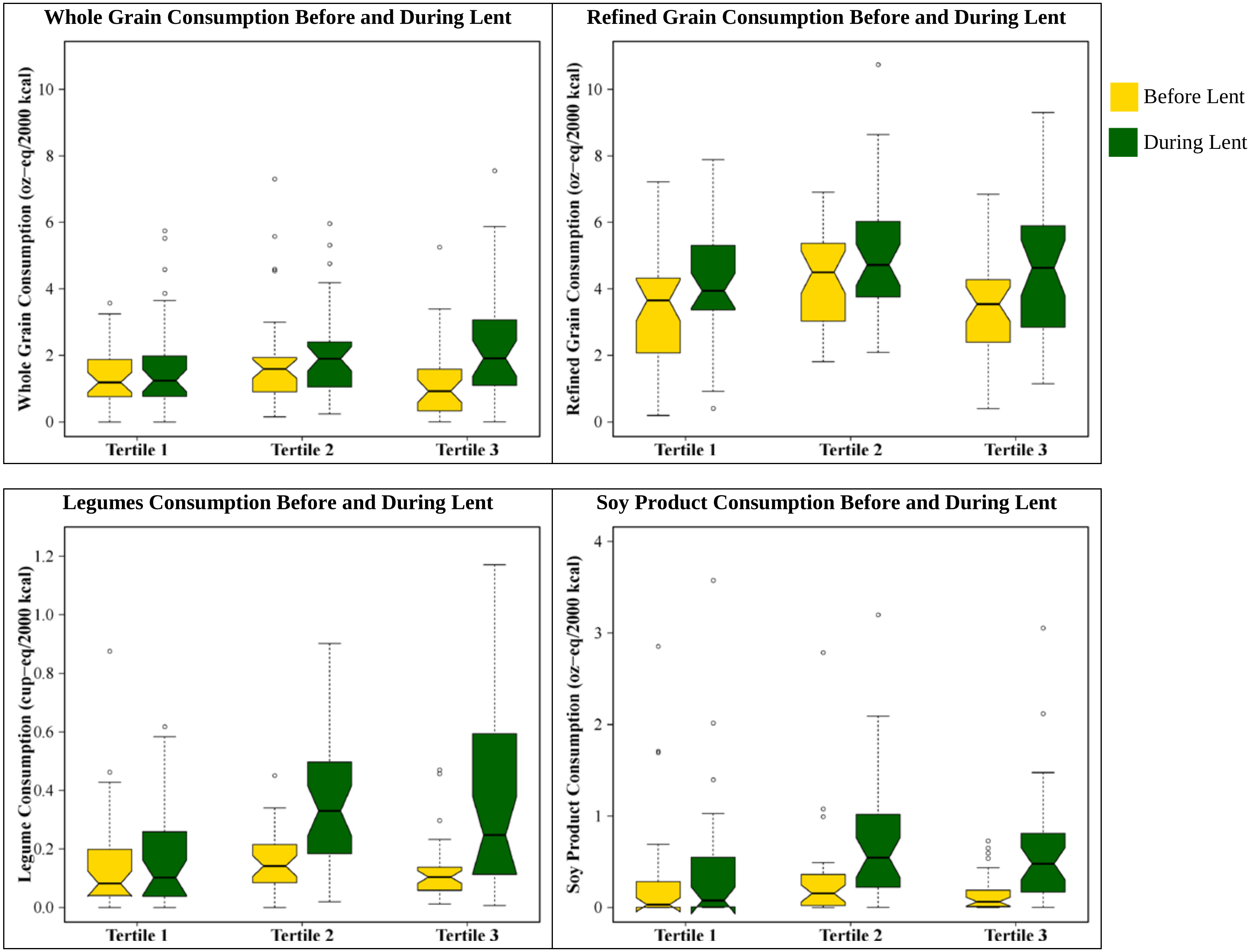
MDE1: 1.6-6.4
MDE2: 0.04-4.9

Tertile 3 (n=33)
Mean MDEΔ Score: -3.1
Range: -2.2 to -4.9

MDE1: 2.3-5.0
MDE2: 0.02-2.1

*Serving defined as 3 ounces of unprocessed meat, 2 ounces of processed meat, 1 cup-equivalent of dairy, or a 2-ounce-equivalent of eggs (2 eggs) per 2000 kcal.

Figure 2.2. Consumption of major plant-based foods before Lent and during Lent by MDEΔ tertiles.



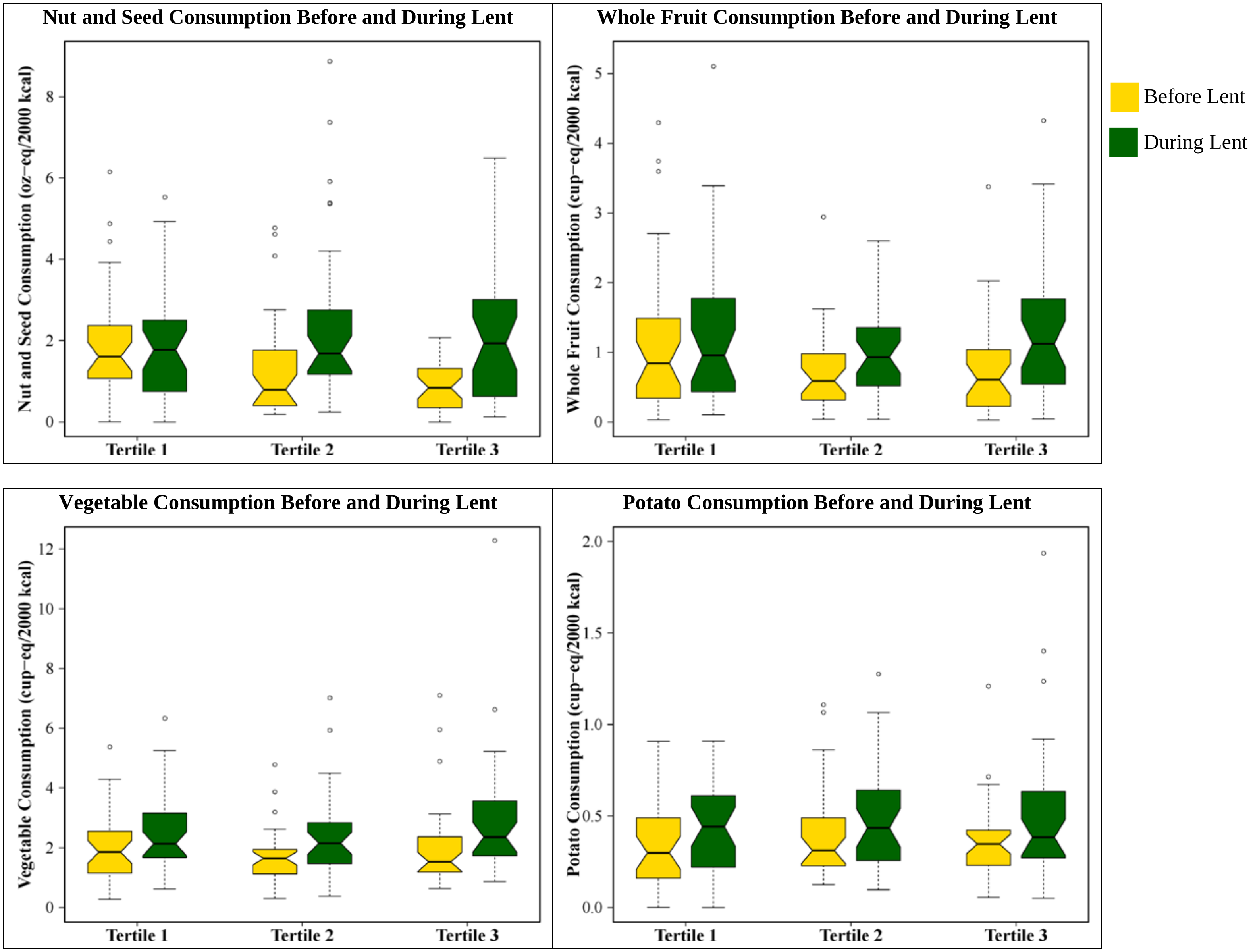
Whole Grain Consumption Before and During Lent

Refined Grain Consumption Before and During Lent

Legumes Consumption Before and During Lent

Soy Product Consumption Before and During Lent

Figure 2 (cont). Consumption of major plant-based foods before Lent and during Lent by MDEΔ tertiles.



Nut and Seed Consumption Before and During Lent

Whole Fruit Consumption Before and During Lent

Vegetable Consumption Before and During Lent

Potato Consumption Before and During Lent

Figure 2 (cont). Consumption of major plant-based foods before Lent and during Lent by MDEΔ tertiles.

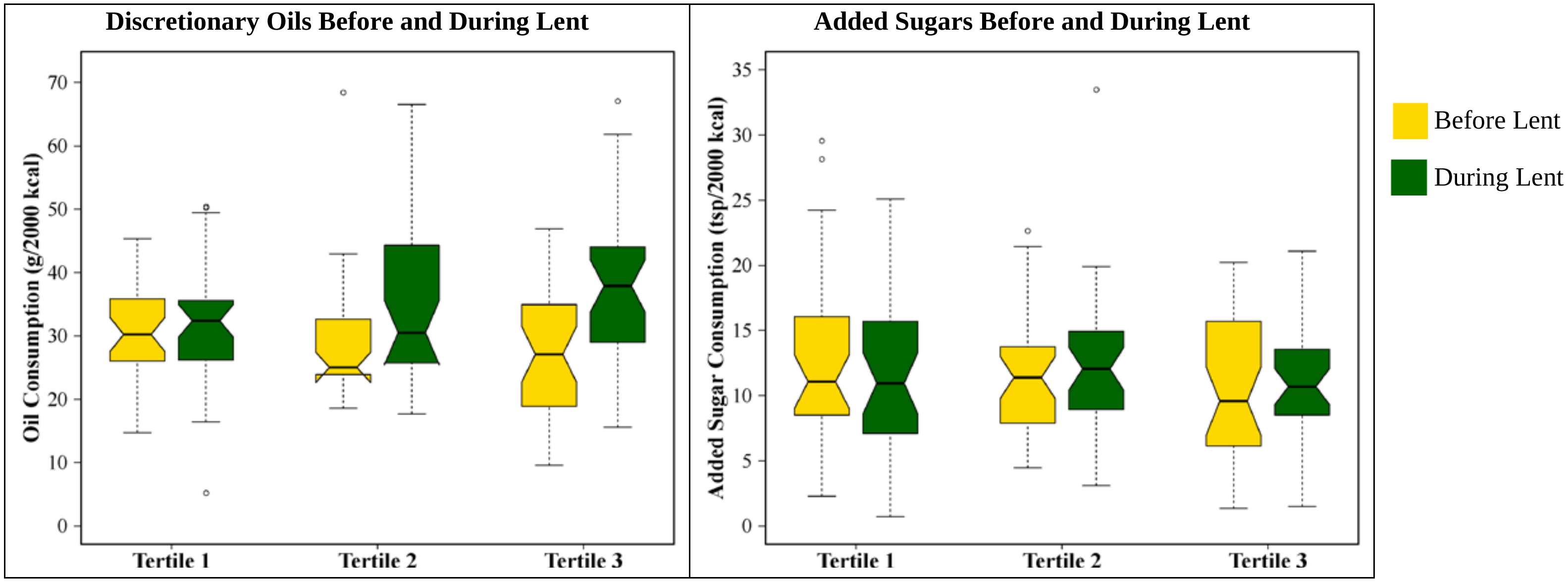


Figure 2.3. Change in consumption of major plant-based foods by MDEΔ Score.

Figure 2.3a. Whole Grain Consumption by MDEΔ Score

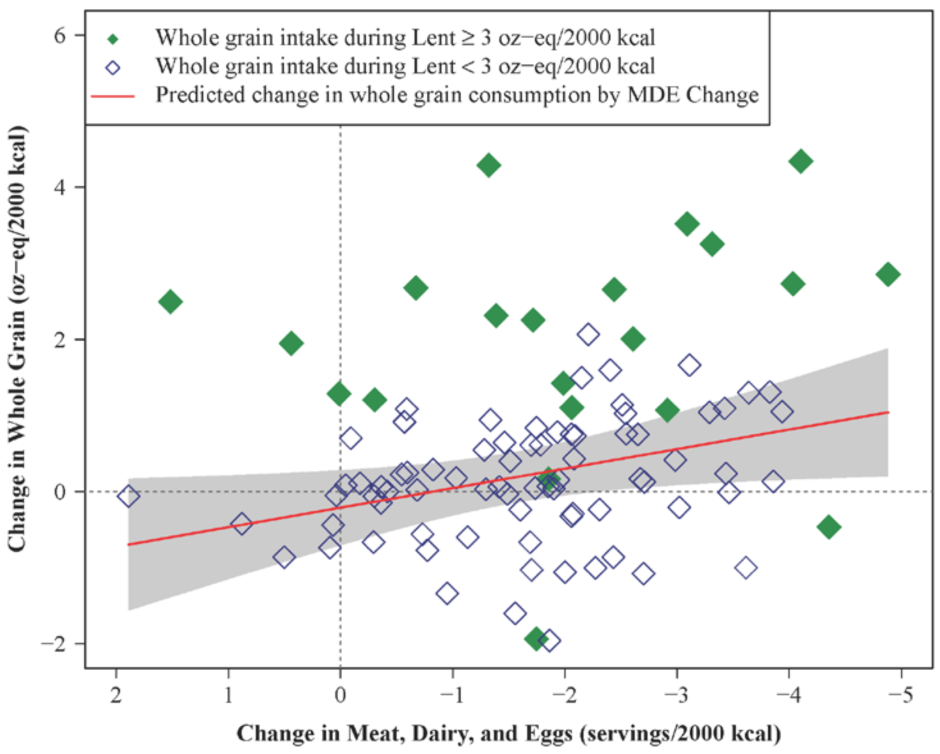
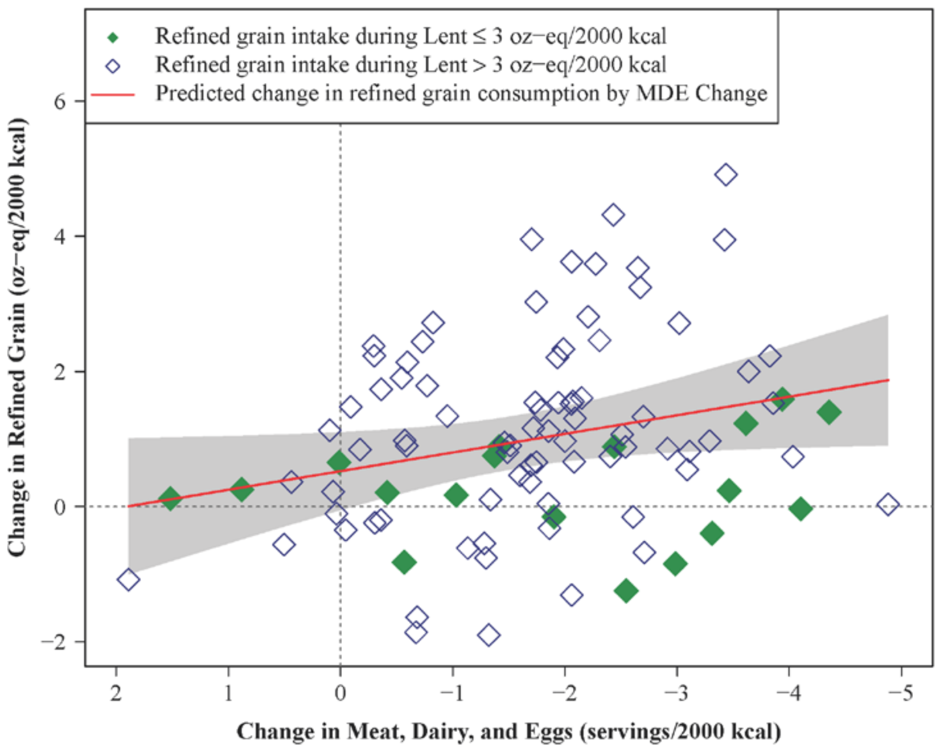


Figure 2.3b. Refined Grain Consumption by MDEΔ Score



Figures 2.3 (cont.) Change in consumption of major plant-based foods by MDEΔ Score.

Figure 2.3c. Legume Consumption by MDEΔ Score

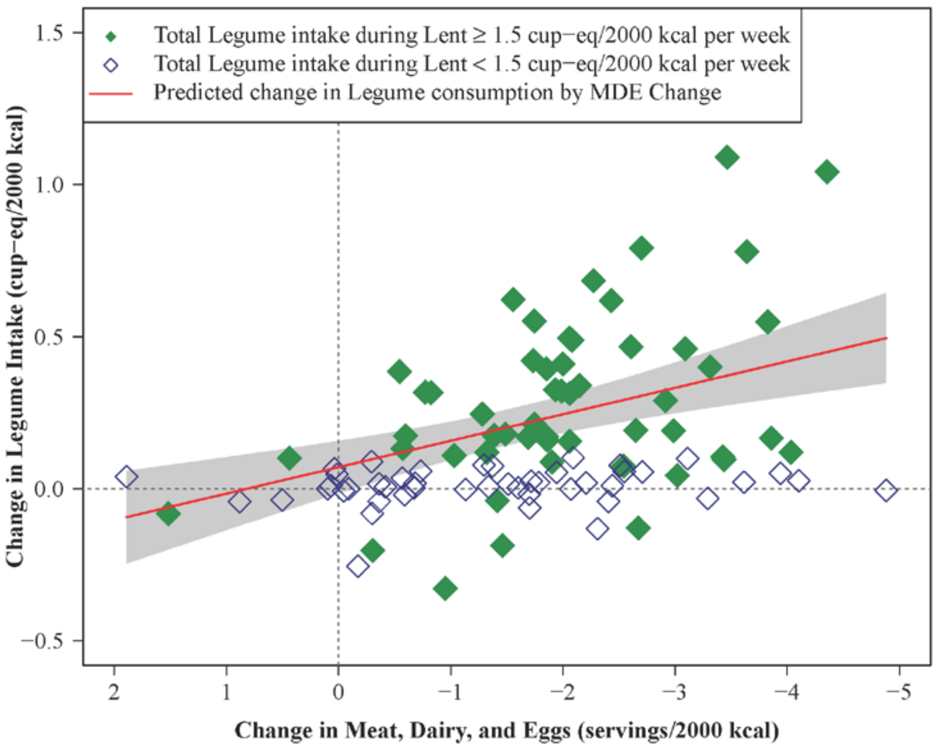
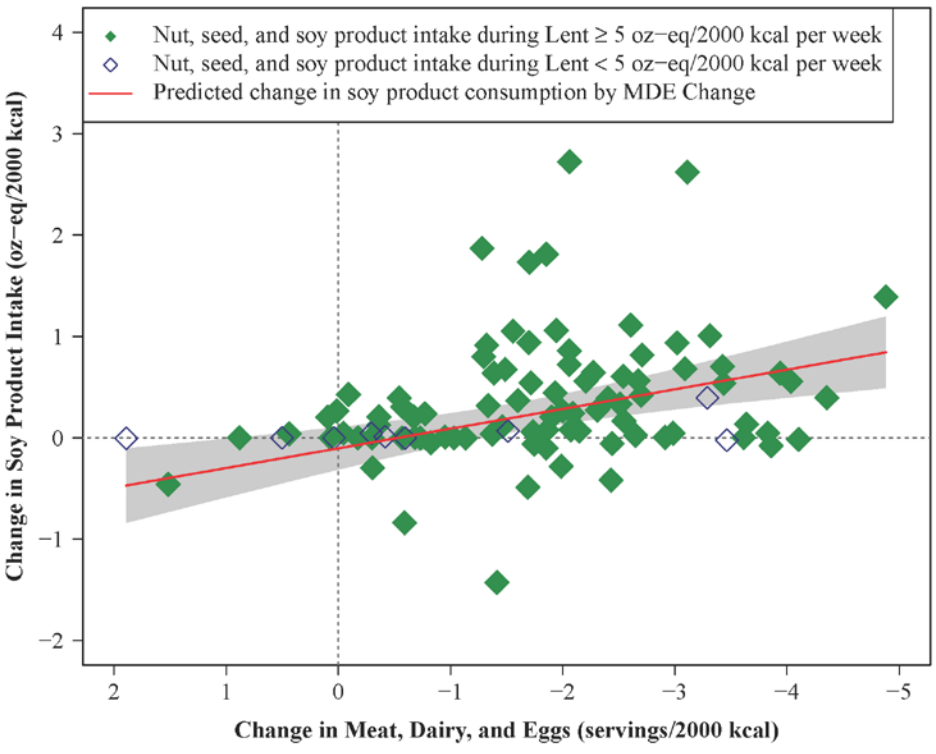


Figure 2.3d. Soy Product Consumption by MDEΔ Score



Figures 2.3 (cont.) Change in consumption of major plant-based foods by MDEΔ Score.

Figure 2.3e. Nut and Seed Consumption by MDEΔ Score

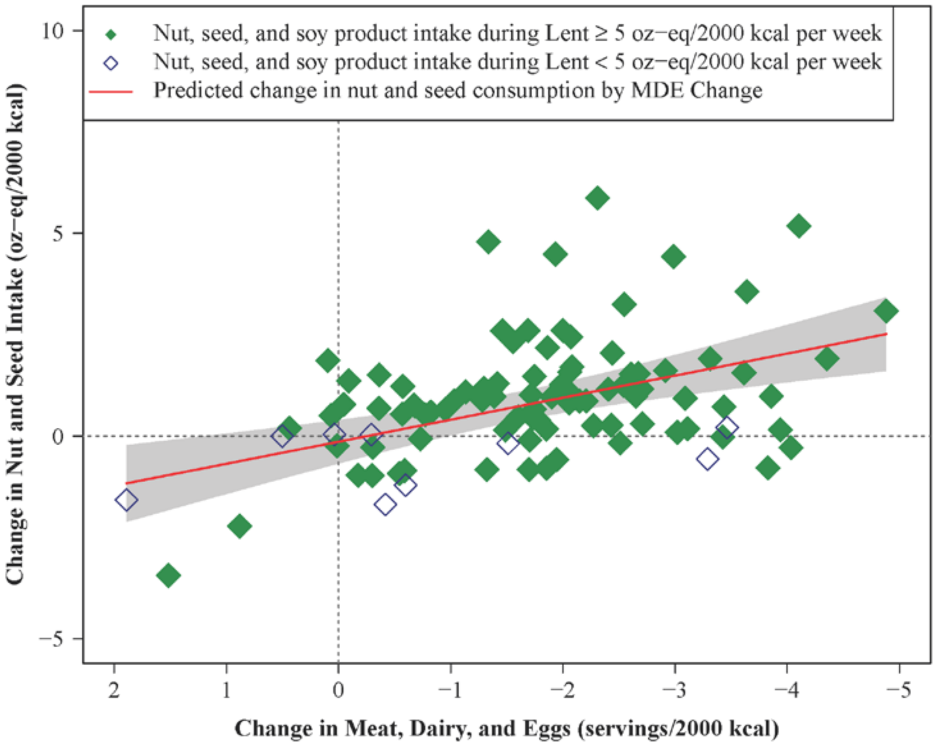


Figure 2.3f. Whole Fruit Consumption by MDEΔ Score

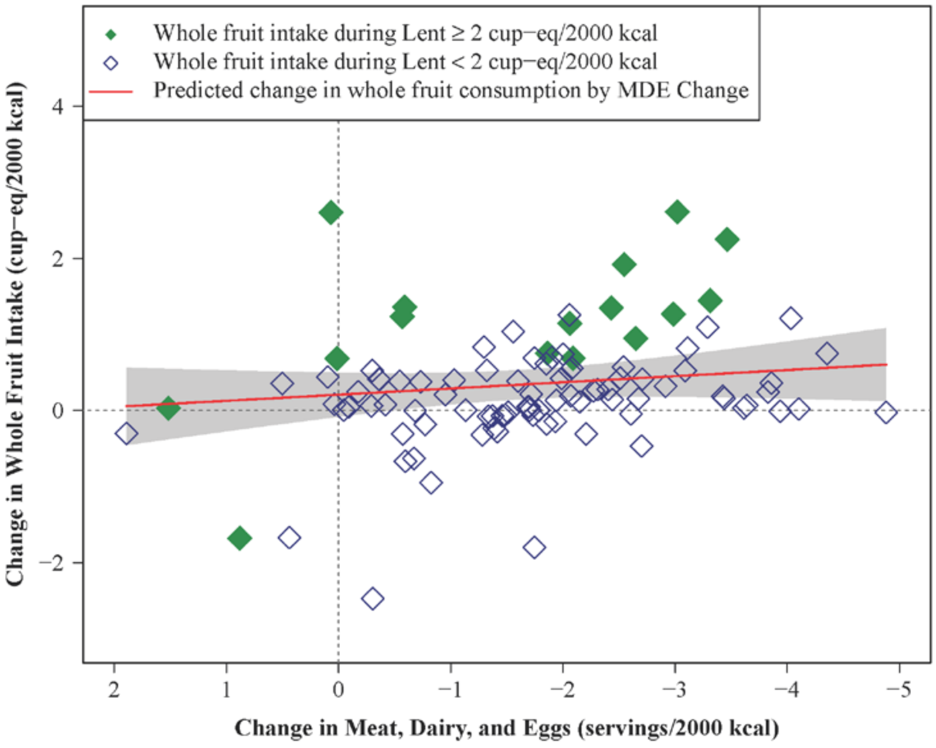


Figure 2.3 (cont.) Change in consumption of major plant-based foods by MDEΔ Score.

Figure 2.3g. Vegetable Consumption by MDEΔ Score

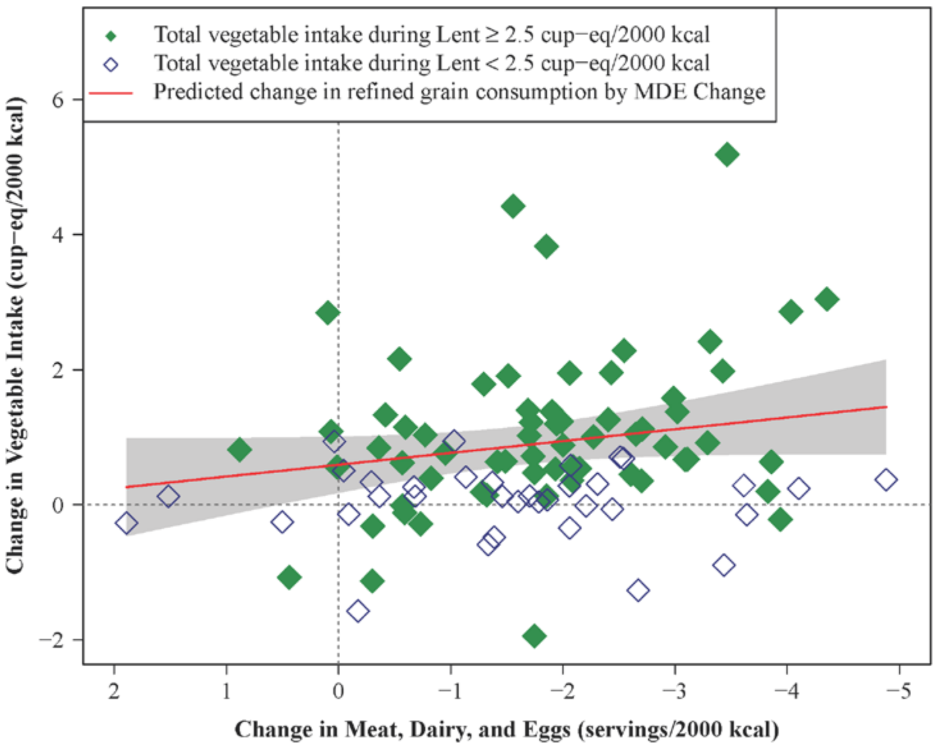
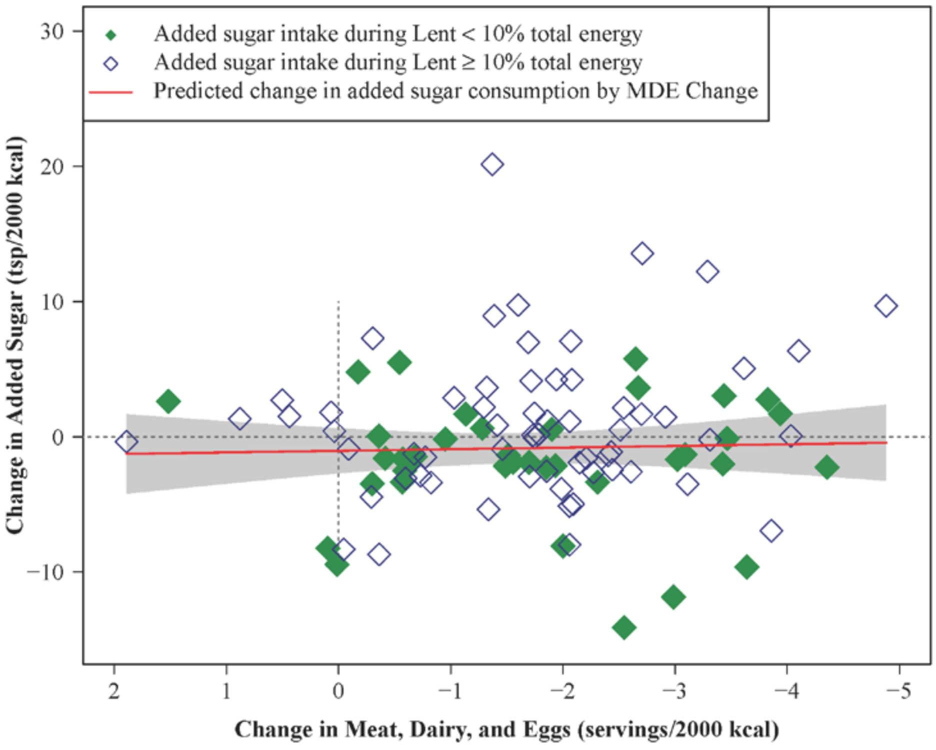


Figure 2.3h. Added Sugar Consumption by MDEΔ Score



CHAPTER 3: IS THE EFFECT OF A SPIRITUALLY-MOTIVATED MEAT, DAIRY, AND EGG FAST ON BIOMARKERS OF CARDIOMETABOLIC HEALTH MODIFIED BY CONCURRENT CHANGES IN DIETARY COMPOSITION?

CHAPTER 3 ABSTRACT

Plant-based diets have received growing attention for their potential to reduce the risk of developing and dying prematurely from cardiovascular and metabolic diseases. Yet, it is not clear from the literature whether complete omission of all animal products is necessary for optimal health, and limited evidence suggests that the health effects of omitting or reducing animal products may depend on the quality of plant-based foods consumed as caloric replacements. To test if and how consumption of distinct plant-based foods may modify any health effects of reducing animal products, this study followed a sample of 99 individuals with varying degrees of adherence to Orthodox Christian (OC) guidance to abstain from meat, dairy, and egg (MDE) products during Lent, the 48-day period prior to Easter. Estimates of dietary composition from food frequency questionnaires and measures of body fat, blood lipids, glucose metabolism, and inflammation were obtained prior to and at the end of Lent. A composite score representing decreases in servings of MDE products was significantly associated with reductions in total and LDL cholesterol, and this association was only partly due to weight loss. No significant associations between MDE restrictions and shifts in measures of body fat, glucose, insulin, or C-reactive protein were observed. Post-hoc analyses suggested that shifts in dairy were what most strongly accounted for the observed relationship between MDE restriction and decreases in blood lipids. There was no evidence that the health biomarker changes associated with MDE reduction during Lent were modified by the change in calories, fish, whole grains, refined grains, legumes, nuts and seeds, fruits and vegetables, discretionary oils, or added sugars. The reductions in total and LDL cholesterol observed in this US-based study sample during Lent align with previous reports of beneficial changes in health biomarkers among non-US OCs during MDE fasting periods, as well as other studies that have tested the cardiometabolic health

effects of vegetarian or vegan dietary interventions. The study may not have been sufficiently powered to detect additive or interactive effects of concurrent shifts in calories, fish, and plant-sourced foods, but the study results may suggest that a reduction in MDE alone is sufficient to improve total and LDL cholesterol. Whether these shifts translate into improvements in LDL particle distributions and long-term health benefits, however, remains unknown.

INTRODUCTION

The United States (US) faces a high economic and public health burden of cardiovascular and metabolic diseases (Benjamin et al. 2017; Dall et al. 2014; Guariguata et al. 2014), and a substantial proportion of this burden is thought to be attributable to dietary factors (US Burden of Disease Collaborators 2013). Though a variety of political, structural, economic, behavioral, and neurobiological factors contribute to the challenge of motivating Americans to change their diets, a primary obstacle for addressing the nutrition-related noncommunicable disease burden is the lack of consensus on which foods should or should not be allowed in a diet designed to prevent and manage cardiometabolic imbalances. Much debate exists in particular about whether animal products, including meat, dairy, and egg (MDE) products, can or should be part of a health-promoting diet. On the one hand, some observational studies among industrialized populations have suggested that higher consumption of red and processed meats is associated with increased cardiometabolic diseases and mortality (Chen et al. 2013; Larsson and Orsini 2014; Micha et al. 2012; Micha et al. 2010; Pan et al. 2012a; Pan et al. 2011; Rohrmann et al. 2013; Sinha et al. 2009) and that, relative to omnivores, populations that eliminate or reduce many or all animal products from their diet tend to have better cardiometabolic health profiles (Bradbury et al. 2014; Dinu et al. 2017; Ferdowsian and Barnard 2009; Fraser et al. 2015a; Rizzo et al. 2011;

Yokoyama et al. 2014; Yokoyama et al. 2017), lower prevalence and incidence of cardiometabolic diseases (Rizzo et al. 2011; Tonstad et al. 2009; Tonstad et al. 2013), and lower risk of premature mortality (Crowe et al. 2013; Orlich et al. 2013). A number of randomized controlled trials further support arguments that vegan and vegetarian diets can lead to weight loss and improved blood lipid profiles and glucose metabolism (Barnard et al. 2009a; Barnard et al. 2006; Barnard et al. 2000; Barnard et al. 2005; Jenkins et al. 1997; Kahleova et al. 2011; Mishra et al. 2013; Turner-McGrievy et al. 2015; Wright et al. 2017).

On the other hand, the data relating meatless diets to better health and longevity are far from consistent (Key et al. 1999; Kwok et al. 2014; Orlich et al. 2013). Moreover, they do not support the need for complete elimination of animal products (Orlich et al. 2013; Satija et al. 2016; Satija et al. 2017). First, the prevalence of overweight and obesity, dyslipidemia, and elevated fasting glucose remains rare among non-industrialized horticulturalist and extant hunter-gather populations (Eaton et al. 1988; Kaplan et al. 2017; Lindeberg et al. 1997; O'Keefe et al. 2004), despite sometimes relying heavily on hunted and/or fished foods (Cordain et al. 2000; Kaplan et al. 2000). Second, several randomized controlled trials (Boers et al. 2014; Jönsson et al. 2009a; Lindeberg et al. 2007; Mellberg et al. 2014) have demonstrated that even diets with unrestricted amounts of lean, unprocessed meat can improve cardiometabolic health markers of individuals with obesity or diabetes when combined with a variety of whole vegetables and fruits, moderate amounts of nuts and seeds, and elimination of most or all grains and added sugars. Finally, studies on the protective effects on health biomarkers and reduced morbidity and mortality risk, albeit also inconsistent (Bloomfield et al. 2016; Liyanage et al. 2016; Rees et al. 2013), have been observed among populations that voluntarily (Sofi et al. 2014) or via an intervention (Esposito et al. 2015; Estruch et al. 2013) follow a Mediterranean type of diet, which only limits but does not completely omit meat or dairy. It remains unclear what proportion of the observed benefits of Mediterranean style diets relates to low meat consumption, relatively high intake of "healthy" plant-based foods (e.g., whole grains, legumes, nuts/seeds, fruits, and vegetables), or negligent consumption of "unhealthy" plant-based foods (e.g., refined grains and added sugars).

Given that the standard American diet tends to be high in both animal products and refined grains and added sugars (Grotto and Zied 2010), the question arises whether simply reducing or eliminating animal products without simultaneously increasing "healthy" plant-based foods and reducing intake of "unhealthy" plant-sourced foods would necessarily lead to improvements in health biomarkers. Research suggests, for example, that replacing saturated fats from animal products with refined sources of carbohydrates may decrease total and low-density lipoprotein (LDL) cholesterol while simultaneously increasing triglyceride levels, which may ultimately increase rather than decrease risk of cardiometabolic diseases (Jakobsen et al. 2010; Mensink et al. 2003; Miller et al. 2011; Sacks and Katan 2002; Sacks et al. 2017). One observational study using data from three large US-based cohorts even demonstrated that individuals who consume relatively few MDE products but high amounts of refined grains, potatoes, and sugar-sweetened beverages and desserts were actually at higher risk for developing type 2 diabetes and coronary heart disease relative to those consuming more animal products but fewer unhealthy plant-based foods (Satija et al. 2016; Satija et al. 2017). Another 21-day randomized dietary intervention study suggested that blood lipids of participants following a vegan diet with no restrictions on processed foods led to unfavorable (albeit not statistically significant) changes in blood lipids while both vegan and omnivorous diets that omitted processed foods and added sugars led to trends toward improved blood lipids (Bloomer et al.

2015). There is reason to expect, therefore, that the health effects of reducing or eliminating animal products would be more pronounced if they are replaced with “healthy” whole grains, legumes, nuts/seeds, fruits, and vegetables but less pronounced or null if they are replaced with “unhealthy” refined grains and added sugars.

In an attempt to further test this hypothesis, this study aimed to 1) examine whether a temporary reduction in MDE consumption for spiritual purposes necessarily leads to beneficial changes in common biomarkers of cardiometabolic health and 2) test whether the magnitude and direction of changes in cardiometabolic health markers depend on concurrent shifts in calories and consumption of “healthy” and “unhealthy” non-MDE foods. In order to capture natural variation in omnivorous and plant-based diets, the focus of this study was on the voluntary dietary shifts made by Orthodox Christians (OCs) during the period of Lent, which in the OC church is a 48-day period during which adherents are encouraged to eliminate MDE products. To date, few known studies have explored the health effects of these dietary shifts among OCs. Reductions in BMI and total and LDL-cholesterol were observed in two small Greek OC samples in Crete (Papadaki et al. 2008; Sarri et al. 2003) and one Egyptian sample population (Elshorbagy et al. 2017). A decline in blood glucose was observed in one Coptic OC population in Egypt (Morcos et al. 2013), yet there was considerable variability in the degree and direction of change in blood lipids across individuals in this study population. None of these studies directly related the changes in health biomarkers to the specific changes in diet, though there appeared to be increases in consumption of carbohydrates, dietary fiber, legumes, and vegetables, as well as reductions in intake of saturated fat, trans fats, and protein in one or both of the Greek study populations during periods of restricting animal products (Papadaki et al. 2008; Sarri et al. 2003).

Of course, the Mediterranean diet pattern of Greece is already considered healthier than the standard American diet in the US (Willett et al. 1995). Being more accustomed to including whole grains, legumes, fruits, vegetable, nuts, and seeds in the diet, OCs in Greece and other nations in that region may customarily choose healthier plant-based foods when reducing their intake of animal products. OCs in the US, however, may not have the same baseline dietary habits, and their meat-restricted diets may be more variable. An earlier study on the dietary shifts of OCs in the same US-based OC population studied herein showed that reduced MDE intake was associated with a moderate decrease in calories and an increase in average consumption of legumes, soy products, nuts and seeds, and unsaturated discretionary oils but not significant increases in average fruit or vegetable intake (See Chapter 2). Moreover, consumption of refined grains and added sugars remained above national recommendations for the majority of OCs during Lent, regardless of the degree to which they restricted MDE products. Given the ambiguity of the health implications of these dietary shifts during Lent, particularly among US-based OCs, this study set out to test the following hypotheses:

Hypothesis 1: A 48-day restriction on MDE products will result in an overall improvement in cardiometabolic risk, as measured by decreases in BMI, body fat percentage, blood lipids, glucose, insulin, and C-reactive protein.

Hypothesis 2: Any observed reductions in cardiometabolic health biomarkers will be more pronounced when MDE reduction is accompanied by decreases in calories or increases in consumption of “healthy” non-MDE foods (e.g., fish, whole grains, legumes, nuts and seeds, fruits and vegetables, or unsaturated discretionary oils) but less pronounced or null when MDE reduction is accompanied by increases in “unhealthy” plant-sourced foods (e.g., refined grains or added sugars).

METHODS

Study sample population

Study volunteers were recruited through oral and written announcements at nine OC churches in three cities in the southern region of the US. As the study aimed to recruit individuals who were and were not intending to follow the OC Lenten dietary restrictions, non-OC individuals were also invited to join the study. Eligibility was limited to non-pregnant, non-lactating women and men between the ages of 18 and 75 who were born or raised in the United States or Canada, but no other exclusion criteria was in place.

At the end of a 5-month study recruitment period, 141 eligible adults signed up and consented to participate in the study, but only 120 actually initiated any of the study protocols. Of those who signed up and began taking part in the study protocols, 114 completed the first two surveys, first food questionnaire, and first health assessment. Of those, 108 participants completed the final survey and second health assessment, and 107 participants completed the second food questionnaire. All study protocols were approved by the University of Washington's Human Subjects Division.

Study design and covariate measurement

This was a short prospective study that followed participants during a 5- to 6-week unrestricted dietary period prior to Lent and then through a subsequent 5- to 6-week period of dietary restrictions during Lent. Across the course of the study, participants were asked to complete three surveys to collect information about demographics; self-rated health status, existing health conditions; medication and supplement usage; usual dietary preferences and eating out behaviors; and tobacco, alcohol, and caffeine consumption.

Measures of physical activity prior to and during Lent were estimated using a modified version of the questionnaire developed for and used in the Aerobics Center Longitudinal Study (Kohl et al. 1997; Kohl et al. 1988). To obtain a measure of energy expenditure, participants were asked about their average weekly engagement in 15 common and specific (walking, hiking, stair climbing, jogging, treadmill use, bicycling, swimming, aerobics, moderate activity sport, vigorous racquet sports, other vigorous sports, weight training, household chores, yard work, and manual labor) and any additional moderate and vigorous physical activities in the previous month and were asked to specify frequency, duration, and average speed (if relevant) for each session of engaging in the activity. Activity-specific metabolic equivalent values (METs), which represent the ratio of the metabolic cost of performing the activity to a standardized resting metabolic rate (Ainsworth et al. 2011), were multiplied by the minutes per week of reported engagement in each activity, summed across all activities, and divided by 60 to obtain a measure of weekly MET hours in each time period.

Diet and Nutrition Assessment

Diet was measured before and during Lent using retrospective self-administered food frequency questionnaires (FFQs) initially designed for the Women's Health Initiative (WHI) (Patterson et al. 1999) and made available through the Nutrition Assessment Shared Resource of the Fred Hutchinson Cancer Research Center. The FFQs asked participants about the frequency (never, once per month, two to three times per month, once per week, twice per week, three to four times per week, five to six times per week, once a day, or twice or more a day) and usual serving size (small, medium, or large, with reference sizes for medium servings provided) of 106 food items and 18 beverage items consumed over the previous 4-5 weeks. An additional 13 adjustment questions asked participants about the kinds of added fats used regularly and the typical fat content of meat and dairy products consumed. Because the FFQs did not cover a comprehensive range of meat and dairy substitutes, participants received additional written instructions from the researcher to count rice, almond, or coconut milk as “soy milk;” coconut oil as “other oils;” almond cheese as “tofu cheese;” and veggie burgers in the “tofu and tempeh” category.

FFQs were reviewed for errors by the researcher and processed by the Nutrition Assessment Shared Resource of the Fred Hutchinson Cancer Research Center, which used the 2015 version of the University of Minnesota Nutrition Data Systems for Research software (Nutrition Coordinating Center: University of Minnesota 2015) to obtain measures of average consumption of major food groups and kilocalories (kcal). The food variables that were generated by this software utilized the MyPyramid Equivalent Database (Bowman et al. 2008), which measures lean meats in ounces (oz); eggs, grains, nuts, and soy products in ounce equivalents (oz-eq); fruit, vegetables, dairy, and legumes (not including soy products) in cup equivalents (cup-eq); and discretionary oils and total added sugars grams (g).

Measurement of cardiometabolic health biomarkers

Basic health assessments involving the measurement of body composition and the collection of capillary blood were conducted before and at the end of Lent. Standing height without shoes was measured at the first visit using a portable stadiometer (Seca-217). Weight and body fat percentage were measured using a full body bioelectric impedance scale (Omron® HBF-514C). Body mass index (BMI) was calculated by dividing weight in kilograms by squared height in meters (kg/m^2).

Capillary blood was collected from a finger prick following a ≥8-hour period without food or caloric beverages. Approximately 3 drops (40 µL) of whole blood were used immediately for the assessment of blood lipids and fasting glucose using the Cholestech LDX® point-of-care device (Gialamas et al. 2010; Shemesh et al. 2006) and commercially available Lipid and Glucose Analyzer cassettes. The LDX® point-of-care device measures total cholesterol, high-density lipoprotein (HDL) cholesterol, triglycerides, and blood glucose directly but calculates low-density lipoprotein (LDL) cholesterol using the Friedewald formula: [total cholesterol – HDL cholesterol – (triglycerides/5)] (Friedewald et al. 1972). For participants with triglyceride levels below the level of detection (n=17 before Lent and n=15 during Lent), the minimal detectable value of 45 mg/dL was imputed as the participants' triglyceride value and LDL cholesterol was calculated manually using the Friedewald formula. Likewise, the minimum value of detection of 100 mg/dL for total cholesterol was imputed as the total cholesterol level for one participant with levels below the limits of detection at the second health assessment, and that value was used to calculate LDL cholesterol manually.

Additional capillary blood was collected in BD Microtainer® tubes with serum separators. Blood was allowed to clot for 30 to 90 minutes and centrifuged at 6000 rpm. Serum was aliquoted and shipped on dry ice to the University of Washington Biological Anthropology and Biodemography Laboratory, where they were kept frozen at -80º C. Insulin was measured by the Northwest Lipid Metabolism and Diabetes Research Laboratories (University of Washington, Seattle, WA) using a two site immune-enzymometric assay on a Tosoh 2000 autoanalyzer (Marcovina et al. 2007); the inter-assay CVs for low, medium, and high levels of control samples for this assay are 2.8%, 2.5%, and 2.0%, respectively. Using the measures of serum insulin obtained by the Northwest Lipid Metabolism and Diabetes Research Laboratories and glucose measured by the Cholestech LDX® point-of-care device, a measure of the homeostatic model assessment of insulin resistance (HOMA-IR) was calculated using the following equation: [glucose (mg/dL) x insulin (μU/mL)]/405 (Matthews et al. 1985).

C-reactive protein (CRP) was measured using an in-house enzyme-linked immunosorbent assay at the University of Washington Biological Anthropology and Biodemography Laboratory (Brindle et al. 2010). The inter-assay CVs for low, medium, and high levels of control for this assay were 16.7%, 7.7%, and 11.6%, respectively; the intra-assay CVs for low, medium, and high CVs was 5.1%, 5.7%, and 10.5%, respectively.

Statistical analyses

After data on caloric intake were reviewed for implausibly low or high estimates of energy intake in either time period (<500 kcal or >4500 kcal for females and <800 kcal or >5000 kcal for males), one male was excluded because of an estimated energy intake >5000 before Lent, and one female was excluded for an estimated energy intake <500 during Lent. Another six participants with complete data were excluded from the analyses for being on a strict weight loss regime during the study period (n=2), following the earlier Catholic Lenten calendar (n=1), already restricting all MDE products at baseline (n=2), or reporting a change in cholesterol- or diabetes-related medications during the study period (n=1). These exclusions resulted in a sample of 99 individuals for most tests. However, sample sizes varied for specific biomarker tests due to missing body fat measures (n=2); unreliable LDL cholesterol estimates due to triglyceride levels >400 mg/dL (Matthews et al. 1985)(n=1); and missing insulin measures at one or both time points (n=16). Furthermore, CRP models excluded individuals reporting changes in regular use of anti-inflammatory medications (n=1); individuals whose acute use of anti-inflammatory medications (24-hours prior to the health assessment) differed from time 1 to time 2 (n=13); or individuals missing CRP measurements for time 1 or time 2 (n=3). No participants needed to be excluded for CRP levels suggestive of acute infection (>10 mg/L).

As errors in reporting of nutrients or foods are highly correlated with errors in measurement of total energy (Willett 2001b; Willett 2013), standardized food and nutrient density variables (intake per 2000 kcal) were used in all analyses to reduce some of this measurement error. Nutrient and food densities also offer a better representation of dietary change, as a decrease or increase in one food inevitably shifts the dietary proportions. To generate these standardized density measures, each food and nutrient variable from each collection period was divided by the respective estimated calorie intake and multiplied by 2000.

Composite measures of participants' MDE consumption of at time 1 (MDE1 score) and time 2 (MDE2 score) were created by adding the number of servings/2000 kcal of MDE consumed in each period. For the purposes of this composite score, a MDE "serving" was defined as 3 oz of unprocessed meat, 2 oz of processed meat, 1 cup-eq of dairy, or a 2 oz-eq of eggs. The difference between the MDE1 score from the MDE2 score in each dataset was then used to create a composite measure of the change in MDE servings (MDEΔ score) between the two time periods.

For descriptive and comparative purposes, demographic characteristics, baseline measures of health biomarkers, and percentage change in biomarkers were tabulated by tertiles of MDEΔ score, with tertile 1 representing the least amount of change in MDE consumption and tertile 3 representing the greatest degree of MDE reduction. Oneway Anova tests were used to assess any differences in dietary characteristics and health biomarkers across MDEΔ tertiles at baseline. Proportions of individuals with suboptimal biomarker values were also tabulated by

MDEΔ tertile. Adult Treatment Panel (ATP) III level classifications defined by the National Cholesterol Education Program were used for categorizing suboptimal levels of total cholesterol as ≥200 mg/dL; LDL cholesterol as ≥100 mg/dL; HDL cholesterol as <40 mg/dL for men and <50 mg/dL for women (Nayor and Vasan 2016; NCEP 2002; Stone et al. 2013)(to convert from mg/dL to mmol/L, multiply total cholesterol, LDL-C or HDL-C by 0.0259). Suboptimal triglycerides levels were those that were ≥100 mg/dL (Miller et al. 2011)(to convert from mg/dL to mmol/L multiply triglycerides by 0.0113). Glucose over ≥100 mg/dL was considered suboptimal (American Diabetes Association 2010) (to convert mg/dL to mmol/L multiply glucose by 0.055). Insulin levels were considered high if ≥12 μU/mL (Després et al. 1996; McAuley et al. 2001) and high HOMA-IR was defined as levels ≥2.5 (Gayoso-Diz et al. 2013; Matthews et al. 1985; Motamed et al. 2016). Finally, BMI values ≥25 kg/m^2 were considered suboptimal (National Institutes of Health 1998), and body fat percentages were considered high by age- and sex-specific cut-offs (Gallagher et al. 2000; Oreopoulos et al. 2010).

Data on clinically or statistically significant changes in biomarkers combined with known day-to-day variation in biomarkers were used to assign cutoff values to different biomarkers for the sake of exploring the proportion of individuals in each MDEΔ tertile that experienced decreases or increases in biomarkers that might be considered clinically meaningful. Previous intervention studies with plant-based diets have reported BMI changes of 5-6% as being statistically significant (Barnard et al. 2009a; Barnard et al. 2006; Barnard et al. 2005; Kahleova et al. 2011; Mishra et al. 2013); hence, this study compared the proportion of individuals in each MDEΔ tertile that experienced a ≥5% change in BMI or body fat percentage. As 10-16% drops in total cholesterol and 12-16% drops in LDL cholesterol are considered clinically relevant shifts (Franz 2006), comparisons were made across individuals with ≥12% increase or decrease total, LDL, or HDL cholesterol. Though an 8% change in triglycerides is considered clinically relevant (Franz 2006), triglycerides tend to have much greater intra-individual variability than other blood lipids (up to 30-40%) (Bookstein et al. 1990; Demacker et al.); thus, comparisons were made across tertiles for individuals who experienced ≥25% change in triglycerides. Intra-individual variation in glucose among healthy individuals is approximately 5-8% (Carlsen et al. 2011; Widjaja et al. 1999), so comparisons were made across individuals with ≥10% glucose change. However, day-to-day variation in insulin is higher (Widjaja et al. 1999), so comparisons were made across tertiles of the proportion of individuals with ≥25% insulin or HOMA-IR. Similarly, CRP can be highly variable (Bogaty et al. 2013), such that even average reductions of 20 to 50% observed in intervention studies have not been considered significant (Barnard et al. 2009a; Bloomer et al. 2015; Bloomer et al. 2010; Kahleova et al. 2011). Consequently, comparisons were made for individuals with ≥50% change in CRP.

To explore sources of variation in baseline health measures, each biomarker was regressed on baseline MDE consumption, caloric intake, age, sex, and physical activity. Next, multiple linear regression analyses with robust standard errors were used to test the hypotheses that measures of cardiometabolic risk would decrease in relation to reductions in MDE consumption (Hypothesis 1) and that the magnitude of change in health biomarkers would be modified by concurrent changes in calories or consumption of "healthy" and "unhealthy" non-MDE foods (Hypothesis 2).

In order to test Hypothesis 1, the percent change in BMI, body fat, total cholesterol, LDL cholesterol, HDL cholesterol, triglycerides, glucose, insulin, HOMA-IR, and CRP were each separately regressed on MDEΔ score controlling for age, sex, baseline BMI, average weekly METs, change in weekly METs, baseline levels of each respective biomarker, baseline MDE score, baseline calories, change in calories, and the number of days following the restricted diet prior to the health assessment (Model I). Bonferroni-adjusted α-values of 0.05/10=0.005 were used to assess statistical significance in Model I analyses. To assess the degree to which weight loss explained the change in any blood biomarkers, regression analyses with significant results in Model I were rerun further controlling for changes in weight (Model IB).

To test Hypothesis 2, Model IB was run for all biomarkers further including (one at a time) main effects and interaction terms for MDEΔ score and changes in calories, fish, whole grains, refined grains, legumes, soy products, nuts and seeds, fruits and vegetables, discretionary oils, or added sugars, further controlling for baseline consumption of each respective food (Model II). Bonferroni-adjusted α-values of 0.05/100=0.0005 were used to assess statistical significance in Model II analyses. Leave-one-out analyses were conducted for Model II analyses that produced main or interactive effects with p-values below the unadjusted α-level of 0.05.

Regression analyses for testing both hypotheses included participants taking medications for the treatment of hypercholesterolemia, hypertension, or diabetes as long as they reported consistent use of medications throughout the study (n=14). However, sensitivity analyses of blood lipids, glucose, and insulin were run excluding these individuals. Sensitivity analysis of CRP were also run excluding individuals taking regularly taking statins, metformin, and low-dose anti-inflammatory medications (n=24).

Finally, one post-hoc test explored the differential effects of changes in meat versus dairy or eggs on changes in total and LDL cholesterol by replacing the MDEΔ score variable in the models used to test Hypothesis 1 with the three separate components of the MDEΔ score: change in servings of total meat, total dairy, and egg consumption, controlling for the same covariates as in previous models, including adjustment for changes in weight (Model III). Wald’s tests were performed to test the difference between the separate coefficients for meat, dairy, and eggs in the models. All analyses were conducted using StataSE 14 or RStudio.

RESULTS

Sample demographics and baseline health characteristics

The adults in this study sample were 19-73 years old (mean=47.7) years; 42% were male, and 94% reported their race as “white or Caucasian” (Table 3.1). Overall, this was a highly educated, high-earning group of individuals, with 92% having received a minimum of a 4-year college degree and 45% reporting an annual household income ≥$100,000. There were no differences across MDEΔ tertiles in age, sex distribution, education level, or income. Only four individuals in the sample did not self-identify as OCs and were in the first MDEΔ tertile (the tertile representing the least amount of change in MDE servings). Among those who identified themselves as OCs, 77% were converts to the practice (i.e., did not grow up with the tradition of OC fasting practices), and the proportion of converts did not differ across MDEΔ tertiles.

Most individuals (90%) rated their health status as “good,” “very good,” or “excellent” at the start of the study. Only 8% of the sample reported that they currently consume some form of tobacco products. Overall, seven participants reported regularly taking cholesterol lowering medication, eleven were regularly taking blood pressure medications, three were taking medication for diabetes, and eleven were taking low-dose NSAIDs or other anti-inflammatories at least multiple times a week.

At baseline (pre-Lent), 66% of the sample was considered overweight at the threshold of 25 kg/m^2 (Flegal et al. 2012; National Institutes of Health 1998) and 70% had what is considered high age- and sex-specific body fat percentage (Gallagher et al. 2000; Oreopoulos et al. 2010)

(Table 3.2 and Figure 3.1). Total cholesterol levels were above optimal (≥200 mg/dL) in 28% of the sample. While 58% of participants had LDL cholesterol levels above optimal (≥100 mg/dL), only 23% had what would be considered borderline high or high levels of LDL cholesterol (≥130 mg/dL; data not shown). Similarly, 35% of participants had suboptimal triglyceride levels, but only 20% had levels in the high-risk category (≥150 mg/dL; data not shown). Approximately one quarter of individuals had fasting glucose and HOMA-IR levels within ranges that are associated with higher risk for metabolic syndrome and type 2 diabetes (American Diabetes Association 2010; Gayoso-Diz et al. 2013; McAuley et al. 2001; Motamed et al. 2016). CRP levels were, on average, within normal ranges for most individuals in the study sample; only 10% of the sample had CRP levels that were in the range associated with low-grade inflammation (3-10 mg/L)(Myers et al. 2004).

Females in this sample had higher baseline body fat percentage and HDL cholesterol and lower triglycerides, glucose, insulin, and HOMA-IR, on average, than males (Table 3.3). Age was positively associated with baseline BMI, total cholesterol, LDL cholesterol, and glucose. Baseline BMI was positively associated with total cholesterol, LDL cholesterol, triglycerides, glucose, insulin, HOMA-IR, and CRP and negatively associated with HDL cholesterol, though the differences were small. Baseline MDE consumption (MDE1 score) was positively associated with baseline BMI and body fat percentage and inversely associated with triglycerides. In other words, baseline BMI and sex were the factors most consistently associated with baseline biomarker levels, while few biomarkers were associated with MDE consumption at baseline.

Baseline dietary characteristics

Five individuals reported regularly following a vegetarian (n=3) or pesco-vegetarian (n=2). Two of the vegetarians still changed their dairy and egg consumption enough to end up in tertile 2. As expected, tertile 3 (the tertile representing the highest degree of change in MDE servings) had the greatest proportion of individuals consuming one or more servings of meat/2000 kcal and the equivalent of at least one egg/2000 kcal prior to Lent. Yet even in that third tertile, about 9% were consuming an <1 serving of meat on a daily basis. There was no difference across tertiles in the proportion of individuals consuming one or more cup-equivalent serving of dairy.

Those in the third MDEΔ tertile consumed, on average, the most total meat (5.1 oz/2000 kcal) and eggs (1 oz-eq/2000 kcal), though those in the first and second tertiles still consumed approximately one meat serving per day (~3.5 oz/2000 kcal)(Table 3.4). However, the differences in any specific category of meat was not significant across the tertiles at baseline, and there were no baseline differences in average consumption of milk, yogurt, cheese, or total dairy across tertiles. With the exception of nuts and seeds, which were consumed in higher quantities in the first MDEΔ tertile, there were no differences across tertiles in consumption of calories, fish, or other plant-based foods at baseline.

Hypothesis 1: Are MDE restrictions associated with improvements in cardiometabolic risk biomarkers?

Each serving decrease in MDE consumption during Lent was associated with an average 3.5% drop in total cholesterol (95% CI: 1.8-5.2%, p<0.0001) and 3.4% drop in LDL cholesterol (95% CI: 1.2-5.6%, p=0.003) after controlling for MDE1 score, baseline calories, change in calories, age, sex, baseline BMI, average weekly METs, change in METs, and number of days on the restricted diet before the Lenten biomarker collection (Table 3.5). This translated into an average 12.1% and 13.2% drop in total and LDL-cholesterol, respectively, in the third MDEΔ tertile in which MDE consumption decreased by an average of three servings (Table 3.6). Of the covariates in the model, baseline cholesterol levels and sex were significantly associated with changes in total and LDL cholesterol. Each 10 mg/dL increase in total and LDL cholesterol at baseline was associated with a 1.3% (95% CI: 0.7-2.1%, $p<0.0001$) and 2.0% (95% CI: 0.9-3.0%, $p<0.0001$) greater decrease in total and LDL cholesterol, respectively, during Lent (data not shown). Males had, on average, an additive 4.8% (95% CI: 0.3-9.2%, p=0.04) drop in total cholesterol and an additive 8.0% (95% CI: 2.1-13.8%, p=0.008) drop in LDL cholesterol relative to females (Figure 3.2). Also, each additional day between the start of Lent and the day of capillary blood collection was associated with a 0.8% (95% CI: 0.3-1.3%, p=0.003) drop in total cholesterol but was not associated with LDL cholesterol (data not shown).

The association between MDEΔ score and total cholesterol (β: -3.0%, 95% CI: -1.5% to -4.5%, p=0.0002) was slightly attenuated when further controlling for weight change (Table 3.7). The association between MDEΔ score and LDL cholesterol (β: -2.8%, 95% CI: -0.4% to -5.2%, p=0.02), however, was no longer significant at the Bonferroni-adjusted α-level. At any given level of MDE reduction, each pound lost during Lent was associated with an average 4.4% (95% CI: 1.5 to 7.3%, p=0.003) decrease in total cholesterol and an average 5.0% (95% CI: 0.9 to 9.2%, p=0.02) decrease in LDL cholesterol.

MDEΔ score was not associated with changes in any other health biomarkers in this sample. Though the beta coefficients for all biomarker changes were in the hypothesized direction, a nontrivial proportion of individuals in the third MDEΔ tertile experienced increases in triglycerides, glucose, insulin, HOMA-IR, and CRP. Only lower MDE1 score, decreases in calories, and increased weekly METs were associated with decreased BMI, and no variables in the model were associated with changes in measures of body fat percentage. The only covariate in the models that was consistently negatively associated with blood biomarkers was the baseline level of each respective biomarker. The sensitivity analyses excluding individuals taking medications for hypercholesterolemia, hypertension, or diabetes did not produce different results for any of the biomarkers tested (Supplemental Table 3.1).

Hypothesis 2: Are associations between MDE restrictions and shifts in cardiometabolic health biomarkers modified by concurrent shifts in calories and "healthy" or "unhealthy" non-MDE foods?

There was no evidence at the Bonferroni-adjusted α-level that the relationships between MDEΔ score and shifts in health biomarkers were modified by changes in calories, fish, added sugars, oils, or major plant-based food categories.[1] Adding the main effect and interaction terms for the plant-based food groups further attenuated the effect size of the association between

---

[1] At the standard unadjusted α-level of 0.05, there was some evidence that at any given level of MDEΔ, each 100 kcal decrease was associated with a 0.2% (95% CI: 0.03 to 0.4%, p=0.02) drop in BMI; this association did not reach significance for body fat percentage (Supplemental Table 3.2). There was similarly some suggestion that each 100 kcal decrease was associated with an average 0.8% (95% CI: 0.1 to 1.6 %, p=0.03) drop in blood glucose (Supplemental Table 3.3). Yet the positive interaction term for MDE and calorie changes (β-interaction=0.4%, 95% CI: 0.1 to 0.8%, p-interaction=0.01) suggested that, when combined with MDEΔ, the effect of calorie reductions on blood glucose would be less pronounced. Leave-one-out analyses offered no indication that these suggestive associations were being driven by any single individual (data not shown). In contrast, there were some suggestive interactive effects of soy products that appeared in the Model II for HDL cholesterol and triglycerides that, according to the leave-one-out analyses, were primarily driven by a few individuals who were at the far ends of soy product consumption shifts and HDL or triglyceride changes (data not shown). Similarly, suggestive associations arose between increased nut/seed consumption and reduced glucose and CRP, but these were driven by just a few individuals with marked shifts in nut/seed consumption combined with substantial shifts in blood glucose or CRP (data not shown).

MDEΔ score and total and LDL cholesterol (Table 3.8). In most cases, the attenuation was so large that the associations were no longer significant at the Bonferroni-adjusted α-level, though none of the non-MDE food groups appeared to be significantly associated with the changes in total or LDL cholesterol.

Post-hoc Test 1: Differential effects of meat, dairy, and eggs on Total and LDL cholesterol

When regressing the change in total and LDL cholesterol on meat, dairy, and eggs as separate variables, the model suggested that it was the change in dairy, and not the change in meat or eggs, that accounted for the relationship between MDEΔ score and shifts in total and LDL cholesterol (Table 3.9). In these revised models, each cup-equivalent decrease in total dairy consumption was associated with an average 5.7% (95% CI: -3.6 to -7.9%, p=<0.0001) decrease in total cholesterol and a 6.7% (95% CI: 3.6-9.8%, p=<0.0001) reduction in LDL cholesterol. On the other hand, neither meat nor egg decreases were associated with cholesterol changes when controlling for shifts in dairy; Wald's tests confirmed that, in both the total and LDL cholesterol models, the beta coefficients for the change in dairy were significantly different than the coefficients for the change in meat (p=0.028 in the total cholesterol model; p=0.005 in the LDL cholesterol model) and the change in eggs (p=0.007 in the total cholesterol model; p=0.013 in the LDL cholesterol model).

DISCUSSION

The data from this study indicate that the decreases in MDE consumption that some OCs make during the Lenten season are associated with statistically significant decreases in total and LDL cholesterol levels. Yet not everyone who reduced their MDE consumption necessarily experienced meaningful reductions in total or LDL cholesterol, and there was no evidence that short-term Lenten MDE reductions lead to significant changes in measures of glucose metabolism, inflammation, or other blood lipid levels. Some of the relationship between MDE and total and LDL cholesterol shifts appears to be explained by modest weight reduction, and it is not clear to what degree the effects of MDE restriction on cholesterol shifts occur independently of increases in plant-based foods. There is some indication that reductions in dairy consumption might drive the observed cholesterol changes more than the reductions in meat or eggs. These data do not provide evidence that concurrent shifts in consumption of fish or different "healthy" or "unhealthy" plant-based foods modify the association between MDE reductions and changes in blood lipids.

The results of this study are in agreement with the data suggesting that diets low in or void of animal products are associated with more optimal blood lipid profiles (Dinu et al. 2017; Yokoyama et al. 2017). Yet the findings that dairy might be the main MDE product driving the results of this study is surprising given the history in the US of viewing meat and eggs as being the more atherogenic of the animal-based foods. On the one hand dairy, particularly cheese, is a significant source of saturated fat in the broader US diet (Huth and Park 2012), and decreases in dairy appeared to account for a greater proportion of the decreases in saturated fat in this study sample. On the other hand, there has been no consistent evidence that either full or low-fat dairy have adverse effects on cardiometabolic disease risk factors or outcomes (Guo et al. 2017; Kratz et al. 2013; Lovegrove and Givens 2016; Mozaffarian 2016). In fact, some of the research suggests that at least some dairy products (e.g., fermented dairy products) may actually be inversely associated with cardiometabolic disease risk (Guo et al. 2017). Moreover, this study sample was not consuming a large amount of dairy to begin with; on average, most individuals were consuming about one serving/2000 kcal of dairy each day, and that included only an average of 0.5 servings/2000 kcal of cheese. There was no indication that the kinds of dairy products varied across MDEΔ tertile or that the number of individuals using whole- versus low- or reduced-fat milk differed across the tertiles.

Then again, neither lean, unprocessed red meats (Beauchesne-Rondeau et al. 2003; Davidson et al. 1999), nor poultry (Beauchesne-Rondeau et al. 2003; Davidson et al. 1999; Sinha et al. 2009), nor regular egg consumption (up to two eggs per day) (Geiker et al. 2017) have been consistently shown to have adverse effects on blood lipids or cardiometabolic health outcomes. Only processed meats have been consistently associated with increased risk of cardiometabolic-related disease risk and mortality (Fretts et al. 2012; Lajous et al. 2012; Larsson and Orsini 2014; Micha et al. 2017; Micha et al. 2010; Michas et al. 2014; Mozaffarian 2016; Rohrmann et al. 2013). Because processed meat consumption was on average already somewhat low (at least slightly lower than national averages (Micha et al. 2015)) and meat consumption declined to some degree across all MDEΔ tertiles, perhaps the change in dairy may be what most sets apart strict adherents to the recommended OC dietary restrictions from those who were only restricting meat. If this were the case, one might expect that change in egg consumption would similarly represent degree of adherence, but egg consumption may not have been frequent or high enough at baseline to provide as much weight.

Similarly, the lack of statistically significant (at the adjusted α-level) interactions with calories or specific plant-based foods was also surprising, given studies showing that even mild caloric reduction can lead to improvements in cardiometabolic health markers (Most et al. 2017) and that vegan or low-meat diets containing more processed foods may not offer protection against adverse cardiometabolic health outcomes (Bloomer et al. 2015; Satija et al. 2016; Satija et al. 2017). Perhaps these null results are due in part to A) so much variability in the combinations of foods individuals consumed more of during Lent and B) the fact that average consumption of any single food category did not tend to increase substantially in relation to MDEΔ (See Chapter 2). Perhaps combinations of healthier and less healthy food choices somewhat cancel each other out. For example, intake of refined grains increased by approximately 1 serving/2000 kcal in the portion of this sample that experienced a ≥12% decrease in LDL cholesterol, but average intake of whole grains, fruits and vegetables, soy products, and nuts and seeds also increased in that group while total calories decreased. Thus, there may simply not have been a large portion of people who increased their intake of refined grains and added sugars without also increasing their intake of healthier plant-based foods, in which case, it might be unlikely that interactions with changes in any single food group would be identified in this data. This suggests that changes in overall dietary pattern may be more important and impactful than changes in any isolated food group. These data also demonstrate the difficulty of ever truly isolating the effect of any single food group, as a change in consumption of one food invariably leads to changes in the relative consumption of other foods.

Comparisons with other OC study populations

The results of this study correspond closely with the findings of other quantitative studies on Lenten shifts in health biomarkers. The approximately 23 mg/dL and 17 mg/dL difference in average total and LDL cholesterol, respectively, in the third MDEΔ tertile are of a similar magnitude as the 22 and 18 mg/dL reductions in average total and LDL cholesterol observed among a mix of Greek OC priests, monastics, and laypersons (n=52) during the Lenten fast (Sarri et al. 2003). The 14 and 13 mg/dL reductions in total and LDL cholesterol observed among Egyptian OCs (n=36) during their 40-day Nativity fast before the Christmas season (Elshorbagy et al. 2017) was only slightly lower than the changes observed in this study. In another study of Egyptian OCs (n=14), average total cholesterol was 11 mg/dL lower during Lent, but average LDL cholesterol was 9 mg/dL higher (Morcos et al. 2013); those Egyptian OCs also experienced an average 48 mg/dL decrease in triglycerides. Finally, a study of Cretan monks (n=10) reported average total and LDL cholesterol levels that just 7 weeks after Lent were 35 and 42 mg/dL higher than respective averages at the end of Lent (Papadaki et al. 2008). However, average triglycerides among those Cretan OC monks were 50 mg/dL higher during Lent than they were following Lent.

No previous studies of OC dietary restrictions have reported significant changes in HDL cholesterol, nor has there been a consistent trend across studies in the direction of average change in HDL cholesterol. Two of the four previous OC fasting studies also reported no significant change in triglycerides (Elshorbagy et al. 2017; Sarri et al. 2003). In agreement with some (Elshorbagy et al. 2017; Papadaki et al. 2008; Sarri et al. 2003) but contrary to one (Morcos et al. 2013) of the other studies on OC dietary restrictions, there were no significant changes in fasting blood glucose observed in this study, despite this study population starting out with slightly higher average baseline glucose levels than in some other OC populations (Elshorbagy et al. 2017; Morcos et al. 2013; Sarri et al. 2003). The only other OC study that measured insulin also reported no changes in relation to OC dietary restrictions (Elshorbagy et al. 2017). No other studies with OCs measured changes in CRP in relation to their dietary restrictions.

Finally, though the changes in BMI observed in the present sample were neither statistically nor clinically significant, the average 0.4 kg/m^2 decrease in BMI in the third MDEΔ

tertile was comparable to the statistically significant 0.5 and 0.4 kg/m^2 drops in BMI reported among Greek and Egyptian OCs, respectively, during a prolonged period of dietary restriction (Elshorbagy et al. 2017; Sarri et al. 2003). The present study sample also started out with a lower average BMI (27.2 kg/m^2 for the entire sample and 26.7 kg/m^2 for the third MDEΔ tertile) compared to the average baseline BMIs reported for the Greek OCs (28.2 kg/m^2) and Egyptian OCs (28.6 kg/m^2) among which statistically significant drops were reported.

Hence, this study's findings corroborate previous reports that OC periodic dietary restrictions on MDE products tend to be associated with significant reductions in total and LDL cholesterol. Changes in other cardiometabolic health markers, however, are more inconsistent across studies.

Comparison with non-OC study populations

It could be argued that the 5- to 6-week period between the start of Lent and the time when participants' biomarkers were collected was not long enough to see the full potential health effects of restricting MDE products from the diet. Indeed, more substantial drops in BMI (Barnard et al. 2006; Mishra et al. 2013; Wright et al. 2017), fasting glucose (Barnard et al. 2006), and total and LDL-cholesterol (Barnard et al. 2006; Wright et al. 2017) have been reported in intervention studies lasting three months or more. Yet, changes in health biomarkers also tend to level out after about 3 months (Barnard et al. 2009a; Kahleova et al. 2011; Wright et al. 2017). It should also be noted that, besides other vegan/vegetarian diet intervention studies having a longer duration, other studies' dietary regimens tend to be more extreme (e.g., discouraging consumption of processed and fried foods, added oils, and fatty plant-based foods like nuts, seeds, avocados, and olives) than the average OC Lenten restrictions. With these more stringent vegan diets, significant drops in BMI and blood lipids have been observed within two (Jenkins et al. 1997), three (Bloomer et al. 2015; Bloomer et al. 2010), and five weeks (Barnard et al. 2000). It is meaningful, therefore, that the less extreme OC Lenten version of a quasi-vegan diet observed in this study produced observable differences in total and LDL cholesterol within a period of five to six weeks. In fact, the degree of change in these blood lipids among the third MDEΔ tertile were greater than the ~12-13 mg/dL decrease in both total and LDL cholesterol estimated from pooling the results of over 10 randomized controlled studies with vegetarian or vegan diets (Wang et al. 2015; Yokoyama et al. 2017). The observed changes in total and LDL cholesterol in both the third and second MDEΔ tertiles were also more substantial than the estimated ~7-9 mg/dL and ~3-7 mg/dL drops in total and LDL cholesterol reported in meta-analyses of Mediterranean type diet interventions (Nordmann et al. 2011; Rees et al. 2013).

In addition to differences in dietary regimes and study duration, another factor that can contribute to distinct results across studies is the baseline health of the participants. Most of the randomized controlled trials that report greater reductions in BMI involve participants with an average baseline BMI above 30 kg/m^2 (Barnard et al. 2006; Barnard et al. 2005; Kahleova et al. 2011; Turner-McGrievy et al. 2015; Wright et al. 2017). Similarly, the studies that report significant drops in glucose or insulin in response to a vegan diet tend to involve patients with diabetes, and even in those studies, the observed decreases have not been found to be more significant than those observed on conventional diabetes diets that include meat (Barnard et al. 2009a; Barnard et al. 2006; Kahleova et al. 2011). Such differences in baseline may partly explain the inconsistent effects of plant-based diets on triglycerides (Ferdowsian and Barnard 2009; Wang et al. 2015; Zhang et al. 2013). Similarly, CRP, though not frequently measured in intervention studies of vegan diets, likewise tends to only decrease to a statistically significant or clinically meaningful degree when average levels are above 3 mg/L at baseline (Barnard et al. 2009a; Bloomer et al. 2010; Kahleova et al. 2011). This current study population was, on average, within normal ranges for blood lipids, glucose, insulin, and CRP and was not far out of the normal BMI range. In fact, though the proportion of individuals in the overweight or obese categories are on par with other nationally representative samples (Yang et al. 2012), a lower proportion of them had elevated total cholesterol and fasting blood glucose. Hence, the lack of significant reductions in measures of glucose metabolism and inflammation should perhaps not be surprising, and the reductions in total and LDL cholesterol observed in this short period are even more impressive when considering the relatively “normal” baseline levels of these biomarkers in this study sample.

Health implications of the study findings

Blood lipids levels, and LDL cholesterol levels in particular, have been causally linked to cardiovascular disease risk (NCEP 2002; Sacks et al. 2017) and are a major target for therapies aimed at preventing major vascular events and premature death (Cholesterol Treatment Trialists' (CTT) Collaborators 2012; Farley et al. 2010; Pletcher et al. 2009; Ridker 2014). The average 12% and 13% difference in total and LDL cholesterol observed in this sample are within the range of what has been considered clinically meaningful drops in total and LDL cholesterol (Franz 2006). If a 30-40 mg/dL decrease in LDL from statin treatment is thought to reduce the risk of major vascular events by about 20-30% (Cholesterol Treatment Trialists' (CTT) Collaborators 2012; Grundy et al. 2004), the approximately 17 mg/dL decrease in the third MDEΔ tertile could potentially have a meaningful impact on health if maintained. However, not only are the health effects unclear due to the temporary nature of the OC dietary restrictions, but there are also a number of other factors that complicate the interpretation of this study's results. For one, any health benefit of a reduction in blood lipids will depend on the baseline levels of those respective biomarkers. Since the individuals in this study had average baseline cholesterol levels that, though similar to US national averages reported in 2013-2014 (Rosinger et al. 2017), were not, on average, in the high risk categories, it thus remains questionable how much of a health benefit there might be from further reduction of total and LDL cholesterol levels that are already within what is considered a "normal" range. Moreover, it may be worth considering that very low cholesterol, particularly at older ages, may also pose health concerns (Mielke et al. 2005; Morgan et al. 1993; Onder et al.). On the other hand, if someone starts out with high cholesterol levels and remains in the high category even after a decrease in cholesterol, such a change may likewise have limited effect on health, especially if only temporary as would be expected in this population. Indeed, the one study of OC monks that looked at changes from Lent to 7 weeks following Lent demonstrated that cholesterol levels tend to rise again once MDE products are allowed back into the diet (Papadaki et al. 2008).

For two, it is important to consider that lowering LDL cholesterol is not always enough to reduce cardiovascular disease risk (Brunzell et al. 2008), and the relationship between LDL cholesterol and cardiovascular disease risk may depend on the number and density of LDL particles and on HDL cholesterol concentrations. Notably, reductions in saturated fat and increases in carbohydrates may lead to reduced LDL cholesterol overall but an increase in the blood concentrations of small, dense LDL particles (Faghihnia et al. 2010; Siri and Krauss 2005), which are more susceptible to oxidation and are thought to be more atherogenic than large buoyant LDL particles (Hirayama and Miida 2012; Ridker 2014; Verhoye and Langlois Michel 2009). Replacing saturated fats with carbohydrates also tends to reduce HDL cholesterol and increase triglycerides, leaving the ratios of “bad” to “good” cholesterol unchanged or potentially worse (Mensink et al. 2003; Siri and Krauss 2005). HDL cholesterol, which is inversely associated with cardiovascular disease risk (Rader and Hovingh 2014), also decreased on average (though not to a significant degree) in this study sample. Consequently, the average total:HDL cholesterol ratio, which may to be a better predictor of cardiovascular disease risk than any single cholesterol value alone (Mora et al. 2009; Ridker), remained steady in all MDEΔ tertiles across the Lenten period. Hence, in light of the decreases in HDL cholesterol and potential increase in concentrations of small, dense LDL particles, the reductions in LDL cholesterol observed in this study may not have a meaningful impact on cardiometabolic disease risk.

Finally, it is unclear if only temporary reductions in blood lipids are beneficial in the long run. One group of researchers proposed that these periodic episodes of MDE restriction could have contributed to the lower rates of cardiovascular disease and increased longevity observed in Cretan populations (Sarri et al. 2004). Yet, if the periodic restriction of MDE products among OCs were to have lasting health benefits, we might expect to see more optimal measures of body fat, blood lipids, and glucose metabolism among those who adhere to the tradition and those who do not, and the limited data does not support this. In the one study that compared the health changes of OCs to a control group, the OCs had higher total and LDL cholesterol, triglycerides, fasting glucose, and BMI at the start of every fasting period throughout the year (Sarri et al. 2003). More than 25% of the monks in Mount Athos, Greece had total and LDL cholesterol levels and insulin levels in the borderline high or high ranges despite restricting meat intake year-round and restricting fish, dairy, and eggs during Lent and other OC fasting periods (Karras et al. 2017). As noted above, in one OC monk population triglyceride levels increased substantially during the Lenten period (Papadaki et al. 2008). Thus, the long-term health effects of the periodic restrictions on MDE products practiced by OCs deserve further investigation.

Study limitations

These study findings need to be interpreted with caution given a number of key limitations. First, there were a number of sources of variability and error in the outcome measures that could, particularly in this small sample, have decreased the power to detect associations and, thus, led to type II statistical error. For instance, blood lipids, glucose, insulin, and CRP may vary within individuals by >20% from one week or month to the next even when not making intentional dietary changes (Bogaty et al. 2013; Bookstein et al. 1990; Carlsen et al. 2011; Demacker et al. ; Mogadam et al. 1990; Widjaja et al. 1999). The fact that triglyceride levels had to be truncated at 45 mg/dL for individuals with levels below detection could have also reduced the amount of change measured in triglycerides and slightly increased the calculated measure of LDL cholesterol, though the latter should not have been off by more than a few mg/dL. On the other extreme, LDL cholesterol calculations may have been less reliable for individuals with high levels of triglycerides (Brunzell et al. 2008). There is also intra- and inter-assay variation that could be a source of error and noise in the data. For example, though the coefficients of variation for the point-of-care device used for measuring blood lipids and glucose were generally below 5%, differences between the minimum and maximum measurements for these biomarkers in some control samples were >10%. Intra- and inter-assay variation for the CRP assay used in this study were also relatively high. Finally, though measures of body fat are generally less variable, the bioelectric impedance scale is not a perfect measure of body fat and can be influenced by hydration status (Dehghan and Merchant 2008; Thompson et al. 1991).

Second, there may be substantial error in the dietary measures due in large part to the retrospective nature of the FFQ, recall bias, and a tendency of individuals to report ideal consumption patterns rather than actual consumption patterns (Kristal et al. 2005; Willett 2013). There is a possibility for sequencing effects from simply being more familiar with the FFQ at the second administration to have led to overinflated estimates of the degree of change in calories and specific foods. FFQs are also limited in the kinds of foods they capture and may overestimate intake of animal foods from mixed dishes while underestimating intake of any non-traditional plant-based foods (e.g., alternative nut milks or nut butters, coconut products, and vegetable-based meat and cheese analogues) that were not perceived by participants to fit the specific categories delineated in the questionnaire. Importantly, the FFQ and the nutritional software used to analyze the FFQ entries may have miscalculated the amounts of different MDE products participants were eating, as it does not differentiate between standard and vegan versions of mixed dishes that might normally have eggs, dairy, and/or meat (e.g., pancakes/cakes, pizza, enchiladas, tacos, and burritos). Such miscalculations, along with potential sequencing effects, may have contributed to the lack of clear trends in blood lipid shifts relative to meat and egg reductions or an inflated measure of the effect of decreased dairy consumption.

Third, the composite measure of MDE products that gave equal weight to a serving decrease in meat, dairy, and eggs does not capture the differential effects that shifts in each of those food categories (or sub-categories of meat and dairy products) may have on health biomarkers. The post-hoc analysis that included each separate component of that variable in the regression model attempted to parse out the varying effects of each component. Even then, however, the categories of separate MDE products do not differentiate between red meat, poultry, or processed meats, meats cooked at high or low temperatures, or grain-fed or pasture-raised meat, all of which are factors that could potentially modify the effect of meat on health markers (Mozaffarian 2016; Uribarri et al. 2010). Similarly, the dairy food group does not differentiate between whole, low-fat, or non-fat milk; fermented or unfermented dairy; sweetened or unsweetened dairy products; pasture-raised or grain-fed sources of milk, which may each have distinct effects on health markers (Kratz et al. 2013; Lovegrove and Givens 2016; St-Onge et al. 2000). Moreover, the lean meat variables produced by the FFQ analysis may not have fully captured the nutrition provided by meat, as the estimated fat content of any meats is lumped into a separate variable that also includes other solid fats, like butter and margarine (Bowman et al. 2008). As that solid fat variable was not included in the creation of the MDEΔ score, it may be failing to account for an important health-effecting component of meat. Given the uncertainty on whether the meat itself (Dominguez et al. 2017; Mozaffarian 2016) or the saturated fat in meat (Sacks et al. 2017) is a greater risk factor for disease, it might be important for future studies to look at the effect of changes in saturated fat in addition to changes in meat consumption.

Fourth, issues of limited power and multicollinearity need to be considered when interpreting the null or attenuated coefficients in Model II. Multicollinearity resulting from two correlated food variables being added to together to the model, along with a highly correlated interaction term for those variables, can lead to an increase in standard errors and loss of stability in the coefficients (Willett 2013). To assess the potential impact of this issue, a post-hoc assessment of the variance inflation factors (VIFs) for all of the covariates, including interaction terms, in the each of the Model II regression analyses was performed. Most VIFs were below 10, which suggests that multicollinearity was not a huge concern in most cases. Nonetheless, this issue, particularly when dealing with a relatively small sample size, may be at least partly responsible for the attenuated coefficients for the relationship between MDEΔ score and total and LDL cholesterol and/or other null coefficients or unexpected interactions in Model II. Issues of collinearity also make it difficult to reliably distinguish between the effects of MDE restriction and concurrent increases in plant-based foods.

Finally, it must be acknowledged that any changes in meal timing, meal frequency, and/or eating windows, may influence weight, blood lipids, and glucose and insulin metabolism independent of changes in food and nutrient composition (St-Onge et al. 2017). Given the nature of the dietary restrictions encouraged by the OC church during Lent being part of a larger spiritual practice aimed at harnessing willpower and practicing self-discipline, many devout adherents might also reduce their number of meals or snacks and/or experience longer bouts between meals. As those inclined to be stricter about omitting MDE products during Lent are also likely more inclined to be more mindful about consumption patterns and disciplined in other aspects during Lent, this could be a major source of confounding in this study. Such confounding may artificially inflate the association between MDE reduction and drops in total and LDL cholesterol. Shifts in meal timing and periods of complete fasting could also help explain why there were not more apparent interactions between MDE foods and plant-based foods.

Apart from these study limitations, it is also important to consider that, even had there been no variation or error in the measurement of health biomarkers or dietary intake, there could still be other unmeasured biological and lifestyle factors that could contribute to variation in how an individual may respond to a given shift in diet. For example, carriers of the apolipoprotein (apo) E4 allele, may be more responsive than those with only apoE2 or apoE3 alleles to the reductions in dietary fat (Lopez-Miranda et al. 1994; Sarkkinen et al. 1998) and increases in soy products (Gaddi et al. 1991) observed in this study population during Lent (See Chapter 2). Additionally, differences in the gut microbiota have been linked to between-person variation in glycemic responses to a given food or meal (Zeevi et al.). Early childhood environments could further shape a person's metabolic responses to foods and susceptibility to altered cholesterol, glucose, and insulin levels (Wadhwa et al. 2009) (Victora et al. 2008). Variations in sleep quality and duration (Mullington et al. 2009; Spiegel et al. 2009) and psychosocial stress (Anagnostis et al. 2009; Rosmond et al. 1998) could also influence metabolic processes. Yet even had this study measured these sources of variation, it would not have had enough power to test so many interactions simultaneously.

Overall, this study contributes to the limited body of literature on the health effects of Lenten dietary restrictions practiced by OCs around the world, presents the first quantitative data on shifts in health biomarkers among a US-based OC population, and performs one of the most comprehensive set of analyses of the relationships between dietary and health biomarker shifts. It is one of the few studies to attempt to explore how the health effects of changing consumption of one group of foods may depend on corresponding changes in consumption of a different group of food. Though this was an observational study that lacked a clear control group, the varying degrees of MDE product reduction in this study sample offered a unique opportunity to capture the kind of variation that exists within the general OC population and allowed for the exploration of a dose-response relationship. Together with the comparable findings in previous studies of other OC populations, this study provides support for the notion that OC dietary restrictions on MDE products may provide some health benefit, but the benefits may be limited and may not be universal across all individuals adhering to this practice.

CONCLUSIONS

These data demonstrate how complex the study of diet-disease relationships is and how variable dietary regimens and physiological responses to a given diet can be in free-living populations. This study suggests that the reductions in MDE products made by OCs in the US during their period of Lent can lead to modest reductions in total and LDL cholesterol that are comparable to blood lipid shifts observed in other non-US OC populations. The short-term Lenten restrictions on MDE products did not, however, appear to lead to significant changes in weight, glucose metabolism, or inflammation in this US OC study sample. This study also provided no reliable evidence that concurrent shifts in calories, fish, or any single plant-based food modified the relationship between MDE reductions and the modest changes in health biomarkers.

Limited change in any single food group and lack of statistical power may have prevented identification of effect modification. Hence, similarly-designed studies of MDE fasting with substantially larger sample sizes and, perhaps, the use of composite scores for “healthy” and “unhealthy” plant-based foods are needed to more reliably assess if and how the effects of MDE restriction on markers of cardiometabolic health may be modified by concurrent shifts in qualitatively and nutritionally different non-MDE foods. The finding that reductions in dairy consumption are the largest contributors to the blood lipid shifts observed in this study population also warrants further investigation. Finally, though this study provides valuable information on which short-term changes in cardiometabolic health markers might be expected from the MDE fast practiced by OCs in the US, further research is needed to investigate the potential long-term health effects of intermittent MDE fasts as practiced by OCs throughout the year.

CHAPTER 3 TABLES

Table 3.1. Baseline demographic, lifestyle, and dietary characteristics of study participants by MDEΔ tertiles (n=99).

	Entire Sample (n=99)	Tertile 1 (n=33) (Mean MDEΔ Score: -0.3)	Tertile 2 (n=33) (Mean MDEΔ Score: -1.8)	Tertile 3 (n=33) (Mean MDEΔ Score: -3.1)
	Mean (range)	Mean (range)	Mean (range)	Mean (range)
Age (years)	46.7 (19.1-73.2)	48.1 (26.2-73.2)	45.5 (19.1-67.8)	46.6 (24.2-67.6)
Average weekly MET hours[a]	20.1 (0-128.4)	22.7 (1.1-128.4)	16.7 (0-54)	20.7 (1.2-52.3)
Average change in weekly MET hours[a]	-2.8 (-57.5-30.5)	-2.2 (-50-18.2)	-3.3 (-57.5-29.8)	-2.8 (-47-30.5)
	%	%	%	%
% Male	42.4%	39.4%	39.4%	48.5%
% Self-reported race as "White or Caucasian"	93.9%	97.0%	90.9%	93.9%
% Annual income ≥ $100,000[b]	44.7%	40.6%	46.9%	46.7%
% 4-year college degree or higher	91.8%	97.0%	87.9%	90.6%
% Orthodox Christian	96.0%	87.9% [2,3]	100.0% [1]	100.0% [1]
% Convert	76.8%	69.0%	87.9%	72.7%
% Self-rated health "Good" to "Excellent"	89.9%	90.9%	87.9%	90.9%
% Reporting mostly sedentary occupations	52.5%	57.6%	54.5%	45.5%
% Current Smokers	8.1%	9.1%	3.0%	12.1%
% Consuming >7 alcohol drinks/week	24.2%	24.2%	18.2%	30.3%
% Taking medications for dyslipidemia	6.1%	6.1%	3.0%	9.1%
% Taking medications for hypertension	10.1%	15.2%	3.0%	12.1%
% Taking medications for diabetes	3.0%	3.0%	3.0%	3.0%
% Regularly taking anti-inflammatory medications	10.1%	18.2% [2]	0.0% [1,3]	12.1% [2]
% Vegan, Vegetarian, or Pesco-Vegetarian	5.1%	9.1%	6.1%	0.0%
% Consuming 1+ serving meat/2,000 kcal	67.7%	51.5% [3]	60.6% [3]	90.9% [1,2]
% Consuming 1+ serving dairy/2,000 kcal	52.5%	51.5%	42.4%	63.6%
% Consuming 1+ egg/2,000 kcal	20.2%	12.1% [3]	12.1% [3]	36.4% [1,2]

[a] Metabolic equivalent values for moderate to vigorous physical activities; [b] Estimated from the 32 in tertile 1, 32 in tertile 2, and 30 in tertile 3 who responded to the question on household income; [1] Significantly different proportion in Tertile 1 at alpha level of 0.05; [2] Significantly different proportion in Tertile 2 at alpha level of 0.05; [3] Significantly different proportion in Tertile 3 at alpha level of 0.05

Table 3.2. Baseline health measures and proportions of participants with suboptimal biomarker levels by MDEΔ tertiles.

		Entire Sample (n=99)	Tertile 1 (n=33)	Tertile 2 (n=33)	Tertile 3 (n=33)
BMI (kg/m^2)	Mean (range)	27.3 (18.1 to 43.8)	28.3 (19.7 to 42.3)	27.3 (18.7 to 43.8)	26.4 (18.1 to 40.9)
	% above optimal (≥ 25 m/kg^2)	65.7%	69.7%	63.6%	63.6%
Body Fat Percentage[a]	Mean (range)	34.0 (7.2 to 56.7)	35.5 (16.7 to 56.7)	34.6 (14.6 to 55.2)	32.0 (7.2 to 46.1)
	% above optimal (age and sex-specific)	70.1%	66.7%	75.0%	68.8%
Total Cholesterol (mg/dL)	Mean (range)	184.1 (103.0 to 275.0)	183.5 (114.0 to 275.0)	184.4 (103.0 to 247.0)	184.5 (128.0 to 251.0)
	% above optimal (≥ 200 mg/dL)	28.3%	30.3%	30.3%	24.2%
LDL-Cholesterol (mg/dL)[b]	Mean (range)	109.0 (49.0 to 189.8)	110.7 (53.2 to 189.8)	106.3 (49.0 to 159.2)	110.1 (55.6 to 179.0)
	% above optimal (≥ 100 mg/dL)	58.2%	59.4%	60.6%	54.5%
HDL-Cholesterol (mg/dL)	Mean (range)	55.3 (18.0 to 98.0)	53.5 (28.0 to 84.0)	57.1 (18.0 to 98.0)	55.4 (20.0 to 84.0)
	% below optimal [≤ 40 (men) or ≤ 50 (women)]	23.5%	25.0%	27.3%	18.2%
Triglycerides (mg/dL)	Mean (range)	99.2 (45.0 to 271.0)	97.7 (45.0 to 271.0)	104.5 (45.0 to 261.0)	95.4 (45.0 to 253.0)
	% above optimal (≥ 100 mg/dL)	35.4%	36.4%	42.4%	27.3%
TC:HDL	Mean (range)	3.7 (2.0 to 9.4)	3.7 (2.1 to 6.8)	3.6 (2.0 to 7.5)	3.8 (2.0 to 9.4)
	% above optimal (≥ 4.5)	19.2%	24.2%	18.2%	15.2%
Glucose (mg/dL)	Mean (range)	94.3 (68.0 to 166.0)	93.5 (68.0 to 116.0)	94.2 (80.0 to 166.0)	95.2 (68.0 to 156.0)
	% above optimal (≥ 100 mg/dL)	29.3%	36.4%	24.2%	27.3%
Insulin (µU/mL)[c]	Mean (range)	10.0 (1.6 to 99.3)	8.4 (2.8 to 26.2)	13.3 (1.6 to 99.3)	8.4 (2.1 to 24.9)
	% above optimal (≥ 12 µU/mL)	18.1%	10.7%	18.5%	25.0%
HOMA-IR[c]	Mean (range)	2.5 (0.3 to 27.5)	2.0 (0.5 to 7.5)	3.5 (0.3 to 27.5)	2.1 (0.4 to 7.1)
	% above optimal (≥ 2.5)	24.1%	25.0%	22.2%	25.0%
C-reactive protein (mg/L)[d]	Mean (range)	1.4 (0.1 to 4.9)	1.5 (0.1 to 4.9)	1.3 (0.1 to 4.2)	1.5 (0.1 to 4.9)
	% above optimal (≥ 3 mg/dL)	10.1%	15.4%	10.3%	7.4%

[a] Excluding one individual in Tertile 2 and one individual in Tertile 3 with missing body fat measurements at one or more time points.

[b] Excluding one individuals in Tertile 2 with unreliable LDL measurement due to high triglycerides at time 2.

[c] Excluding five individuals in Tertile 1, six individuals in Tertile 2, and five individuals in Tertile 3 with missing insulin measures at one or both time points

[d] Excluding seven individuals in Tertile 1, four individuals in Tertile 2, and six individuals in Tertile 3 with missing CRP measures or inconsistent use of anti-inflammatory medication

HOMA-IR=Homeostatic Model Assessment of Insulin Resistance: [Glucose(mg/dL) x Insulin (µU/mL)/405].

To convert mg/dL to mmol/L, multiple total, LDL, or HDL cholesterol by 0.0259, triglycerides by 0.0113, and glucose by 0.056.

Table 3.3. Baseline health biomarkers in relation to baseline demographics, diet, and activity levels (n=99). [a]

	MDE1 Score	Baseline Calories (500 kcal)	Age (years)	Female	Average MET Hours	Baseline BMI
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
BMI	1.1 ± 0.5*	-0.2 ± 0.4	0.1 ± 0.04*	-0.4 ± 1.2	-0.03 ± 0.03	
Body Fat Percentage [b]	1.6 ± 0.8*	-1.0 ± 0.6	0.1 ± 0.06	12.5 ± 1.7*	-0.04 ± 0.04	
Total Cholesterol	-1.3 ± 2.6	0.0 ± 2.5	0.6 ± 0.2*	6.3 ± 6.4	0.2 ± 0.1	1.2 ± 0.5*
LDL-Cholesterol [c]	-1.0 ± 2.5	-0.134 ± 2.4	0.5 ± 0.2*	-6.1 ± 5.9	0.2 ± 0.2	1.5 ± 0.5*
HDL-Cholesterol	0.3 ± 1.1	0.4 ± 0.9	0.1 ± 0.1	17.5 ± 2.7*	0.1 ± 0.07	-1.2 ± 0.3*
Triglycerides	-4.7 ± 4.7	-2.2 ± 4.8	0.1 ± 0.4	-31.5 ± 11.7*	-0.1 ± 0.2	5.3 ± 1.3*
Glucose	-0.3 ± 1.2	-0.7 ± 1.3	0.2 ± 0.09*	-9.2 ± 3.2*	0.05 ± 0.06	0.8 ± 0.2*
Insulin [d]	-0.4 ± 1.1	0.5 ± 1.2	0.05 ± 0.09	-5.5 ± 2.3*	-0.1 ± 0.09	0.9 ± 0.2*
HOMA-IR [d]	-0.1 ± 0.3	0.1 ± 0.4	0.02 ± 0.03	-1.8 ± 0.7*	-0.02 ± 0.02	0.2 ± 0.1*
C-reactive protein [e]	0.147 ± 0.1	-0.1 ± 0.1	0.002 ± 0.01	0.3 ± 0.2	0.001 ± 0.004	0.1 ± 0.02*

[a] Regression results when regressing each baseline biomarker by MDE1 score, baseline calories, age, sex, average MET hours, and baseline BMI together.

[b] Excluding two individuals with missing body fat measurements.

[c] Excluding one individual without reliable LDL measure due to triglycerides>400 mg/dL at time 2.

[d] Excluding 16 individuals with missing insulin measures at one or both time points.

[e] Excluding 17 individuals with missing CRP measures or inconsistent use of anti-inflammatory medication.

* Significant at α-level of 0.05.

Table 3.4. Baseline consumption of major animal- and plant-based foods (standardized to 2000 kcal/day) by MDEΔ tertiles.

	Tertile 1 (n=33)	Tertile 2 (n=33)	Tertile 3 (n=33)
	Mean MDEΔ = -0.3 (1.9 to -1.3)	Mean MDEΔ = -1.8 (-1.3 to -2.1)	Mean MDEΔ = -3.1 (-2.2 to -4.9)
	Mean (5th-95th%)	Mean (5th-95th%)	Mean (5th-95th%)
Calories	2173 (1223-4170)	2180 (945-3733)	2028 (1173-3212)
Animal-Based Foods	**Mean (5th-95th%)**	**Mean (5th-95th%)**	**Mean (5th-95th%)**
All Meat (oz)	3.7 (0.2-8.1)	3.6 (0.3-7.6)[3]	5.1 (2.3-9.7)[2]
Red Meat (oz)	1.9 (0.1-4.7)	1.9 (2-6.0)	2.6 (0.6-7.7)
Poultry (oz)	1.3 (0.0-4.7)	1.2 (2-2.7)	1.6 (0.5-3.4)
Processed Meat (oz)	0.5 (2-2.1)	0.5 (2-1.4)	0.8 (2-2.0)
Fish & Shellfish (oz)	0.9 (0.0-2.7)	0.8 (2-2.2)	1.0 (2-2.1)
Eggs (oz eq)	0.5 (0.0-1.5)[3]	0.6 (2-1.6)[3]	1.0 (2-4.0)[1,2]
All Dairy (cup eq)	1.2 (0.2-2.4)	1.0 (0.5-1.6)	1.3 (0.4-2.5)
Milk (cup eq)	0.5 (0.0-2.0)	0.4 (2-0.6)	0.6 (0.1-1.4)
Yogurt (cup eq)	0.2 (2-0.9)	0.1 (2-0.5)	0.2 (2-0.8)
Cheese (cup eq)	0.5 (0.0-1.1)	0.5 (2-0.9)	0.6 (0.2-1.2)
Plant-Based Foods	**Mean (5th-95th%)**	**Mean (5th-95th%)**	**Mean (5th-95th%)**
Whole Grain (oz eq)	1.4 (0.1-3.2)	1.9 (0.3-5.6)	1.3 (0.0-3.4)
Refined Grain (oz eq)	3.6 (0.7-6.9)	4.3 (1.9-6.8)	3.4 (1.0-6.4)
Legumes (cup eq)	0.1 (2-0.5)	0.2 (2-0.3)	0.1 (2-0.5)
Soy Products (oz eq)	0.3 (2-1.7)	0.3 (2-1.1)	0.2 (2-0.6)
Nuts & Seeds (oz eq)	1.9 (2-0.7)[3]	1.3 (2-1.1)	0.9 (2-0.5)[1]
Fruit (cup eq) [a]	1.2 (2-4.9)	0.8 (0.2-4.6)	0.7 (2-2.1)
Vegetables (cup eq) [b]	2.0 (0.1-3.7)	1.7 (0.2-1.6)	2.1 (2-2.0)
White Potatoes (cup eq)	0.4 (0.7-4.3)	0.4 (0.3-3.9)	0.4 (0.8-5.9)
Discretionary Oil (g)	30.5 (0.0-0.9)	29.0 (2-1.1)	27.2 (0.1-0.7)
Added Sugar (g)	55.3 (14.9-44.1)	52.5 (2-43.0)	44.9 (14.2-46.4)

MDEΔ represents the number of meat, dairy, and egg servings given up during Lent.

[a] Excluding fruit juice

[b] Excluding white potatoes

[1] Significantly different than mean in Tertile 1 at α-level of 0.017

[2] Significantly different than mean in Tertile 2 at α-level of 0.017

[3] Significantly different than mean in Tertile 3 at α-level of 0.017

Table 3.5. Model I. Multiple linear regression analysis results for relationship between percent change in biomarkers and MDEΔ score (n=99). [a]

	β ± SE	(95% CI)	p-value	Adj-R^2
BMI	-0.4% ± 0.3%	(-0.9% to 0.2%)	0.17	0.15
Body Fat Percentage [b]	-0.4% ± 0.8%	(-2.1% to 1.3%)	0.62	0.06
Total Cholesterol	-3.5% ± 0.9%	(-5.2% to -1.8%)	<0.0001*	0.33
LDL-Cholesterol [c]	-3.4% ± 1.1%	(-5.6% to -1.2%)	0.003*	0.28
HDL-Cholesterol	-2.7% ± 1.4%	(-5.4% to 0.0%)	0.05	0.15
Triglycerides	-5.1% ± 4.2%	(-13.4% to 3.2%)	0.22	0.14
Glucose	-3.5% ± 1.1%	(-3.3% to 1.2%)	0.35	0.28
Insulin[d]	-1.1% ± 1.1%	(-14.8% to 3.1%)	0.20	0.12
HOMA-IR [d]	-5.8% ± 4.5%	(-22.5% to 3.1%)	0.14	0.09
C-reactive protein [e]	-9.7% ± 6.4%	(-17.4% to 21.3%)	0.84	0.22

[a] Controlling for baseline biomarker value, baseline MDE score, baseline calories, change in calories, age, sex, baseline BMI, average METs, change in METs, and number of days on restricted diet before biomarker collection.

[b] Excluding two individuals with missing body fat measurements.

[c] Excluding one individual without reliable LDL measure due to triglycerides>400 mg/dL at time 2.

[d] Excluding 16 individuals with missing insulin measures at one or both time points.

[e] Excluding 17 individuals with missing CRP measures or inconsistent use of anti-inflammatory medication.

* Significant at a Bonferroni-adjusted α-level of 0.005.

HOMA-IR=Homeostatic Model Assessment of Insulin Resistance: [Glucose (mg/dL) x Insulin (uU/mL)/405].

Table 3.6. Change in biomarkers across MDEΔ tertiles.

	Tertile 1 (n=33) Mean MDEΔ = -0.3 (1.9 to -1.3)	**Tertile 2 (n=33)** Mean MDEΔ = -1.8 (-1.3 to -2.1)	**Tertile 3 (n=33)** Mean MDEΔ = -3.1 (-2.2 to -4.9)
	Mean (Min-Max)	**Mean (Min-Max)**	**Mean (Min-Max)**
BMI (% change)	-0.3% (-5.4% to 5.8%)	-1.4% (-6.1% to 3.7%)	-1.7% (-6.1% to 3.4%)
(Additive Change, kg/m^2)	*-0.05 (-1.1 to 1.4)*	*-0.4 (-2.1 to 0.9)*	*-0.4 (-1.7 to 0.8)*
% with ≥5% decrease / increase	3.0% / 3.0%	15.2% / 0%	9.1% / 0%
Body Fat Percentage [a] (% change)	-1.5% (-17.1% to 11.0%)	-3.4% (-20.9% to 8.0%)	-3.7% (-29.8% to 41.5%)
(Additive Change, mg/dL)	*-0.4 (-4.1 to 3.9)*	*-1.2 (-8.3 to 2.8)*	*-1.3 (-7.9 to 7.6)*
% with ≥5% decrease / increase	18.2% / 9.1%	31.3% / 9.4%	50.0% / 6.3%
Total Cholesterol (% change)	-0.3% (-31.7% to 20.9%)	-9.0% (-32.0% to 15.1%)	-12.1% (-27.7% to 21.1%)
(Additive Change, mg/dL)	*-1.7 (-51.0 to 33.0)*	*-17.8 (-73.0 to 31.0)*	*-23.4 (-56.0 to 27.0)*
% with ≥12% decrease / increase	12.1% / 18.2%	45.5% / 3.0%	54.5% / 6.1%
LDL Cholesterol [b] (% change)	-1.1% (-41.9% to 34.2%)	-10.3% (-38.0% to 23.8%)	-13.2% (-43.2% to 18.6%)
(Additive Change, mg/dL)	*-3.2 (-39.0 to 23.2)*	*-11.9 (-48.2 to 25.2)*	*-16.6 (-63.4 to 13.6)*
% with ≥12% decrease / increase	18.8% / 21.9%	45.5% / 6.1%	54.5% / 3.0%
HDL-Cholesterol (% change)	0.8% (-23.6% to 35.0%)	-5.0% (-26.7% to 38.5%)	-8.0% (-35.0% to 80.0%)
(Additive Change, mg/dL)	*0.4 (-13.0 to 21.0)*	*-3.8 (-19.0 to 15.0)*	*-6.5 (-21.0 to 22.0)*
% with ≥12% decrease / increase	18.2% / 18.2%	36.4% / 9.1%	60.6% / 12.1%
Triglycerides (% change)	13.5% (-43.8% to 104.7%)	-0.2% (-55.0% to 97.9%)	6.6% (-60.4% to 175.0%)
(Additive Change, mg/dL)	*10.2 (-109.0 to 225.0)*	*-10.6 (-133.0 to 67.0)*	*-1.7 (-99.0 to 91.0)*
% with ≥25% decrease / increase	15.2% / 27.3%	18.2% / 15.2%	9.1% / 24.2%
TC:HDL Ratio (% change)	0.03% (-22.0% to 26.4%)	-3.1% (-27.8% to 34.1%)	-0.8% (-56.9% to 35.3%)
(Additive Change)	*-0.03 (-1.4 to 1.2)*	*-0.1 (-1.3 to 1.3)*	*-0.3 (-5.3 to 0.9)*
% with ≥12% decrease / increase	15.2% / 18.2%	24.2% / 9.1%	15.2% / 18.2%
Glucose (% change)	3.7% (-13.9% to 44.1%)	-1.1% (-53.0% to 14.8%)	1.4% (-12.4% to 30.9%)
(Additive Change, mg/dL)	*3.1 (-14.0 to 30.0)*	*-2.5 (-88.0 to 13.0)*	*0.8 (-15.0 to 22.0)*
% with ≥10% decrease / increase	6.1% / 18.2%	6.1% / 12.1%	6.1% / 12.1%
Insulin [c] (% change)	9.1% (-43.9% to 186.1%)	-11.1% (-90.8% to 65.5%)	4.0% (-59.6% to 152.4%)
(Additive Change, µU/mL)	*0.3 (-5.0 to 6.7)*	*-5.3 (-90.2 to 1.9)*	*-0.6 (-13.4 to 7.5)*
% with ≥25% decrease / increase	25.0% / 21.4%	37.0% / 11.1%	17.9% / 25.0%
HOMA-IR [c] (% change)	16.6% (-44.4% to 236.0%)	-10.1% (-91.7% to 81.9%)	9.0% (-64.6% to 230.3%)
(Additive Change)	*0.2 (-1.3 to 3.0)*	*-1.6 (-25.2 to 0.5)*	*-0.1 (-3.4 to 3.2)*
% with ≥25% decrease / increase	25.0% / 21.4%	37.0% / 18.5%	21.4% / 28.6%
C-reactive protein [d] (% change)	29.4% (-74.2% to 365.2%)	28.8% (-64.6% to 304.7%)	27.0% (-85.4% to 475.3%)
(Additive Change, mg/L)	*0.2 (-2.5 to 1.9)*	*-0.1 (-1.7 to 1.1)*	*-0.003 (-2.1 to 1.4)*
% with ≥50% decrease / increase	11.5% / 15.4%	10.3% / 24.1%	11.1% / 18.5%

[a] Excluding one individual in Tertile 2 and one individual in Tertile 3 with missing body fat measurements at one or more time points.

[b] Excluding one individuals in Tertile 2 with unreliable LDL measurement due to high triglycerides at time 2.

[c] Excluding four individuals in Tertile 1, six individuals in Tertile 2, and six individuals in Tertile 3 with missing insulin measures at one or both time points

[d] Excluding six individuals in Tertile 1, five individuals in Tertile 2, and six individuals in Tertile 3 with missing CRP measures or inconsistent use of anti-inflammatory medication.

Table 3.7. Model IB. Multiple linear regression analysis results for relationship between percent change in total and LDL cholesterol and MDEΔ score controlling for BMI (n=99). [a]

Total Cholesterol	**β ± SE**	**(95% CI)**	**p-value**	**Adj-R^2**
1 Serving MDE Reduction	-3.0% ± 0.8%	(-4.6% to -1.4%)	0.0003	0.39
Weight change (lb)	-0.6% ± 0.2%	(-1.1% to -0.2%)	0.006	
LDL Cholesterol[b]	**β ± SE**	**(95% CI)**	**p-value**	**Adj-R^2**
1 Serving MDE Reduction	-2.8% ± 1.2%	(-5.3% to -0.4%)	0.02	0.32
Weight change (lb)	-0.7% ± 0.3%	(-1.4% to -0.1%)	0.03	

[a] In addition to controlling for weight change, also adjusting for baseline biomarker value, baseline MDE score, baseline calories, change in calories, age, sex, baseline BMI, average METs, change in METs, and number of days on restricted diet before biomarker collection.

[b] Excluding 1 individual without reliable LDL measure due to triglycerides>400 mg/dL at time 2.

Table 3.8. Model II. Multiple linear regression analysis results for relationship between percent change in total and LDL cholesterol and MDEΔ score testing for interactions. [a]

	Total Cholesterol (n=99)		LDL Cholesterol (n=98)	
	β (95% CI)	p-value[b]	β (95% CI)	p-value[b]
MDEΔ Score (1 serving reduction)	-3.5% (-5.5% to -1.4%)	0.001	-3.3% (-6.2% to -0.5%)	0.02
Kilocalories (100 kcal decrease)	-0.2% (-1.1% to 0.7%)	0.70	-0.3% (-1.5% to 0.9%)	0.60
Interaction	0.12% (-0.2% to 0.4%)	0.45	0.12% (-0.3% to 0.5%)	0.54
MDEΔ Score (1 serving reduction)	-3.1% (-4.7% to -1.4%)	0.0004	-3.0% (-5.7% to -0.3%)	0.03
Fish (1 oz increase)	2.7% (-0.7% to 6.1%)	0.12	1.0% (-4.5% to 6.6%)	0.71
Interaction Term	-0.1% (-1.6% to 1.4%)	0.92	0.4% (-1.8% to 2.5%)	0.74
MDEΔ Score (1 serving reduction)	-3.0% (-4.8% to -1.2%)	0.002	-2.7% (-5.2% to -0.3%)	0.03
Whole Grain (1 oz eq increase)	0.3% (-2.9% to 3.4%)	0.86	0.5% (-3.8% to 4.8%)	0.83
Interaction Term	0.23% (-1.0% to 1.4%)	0.71	0.4% (-1.3% to 2.1%)	0.65
MDEΔ Score (1 serving reduction)	-2.9% (-4.6% to -1.3%)	0.0005	-3.6% (-6.1% to -1.1%)	0.01
Refined Grain (1 oz eq increase)	-0.8% (-3.9% to 2.2%)	0.58	-2.1% (-6.9% to 2.7%)	0.38
Interaction Term	0.2% (-1.1% to 1.5%)	0.76	1.3% (-0.7% to 3.2%)	0.20
MDEΔ Score (1 serving reduction)	-2.2% (-4.1% to -0.3%)	0.02	-2.5% (-5.2% to 0.3%)	0.08
Legumes (1 cup eq increase)	-6.2% (-25.7% to 13.3%)	0.53	-23.7% (-53.1% to 5.7%)	0.11
Interaction Term	0.2% (-5.5% to 5.8%)	0.95	7.1% (-1.4% to 15.6%)	0.10
MDEΔ Score (1 serving reduction)	-2.3% (-4.0% to -0.7%)	0.006	-2.0% (-4.9% to 0.9%)	0.17
Meat Alternatives (1 oz eq increase)	0.9% (-6.2% to 8.0%)	0.80	-0.7% (-13.8% to 12.4%)	0.91
Interaction Term	-1.5% (-4.3% to 1.2%)	0.27	-1.3% (-6.3% to 3.7%)	0.61
MDEΔ Score (1 serving reduction)	-2.9% (-4.7% to -1.0%)	0.002	-2.5% (-5.1% to 0.0%)	0.05
Nuts & Seeds (1 oz eq increase)	0.3% (-2.0% to 2.6%)	0.80	-1.2% (-5.1% to 2.7%)	0.54
Interaction Term	-0.2% (-1.0% to 0.7%)	0.69	0.3% (-1.1% to 1.8%)	0.65
MDEΔ Score (1 serving reduction)	-2.8% (-4.8% to -0.9%)	0.006	-3.2% (-5.8% to -0.6%)	0.01
Fruit & Vegetables (1 cup eq increase)	-0.9% (-2.9% to 1.2%)	0.39	-2.5% (-5.2% to 0.1%)	0.06
Interaction Term	0.2% (-0.7% to 1.0%)	0.71	0.9% (0.0% to 1.9%)	0.06
MDEΔ Score (1 serving reduction)	-2.4% (-4.2% to -0.5%)	0.01	-2.1% (-4.7% to 0.5%)	0.11
Oil (10 gram increase)	-0.8% (-3.7% to 2.1%)	0.59	-3.7% (-8.5% to 1.2%)	0.14
Interaction Term	-0.3% (-1.4% to 0.8%)	0.59	0.6% (-1.3% to 2.5%)	0.52
MDEΔ Score (1 serving reduction)	-2.8% (-4.5% to -1.1%)	0.001	-2.5% (-5.1% to 0.1%)	0.06
Added Sugar (10 gram increase)	-0.4% (-1.9% to 1.1%)	0.55	-0.7% (-2.9% to 1.5%)	0.51
Interaction Term	-0.04% (-0.6% to 0.5%)	0.90	0.08% (-0.8% to 0.9%)	0.85

[a] Controlling for baseline biomarker value, baseline MDE score, baseline intake of non-MDE food being tested, baseline calories, change in calories, age, sex, baseline BMI, change in weight, average METs, change in METs, and number of days on restricted diet before biomarker collection.

[b] All p-values are unadjusted, but significance was determined at the Bonferroni-adjusted α-level of 0.0005.

Table 3.9. Model III. Multiple linear regression analysis results for relationship between percent change in total and LDL cholesterol and reductions in meat, dairy, and egg servings entered as separate variables (n=99). [a]

Total Cholesterol	**β ± SE**	**(95% CI)**	**p-value**	**Adj-R^2**
1 Serving Meat Reduction	-0.9% ± 1.7%	(-4.3% to 2.4%)	0.58	0.41
1 Serving Dairy Reduction	-5.7% ± 1.1%	(-7.9% to -3.6%)	<0.0001	
1 Serving Egg Reduction	1.8% ± 2.2%	(-2.5% to 6.2%)	0.41	
LDL Cholesterol [b]	**β ± SE**	**(95% CI)**	**p-value**	**Adj-R^2**
1 Serving Meat Reduction	0.1% ± 1.8%	(-3.5% to 3.8%)	0.94	0.36
1 Serving Dairy Reduction	-6.7% ± 1.6%	(-9.8% to -3.6%)	<0.0001	
1 Serving Egg Reduction	3.4% ± 3.3%	(-3.1% to 9.8%)	0.31	

1 serving meat = 2 oz processed meat or 3 oz unprocessed meat; 1 serving dairy = 1 cup equivalent milk, cheese, or yogurt; 1 serving eggs = 2 oz equivalent of eggs.

[a] Controlling for baseline biomarker value, baseline MDE score, baseline calories, change in calories, age, sex, baseline BMI, change in weight, average METs, change in METs, and number of days on restricted diet before biomarker collection.

[b] Excluding 1 individual without reliable LDL measure due to triglycerides>400 mg/dL at time 2.

Supplemental Table 3.1: Multiple linear regression analysis results for relationship between percent change in biomarkers and MDEΔ score among individuals not taking blood pressure, cholesterol, or diabetes medications (n=85). [a]

	β ± SE	(95% CI)	p-value	Adj-R^2
BMI	-0.4% ± 0.3%	(-1% to 0.2%)	0.24	0.10
Body Fat Percentage [b]	-0.2% ± 1.0%	(-2.1% to 1.8%)	0.87	0.07
Total Cholesterol	-3.8% ± 1.0%	(-5.7% to -1.9%)	0.0002*	0.33
LDL-Cholesterol [c]	-3.8% ± 1.2%	(-6.3% to -1.3%)	0.003*	0.27
HDL-Cholesterol	-3.0% ± 1.6%	(-6.2% to 0.3%)	0.08	0.14
Triglycerides	-6.4% ± 4.1%	(-14.5% to 1.8%)	0.12	0.28
Glucose	-3.7% ± 1.2%	(-2.8% to 1.5%)	0.54	0.27
Insulin [d]	-0.7% ± 1.1%	(-16.7% to 6.5%)	0.38	0.07
HOMA-IR [d]	-5.1% ± 5.8%	(-26% to 8%)	0.29	0.03
C-reactive protein [e]	-9.0% ± 8.5%	(-20.3% to 26.1%)	0.80	0.25

[a] Controlling for baseline biomarker value, baseline MDE score, baseline calories, change in calories, age, sex, baseline BMI, change in weight, average METs, change in METs, and number of days on restricted diet before biomarker collection.

[b] Excluding one individuals with missing body fat measurements.

[c] Excluding one individual without reliable LDL measure due to triglycerides>400 mg/dL at time 2.

[d] Excluding 15 individuals with missing insulin measures at one or both time points.

[e] Excluding 13 individuals with missing CRP measures or inconsistent use of anti-inflammatory medication.

Supplemental Table 3.2. Model II. Relationship between MDEΔ score and change in BMI and body fat, testing for interactions with caloric shifts. [a]

	BMI (n=99)		Body Fat Percentage (n=97)	
	β (95% CI)	p-value[b]	β (95% CI)	p-value[b]
MDEΔ Score (1 serving reduction)	-0.5% (-1.0% to 0.1%)	0.09	-0.7% (-2.6% to 1.2%)	0.46
Kilocalories (100 kcal decrease)	-0.2% (-0.4% to -0.03%)	0.02	-0.5% (-1.1% to 0.07%)	0.08
Interaction	0.02% (-0.05% to 0.10%)	0.54	0.07% (-0.12% to 0.26%)	0.46

Supplemental Table 3.3. Model II. Relationship between MDEΔ score and change in blood glucose, testing for interactions with caloric shifts. [c]

	Glucose (n=99)	
	β (95% CI)	p-value[b]
MDEΔ Score (1 serving reduction)	-2.7% (-5.3% to 0.0%)	0.05
Kilocalories (100 kcal decrease)	-0.8% (-1.6% to -0.1%)	0.03
Interaction	0.4% (0.1% to 0.8%)	0.01

[a] Controlling for baseline biomarker value, baseline MDE score, baseline calories, age, sex, average METs, change in METs, and number of days on restricted diet before biomarker collection.

[b] All p-values are unadjusted, but significance was determined at the Bonferroni-adjusted α-level of 0.0005.

[c] Controlling for baseline biomarker value, baseline MDE score, baseline calories, age, sex, baseline BMI, change in weight, average METs, change in METs, and number of days on restricted diet before biomarker collection.

CHAPTER 3 FIGURES

Figure 3.1. Proportion of individuals in optimal, suboptimal, and high risk health biomarker categories.

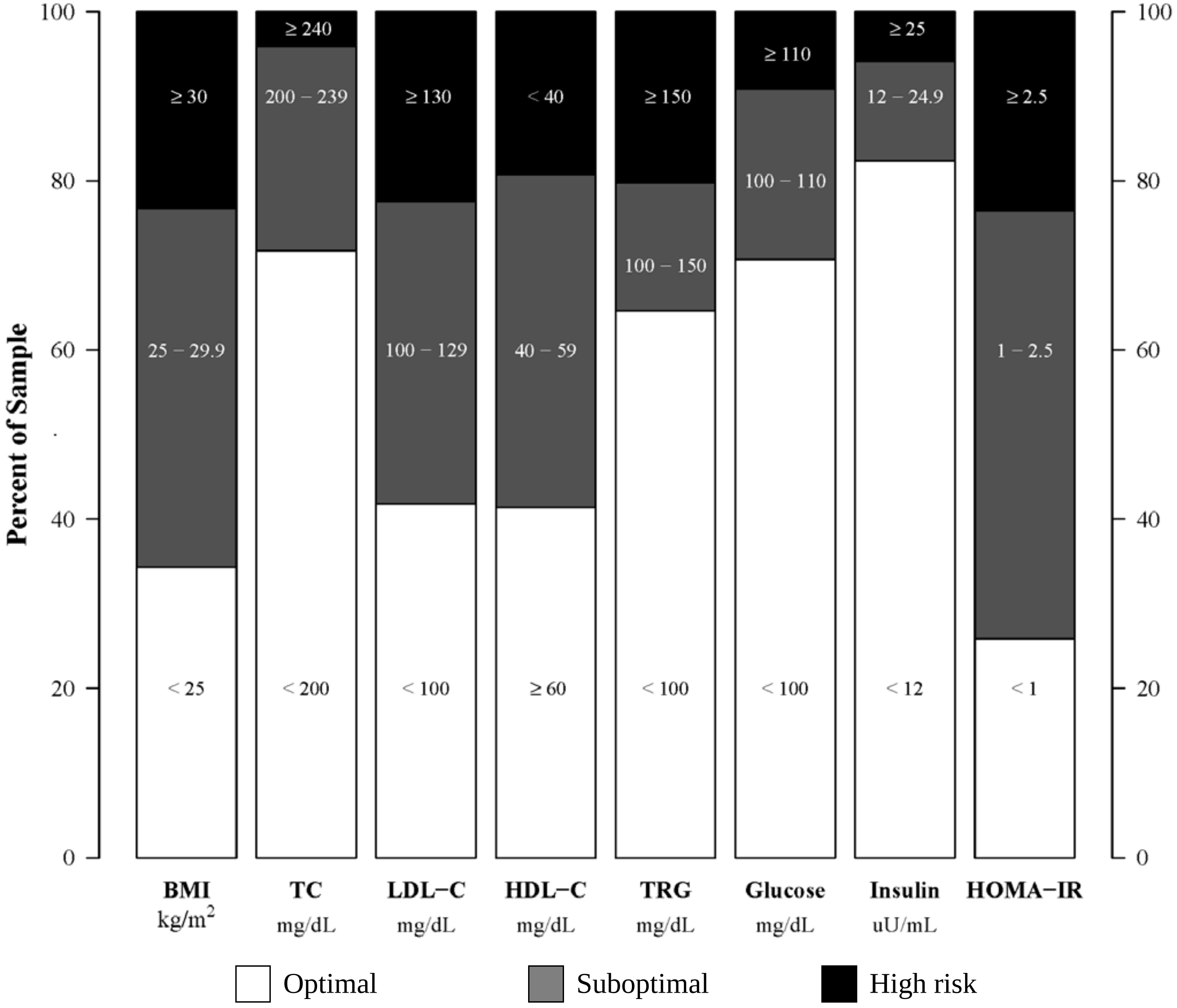
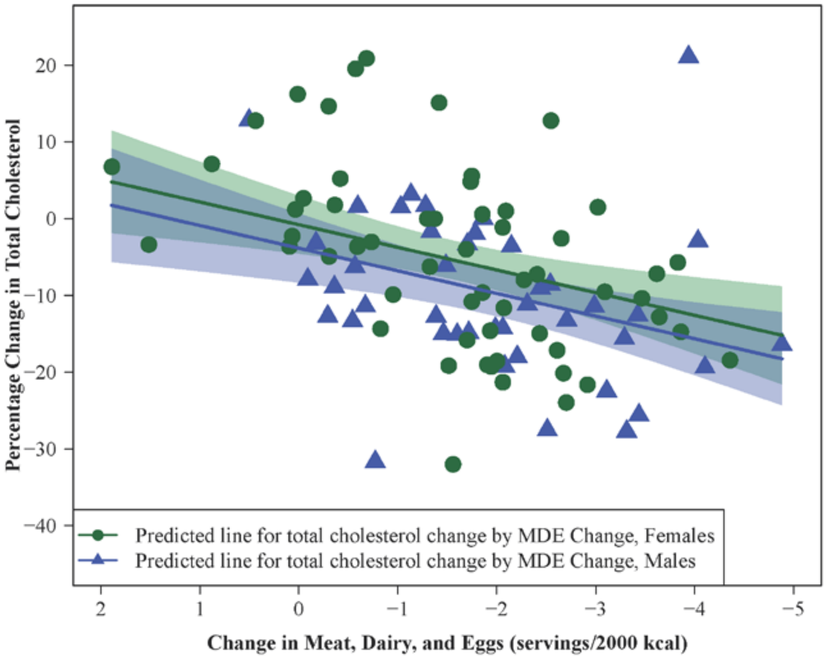
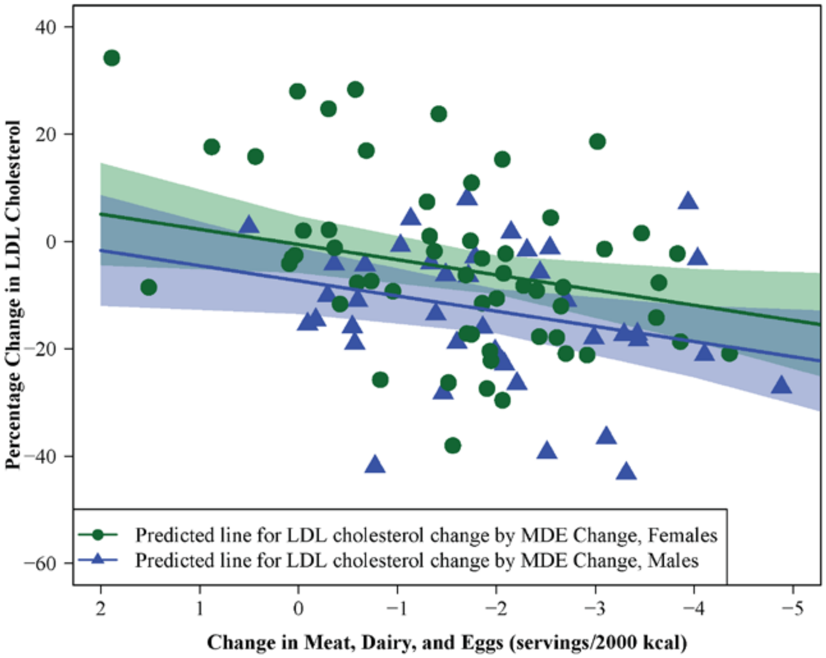


Figure 3.2. Predicted change in total and LDL cholesterol relative to MDEΔ score. [a]

Predicted change in total cholesterol (n=99)



Predicted change in LDL cholesterol (n=98)



[a] Controlling for baseline biomarker value, baseline MDE score, baseline calories, change in calories, age, sex, baseline BMI, change in weight, average METs, change in METs, and number of days on restricted diet before biomarker collection.

CHAPTER 4: A COMPARISON OF FOOD FREQUENCY QUESTIONNAIRE AND UNDOCUMENTED FOOD RECORD DATA FOR MEASURING DIETARY CHANGES AND ASSOCIATED CARDIOMETABOLIC HEALTH BIOMARKERS

CHAPTER 4 ABSTRACT

Food frequency questionnaires (FFQs) offer notoriously inaccurate and imprecise estimates of energy and nutrients compared with more detailed dietary intake instruments and available nutrient recovery biomarkers. The resultant measurement error has the potential to substantially attenuate diet-disease associations. Several studies have explored the degree to which use of the FFQ as the main dietary instrument can lead to weak and attenuated or even null effect sizes between dietary fat or fiber and specific cancers compared with stronger and statistically significant effect sizes for the relationship observed when using data from multiple day food records (FRs). No known studies have evaluated the performance of FRs relative to FFQs for estimating the dietary composition of individuals switching from an omnivorous to a more plant-based diet or for testing the relationship between dietary change and shifts in associated health biomarkers. This study examines the performance of a standard FFQ and a 7-day undocumented FR for measuring reductions in meat, dairy, and egg (MDE) products and relating those reductions to changes in measures of body fat, cholesterol, glucose metabolism and inflammation among a sample of 90 Orthodox Christians (OCs) and four non-OCs in the United States during the 48-day period of OC Lent. Though systematically biased in some cases, specific food measures are highly correlated across the two instruments. Both FFQ and FR data sources reveal similar reductions in MDE products across the Lenten period that are in turn associated with 1) increases in consumption of legumes, meat alternatives, nuts and seeds, and unsaturated discretionary oils and 2) significant decreases in total and LDL cholesterol. The FFQ data suggests that shifts in dairy are the dietary change most driving the association between MDE change and health markers; the FR data does not support this finding, however. In conclusion, when measuring relationships between shifts in MDE products and concurrent

dietary changes or testing associations between dietary changes and shifts in relevant health biomarkers, the methods perform quite similarly; contrary to expectations, this study did not find that the FR data consistently produced larger or more strongly significant effect sizes relative to those produced by the FFQ data.

INTRODUCTION

Unresolved debates regarding the role of meat and animal fat in cardiometabolic health have led to uncertainty about whether or not meat, dairy, and egg (MDE) products can or should be included in a health-promoting diet. Many meta-analyses attempt to measure the overall trend across studies but also highlight the variation in the direction, strength and precision of relationships between cardiometabolic health outcomes and unprocessed meats (Aune et al. 2009; Larsson and Orsini 2014; Micha et al. 2012; Micha et al. 2010; Pan et al. 2011), dairy (Aune et al. 2013a; Gijsbers et al. 2016; Guo et al. 2017), eggs (Rong et al. 2013; Shin et al. 2013), dairy fat (Pimpin et al. 2016), or total saturated fat (de Souza et al. 2015; Siri-Tarino et al. 2010). At the same time, similar variation exists across studies on the health effects of foods often assumed to be unquestionably beneficial for cardiometabolic health, such as whole grains (Aune et al. 2016b; Aune et al. 2013b; Hollænder et al. 2015), legumes (Afshin et al. 2014), nuts and seeds (Afshin et al. 2014; Aune et al. 2016a; Luo et al. 2014), and fruits and vegetables (Carter et al. 2010; Shin et al. 2015; Wang et al. 2014b). Residual confounding from dietary and lifestyle factors that tend to correlate with intake of animal products and plant-based foods may be one explanation for inconsistent study results.

A critically important source of variation in the effect size and precision of diet-disease relationships is the high degree of measurement error in common methods of assessing dietary intake in observational studies. Most population-based studies rely on retrospective food frequency questionnaires (FFQs) for estimating "usual" dietary patterns, as they are more affordable and less burdensome for both participants and researchers than the open-ended, more detailed multiple day food records (FRs) or 24-hour recalls. FFQs are, nonetheless, cognitively challenging to answer accurately, relying on generic rather than specific memory; and they capture a limited range of foods, necessitating assumptions about the nutritional content of each food category (Kristal et al. 2005; Kristal and Potter 2006; Thompson and Subar 2013). The consequential lack of precision in nutritional intake estimates from FFQs is thought to lead to attenuated or obscured diet-disease associations (Freedman et al. 2011). This may explain why one case-control study (Bingham et al. 2003) and another nested case-control study (Freedman et al. 2006) reported larger and statistically significant relative risk estimates when analyzing the relationship between breast cancer and fat using data from 4- to 7-day FRs but observed no significant associations when using FFQ-derived estimates of dietary fat. Similarly, a nested case-control study assessing the association between dietary fiber and colorectal cancer found significant inverse associations when estimating fiber intake from 4- to 7-day FRs but not when using FFQ estimates of fiber intake (Dahm et al. 2010). These instrument-dependent results have raised further concerns about the already questionable validity of FFQs for assessing diet-disease associations (Freedman et al. 2007; Kristal et al. 2005; Kristal and Potter 2006; Willett and Hu 2006; Willett and Hu 2007).

Measurement error from FFQ data may also obscure relationships between less frequently consumed foods and health markers or outcomes. This may especially be an issue when the study population is small and/or follows a dietary pattern that deviates from a typical omnivorous diet after which most FFQs are modeled. Many standard FFQs may not, for example, adequately capture the variety of whole and manufactured plant-based foods and meat- and dairy-substitutes potentially consumed by vegetarian or vegan populations in industrialized settings, and they generally do not account for the possibility of consuming vegan versions of mixed food items, such as pizza, lasagna, tacos, enchiladas, and desserts. This could lead to misclassification of the amount of MDE products a person consumes, as well as error in the measurement of the intake and nutritional contribution of less common oils (e.g., coconut or avocado), grain and legume products (e.g., quinoa, lentil pasta), nut products (e.g., nut-based cheeses), or other novel vegan food items. For these same reasons, standard FFQs may also be inadequate for measuring dietary change involving a shift from an omnivorous to a more plant-based diet, as is seen at different points of the year among Orthodox Christians (OCs) (Sarri et al. 2004), in dietary intervention studies (Wang et al. 2015; Yokoyama et al. 2014; Yokoyama et al. 2017), and in a growing vegetarian-inclined segment of the United States (US) and European populations (Janssen et al. 2016; Radnitz et al. 2015).

In response to some of the known limitations of standard FFQs, at least two research groups have attempted to design modified FFQs that incorporate a broader range of plant-based foods (Dyett et al. 2014; Jaceldo-Siegl et al. 2010). These modified FFQs have been validated against either 24-hour recalls (Jaceldo-Siegl et al. 2010) or FRs (Dyett et al. 2014) for measuring major macro and micronutrients among largely vegetarian or vegan populations in the US and Canada. These validation studies did not, however, assess whether the modified 204-item (Jaceldo-Siegl et al. 2010) or 369-item (Dyett et al. 2014) FFQs perform better than the less burdensome standard ~120/130- item FFQs when measuring the diet of vegetarian or vegan study samples. Nor did they evaluate the performance of the modified FFQs for estimating intake of major food groups or measuring dietary change. Moreover, as the instruments against which the modified FFQs were validated have their own errors and biases (Freedman et al. 2011; Kipnis et al. 2003; Prentice et al. 2011; Willett 2013), these validation studies offer no evidence that FFQs designed to capture vegetarian and vegan diets will perform better than other dietary instruments when attempting to test associations between plant-based diets and measures of health.

More precise and detailed alternatives to FFQs, such as documented FRs (i.e., where research staff meet with each participant to review their FR for thoroughness and possible omissions), can be prohibitively time-consuming, costly, and logistically challenging in observational studies. Recently, an undocumented FR, which does not require extensive staff support, was demonstrated to perform similarly to documented FRs when adequate instruction was provided (Kwan et al. 2010). This may offer a more feasible option than documented FRs for obtaining more precise and accurate measures of dietary intake. However, no previous studies have compared the performance of undocumented FRs to FFQs for measuring dietary change and/or testing associations between dietary change and shifts in health biomarkers. The goal of this paper, therefore, is to explore whether the measures of associations among concurrent dietary and health biomarker changes during a temporary MDE fast are different enough when using undocumented FR data relative to when using standard FFQ data to justify the additional burden and cost of the former.

This study draws from data on diet and biomarkers of cardiometabolic health that were collected among a sample of adults in the US before and during the OC period of Lent, the 48-day period prior to Easter during which the OC church encourages adherents to abstain from MDE products. Both FFQ and undocumented FR data were collected, from this sample. Previous analyses of the FFQ data collected for this study suggest that greater reductions in MDE products are associated with increased consumption of legumes, nuts and seeds, and discretionary oils but not necessarily with increased consumption of fruits and vegetables (See Chapter 2). Reductions in MDE products, as measured by the FFQ, were also associated with statistically significant decreases in measures of total and LDL-cholesterol (See Chapter 3). No significant changes in measures of body fat, glucose metabolism, or inflammation were observed when using the FFQ-derived data, and there was no evidence that concurrent shifts in calories or non-MDE foods significantly modified the association between MDE reductions and total or LDL cholesterol. This current study aims to reexamine these analyses previously conducted with FFQ-derived data, this time using data from undocumented 7-day FRs.

Specifically, this study aims to compare the performance of a standard retrospective FFQ relative to a detailed but undocumented FR for 1) describing the pre-Lenten and Lenten diets of individuals with varying degrees of adherence to the OC church guidelines on MDE product restriction; 2) quantifying trends in MDE product consumption across the Lenten MDE fast and concurrent changes in plant-based foods that occur in this population; and 3) detecting main and interactive associations among MDE restriction, concurrent dietary shifts, and alterations in measures of cardiometabolic health.

METHODS

Study sample population

Study volunteers were recruited through oral and written announcements at nine OC churches in three cities in the southern region of the US. As the study aimed to recruit individuals who were and were not intending to follow the OC Lenten dietary restrictions, non-OC individuals were also invited to join the study. Eligibility was limited to non-pregnant, non-lactating women and men between the ages of 18 and 75 who were born or raised in the United States or Canada, but no other exclusion criteria was in place.

At the end of a 5-month study recruitment period, 141 eligible adults signed up and consented to participate in the study, but only 120 initiated the study protocols. Of those who signed up and began taking part in the study protocols, 103 participants completed all three surveys and both FRs, FFQs, and health assessments. All study protocols were approved by the University of Washington's Human Subjects Division.

Study design and covariate measurement

This was a short prospective study that followed participants during a 5- to 6-week unrestricted dietary period prior to Lent and then through a subsequent 5-to 6-week period of dietary restrictions during Lent. Across the course of the study, participants were asked to complete three surveys to collect information about demographics; self-rated health status; existing health conditions; medication and supplement usage; other dietary restrictions and patterns of eating out; and tobacco, alcohol, and caffeine consumption.

Measures of physical activity prior to and during Lent were estimated using a modified version of the questionnaire developed for and used in the Aerobics Center Longitudinal Study (Kohl et al. 1997; Kohl et al. 1988). To obtain a measure of energy expenditure, participants were asked about their average weekly engagement in 15 common and specific (walking, hiking, stair climbing, jogging, treadmill use, bicycling, swimming, aerobics, moderate activity sport, vigorous racquet sports, other vigorous sports, weight training, household chores, yard work, and manual labor) and any additional moderate and vigorous physical activities in the previous month and were asked to specify frequency, duration, and average speed (if relevant) for each session of engaging in the activity. Activity-specific metabolic equivalent values (METs), which represent the ratio of the metabolic cost of performing the activity to a standardized resting metabolic rate (Ainsworth et al. 2011), were multiplied by the minutes per week of reported engagement in each activity, summed across all activities, and divided by 60 to obtain a measure of weekly MET hours in each time period.

Dietary Intake Measurement

Diet was assessed using both undocumented 7-day FRs and retrospective self-administered FFQs. Each participant completed one FR and one FFQ before Lent and one FR and one FFQ during Lent. Participants were instructed to record each FR during a week of their choice within the 4- to 5-week span preceding each biomarker collection period, while each FFQ was administered at the time of the biomarker collection (right before Lent and again at the end of Lent). The FR booklets were, with permission, modeled after undocumented multiple day FRs developed by the Nutrition Assessment Shared Resource (NASR) of the Fred Hutchinson Cancer Research Center (FHCRC) (Kwan et al. 2010; NASR). The booklets offered prompts to include information on the amount of food, method of preparation, and brand name of food (if applicable). They included instructions, example food entries, pages for entering recipes, and guidelines for reporting portion size with pictures and tips for estimating food volumes using standard household objects as references. Participants were also provided an online video tutorial created by the researcher on how to complete the FR. All participants were asked to complete seven consecutive days of recording during a week of their choice within each collection period but were given the option to skip days and resume later if sick or if unusual circumstances substantially altered their eating in the middle of the recording period.

The FFQs used in this study were made available through the Nutrition Assessment Shared Resources of the Fred Hutchinson Cancer Research Center (NASR). These FFQs have been used in the Women's Health Initiative study and validated against the average of four 24-hour recalls and a 4-day FR for the measurement of energy intake and major nutrients (Patterson et al. 1999). The FFQs asked participants about the frequency (never, once per month, two to three times per month, once per week, twice per week, three to four times per week, five to six times per week, once a day, or twice or more a day) and usual serving size (small, medium, or large, with reference sizes for medium servings provided) of 106 food items and 18 beverage items consumed over the previous 4-5 weeks. Thirteen additional adjustment questions asked participants about the kinds of added fats used regularly and the typical fat content of meat and dairy products consumed. Because the FFQs did not cover a comprehensive range of meat and dairy substitutes, participants received additional written instructions from the researcher to count rice, almond, or coconut milk as "soy milk;" coconut oil as "other oils;" almond cheese as "tofu cheese;" and veggie burgers as "tofu and tempeh."

Data from the FRs and FFQs were processed using the University of Minnesota Nutrition Data Systems for Research (NDSR) software (Nutrition Coordinating Center: University of Minnesota 2015; Schakel 2001; Schakel et al. 1997; Schakel et al. 1988). The FFQs were processed by the Nutrition Assessment Shared Resources of the Fred Hutchinson Cancer Research Center. The processing generated data on estimated daily intake of kilocalories (kcal), nutrients, and consumption of 32 major food groups based on the MyPyramid Equivalent Database (MPED) version 2.0 (Bowman et al. 2008).

FR data was entered into the NDSR software by the primary researcher and three trained research assistants. A system of data entry defaults were used to assign serving sizes for food items for which specific size (e.g., medium piece of fruit, large egg, 8-inch tortilla) was not written by the participant. All data entries were double-checked by the primary investigator. In contrast to the output generated from the FFQs, the output generated from the FR data uses the Nutrition Coordinating Center (NCC) Food Group Serving Count System (Nutrition Coordinating Center: University of Minnesota 2015), which assigns foods consumed each day to one of 168 food groups. To get an estimate of daily intake, each of the NCC food groups was averaged across the days within the respective collection periods. For most individuals, this meant an average of seven days for both FRs. For a few individuals before Lent 1 (n=4) and during Lent (n=7) the averages were based on 6 days of entry due to either missing days or to exclusion of a day indicated by participants to be unusual due to illness and/or an atypical event. Some individuals before Lent (n=8) and during Lent (n=2) had >7 days of recording; in such cases only the first seven days were used to estimate averages, except when it was made explicit that additional days were entered by participants to make up for illness or unusual circumstances on one of the previous days.

Aggregation and Definition of Food Group Variables

Both the MPED and NCC systems had similar definitions for servings of nuts and seeds, meat alternatives/soy products, whole grains, and refined grains. All measures of macronutrients, fiber, and total and added sugars were provided in the same units across the two nutritional analysis systems. However, the grouping of some major food groups examined in this study followed a slightly distinct process for the FR data relative to the FFQ data (See Supplemental Table 4.1). One major difference between the MPED and NCC systems of generating food group estimates for FFQs and FRs, respectively, is in the way the former disaggregates components of foods into food groups (e.g., fatty meats disaggregated into lean meat and discretionary solid fat groups; ice cream disaggregated into milk and added sugar groups). The MPED variables for red meat, poultry, and processed meat, were, therefore, based on lean meat; any fat content above the “allowable” 9.28 grams per 100 grams in meat products was disaggregated into a separate discretionary solid fat variable (Bowman et al. 2008), which was not incorporated in the analyses due to its inclusion of non-animal sources of solid fat (e.g., vegetable margarine and coconut oil). In contrast, The NCC variables had to be grouped manually and without disaggregation. Hence, red meat in the FR data set was defined as the combination of lean and non-lean beef, veal, lamb, and pork, excluding cold cuts, cured pork, and sausages. Poultry was defined as the combination of lean, non-lean, and fried poultry products. Processed meat was defined as the combination of cured lean and non-lean pork and lean and non-lean cold cuts and sausages. The estimates for fresh and smoked fish and shellfish were combined with the estimates of fried fish and fried shellfish produced by the NCC system to generate a comparable variable to the MPED variable for fish intake, which does not separate fish by cooking method. Similarly, to generate a comparable count of total dairy servings using the NCC data, it was necessary to combine whole, low-fat, and non-fat cup equivalents of unsweetened and sweetened milk; unsweetened, sweetened, and artificially sweetened yogurt; cheese; and dairy-based dessert products.

The serving sizes of fruit, vegetables, potatoes, and legumes are twice as large in the MPED system as they are in the NCC system. Thus, 0.5 was multiplied by the NCC variables for servings of citrus and non-citrus whole fruit (excluding fruit juices); green, orange, starchy, and other vegetables (excluding fried and non-fried potatoes); white potatoes (including friend and non-fried forms); and legumes.

Finally, the discretionary oil variable generated from the MPED system included oils from fish, nuts, seeds, liquid margarine, and added vegetable oils. As no parallel existed with the NCC data, FR estimates of saturated and trans fat intake was subtracted from the FR estimates of total fat intake in an attempt to create a variable that would be more comparable to the MPED variable than the NCC variable for oil consumption.

Measurement of cardiometabolic health biomarkers

Basic health assessments involving the measurement of body composition and the collection of capillary blood were conducted the 1-3 weeks before Lent and again in the last 1-2 weeks of Lent. Standing height without shoes was measured at the first visit using a portable stadiometer (Seca-217). Weight and body fat percentage were measured using a full body bioelectric impedance scale (Omron® HBF-514C). Body mass index (BMI) was calculated by dividing weight in kilograms by squared height in meters (kg/m^2).

Capillary blood was collected from a finger prick following a ≥8-hour period without food or caloric beverages. Approximately 3 drops (40 µL) of whole blood were used immediately for the assessment of blood lipids and fasting glucose using the Cholestech LDX® point-of-care device (Gialamas et al. 2010; Shemesh et al. 2006) and commercially available Lipid and Glucose Analyzer cassettes. The LDX® point-of-care device measures total cholesterol, high-density lipoprotein (HDL) cholesterol, triglycerides, and blood glucose directly, and it calculates low-density lipoprotein (LDL) cholesterol using the Friedewald formula: [total cholesterol – HDL cholesterol – (triglycerides/5)] (Friedewald et al. 1972). This formula offers a reliable measure of LDL cholesterol when triglycerides are <400 mg/dL; LDL cholesterol was unmeasurable during Lent in one participant whose triglyceride levels were above that threshold.

For participants with triglyceride levels below the level of detection (n=17 before Lent and n=15 during Lent), the minimal detectable value of 45 mg/dL was imputed as the participants' triglyceride value and LDL cholesterol was calculated manually using the Friedewald formula. Likewise, the minimum value of detection of 100 mg/dL for total cholesterol was imputed as the total cholesterol level for one participant with levels below the limits of detection at the second health assessment, and that value was used to calculate LDL cholesterol manually.

Additional capillary blood was collected in BD Microtainer® tubes with serum separators. Blood was allowed to clot for 30 to 90 minutes and centrifuged at 6000 rpm. Serum was aliquoted and shipped on dry ice to the University of Washington Biological Anthropology and Biodemography Laboratory, where it was kept frozen at -80º C. Insulin was measured by the Northwest Lipid Metabolism and Diabetes Research Laboratories (University of Washington, Seattle, WA) using a two site immune-enzymometric assay on a Tosoh 2000 autoanalyzer (Marcovina et al. 2007); the inter-assay CVs for low, medium, and high levels of control samples for this assay are 2.8%, 2.5%, and 2.0%, respectively. Using the measures of serum insulin obtained by the Northwest Lipid Metabolism and Diabetes Research Laboratories and glucose measured by the Cholestech LDX® point-of-care device, a measure of the homeostatic model assessment of insulin resistance (HOMA-IR) was calculated using the following equation: [glucose (mg/dL) x insulin (μU/mL)]/405 (Matthews et al. 1985). C-reactive protein (CRP) was measured using an in-house enzyme-linked immunosorbent assay at the University of Washington Biological Anthropology and Biodemography Laboratory (Brindle et al. 2010). The inter-assay CVs for low, medium, and high levels of control for this assay were 16.7%, 7.7%, and 11.6%, respectively; the intra-assay CVs for low, medium, and high CVs were 5.1%, 5.7%, and 10.5%, respectively.

Statistical analyses

Six of the 108 participants who completed both health assessments were missing data for one or more FR and/or FFQ. After data on caloric intake were reviewed for implausibly low or high estimates of energy intake in either time period (<500 kcal or >4500 kcal for females and <800 kcal or >5000 kcal for males), one male was excluded because of an estimated energy intake >5000 on the FFQ before Lent, and one female was excluded for an estimated energy intake <500 on the FFQ during Lent. Another six participants were excluded from the analyses for being on a strict weight loss regime during the study period (n=2), following the earlier Catholic Lenten calendar (n=1), already restricting all MDE products at baseline (n=2), or reporting a change in cholesterol- or diabetes-related medications during the study period (n=1). These exclusions resulted in a sample of 94 individuals for comparisons of FR and FFQ data and for most biomarker analyses. However, sample sizes varied for specific biomarker tests due to missing body fat measures (n=2); unreliable LDL cholesterol estimates due to triglyceride levels >400 mg/dL (Matthews et al. 1985)(n=1); and missing insulin measures at one or both time points (n=15). Furthermore, CRP models excluded individuals reporting changes in regular use of anti-inflammatory medications (n=1); individuals whose acute use of anti-inflammatory medications (24-hours prior to the health assessment) differed from time 1 to time 2 (n=11); or individuals missing CRP measurements for time 1 or time 2 (n=3). No participants needed to be excluded for CRP levels suggestive of acute infection (>10 mg/L). As a previous sensitivity analysis showed no difference in results when excluding individuals consistently taking cholesterol or diabetes medications (See Chapter 3), this analysis included participants taking statins (n=6), diabetes-related medications (n=3), and low dose anti-inflammatory medications (n=8).

Because errors in reporting of nutrients or foods are highly correlated with errors in measurement of total energy (Willett 2001b; Willett 2013), standardized food and nutrient density variables (intake per 2000 kcal) were used in all analyses to reduce the degree measurement error. Nutrient and food densities also offer a better representation of dietary change, as a decrease or increase in one food inevitably shifts the dietary proportions. To generate these standardized density measures using the FR data, each food group and nutrient variable within each collection period, having already been averaged across the 6-7 days of FR recording, was divided by the average calorie intake in each period and multiplied by 2000. Similarly, using the FFQ data, each food and nutrient variable from each collection period was divided by the respective estimated calorie intake and multiplied by 2000.

Composite measures of participants' consumption of MDE products before Lent (MDE1 score) and during Lent (MDE2 score) were created by adding energy-adjusted servings of each MDE product consumed in each period. For the purposes of this composite score, a MDE "serving" was defined as 3 oz of unprocessed meat, 2 oz of processed meat, 1 cup-eq of dairy, or a 2 oz-eq of eggs. The difference between the MDE1 score from the MDE2 score in each dataset was used to create a composite measure of the change in MDE servings based on either FR data (FR MDEΔ score) or the FFQ data (FFQ MDEΔ score). These composite MDE scores served as the independent variable in models testing the dependent changes in calories and non-MDE foods and resulting shifts in cardiometabolic health biomarkers.

Pearson correlation coefficients were calculated to assess the agreement between the FR and FFQ estimates of food and nutrient densities, as well as between the measures of change in each food and nutrient density between the pre-Lenten and Lenten periods. Paired t-tests were performed to identify when the FFQ and FR differed significantly in estimates for mean intake of or mean change in each nutrient and food density of interest.

Multiple linear regression analyses performed previously (See Chapters 2 and 3) to assess the relationships between FFQ MDEΔ and changes in non-MDE foods (Food Models) or between FFQ MDEΔ and shifts in biomarkers (Biomarker Models) were re-run separately using both the FR and FFQ data for the slightly smaller sample of 94 individuals (previous n=99). The Food Models regressed the change in calories, fish, and twelve plant-based foods (whole grains, refined grains, legumes, meat alternatives, nuts and seeds, fruits, vegetables, potatoes, discretionary oils, and added sugars) on MDEΔ, controlling for age, sex, baseline BMI, average weekly METs, change in weekly METs, baseline calories, change in calories, and MDE1 score. The Biomarker Model I regressed the change in ten biomarkers (BMI, body fat, total cholesterol, LDL cholesterol, HDL cholesterol, triglycerides, glucose, insulin, HOMA-IR, and CRP) on MDEΔ, controlling for age, sex, baseline BMI, average weekly METs, change in weekly METs, baseline levels of each respective biomarker, baseline caloric intake, change in calories, MDE1 score, and the number of days following the restricted diet prior to the health assessment. Biomarker Model IB further adjusted for change in weight to assess the degree to which weight loss explained significant associations in Biomarker Model I. Biomarker Model II maintained adjustment for weight loss and other covariates and added terms for the main and interactive effects of calories and specific food correlates (each tested separately): fish, whole grains, refined grains, legumes, meat alternatives, nuts and seeds, fruits and vegetables, discretionary oils, and added sugars. Because false positive interactions can arise as a result of an influential outlier, leave-one-out cross-validation analyses were performed for models in which significant effect modification was arose. Finally, for the biomarkers that showed consistent change in the previous models, Biomarker Model III regressed the change in health biomarkers on change in meat, dairy, and eggs entered simultaneously as three separate independent variables to assess which of the components of the MDEΔ score had the greatest impact on biomarker change. Wald's tests were used to verify whether the coefficients for meat, dairy, and eggs in Biomarker Model III were significantly different from each other.

No attempts were made to calibrate or deattenuate (i.e., adjust for an estimated attenuation factor) the beta-coefficients estimated from the food or biomarker models, as the consecutive days for each food diary preclude reliable estimates of within-person variation; additionally, such methods rely on the assumption that the FR is a more precise measure of diet, though it is unclear that such an assumption can be made for undocumented FRs. All regression analyses used robust standard errors to account for heteroscedasticity of errors in the data. Statistical significance for the Food Model was determined by a Bonferroni-adjusted α-value of 0.004 to correct for the twelve food categories examined. Statistical significance for the Biomarker Models was determined by a Bonferroni-adjusted α-value of 0.005 to correct for multiple testing of each biomarker with 10 separate food groups in Biomarker Model II. However, the p-values presented are uncorrected. Analyses were conducted using StataSE 14 or RStudio.

RESULTS

Baseline Demographic and Health Characteristics

Though the excluding five individuals that had been included in previous analyses but had incomplete FR data, the demographic makeup of this sample remains the same as before

(Table 4.1) (See Chapters 2 and 3 for comparison). The adults in this study sample were 19-73 years old (mean=46.7); 44% were male; 94% reported their race as “white or Caucasian.” Most individuals (93%) had received a minimum of a 4-year college degree, and almost half (46%) reporting an annual household income ≥$100,000. Most individuals (92%) rated their health status as “good,” “very good,” or “excellent” at the start of the study. Only 8% of the sample reported that they were currently consuming some form of tobacco products. Four individuals did not self-identify as OC, and 5% consistently restricted meat from their diets even apart from the OC Lenten practice.

Prior to Lent, 64% of the sample was considered overweight at the threshold of 25 kg/m^2 (Flegal et al. 2012; National Institutes of Health 1998)and 69% had what is considered high age- and sex-specific body fat percentage (Gallagher et al. 2000; Oreopoulos et al. 2010) (Table 4.2). Total cholesterol levels were above optimal (≥200 mg/dL) in 27% of the sample (Nayor and Vasan 2016; NCEP 2002; Stone et al. 2013). Over half of the participants (57%) had LDL cholesterol levels above optimal levels (≥100 mg/dL), and 34% had suboptimal (≥100 mg/dL) triglyceride levels. Approximately 29% and 23% of participants had fasting glucose and HOMA-IR levels, respectively, in ranges that are associated with higher risk for metabolic syndrome and diabetes (American Diabetes Association 2010; Gayoso-Diz et al. 2013; McAuley et al. 2001; Motamed et al. 2016). CRP levels were, on average, within normal ranges for most individuals in the study sample, though 10% of the sample had CRP levels that were in the range associated with low-grade inflammation (3-10 mg/L) (Myers et al. 2004). With the exception of total and LDL cholesterol, there was little change in the proportions of participants with suboptimal biomarker ranges during Lent.

Aim 1: Comparison of FR and FFQ data for measuring the pre-Lenten and Lenten diets

At time 1 (before Lent), Pearson correlation coefficients suggested moderate to strong ($r \geq 0.40$) linear relationships between most FFQ- and FR-derived energy-adjusted food and nutrient density variables, with the exception of caloric intake among males ($r=0.27$), caloric intake among females ($r=0.35$), legumes ($r=0.35$), and meat alternatives ($r=0.20$) (Table 4.3a and Table 4.3b). The FFQ- and FR-derived MDE1 scores were highly correlated ($r=0.69$). Paired t-tests indicated that, relative to the FFQ, the 7-day undocumented FRs tended to estimate statistically significantly higher sample means for measures of total, saturated, and monounsaturated fats; poultry and processed meats; cheese; whole and refined grains; and discretionary oils but lower sample means for measures of total sugar, red meat, milk, dairy, fruit, vegetables, and white potatoes. Estimates of mean calories, total and specific proteins, added sugar, fiber, total meat, fish, total dairy, eggs, legumes, meat and dairy alternatives, and nuts/seeds were comparable across both dietary instruments. Apart from the estimates of caloric intake, which had higher variances for males and females in the FFQ data, the standard deviations for most food and nutrient estimates were not strikingly different between the FFQ and FR data at time 1.

At time 2 (during Lent), all Pearson correlation coefficients for the FFQ- and FR-derived food and nutrient density variables were again ≥ 0.40, with the exception of caloric intake among males ($r=0.27$) and nuts and seeds ($r=0.31$). The FFQ- and FR-derived MDE2 scores were highly correlated ($r=0.90$). As in time 1, relative to the FFQ, the FR tended to estimate higher mean intake of total and specific fats, whole and refined grains, and discretionary oils while estimating lower meant intake of total sugars, red meat, milk, fruit, vegetables, and white potatoes. This time, however, the FR also estimated statistically significantly higher caloric intake among males, as well as lower mean total carbohydrate intake, higher added sugar intake, and higher legume intake among the total sample. Estimates of total and specific protein density, fiber, total meat, total dairy, fish, eggs, meat and dairy alternatives, and nuts/seeds remained comparable between the two instruments. As in time 1, there were no notable differences in standard deviations for most FFQ- and FR-derived variables.

Aim 2: Comparison of FR and FFQ data for quantifying changes in MDE consumption and concurrent changes in non-MDE foods during Lent

The FR MDEΔ score and the FFQ MDEΔ score, the main predictors of interest in the regression analyses, were strongly correlated (*r*=0.71). Nonetheless, this did not translate into perfectly aligned tertile divisions (Figure 4.1). About 27% of the sample was classified into different tertiles depending on which data source was used. Three individuals who had been grouped into the third FFQ MDEΔ tertile (i.e., greatest amount of change in MDE products) were grouped into the first FR MDEΔ tertile. Another ten individuals in the third FFQ MDEΔ tertile and five individuals in the second FFQ MDEΔ tertile moved one tertile down in the FR MDEΔ tertiles; eight and 13 individuals moved up one tertile from being in the first and second FFQ MDEΔ tertile, respectively, to being in second and third FR MDEΔ tertile, respectively.

Overall, the measures of change in nutrient and food intake between the two time periods had slightly lower correlations than the measures of food and nutrient intake within either collection period (Table 4.3a and Table 4.3b; Figure 4.2). Nonetheless, the FFQ- and FR-derived data estimated similar magnitudes of change in the majority of food and nutrient density variables, including total and specific protein; total, saturated, and monounsaturated fats; total carbohydrates and sugars; fiber; total meat and poultry; fish; milk; yogurt; eggs; whole and refined grains; legumes; meat and dairy alternatives; nuts and seeds; fruit; white potatoes; and discretionary oils.

There were only a few areas in which the FFQ and FR data estimated significantly different magnitudes of change in dietary composition between time 1 and time 2. Relative to the FFQ data, the estimates of mean caloric reductions were less pronounced in the FR data, though the estimated mean change in calories was only statistically significantly different for females. The FR data also did not estimate as great of a decrease in red meat or as great of an increase in vegetables as was estimated by the FFQ data. Finally, relative to the FFQ data, the FR data estimated statistically significantly larger mean increases in polyunsaturated fats, added sugars and greater mean decreases in processed meats, total dairy, and cheese.

There was considerable agreement between the FFQ-derived and FR-derived food models (Table 4.4). Both datasets provide similar evidence that each serving decrease in MDE products is associated with an approximately 0.09 oz/2000 kcal increase in legumes, 0.2 oz/2000 kcal increase in meat alternatives, and 0.6-0.7 oz/2000 kcal increase in nuts and seeds, on average (all 95% CIs relatively similar and all p-values≤0.001). The FR Food Model estimated a 5.7 g/2000 kcal increase (95% CI 3.5 to 7.9, p<0.0001) in discretionary oil relative to each MDE serving reduction, while the FFQ Food Model estimated a 3.1 g/2000 kcal increase (95% CI 1.7 to 5.4, p=0.0002). The FR data suggested there was no change in calories in relation to MDE restriction (β: -24; 95% CI -42 to 96, p=0.5), while the FFQ data estimated an average 97 calorie decrease (95% CI 36 to 157, p=0.002) for each serving decrease in MDE products. The estimated 0.27 oz/2000 kcal increase (95% CI 0.10 to 0.43, p=0.002) in whole grain and 0.10 cup-eq/2000 kcal increase (95% CI 0.03 to 0.16, p<0.0001) in fruit were significant at the Bonferroni-adjusted α-level when using the FR data but were only significant at the unadjusted α-level of 0.05 in the

FFQ data, though the beta coefficients were similar with both sources of dietary data. Neither data source suggested that there was a significant change in fish, refined grains, vegetables, white potatoes, or added sugars relative to the MDEΔ score. Overall, the food models demonstrate that, even when the measures of change in food densities are only moderately correlated, the change in non-MDE foods show comparable associations with MDE restrictions in both data sets.

Aim 3: Comparison of FR and FFQ data for detecting main and interactive effects of MDE and concurrent dietary change on cardiometabolic health markers

Both the FR- and FFQ-derived data suggested that a serving decrease in MDE products was associated with a significant decrease in total and LDL cholesterol and no other significant biomarker changes at the Bonferroni-corrected α-value of 0.005 (Table 4.5). However, the average 2.8% (95% CI: 1.1% to 4.4%, p=0.001) drop in total cholesterol estimated for a one-unit change in the FR MDEΔ score was slightly lower than the 3.7% (95% CI: 1.9% to 5.5%, p<0.0001) drop estimated when using the FFQ MDEΔ score. The average 3.3% (95% CI: 1.4% to 5.2%, p=0.001) decrease in LDL cholesterol estimated for a one-unit change in the FR MDEΔ score was very close to the 3.6% (95% CI: 1.2% to 6.0%, p=0.004) decrease estimated with the FFQ data. No other associations between MDEΔ and biomarkers shifts were observed in either data set at the Bonferroni-adjusted α-value, and effect sizes for the other biomarkers were roughly the same across the FR and FFQ biomarker models, with the exception of a smaller coefficient for triglycerides and a negative coefficient for CRP in FR biomarker model.

Controlling for weight reductions during Lent attenuated the observed effect of both the FF and FR MDEΔ scores on reductions in total and LDL cholesterol (Table 4.6). The change in total cholesterol in relation to MDEΔ remained significant in both the FFQ- and FR-derived versions of the Biomarker Model IB. However, the change in LDL cholesterol in relation to MDEΔ only remained significant at the unadjusted α-level of 0.05 in the FFQ and FR Biomarker IB models.

Effect sizes for changes in total and LDL cholesterol were reduced even further in the Biomarker Model II analyses that controlled for weight loss and included main and interactive effects for calories, fish, or separate plant-based foods (Table 4.7a and Table 4.7b). However, there were no significant interactions in either data source that could not, through further examination of the data and diagnostic leave-one-out analyses, be attributed to influential outliers and/or potential nonlinear relationships across different degrees of change in non-MDE foods.[1]

---

[1] Though a few significant (at the Bonferroni-adjusted α-level) interactions arose in the FR Biomarker II models for BMI, total cholesterol, and LDL cholesterol, diagnostic leave-one-out analyses demonstrated that all but one of the significant interactions could be attributed to one or two outliers in the dataset who, for example, increased their consumption of legumes or meat alternatives but experienced a small increase in weight or total cholesterol. The interaction between meat alternatives and FR MDEΔ in the total cholesterol Biomarker II model was removed when excluding one outlier; the interaction between legumes and FR MDEΔ in that same model was attenuated, and the sign of the coefficient for legumes was reversed, when two outliers were excluded (Supplemental Table 4.2). Even after removing influential outliers, however, neither total cholesterol nor LDL cholesterol were associated with MDE reductions in the FR Biomarker II models that included the main and interactive effects for legumes. There was some indication at the unadjusted α-level only (p-interaction=0.04) that MDE restriction and increases in legume intake might work synergistically to reduce total and HDL cholesterol.

In contrast, no single or few individuals could be identified as the cause for the highly significant interaction between changes in whole grain consumption and MDEΔ in the FR Biomarker II model for LDL cholesterol (Supplemental Figure 4.1a). However, a closer examination of the data suggested that the unexpectedly positive interaction may be explained by a nonlinear relationship caused by a mix of A) several participants experiencing large drops in LDL cholesterol in relation to greater MDE reductions despite reported decreases in whole grain intake, and B) several individuals who started out with relative low LDL cholesterol and experienced increases in LDL cholesterol despite greater degrees of MDE restriction and small increases in whole grain intake (Supplemental Figure 4.1b).

The diagnostic leave-one-out analyses also identified one individual who, when left out of the Biomarker II models for BMI, increased the effect size and produced a significant p-value for the change in BMI in relation to FR MDEΔ score (Supplemental Figures 4.2a and 4.2b). The FFQ and FR Biomarker III models for BMI were, therefore, rerun excluding that individual (Supplemental Table 4.3). The FFQ biomarker models of BMI did not, however, reach significance when excluding this outlier except in the models that controlled for the main and interactive effects of FFQ-derived measures of shifts in fruit and vegetable or oil consumption.

Finally, in Biomarker Model III, when FFQ and FR estimates of meat, dairy, and egg servings were entered as separate variables in the fully adjusted regression model that did not include any non-MDE foods (i.e., Biomarker Model 1B), it was the measure of dairy servings, and not the measures of meat or egg servings, that in both datasets had a large effect size and significant p-value (Table 4.8). However, Wald's tests revealed that only in the FFQ Biomarker III model for LDL cholesterol was the coefficient for the change in dairy significantly different than the coefficients for both eggs (p=0.03) and meat (p=0.01). In the FFQ Biomarker III model for total cholesterol, the coefficient for the change in dairy was only significantly different from the coefficient for the change in eggs (p=0.03) but not different from the coefficient for the FFQ measure of the change in meat (p=0.06). Coefficients for meat, dairy, and eggs were not statistically significantly different from each other in the FR Biomarker III models.

In summary, both the FFQ and FR data provide support that each serving decrease in MDE products is associated with statistically significant decreases in total and LDL cholesterol but that at least some of those decreases are attributed to small reductions in weight loss. Adding main and interactive effects for concurrent shifts in non-MDE foods, particularly FR measures of legumes, attenuated the relationships between MDEΔ and cholesterol shifts. However, after considering influential outliers and potential nonlinear relationships, there was no strong or convincing evidence in either dataset that shifts in non-MDE modified relationships between MDEΔ score and shifts in biomarkers. There was evidence in the FFQ data for the relationship between MDE reductions and cholesterol shifts might be driven by reductions in dairy consumption. However, the FR data did not provide the same statistical support for this notion.

DISCUSSION

This study aimed to compare a standard FFQ to an undocumented 7-day FR for 1) describing the unrestricted and restricted diets of OCs before and during Lent; 2) measuring changes in MDE product consumption and concurrent changes in non-MDE foods that occur during Lent; and 3) testing the main and interactive associations between those concurrent dietary changes and shifts in common markers of cardiometabolic health. The first major finding of this study was that most nutrient and food densities estimated by the FFQ and FR dietary instruments were relatively highly correlated, both before and during Lent, and yet often estimated statistically significantly different mean distributions. This latter finding could (among other reasons described in greater detail below) be an indication of systematic error (i.e., a tendency to under-report consumption of red and processed meats, cheese, and grain-based products but over-report fruits, vegetables, and potato products on FFQs relative to FRs).

The second major finding of this study was that measures of average dietary change were, for most foods, in the same range for both the FFQ and FR derived estimates of food density. Importantly, both sources of data led to findings that a serving decrease in MDE products was, on average, associated with an approximately 0.09 serving increase in legumes, 0.2 serving increase of meat alternatives, 0.6 serving increase in nuts and seeds, and 3.5- to 5.7-gram increase in unsaturated discretionary oils among this sample of OCs during Lent. These findings are encouraging considering that the FFQ- and FR-derived estimates of food density change were not as highly correlated as estimates of food densities within any single timeframe.

Given the greater estimates of caloric reductions in the FFQ data and low correlation between FFQ and FR measures of caloric intake, there was a large discrepancy in the food models estimating the relationship between MDEΔ and calories. Otherwise, when the coefficients for the food models reached Bonferroni-adjusted levels of significance in one dataset (e.g., whole grain and fruit in the FR dataset) and not the other, the effect sizes tended to be comparable.

The third major finding was that both the FFQ and FR sources of dietary data led to strikingly similar findings that each MDE serving reduction during Lent was associated with an average 2-3% reduction in total and LDL cholesterol that was only partially attributable to the small degrees of weight loss observed in this study sample. Neither data source provided convincing evidence that calories, fish, or plant-based foods modified the relationships between MDEΔ score and total and LDL cholesterol, though the FR data appeared to be more susceptible to spurious interactions caused by outlier data points. Both data sources also produced null associations between changes in MDE food intakes and changes in measures of glucose metabolism or inflammation.

Beyond the tendency of the FR data to produce more spurious interactions in the Biomarker II models, there were only a few discrepancies among the biomarker models, and many of them came down to divergent p-values. For instance, after the outlier was removed from the Biomarker II model for BMI, MDEΔ score was mostly consistently significantly associated with reductions in BMI in the FR dataset and not consistently in the FFQ dataset, though the coefficients were not substantially different between the two data sources. Likewise, both the FFQ and FR Biomarker III models suggested that dairy reductions were statistically significantly associated with reductions in cholesterol after controlling for meat and egg reductions, though only with the FFQ data was the Wald’s test able to provide statistical support for the coefficient for dairy being significantly greater than the coefficient for meat or eggs. Perhaps the largest discrepancies between the data sources were A) the degree to which the inclusion of the main and interactive effects of legumes reduced the association between MDE and total cholesterol reductions in the FR data, even after excluding influential outliers, and B) the strong suggestion of main and antagonistic interactive effects of whole grains on LDL cholesterol in the FR but not the FFQ data. Otherwise, the two data sources had high agreement in their measurement of MDE restrictions and their associations with shifts in cardiometabolic health biomarkers.

Methodological implications of study results and comparisons with other studies

Previous analyses of OC dietary patterns have measured diet with multiple-day FRs (Papadaki et al. 2011; Papadaki et al. 2008; Sarri et al. 2004), FFQs (Elshorbagy et al. 2017) or 24-hour recalls (Karras et al. 2017), but none have compared the performance of different dietary instruments for measuring Lenten dietary patterns nor tested how specific dietary changes relate to the degree of change observed in health biomarkers during the OC Lenten period. This was the first study to use two separate sources of dietary intake data to measure dietary change during the OC MDE fasting period and do relate those dietary changes to shifts in biomarkers of cardiometabolic health.

The findings from this study have several important methodological implications for future studies aiming to measure relationships between concurrent dietary health biomarker changes. For one, they suggest that, at the descriptive level, different dietary instruments might lead to contrasting conclusions about the average number of servings of a given food a study sample regularly consumes or the proportion of individuals in a sample meeting dietary recommendations. The reasons for these differences in this study could include different impacts of systematic and random biases in the study instruments (Kipnis et al. 1999; Neuhouser et al. 2008; Prentice et al. 2011), differences in the time scale being measured (one versus four/five weeks), and differences in how the some food groups were defined across the two data sets. This study is not alone in showing these kinds of discrepancies; other studies have also demonstrated that estimates of absolute nutrient (Subar et al. 2001) and food (Millen et al. 2006) intake frequently differ by more than 15% when comparing FFQs to 24-hour recalls, even when the variables are relatively highly correlated, as they were in this study. The comparison of nutrient and food densities in this study, as opposed to estimates of absolute intake, should have helped reduce some of the measurement error, but it also makes it difficult to discern to what degree the differences in food densities are due to differences in reported intake of the given food, differences in estimates of total energy, or both. Relative to other dietary instruments, FFQs offer a notoriously poor estimate of total energy consumption (Freedman et al. 2014; Kipnis et al. 2003; Neuhouser et al. 2008; Schatzkin et al. 2003; Thompson and Subar 2013). Hence, it is possible that the apparent higher intake of meat at time 1 or the higher degree of estimated change in MDE products in the FFQ data is simply due to the FFQ tending to underestimate caloric intake at time two and overestimating the change in calories. This demonstrates the limited usefulness of paired t-tests for comparing different dietary instruments' ability to measure sample distributions and suggests that a more robust evaluation of the two instruments is offered from the multiple regression analyses that control for baseline caloric intake and caloric change, in addition to important sources of systematic bias (e.g., age, sex, BMI, activity levels). Another important implication of these findings is that comparisons of dietary composition across study populations may be ill-advised when distinct dietary instruments have been used.

For two, the similar degree of agreement between study instruments in measures of nutrient and food densities before and during Lent suggest that a standard FFQ is comparable to an undocumented FR in estimating the dietary composition of a diet that is largely plant-based, despite the fact that standard FFQs ask about a limited number of MDE substitutes and do not account for vegan versions of mixed dishes that typically contain MDE products. In fact, the Pearson correlation coefficients for energy intake and energy adjusted total protein, total fat, and total carbohydrates during the Lenten collection period were higher than those reported in a validation study that compared this same FFQ to the average of four 24-hour recalls and a 4-day FR in a subsample of the Women's Health Initiative study population (Patterson et al. 1999) (Supplemental Table 4.4). Validation studies for other standard FFQs, including the Willett, Block, and Diet and Health Questionnaire (DHQ) (McKeown et al. 2001; Subar et al. 2001), have also reported similar, and in some cases lower, correlation coefficients (even after adjusting for the estimated attenuation factor) for calories in females and energy-adjusted protein, fat, and carbohydrates. Even the 204 AHS-2 FFQ designed specifically to include a broader array of plant-based foods did not, when compared to the average of three to six 24-hour recalls, report as strongly correlated estimates for energy intake and energy-adjusted total, animal- and plant-based protein; total, saturated, and monounsaturated fats; and total carbohydrates (Jaceldo-Siegl et al. 2010). Few studies have validated the use of FFQs relative to FRs for measuring intake of specific food groups as opposed to nutrients, and some of those that do fail to adjust for estimates of energy intake (Hu et al. 1999; Salvini et al. 1989), a process that is known to increase the correlation of nutrients measured in FFQs to those measured by other instruments or recovery biomarkers (Freedman et al. 2011; Kipnis et al. 2003; Willett 2001a; Willett 2013; Willett et al. 1997). One known study that compared the DHQ FFQ to four 24-hour recalls in a US population (Millen et al. 2006) reported Pearson correlation coefficients for meat, fish, egg, and dairy groups that were lower than those estimated in this study during the Lenten period, though their coefficients for whole and refined grains, nuts and seeds, fruits and vegetables, and discretionary oil were higher (Supplemental Table 4.5).

For three, this study was not alone in finding correlation coefficients for changes in nutrient and food densities that were in most cases substantially lower than those for intake densities at any single time point (Brown et al. 1996; Willett 2013). One reason for this is the fact that estimation of dietary change requires the combination of data from two imperfect dietary assessments, essentially doubling the amount of measurement error (Willett 2013). Large amounts of measurement error will inflate the variance of average dietary change estimates, and this can make it particularly difficult to measure relatively small changes in diet (Kristal et al. 1994). Importantly, however, this study showed that moderately correlated measures of diet change showed similar associations across the two different diet information instruments, when appropriately controlling for sources of within- and between-person variation, including age, sex, baseline BMI, activity levels, and changes in activity and energy intake.

For four, the similar findings across the multiple linear regression models demonstrate that FR data does not consistently lead to greater effect sizes or more strongly significant associations between diet and health measures, suggesting that the extra participant and researcher burden of collecting FR data may not always be justifiable. These findings contrast with the few studies that showed greater and statistically significant effect sizes between FR measures of dietary fat (Bingham et al. 2003; Freedman et al. 2006) or fiber (Dahm et al. 2010) and risk of breast or colorectal cancer, respectively, but no significant relationship and smaller effect sizes for FFQ measures of dietary fat or fiber and risk of those respective cancers. There are, however, some major differences between those other studies and the present one. First, each of those studies were looking at associations between disease risk and quintiles of dietary exposure. As this and other studies (Chacko George et al. 2004; Chiu et al. 2014; McKeown et al. 2001) have demonstrated, it is not uncommon for different dietary instruments to lead to mismatching quantile assignments, so the different study results when using FFQ and FR data may partly be explained by differences in categorization of exposure groups. Second, participants in the present study were completing the FR within a few weeks prior to the FFQ; this may have conditioned them to be more aware of their diets and, thus, could have contributed to more accurate reporting on the FFQ (Thompson and Subar 2013; Willett 2013). Third, this study was looking at dietary change as opposed to usual diet at any given time point. Consequently, as described above, the resulting increase in measurement error of a dietary measurement may have led to the variance of the FFQ- and FR-derived data in the present study being too large to detect differences in precision of one instrument over another. Because of this, and because of a number of other limitations of undocumented FRs, as discussed below, the present study findings should be interpreted with caution.

Strengths and weaknesses of the undocumented FR relative to the FFQ

It is reassuring that both sources of dietary intake data produced similar conclusions with respect to the effects of MDE restrictions on concurrent dietary changes and shifts in health biomarkers. However, the inherent error in both instruments and lack of a gold standard measure for MDE products or other food groups makes the study results challenging to interpret. It remains nebulous which set of regression coefficients and standard errors represents a closer approximation of the “true” relationship between reductions in MDE consumption and changes in health biomarkers. Traditionally, FR data have been considered a closer approximation of actual dietary intake than FFQ data, which is why FRs are often used as references instruments in FFQ validation studies. Because FRs are open-ended and track food as it is being consumed, they do not rely on limited long-term memory; are not restricted by a set of pre-defined food groups; and allow for more detail on ingredients of mixed foods, serving size, and cooking methods, hence, theoretically relying on fewer assumptions. Indeed, FRs have been shown to provide estimates of energy intake and protein that are closer, albeit still not extraordinarily so, to measures of these components obtained through recovery biomarkers (Day et al. 2001; McKeown et al. 2001; Prentice et al. 2011). Yet despite these relative advantages, there are a number of reasons to speculate that the undocumented FR used in this study may not have provided better measures of dietary intake or dietary change than those provided by the standard FFQ.

First and foremost, there were sources of random and systematic error in every step of the FR recording and data entry process. To begin with, because the instruction on recording procedures was limited and the researcher did not meet with the participants afterward to review the FR and correct any errors or fill in missing details, there was substantial room for misinformation or lost information in the crucial initial recording process. Even when participants were detailed in their documentation, it cannot be guaranteed that they remembered to record everything or that they accurately estimated food quantities or ingredients in mixed dishes consumed outside of the home. Then, both as a result of varying degrees of detail in FRs and because of limitations with the nutritional database, there was potential for mistakes in the following step of interpretation and entry of the information provided in the FRs. Despite efforts to create a list of default choices when data on food brand names and exact serving sizes or cooking methods were excluded, these default choices could have been incorrect and could have been a source of systematic bias across individuals by the degree of thoroughness in their recording. Furthermore, the nutritional database used for entering FR data lacked many brand name items. As a result, the best generic versions of a product had to be chosen or new recipes had to be created for many recorded foods. This left room for some of the same kinds of assumptions, only perhaps made in a less systematic manner, as those made in the FFQ about ingredients of mixed foods. Consequently, the final step of the process, the calculation of nutrients and food groups, may have produced erroneous estimates, and this accumulation of errors in the process of recording, interpreting, entering, and computing food intake with FRs may have led to estimates of dietary composition that were no more precise and accurate than the estimates produced by the FFQs.

Second, even had the recording, interpretation, entry, composition of FR data been perfect, there still may have been bias in the FR data resulting from altered eating behavior or from the failure of the FR to capture consumption of foods consumed episodically. It is well-known that the simple act of recording food intake can change what and how much a person consumes (Goris et al. 2000; Rebro et al. 1998; Thompson and Subar 2013; Vuckovic et al. 2000). In dietary interventions, this can lead to a compliance bias and overestimation of dietary change (Buzzard et al. 1996). Additionally, knowing that someone else will be looking at the FR and attempts to align behavior with what is perceived to be socially desirable can lead to food- and nutrient-specific under- or over-reporting (Hebert et al. 2002; Hebert et al. 2008). Compliance and social desirability biases may have had a particularly strong influence on the Lenten FR data, as some OCs may have been embarrassed to report consumption of MDE products, desserts, or indulgent snacks during a time that was, for many OCs, supposed to be somewhat sacrificial and disciplined. Though FFQs are also susceptible to social desirability biases (Hebert et al. 2002; Hebert et al. 2008), they are less likely to influence behavior in the moment, and some individuals may be more willing to report consumption of such foods retrospectively. The FFQ may have also been better able to capture any infrequent intake of MDE products or indulgent foods that may not have been consumed during the 7-day FR recording period. At the same time, the FFQ is less likely than the FR to produce outlier estimates of intake of a given food due to unusual circumstances (e.g., illness or special event) or a bout of eating leftovers three days in a row.

Third, data errors and behavior change aside, the FR may not have been able to capture the degree of variation in consumption patterns that exists within and across weeks for some OCs, particularly during Lent. This includes variation within weekdays due to the ritual among some OCs to avoid animal products and potentially restrict the timing and frequency of meals on Wednesdays and Fridays most weeks of the year. This also includes variation within the weekend due to the tendency to refrain from eating before the Sunday morning church service. This variation within the week may be heightened during Lent, when the increase in church services and guidelines to avoid food prior to certain services can alter eating patterns beyond the decrease in MDE products. The justification for having participants keep a 7-day FR as opposed to a 3- or 4-day FR was to attempt to capture this variation within the week. This was also the reason for asking participants to aim to keep the FR on consecutive days. However, the tradeoff of this design was that the separate FR entries cannot be treated as independent data, meaning that they do not provide a reliable estimate of within-person variation for which to adjust but rather have to be treated as one single collection. Moreover, given the aforementioned issues with the recording, interpretation, entry, and computation processes, the consecutive days of recording could lead to inflation of errors among individuals who, either by habit or because of the burden of recording their food intake, tended to consume and report the same foods across days within the weeks of FR recording. This could have contributed to the appearance of the outliers in the FR data that led to spuriously significant main and interactive effects in Biomarker Model II.

Together, these issues of FR recording, interpretation, and entry errors; behavior modification; and within-person variation provide good reason to doubt that FRs, or at least undocumented FRs, offer substantially better estimates of true nutrient and food intake densities than FFQs. These findings corroborate previous suggestions that FRs are not an ideal reference instrument from which to calibrate FFQ data (Kipnis et al. 1999; Kipnis et al. 2001), and this study suggests that this is particularly the case when measuring dietary change. Moving forward, researchers may want to consider alternative options for measuring diet. Currently the gold standard method of measuring usual diet to reduce errors is to administer multiple random 24-hour recalls, which are less cognitively challenging than FFQs but are still retrospective and, hence, not likely to influence consumption behavior. Though this method can be biased by substantial within-person variation and may not adequately capture foods consumed only episodically, a variety of modeling strategies have been proposed to combine this method with data from FFQs to control for within-person error and estimate the probability of consuming a given food (Dodd et al. 2006; Haubrock et al. 2011; Kipnis et al. 2009). The main challenge of this method in the OC population would be balancing efforts to capture within week (Wednesdays and Fridays relative to other weekdays) and within weekend (Sundays versus Saturdays) dietary variation with the burden of too many 24-hour recalls in a short period. Nonetheless, multiple random 24-hour recalls, ideally in combination with FFQs, may be worth considering as an alternative to FRs in future studies.

Study limitations

Aside from the aforementioned reasons for questioning the reliability of FR data relative to FFQ data in this population, there are other limitations of this study and of the study instruments that need to be considered in the interpretation of this study's findings. One limitation, as alluded to above, includes the inability to adjust for the within-person day-to-day variability that adds a source of measurement error to the FR data. The correlation between measures of dietary change could probably have been strengthened by correcting for within-person variation if multiple independent measures within each period were collected, but no such measures were available for this study. Having a second FR or splitting the FR across different weeks within each collection period may have more closely captured some degree of week-to-week variation and would have allowed for the adjustment of some of the within-person variation.

Another limitation includes the distinct systems of defining the food variables used for the analyses. Because foods from the NCC dataset could not easily be disaggregated into the MPED variables generated from the FFQ dataset, the variables for meat, dairy, and fish were not defined equivalently. These differences (e.g., the inclusion of both lean and non-lean meat in the meat variable or the inclusion of non-disaggregated dairy-based desserts in the dairy variable) could have contributed to the inconsistencies in the ranking of individuals by degree of MDEΔ score. These issues also meant that this study was not only comparing the quality of each instrument to estimate nutrient and food densities but was also comparing methods of defining and grouping variables. Yet it is encouraging that, despite these distinct processes of variable generation, the two MDEΔ scores were strongly correlated and the results from the food and biomarker regression analyses generally led to similar support for a relationship between MDEΔ and concurrent dietary shifts and between MDEΔ and drops in total and LDL cholesterol.

Another study limitation is the potential for inter-individual variation in the timing of recording the FR relative to the FFQ to result in discrepancies between the data sources. Individuals were able to choose which week within the pre-Lenten and Lenten periods preceding each biomarker collection to record their FR; the FFQs were then administered at each biomarker collection. Thus, the period between recording the FR and completing the FFQ could have ranged from one to five weeks across participants. As FFQs tend to be biased by more recent consumption patterns (Thompson and Subar 2013; Willett 2013), there may be differences arising from differential degrees of gap between the time of the FR and the FFQ. Additionally, individuals may have chosen particularly easy weeks to record their FR, and their recordings may not represent the degree of variation they may have experiences on weeks when they attended events, ate out more frequently, or were too busy to complete the FR. Finally, because all study participants recorded their FRs and completed their FFQs in the same sequence, this study cannot rule out the possibility that some of the estimated change in diet were due to sequencing effects (i.e., becoming more or less careful with completion of the instrument the second time around). Such effects may be exaggerated in the FR data relative to the FFQ data due to the greater participant burden of completing FRs.

An important statistical issue to consider is that the moderate correlations among concurrent dietary changes make it difficult to isolate the effects of shifts in any one food, nutrient, or food group. Thus, even before other food intake variables were introduced into the biomarker models, the regression analyses for Biomarker Model I and IB were inherently testing not only for the effects of shifts in MDE products but also indirectly for the effects of shifts in plant-based foods that are correlated with MDE changes. Such correlations also introduce issues of multicollinearity in models that added main and interactive effects for non-MDE foods, and this can inflate standard errors and make coefficients less stable (Willett 2013). To assess the degree to which this may have been a problem, a post-hoc assessment of the variance inflation factors (VIFs) for all of the covariates, including interaction terms, in the each of the biomarker models was performed. With the exception of meat alternatives in the FR data, most VIFs were below 10, which, in combination with stable coefficients across models that adjusted for different plant-based foods, suggests that multicollinearity was not a huge concern in these analyses. Nonetheless, this issue may have been at least partly responsible for the major reduction in the association between MDEΔ and total and LDL cholesterol when main and interactive effects of legume intake were added to the FR- Biomarker II models, as well as other differences in the coefficients and standard errors across the FR Biomarker II models that included different plant-based foods with varying degrees of correlation with MDEΔ score. Issues of multicollinearity, particularly in combination with a limited sample size, also prevented the simultaneous adjustment of more than a few dietary variables in the food and biomarker models at a time, hindering the ability to more appropriately isolate the effects of changes in specific plant-based foods relative to MDE change.

Ultimately, small sample size and inadequate power are the largest limitations of this study. The study may be underpowered such that some associations and interactions would not be detected even if both data sources were accurate and precise. As it stands, the models presented herein may have included more variables than for which there is adequate statistical power. Nevertheless, the fact that shifts in total and LDL cholesterol were apparent using both datasets despite this study being so underpowered, suggests that those associations are real.

However, there is no guarantee that there are not some false negatives amidst the null associations between either MDEΔ score and other health biomarkers or null interactions between MDEΔ score and changes in non-MDE food groups. Given that diet can never be measured without error, substantially larger sample sizes are needed to more reliably compare the performance of the FFQ and undocumented FR for testing the main and interactive effects of the temporary dietary shifts of OCs on health markers.

CONCLUSIONS

This study aimed to compare the degree to which study results might differ when using undocumented 7-day FRs versus standard FFQs for 1) measuring the dietary and nutritional composition of the intermittent MDE-restricted and unrestricted diets of a sample of OCs in the US; 2) estimating the degree of change in MDE foods and corresponding changes in calories and non-MDE foods experienced by sample of US-based OCs during the Lenten MDE fast; and 3) relating MDE restrictions and concurrent dietary changes to shifts in common markers of cardiometabolic health. Even though the two dietary assessment instruments estimated slightly different standardized mean intake levels for many foods and nutrients, most of the FR- and FFQ-derived food and nutrient measures were moderately to highly correlated. Both data sources led to similar conclusions that Lenten MDE restrictions are associated with small but statistically significant increases in legumes, meat alternatives, nuts and seeds, and unsaturated discretionary oils. Contrary to previous studies that reported stronger estimates of diet-disease associations when using FR data compared to when using FFQ data, this study found few differences between the two dietary assessment instruments when testing associations between concurrent dietary changes and shifts in measures of body fat, blood lipids, glucose metabolism, or inflammation.

Both of the FR- and FFQ-derived data provide evidence that short-term reductions in MDE products are associated with decreases in total and LDL cholesterol that are at least partially independent of concurrent reductions in weight and calories and shifts in plant-based foods, though limited power may have prevented identification of main and interactive effects of correlated dietary changes. Where hints of effect modification did occur, they generally occurred with the FR-derived data and appeared to be caused by influential outliers. Further research with larger study populations is needed to more thoroughly investigate if and how physiological responses to MDE restrictions depend on variations in plant-based MDE replacements and to assess any differential health effects of nutritionally distinct MDE foods. Such studies may want to consider combining random 24-hour recalls and FFQs to obtain more robust estimates of changes in MDE and non-MDE foods.

CHAPTER 4 TABLES

Table 4.1. Demographic, lifestyle, and dietary characteristics of study participants (n=94).

	Entire Sample (n=94)
	Mean (range)
Age (years)	46.7 (19.1 to 73.2)
Average weekly MET hours [a]	20.5 (0 to 128.4)
Average change in weekly MET hours [a]	-2.8 (-57.5 to 30.5)
	%
% Male	43.6%
% Self-reported race as "White or Caucasian"	93.6%
% Annual income ≥ $100,000[b]	46.1%
% 4-year college degree or higher	92.5%
% Orthodox Christian	95.7%
% Convert Orthodox Christians	76.7%
% Self-rated health "Good" to "Excellent"	91.5%
% Reporting mostly sedentary occupations	53.2%
% Current Smokers	8.5%
% Taking medications for dyslipidemia	6.4%
% Taking medications for hypertension	7.4%
% Taking medications for diabetes	3.2%
% Regularly taking anti-inflammatory medications	8.5%
% Vegan, Vegetarian, or Pesco-Vegetarian	5.3%

[a] Metabolic equivalent values for common moderate to vigorous physical activities

[b] Estimated from the 89 participants who responded to the question on household income.

Table 4.2. Baseline health measures and proportions of participants with suboptimal biomarker levels (n=94).

Health Biomarker		Pre-Lent	Lent
BMI (kg/m^2)	Mean (range)	27.0 (18.1 to 43.8)	26.7 (17.5 to 44.3)
	% above optimal (≥ 25 m/kg^2)	63.8%	62.8%
Body Fat Percentage [a]	Mean (range)	33.4 (7.2 to 55.2)	32.5 (6.7 to 56.0)
	% above optimal (age and sex-specific)	68.5%	65.2%
Total Cholesterol (mg/dL)	Mean (range)	183.1 (103.0 to 275.0)	168.6 (101.0 to 265.0)
	% above optimal (≥ 200 mg/dL)	26.6%	10.6%
LDL-Cholesterol (mg/dL) [b]	Mean (range)	108.3 (49.0 to 189.8)	97.5 (47.4 to 175.2)
	% above optimal (≥ 100 mg/dL)	57.0%	43.0%
HDL-Cholesterol (mg/dL)	Mean (range)	55.5 (18.0 to 98.0)	51.9 (21.0 to 94.0)
	% below optimal [≤ 40 (men) or ≤ 50 (women)]	22.6%	32.3%
Triglycerides (mg/dL)	Mean (range)	97.3 (45.0 to 261.0)	98.0 (45.0 to 440.0)
	% above optimal (≥ 100 mg/dL)	34.0%	36.2%
TC:HDL	Mean (range)	3.7 (2.0 to 9.4)	3.5 (1.8 to 7.9)
	% above optimal (≥ 4.5)	18.1%	21.3%
Glucose (mg/dL)	Mean (range)	94.1 (68.0 to 166.0)	94.6 (78.0 to 161.0)
	% above optimal (≥ 100 mg/dL)	28.7%	27.7%
Insulin (µU/mL) [c]	Mean (range)	9.8 (1.6 to 99.3)	8.1 (1.5 to 40.6)
	% above optimal (≥ 12 µU/mL)	16.5%	16.5%
HOMA-IR [c]	Mean (range)	2.5 (0.3 to 27.5)	2.0 (0.3 to 11.4)
	% above optimal (≥ 2.5)	22.8%	20.3%
C-reactive protein (mg/L) [d]	Mean (range)	1.4 (0.1 to 4.9)	1.4 (0.1 to 6.8)
	% above optimal (≥ 3 mg/dL)	10.1%	8.9%

[a] Excluding two individuals with missing body fat measurements.

[b] Excluding one individual without reliable LDL measure due to triglycerides>400 mg/dL at time 2.

[c] Excluding 15 individuals with missing insulin measures at one or both time points.

[d] Excluding 15 individuals with missing CRP measures or inconsistent use of anti-inflammatory medication.

Table 4.3a. Comparison of mean calories and nutrient densities (standardized to 2000 kcal) for FR and FFQ data (n=94).

Nutrient	Time 1 (Pre-Lent)			Time 2 (Lent)			Difference: Time 2 - Time 1		
	FFQ Mean ± SD	Food Record Mean ± SD	*r*	FFQ Mean ± SD	Food Record Mean ± SD	*r*	FFQ Mean ± SD	Food Record Mean ± SD	*r*
Kilocalories (males, n=41)	2347 ± 820	2416 ± 448	0.27	1745 ± 553	2069 ± 540*	0.27	-602 ± 628	-347 ± 530	0.24
Kilocalories (females, n=53)	1973 ± 657	1891 ± 410	0.35	1540 ± 556	1712 ± 419	0.50	-433 ± 402	-179 ± 353**	0.10
Total Protein (g)	84.6 ± 17.8	81.9 ± 17.1	0.51	70.3 ± 15.1	68.5 ± 18.7	0.70	-14.3 ± 15.3	-13.4 ± 15.0	0.24
Animal Protein (g)	54.3 ± 22.3	51.0 ± 20.3	0.60	25.9 ± 21.9	24.6 ± 25.4	0.88	-28.5 ± 21.0	-26.4 ± 19.7	0.61
Plant Protein (g)	30.2 ± 9.0	30.8 ± 8.0	0.56	44.4 ± 12.4	43.9 ± 13.0	0.75	14.2 ± 11.3	13.1 ± 11.0	0.65
Total Fat (g)	82.8 ± 14.9	88.8 ± 16.4**	0.71	73.3 ± 18.1	80.2 ± 15.6**	0.66	-9.5 ± 15.1	-8.6 ± 13.8	0.34
Saturated Fat (g)	26.0 ± 5.8	29.0 ± 7.7**	0.67	18.0 ± 6.6	19.8 ± 7.9*	0.75	-8.0 ± 7.1	-9.2 ± 8.7	0.66
Monounsaturated Fat (g)	30.4 ± 6.3	32.8 ± 8.0**	0.66	28.6 ± 8.3	31.0 ± 8.2**	0.52	-1.8 ± 6.8	-1.9 ± 8.0	0.12
Polyunsaturated Fat (g)	19.1 ± 4.6	19.7 ± 4.7	0.48	20.8 ± 5.0	23.5 ± 5.5**	0.41	1.7 ± 4.7	3.8 ± 5.9*	0.28
Total Carbohydrates (g)	223.9 ± 51.4	217.0 ± 47.3	0.80	270.2 ± 52.9	256.8 ± 50.0**	0.80	46.3 ± 41.8	39.8 ± 36.8	0.53
Total Sugars (g)	94.5 ± 33.6	78.1 ± 26.0**	0.71	100.2 ± 29.5	80.0 ± 26.7**	0.65	5.7 ± 25.2	1.8 ± 19.5	0.12
Added Sugars (g)	51.0 ± 24.3	50.6 ± 26.3	0.86	53.0 ± 23.8	58.3 ± 25.3**	0.82	2.0 ± 23.2	7.8 ± 24.2**	0.87
Fiber (g)	22.9 ± 7.3	23.3 ± 7.3	0.55	32.4 ± 11.2	31.4 ± 9.9	0.68	9.5 ± 9.4	8.1 ± 7.6	0.55

r = Pearson's Correlation Coefficient

*Significant difference between FR and FFQ averages at the 0.01 level; **Significant difference between FR and FFQ averages at the 0.001 level.

Table 4.3b. Comparison of MDE scores and food intake densities (standardized to 2000 kcal) for FR and FFQ data (n=94).

Food Component	Time 1 (Pre-Lent)			Time 2 (Lent)			Difference: Time 2 - Time 1		
	FFQ Mean ± SD	Food Record Mean ± SD	*r*	FFQ Mean ± SD	Food Record Mean ± SD	*r*	FFQ Mean ± SD	Food Record Mean ± SD	*r*
MDE Score [a]	3.0 ± 1.1	3.0 ± 1.2	0.69	1.2 ± 1.3	1.1 ± 1.6	0.90	-1.8 ± 1.3	-2.0 ± 1.4	0.71
All Meat (oz) [b]	4.1 ± 2.5	3.9 ± 2.2	0.60	1.0 ± 1.8	1.0 ± 2.2	0.88	-3.1 ± 2.3	-2.9 ± 2.2	0.54
Red Meat (oz)	2.1 ± 1.9	1.2 ± 1.2**	0.50	0.5 ± 0.8	0.3 ± 0.7*	0.68	-1.6 ± 1.7	-0.9 ± 1.1**	0.41
Poultry (oz)	1.4 ± 1.1	1.7 ± 1.4*	0.51	0.4 ± 0.8	0.5 ± 1.1	0.83	-1.0 ± 1.1	-1.2 ± 1.5	0.37
Processed Meat (oz)	0.6 ± 0.6	1.0 ± 1.0**	0.54	0.1 ± 0.4	0.2 ± 0.6	0.88	-0.5 ± 0.5	-0.8 ± 1.0*	0.46
Fish & Shellfish (oz)	0.9 ± 0.8	0.8 ± 0.9	0.64	1.3 ± 1.2	1.4 ± 1.6	0.69	0.4 ± 1.1	0.6 ± 1.6	0.57
All Dairy (cup eq) [c]	1.1 ± 0.6	1.3 ± 0.7	0.60	0.7 ± 0.8	0.6 ± 0.9	0.83	-0.5 ± 0.7	-0.7 ± 0.9*	0.60
Milk (cup eq)	0.5 ± 0.4	0.3 ± 0.5**	0.69	0.3 ± 0.5	0.2 ± 0.5**	0.90	-0.2 ± 0.4	-0.1 ± 0.4	0.39
Yogurt (cup eq)	0.2 ± 0.2	0.1 ± 0.2**	0.63	0.1 ± 0.2	0.05 ± 0.1	0.74	-0.1 ± 0.2	-0.03 ± 0.2	0.57
Cheese (cup eq)	0.5 ± 0.3	0.8 ± 0.5**	0.47	0.3 ± 0.3	0.3 ± 0.5	0.65	-0.2 ± 0.3	-0.5 ± 0.7**	0.47
Eggs (oz eq)	0.7 ± 0.8	0.6 ± 0.6	0.73	0.3 ± 0.7	0.3 ± 0.6	0.80	-0.4 ± 0.8	-0.4 ± 0.6	0.71
Whole Grain (oz eq)	1.5 ± 1.3	2.1 ± 1.4**	0.58	2.0 ± 1.6	2.6 ± 1.5**	0.52	0.5 ± 1.4	0.5 ± 1.4	0.21
Refined Grain (oz eq)	3.8 ± 1.7	4.8 ± 2.3**	0.73	4.7 ± 2.0	5.6 ± 2.5**	0.55	0.9 ± 1.5	0.8 ± 2.1	0.37
Legumes (cup eq)	0.1 ± 0.1	0.2 ± 0.2	0.35	0.3 ± 0.3	0.4 ± 0.4*	0.66	0.2 ± 0.3	0.2 ± 0.3	0.43
Meat Alternatives (oz eq)	0.3 ± 0.5	0.2 ± 0.5	0.20	0.6 ± 0.7	0.6 ± 1.0	0.39	0.3 ± 0.6	0.4 ± 1.1	0.29
Non-dairy milks (cup)	0.2 ± 0.4	0.2 ± 0.3	0.74	0.3 ± 0.5	0.4 ± 0.5	0.58	0.1 ± 0.5	0.2 ± 0.3	0.33
Nuts & Seeds (oz eq)	1.4 ± 1.2	1.3 ± 1.3	0.48	2.2 ± 1.8	2.3 ± 2.0	0.31	0.9 ± 1.5	1.1 ± 1.9	0.28
Fruit (cup eq) [d]	0.9 ± 0.9	0.6 ± 0.7**	0.59	1.2 ± 0.9	0.8 ± 0.7**	0.67	0.3 ± 0.7	0.2 ± 0.6	0.21
Vegetables (cup eq) [e]	1.9 ± 1.2	1.5 ± 0.8**	0.52	2.6 ± 1.7	1.7 ± 1.0**	0.54	0.7 ± 1.1	0.2 ± 0.7**	0.36
White Potatoes (cup eq)	0.4 ± 0.2	0.2 ± 0.2**	0.51	0.5 ± 0.3	0.3 ± 0.3**	0.44	0.1 ± 0.3	0.1 ± 0.3	0.27
Discretionary Oil (g) [f]	29.1 ± 9.4	47.2 ± 13.4**	0.43	35.6 ± 12.2	57.1 ± 15.6**	0.42	6.5 ± 11.4	9.8 ± 17.1	0.33

r = Pearson’s Correlation Coefficient; [a] MDE score represents the number of meat, dairy, and egg servings; [b] Includes organ meat in addition to red meat, processed meat, and poultry; [c] Includes servings of dairy from dairy-based desserts (incorporated into the milk variable in the FFQ data); [d] Excluding fruit juice; [e] Excluding white potatoes; [f] Calculated as the total fat – (trans-fat + saturated fat) in the FR data; *Significant difference between FR and FFQ averages at the 0.01 level; **Significant difference between FR and FFQ averages at the 0.001 level.

Table 4.4. Additive change in calories, fish and plant-based foods in relation to the FR MDEΔ Score (FR Food Model) or FFQ MDEΔ Score (FFQ Food Model) (n=94).

	FFQ Data			Food Record Data		
	β [a] (95% CI)	p-value	Adj-R^2	β [a] (95% CI)	p-value	Adj-R^2
Energy (kilocalories)	-97 (-157 to -36)	0.002*	0.49	-27 (-96 to 42)	0.44	0.18
Fish (oz/2,000 kcal)	0.001 (-0.18 to 0.18)	1.00	0.17	0.20 (0.01 to 0.38)	0.04	0.28
Whole Grain (oz eq/2,000 kcal)	0.25 (0.03 to 0.46)	0.02	0.12	0.27 (0.10 to 0.43)	0.002*	0.27
Refined Grain (oz eq/2,000 kcal)	0.26 (0.01 to 0.51)	0.04	0.02	0.13 (-0.15 to 0.42)	0.37	0.13
Legumes (cup eq/2,000 kcal)	0.09 (0.05 to 0.13)	<0.0001*	0.25	0.09 (0.05 to 0.12)	<0.0001*	0.08
Meat Alternatives (oz eq/2,000 kcal)	0.20 (0.12 to 0.29)	<0.0001*	0.22	0.21 (0.08 to 0.33)	0.001*	0.19
Nuts & Seeds (oz eq/2,000 kcal)	0.59 (0.35 to 0.84)	<0.0001*	0.19	0.67 (0.38 to 0.96)	<0.0001*	0.31
Fruit (cup eq/2,000 kcal) [b]	0.14 (0.02 to 0.26)	0.03	0.13	0.10 (0.03 to 0.16)	0.004*	0.24
Vegetables (cup eq/2,000 kcal) [c]	0.22 (0.05 to 0.39)	0.01	0.15	0.07 (-0.02 to 0.16)	0.13	0.21
White Potatoes (cup eq/2,000 kcal)	0.02 (-0.02 to 0.06)	0.30	0.13	0.02 (-0.02 to 0.05)	0.29	0.22
Discretionary Oil (g/2,000 kcal)	3.5 (1.7 to 5.4)	0.0002*	0.21	5.7 (3.5 to 7.9)	<0.0001*	0.40
Added Sugar (g/2,000 kcal)	3.1 (0.1 to 6.2)	0.04	0.31	1.3 (-1.1 to 3.8)	0.28	0.33

[a] Beta coefficients represent the additive change in each variable of interest relative to a 1 serving decrease in MDE products (measured by FR or FFQ), controlling for the respective MDE1 score, baseline intake of the dependent nutrient/food variable, age, sex, baseline BMI, baseline calories, change in calories, average METs, and change in METs; [b] Excluding fruit juice; [c] Excluding white potatoes; *Significant at the Bonferroni-adjusted α-level of 0.004.

Table 4.5. Multiple linear regression analysis results for relationship between percent change in biomarkers and FR MDEΔ Score (FR Biomarker I Model) or FFQ MDEΔ Score (FFQ Biomarker I Model) (n=94).

	FFQ Data			Food Record Data		
	β [a] (95% CI)	p-value	Adj-R^2	β [a] (95% CI)	p-value	Adj-R^2
BMI	-0.3% (-0.9% to 0.2%)	0.23	0.13	-0.4% (-0.9% to 0.1%)	0.16	0.14
Body Fat Percentage [b]	-0.4% (-2.2% to 1.3%)	0.62	0.04	-0.6% (-2.1% to 0.9%)	0.43	0.05
Total Cholesterol	-3.7% (-5.5% to -1.9%)	<0.0001*	0.28	-2.8% (-4.4% to -1.1%)	0.001*	0.26
LDL-Cholesterol [c]	-3.6% (-6.0% to -1.2%)	0.004*	0.24	-3.3% (-5.2% to -1.4%)	0.001*	0.22
HDL-Cholesterol	-2.4% (-5.2% to 0.5%)	0.10	0.14	-2.6% (-5.1% to -0.2%)	0.04	0.16
Triglycerides	-6.2% (-14.6% to 2.2%)	0.15	0.14	-1.8% (-7.9% to 4.4%)	0.57	0.14
Glucose	-1.0% (-3.4% to 1.5%)	0.43	0.27	-0.9% (-2.5% to 0.8%)	0.31	0.25
Insulin [d]	-5.1% (-14.4% to 4.3%)	0.28	0.08	-6.2% (-17.0% to 4.7%)	0.26	0.08
HOMA-IR [d]	-8.8% (-22.3% to 4.6%)	0.20	0.06	-8.9% (-23.1% to 5.3%)	0.21	0.06
C-reactive protein [e]	1.9% (-17.6% to 21.5%)	0.84	0.19	-2.7% (-20.6% to 15.2%)	0.77	0.20

[a] Beta coefficients represent the percent change in biomarker for a one serving decrease in MDE products (measured by FR or FFQ), controlling for age, sex, baseline BMI, average METs, change in METs, baseline biomarker value, baseline MDE score, baseline calories, change in calories, and number of days on restricted diet.
[b] Excluding two individuals with missing body fat measurements.
[c] Excluding one individual without reliable LDL measure due to triglycerides>400 mg/dL at time 2.
[d] Excluding 15 individuals with missing insulin measures at one or both time points.
[e] Excluding 15 individuals with missing CRP measures or inconsistent use of anti-inflammatory medication.
* Significant at a Bonferroni-adjusted α-level of 0.005.
HOMA-IR=Homeostatic Model Assessment of Insulin Resistance: [Glucose (mg/dL) x Insulin (uU/mL)/405].

Table 4.6. Multiple linear regression analysis results for relationship between percent change in biomarkers and FR MDEΔ Score (FR Biomarker IB Model) or FFQ MDEΔ Score (FFQ Biomarker IB Model) with further adjustment for weight loss (n=94).

	Food Frequency Questionnaire Data			Food Record Data		
	β [a] (95% CI)	p-value	Adj-R^2	β [a] (95% CI)	p-value	Adj-R^2
Total Cholesterol						
MDEΔ Score	-3.1% (-4.8% to -1.5%)	0.0003*	0.37	-2.3% (-3.8% to -0.8%)	0.004*	0.32
Weight (1 lb reduction)	-0.7% (-1.2% to -0.3%)	0.003*		-0.8% (-1.3% to -0.2%)	0.005	
LDL Cholesterol[b]						
MDEΔ Score	-2.9% (-5.5% to -0.2%)	0.04	0.28	-2.7% (-4.9% to -0.5%)	0.02	0.24
Weight (1 lb reduction)	-0.7% (-1.4% to -0.054%)	0.04		-0.7% (-1.3% to -0.07%)	0.03	

[a] Beta coefficients represent the percent change in biomarker for a one serving decrease in MDE products (measured by FR or FFQ), controlling for age, sex, baseline BMI, average METs, change in METs, baseline biomarker value, baseline MDE score, baseline calories, change in calories, and number of days on restricted diet.
[b] Excluding one individual without reliable LDL measure due to triglycerides>400 mg/dL at time 2.
* Significant at a Bonferroni-adjusted α-level of 0.005.

Table 4.7a. Relationship between percent change in total cholesterol and FR MDEΔ Score (FR Biomarker II Model) or FFQ MDEΔ Score (FFQ Biomarker II Model) when including main and interactive effects for calories, fish, and plant-based foods (n=94).

	FFQ Data			Food Record Data		
TOTAL CHOLESTEROL	β^a (95% CI)	p-value	Adj-R^2	β^a (95% CI)	p-value	Adj-R^2
MDEΔ Score (1 serving reduction)	-3.6% (-5.8% to -1.5%)	0.001*	0.37	-2.6% (-4.2% to -1.0%)	0.002*	0.32
Kilocalories (100 kcal decrease)	-0.15% (-1.1% to 0.8%)	0.75		0.0% (-1.0% to 0.9%)	1.00	
Interaction	0.12% (-0.2% to 0.5%)	0.51		0.2% (-0.2% to 0.5%)	0.40	
MDEΔ Score (1 serving reduction)	-3.2% (-4.9% to -1.5%)	0.0004*	0.42	-2.5% (-4.0% to -1.0%)	0.002*	0.32
Fish (1 oz increase)	2.9% (-0.6% to 6.4%)	0.10		-0.1% (-3.7% to 3.5%)	0.97	
Interaction Term	-0.2% (-1.8% to 1.4%)	0.81		0.3% (-0.8% to 1.4%)	0.57	
MDEΔ Score (1 serving reduction)	-3.1% (-5.1% to -1.2%)	0.002*	0.39	-3.1% (-5.0% to -1.3%)	0.001*	0.36
Whole Grain (1 oz eq increase)	-0.2% (-3.3% to 2.9%)	0.90		-5.2% (-9.3% to -1.2%)	0.01	
Interaction Term	0.4% (-0.9% to 1.6%)	0.55		1.9% (0.4% to 3.4%)	0.01	
MDEΔ Score (1 serving reduction)	-3.2% (-4.9% to -1.5%)	0.0004*	0.37	-2.0% (-3.6% to -0.4%)	0.02	0.33
Refined Grain (1 oz eq increase)	-0.8% (-3.8% to 2.2%)	0.61		1.2% (-0.4% to 2.9%)	0.15	
Interaction Term	0.2% (-1.2% to 1.5%)	0.80		-0.6% (-1.3% to 0.1%)	0.07	
MDEΔ Score (1 serving reduction)	-2.5% (-4.5% to -0.5%)	0.02	0.38	0.1% (-1.7% to 1.8%)	0.94	0.44
Legumes (1 cup eq increase)	-7.6% (-27.6% to 12.5%)	0.46		10.9% (-1.8% to 23.5%)	0.09	
Interaction Term	0.5% (-5.2% to 6.3%)	0.86		-9.2% (-14.5% to -3.8%)	0.001*	
MDEΔ Score (1 serving reduction)	-2.5% (-4.3% to -0.7%)	0.007	0.39	-2.9% (-4.3% to -1.5%)	<0.0001*	0.38
Meat Alternatives (1 oz eq increase)	1.0% (-6.5% to 8.4%)	0.80		-3.3% (-7.6% to 1.0%)	0.13	
Interaction Term	-1.6% (-4.5% to 1.3%)	0.28		1.8% (0.6% to 3.0%)	0.004*	
MDEΔ Score (1 serving reduction)	-3.0% (-5.0% to -1.1%)	0.003*	0.35	-1.6% (-3.4% to 0.1%)	0.07	0.33
Nuts & Seeds (1 oz eq increase)	0.4% (-2.0% to 2.8%)	0.73		-1.0% (-2.8% to 0.7%)	0.24	
Interaction Term	-0.2% (-1.1% to 0.7%)	0.63		0.0% (-0.6% to 0.5%)	0.93	
MDEΔ Score (1 serving reduction)	-3.0% (-5.0% to -1.0%)	0.004*	0.37	-2.0% (-3.7% to -0.2%)	0.03	0.37
Fruit & Vegetables (1 cup eq increase)	-0.9% (-3.2% to 1.5%)	0.48		-5.2% (-9.7% to -0.6%)	0.03	
Interaction Term	0.2% (-0.7% to 1.1%)	0.71		1.0% (-0.6% to 2.6%)	0.23	
MDEΔ Score (1 serving reduction)	-2.5% (-4.5% to -0.6%)	0.01	0.37	-1.8% (-3.6% to -0.1%)	0.04	0.33
Oil (10 gram increase)	-0.04% (-0.3% to 0.3%)	0.79		-1.1% (-2.9% to 0.8%)	0.26	
Interaction Term	-0.04% (-0.1% to 0.1%)	0.45		0.02% (-0.5% to 0.6%)	0.94	
MDEΔ Score (1 serving reduction)	-3.0% (-4.7% to -1.2%)	0.001*	0.36	-2.1% (-3.6% to -0.6%)	0.008	0.31
Added Sugar (10 gram increase)	-0.05% (-0.2% to 0.1%)	0.52		-0.6% (-3.0% to 1.9%)	0.66	
Interaction Term	-0.003% (-0.1% to 0.1%)	0.92		0.2% (-0.7% to 1.1%)	0.64	

[a] Adjusting for age, sex, baseline BMI, change in weight, average METs, change in METs, baseline biomarker value, baseline MDE score, baseline calories, change in calories, and number of days on restricted diet.

* Significant at a Bonferroni-adjusted α-level of 0.005.

Table 4.7b. Relationship between percent change in LDL cholesterol and FR MDEΔ Score (FR Biomarker II Model) or FFQ MDEΔ Score (FFQ Biomarker II Model) when including main and interactive effects for calories, fish, and plant-based foods (n=93).

	FFQ Data			Food Record Data		
LDL CHOLESTEROL	β[a] (95% CI)	p-value	Adj-R^2	β[a] (95% CI)	p-value	Adj-R^2
MDEΔ Score (1 serving reduction)	-3.3% (-6.2% to -0.3%)	0.03	0.28	-2.3% (-4.8% to 0.1%)	0.06	0.24
Kilocalories (100 kcal decrease)	-0.2% (-1.4% to 0.9%)	0.70		1.0% (-0.4% to 2.4%)	0.15	
Interaction	0.08% (-0.3% to 0.5%)	0.71		-0.2% (-0.6% to 0.2%)	0.37	
MDEΔ Score (1 serving reduction)	-3.1% (-6.0% to -0.1%)	0.04	0.28	-2.8% (-5.2% to -0.3%)	0.03	0.22
Fish (1 oz increase)	1.4% (-5.2% to 7.9%)	0.68		-1.5% (-6.0% to 2.9%)	0.50	
Interaction Term	0.2% (-2.3% to 2.7%)	0.88		0.5% (-0.7% to 1.6%)	0.42	
MDEΔ Score (1 serving reduction)	-2.8% (-5.4% to -0.1%)	0.04	0.33	-4.3% (-6.8% to -1.8%)	0.0009*	0.33
Whole Grain (1 oz eq increase)	-0.02% (-4.3% to 4.3%)	0.99		-8.7% (-13.2% to -4.2%)	0.0002*	
Interaction Term	0.5% (-1.2% to 2.2%)	0.55		3.4% (1.7% to 5.1%)	0.0001*	
MDEΔ Score (1 serving reduction)	-3.7% (-6.4% to -1.1%)	0.007	0.28	-2.8% (-5.0% to -0.7%)	0.01	0.22
Refined Grain (1 oz eq increase)	-1.9% (-6.6% to 2.7%)	0.42		-0.5% (-2.8% to 1.9%)	0.70	
Interaction Term	1.2% (-0.7% to 3.1%)	0.22		0.3% (-0.7% to 1.3%)	0.55	
MDEΔ Score (1 serving reduction)	-2.6% (-5.5% to 0.3%)	0.08	0.30	-1.4% (-4.5% to 1.6%)	0.35	0.24
Legumes (1 cup eq increase)	-26.1% (-55.8% to 3.7%)	0.09		1.3% (-16.8% to 19.4%)	0.89	
Interaction Term	7.8% (-0.9% to 16.4%)	0.08		-3.9% (-11.6% to 3.8%)	0.32	
MDEΔ Score (1 serving reduction)	-2.1% (-5.2% to 0.9%)	0.17	0.30	-3.2% (-5.6% to -0.7%)	0.01	0.24
Meat Alternatives (1 oz eq increase)	-1.1% (-14.8% to 12.6%)	0.88		-3.6% (-10.0% to 2.7%)	0.26	
Interaction Term	-1.1% (-6.4% to 4.2%)	0.67		1.6% (-0.144% to 3.3%)	0.07	
MDEΔ Score (1 serving reduction)	-2.6% (-5.3% to 0.2%)	0.07	0.27	-2.2% (-4.6% to 0.3%)	0.08	0.24
Nuts & Seeds (1 oz eq increase)	-1.1% (-5.1% to 2.9%)	0.60		-2.8% (-5.7% to 0.1%)	0.06	
Interaction Term	0.3% (-1.2% to 1.8%)	0.72		0.7% (-0.1% to 1.5%)	0.08	
MDEΔ Score (1 serving reduction)	-3.2% (-5.7% to -0.7%)	0.01	0.33	-2.3% (-4.6% to -0.1%)	0.04	0.27
Fruit & Vegetables (1 cup eq increase)	-3.1% (-5.9% to -0.3%)	0.03		-6.5% (-11.8% to -1.3%)	0.02	
Interaction Term	1.1% (0.1% to 2.1%)	0.03		1.2% (-0.5% to 2.9%)	0.15	
MDEΔ Score (1 serving reduction)	-2.2% (-5.0% to 0.5%)	0.11	0.29	-2.3% (-4.5% to -0.1%)	0.04	0.25
Oil (10 gram increase)	-0.3% (-0.9% to 0.17%)	0.19		-2.4% (-5.4% to 0.6%)	0.11	
Interaction Term	0.1% (-0.1% to 0.3%)	0.57		0.6% (-0.3% to 1.4%)	0.20	
MDEΔ Score (1 serving reduction)	-2.6% (-5.3% to 0.1%)	0.06	0.27	-2.4% (-4.7% to -0.1%)	0.04	0.23
Added Sugar (10 gram increase)	-0.08% (-0.3% to 0.1%)	0.49		-0.1% (-3.3% to 3.1%)	0.94	
Interaction Term	0.008% (-0.1% to 0.1%)	0.84		0.08% (-1.1% to 1.3%)	0.89	

[a] Adjusting for age, sex, baseline BMI, change in weight, average METs, change in METs, baseline biomarker value, baseline MDE score, baseline calories, change in calories, and number of days on restricted diet.

* Significant at a Bonferroni-adjusted α-level of 0.005.

Table 4.8. Multiple linear regression analysis results for relationship between percent change in total and LDL cholesterol and concurrent change in FR MDE servings (FR Biomarker Model III) or FFQ MDE servings (FFQ Biomarker Model III) (n=94).

	FFQ Data			Food Record Data		
	β [a] (95% CI)	p-value	Adj-R^2	β [a] (95% CI)	p-value	Adj-R^2
Total Cholesterol						
Meat (1 serving reduction)	-1.3% (-4.8% to 2.1%)	0.44	0.36	-1.1% (-4.2% to 2.1%)	0.50	0.31
Dairy (1 serving reduction)	-5.7% (-8.1% to -3.3%)*	<0.0001		-3.3% (-5.6% to -0.9%)	0.007	
Eggs (1 serving reduction)	1.3% (-3.6% to 6.1%)	0.60		-1.1% (-8.2% to 5.9%)	0.75	
LDL Cholesterol [b]						
Meat (1 serving reduction)	-0.1% (-3.8% to 3.7%)	0.96	0.30	-0.02% (-4.2% to 4.2%)	0.99	0.27
Dairy (1 serving reduction)	-6.7% (-10.4% to -3.0%)**	0.001		-4.6% (-8.4% to -0.8%)	0.02	
Eggs (1 serving reduction)	3.0% (-4.0% to 10.0%)	0.40		-2.2% (-11.8% to 7.5%)	0.65	

[a] Adjusting for age, sex, baseline BMI, change in weight, average METs, change in METs, baseline biomarker value, baseline MDE score, baseline calories, change in calories, and number of days on restricted diet.

[b] Excluding one individual without reliable LDL measure due to triglycerides>400 mg/dL at time 2.

* Beta coefficient significantly different than the coefficient for eggs (p=0.028)

** Beta coefficient significantly different than the coefficient for meat (p=0.013) and eggs (p=0.034)

Supplemental Table 4.1. Variable creation based on MyPyramid Equivalents Database (MPED) 2.0 components obtained from FFQ data or Nutrition Coordinating Center (NCC) components obtained from food record data.

	FFQ DATA		FOOD RECORD DATA	
Variable	**MPED Variable Components**	**MPED Serving Size**	**NCC Variable Components**	**NCC Serving Size**
Red meat	Lean* meat from beef, veal, pork, lamb, and game	1 oz (cooked)	Beef Lean beef (≤10% fat) Veal Lean veal (≤10% fat) Lamb Lean lamb (≤10% fat) Fresh pork Lean fresh pork (≤10% fat) Game	1 oz (cooked)
Processed meat	Lean* meat from franks, sausages, luncheon meats	1 oz (cooked)	Cured pork Lean cured pork (≤10% fat) Cold cuts and sausage Lean cold cuts and sausage	1 oz (cooked)
Poultry	Lean* meat from chicken, poultry, and other poultry	1 oz (cooked)	Poultry Lean poultry (≤10% fat) Fried chicken	1 oz (cooked)
Fish	Lean* meat from fish and other seafood from high and low omega-3 sources	1 oz (cooked)	Fresh and smoked fish Lean fresh and smoked fish Fried fish Shellfish Fried shellfish	1 oz (cooked)

* Lean meat is defined in the MPED system as any meat, poultry, or fish item that contains ≤9.28 grams of fat and at least 90.72 grams of nonfat meat component per 100 grams of cooked food item. The amount of fat present above the allowable fat level of 9.28 grams per 100 grams of food item is defined as discretionary solid fat.

	FFQ DATA		**FOOD RECORD DATA**	
Variable	**MPED Variable Components**	**MPED Serving Size**	**NCC Variable Components**	**NCC Serving Size**
Milk *NCC variable for frozen dairy desserts was multiplied by 0.5 to better approximate the MPED definition of a serving*	All fluid milk, chocolate milk, lactose-reduced milk, lactose-free milk, filled milk, dry milk, and evaporated milk (including those disaggregated from dairy-based desserts)	1 cup-eq. (e.g., 1 cup milk, 0.5 cup evaporated milk; 1 cup frozen yogurt; 1 cup pudding made with milk; 1.5 cups ice cream)	Whole milk, plain and flavored Reduced fat milk, plain and flavored Low fat and fat-free milk, plain and flavored Dry milk Sweetened flavored milk beverages Frozen dairy desserts Pudding and other dairy desserts	1 cup-eq. milk (e.g., 1 cup milk, 0.5 cup evaporated milk; 1 cup prepared dry milk) 0.5 cup ice cream; 1 cup shake 1 cup pudding made with milk
Cheese	All hard natural cheese, soft cheese, processed cheese, and cheese products	1 cup-eq (e.g., 1.5 oz hard cheese; 0.33 cup shredded cheese; 0.5 cup ricotta cheese; 2 cups cottage cheese)	Full fat cheese Reduced fat cheese Low fat and fat-free cheese	1.5 oz natural cheese 2 oz processed cheese 2 cups cottage cheese 3 cups dry curd 0.5 cup ricotta 2 oz spread cheese
Yogurt	All yogurts such as fat-free, low-fat, reduced-fat, and whole milk yogurt	1 cup-eq (e.g., 8 oz yogurt)	Plain, sweetened, and artificially sweetened whole milk, low-fat, and fat-free yogurt	1 cup-eq (e.g., 8 oz yogurt)
Eggs		1 oz-eq (1 egg)		1 large egg; 2 large egg whites; 2 large egg yokes
Whole grain	Any 100% whole grain product	1 oz-eq (e.g., 0.5 cup pasta, rice, or cooked breakfast cereals; 28.35 g ready-to-eat cereal; 1 regular slice of whole grain bread; 0.5 English muffin; 1 small muffin; 3 cups popped popcorn; 1 small tortilla)	Any 100% whole grain product	1 oz-eq (e.g., 0.5 cup pasta, rice, or cooked breakfast cereals; 28.35 g ready-to-eat cereal; 1 regular slice of whole grain bread; 0.5 English muffin; 1 small muffin; 3 cups popped popcorn)

	FFQ DATA		FOOD RECORD DATA	
Variable	**MPED Variable Components**	**MPED Serving Size**	**NCC Variable Components**	**NCC Serving Size**
Refined grain	Any cooked refined grains or products made with refined flour	1 oz-eq (e.g., 0.5 cup pasta, rice, or cooked breakfast cereals; 28.35 g ready-to-eat cereal; 1 regular slice of whole grain bread; 0.5 English muffin; 1 small muffin; 1 small tortilla)	Any cooked refined grains or products made with refined flour	1 oz-eq (e.g., 0.5 cup pasta, rice, or cooked breakfast cereals; 28.35 g ready-to-eat cereal; 1 regular slice of whole grain bread; 0.5 English muffin; 1 small muffin; 1 small tortilla)
Legumes *NCC variable for legumes multiplied by 0.5 to match the MPED definition of a 1-cup eq serving*	Cooked dry beans and peas	1 cup eq (0.25 cup cooked dry beans or peas; 0.25 cup refried beans or baked beans; 0.5 cup split pea, lentil, or bean soup; 2 Tbs hummus)	Dried beans Lima beans Refried beans Beans in sauce Beans in recipes (e.g., soup)	0.5 cup cooked dry beans 0.5 cup refried beans 0.5 cup beans in sauce
Meat Alternatives	Soy milk Tofu Soy nuts	1 oz-eq from soy products (e.g., 1 cup soy milk; 0.25 cup tofu; 0.25 cup soy nuts; 0.5 soy bean patty)	Veggie burgers Tofu Tempeh TVP Soy nuts	0.5 oz soy nuts; 1 oz tofu, veggie burger, tempeh
Nuts and seeds	Nuts and seeds	1 oz-eq (0.5 oz nuts or seeds; 1 Tbs nut butter)	Nuts and seeds	0.5 oz nuts or seeds; 1 Tbs nut butter
Fruit *NCC variables for fruit multiplied by 0.5 to match the MPED definition of a 1-cup eq serving*	Citrus fruits, melons and berries; non-citrus fruit; avocados	1 cup-eq (e.g., 1 cup sliced or mashed fruit; 1 large piece of fruit; 0.5 cup dried fruit)	Citrus fruit Non-citrus fruit Avocado	0.5 cup chopped fruit or 1 medium piece 0.25 cup dried fruit

	FFQ DATA		FOOD RECORD DATA	
Variable	**MPED Variable Components**	**MPED Serving Size**	**NCC Variable Components**	**NCC Serving Size**
Vegetables *NCC variable for vegetables multiplied by 0.5 to match the MPED definition of a 1-cup eq serving*	Dark green vegetables (leafy greens and broccoli) Orange vegetables (carrots, sweet potato, winter squash) Starchy vegetables (peas and corn) Other vegetables (cabbage, peppers, cucumbers, celery, cauliflower) Tomatoes	1 cup-eq (e.g., 1 cup chopped broccoli; 1 cup cooked greens; 2 cups raw greens; 1 cup chopped carrots; 1 cup mashed pumpkin or squash; 1 cup peas or corn; 1 cup chopped cauliflower; 1 large raw tomato)	Dark green vegetables (leafy greens and broccoli) Deep yellow vegetables (carrots, sweet potato, winter squash) Starchy vegetables (peas and corn) Other vegetables (cabbage, peppers, cucumbers, celery, cauliflower) Tomatoes	1 cup raw leafy greens 0.5 cup cooked leafy greens or non-leafy vegetable in any form
White potatoes *NCC variable for potatoes multiplied by 0.5 to match the MPED definition of a 1-cup eq serving*	White potatoes	1 cup-eq (e.g., 1 cup mashed potato; 20 medium French fries)	White potatoes	0.5 cup chopped or mashed potato
Discretionary oil *NCC variables for saturated fats and trans fats subtracted from variable for total fat to match the MPED definition of discretionary oil*	Fats that are liquid at room temperature, including non-hydrogenated oils from plant sources, oils from fish, nuts, and seeds.		No equivalent variable in database. Subtracted variables for saturated fat and trans fats from variable for total fat.	

Supplemental Table 4.2. Biomarker Model II with total, LDL, and HDL cholesterol examined for legumes and meat alternative interactions after removing outliers.

	FFQ Data			Food Record Data		
TOTAL CHOLESTEROL	β^a (95% CI)	p-value	Adj-R^2	β^a (95% CI)	p-value	Adj-R^2
MDEΔ Score (1 serving reduction) [b]	-3.0% (-5.1% to -1.0%)	0.004	0.42	-0.1% (-1.8% to 1.5%)	0.86	0.48
Legumes (1 cup-eq increase)	-5.8% (-25.8% to 14.1%)	0.56		-2.2% (-15.2% to 10.8%)	0.74	
Interaction Term	0.5% (-5.2% to 6.3%)	0.86		-5.2% (-10.0% to -0.3%)	0.04	
MDEΔ Score (1 serving reduction) [c]	-2.8% (-4.8% to -0.8%)	0.007	0.44	-2.9% (-4.3% to -1.5%)	<0.0001*	0.34
Meat Alternatives (1 oz-eq increase)	2.1% (-5.1% to 9.3%)	0.56		-1.5% (-6.5% to 3.5%)	0.56	
Interaction Term	-2.1% (-4.8% to 0.7%)	0.14		1.0% (-0.9% to 2.9%)	0.31	

	FFQ Data			Food Record Data		
LDL CHOLESTEROL	β^a (95% CI)	p-value	Adj-R^2	β^a (95% CI)	p-value	Adj-R^2
MDEΔ Score (1 serving reduction) [b]	-2.0% (-4.9% to 0.8%)	0.17	0.28	-1.7% (-4.8% to 1.4%)	0.28	0.29
Legumes (1 cup-eq increase)	-24.2% (-53.9% to 5.6%)	0.11		-23.4% (-45.6% to -1.3%)	0.04	
Interaction Term	7.0% (-1.9% to 16.0%)	0.12		3.2% (-4.3% to 10.7%)	0.40	
MDEΔ Score (1 serving reduction) [c]	-1.0% (-3.7% to 1.7%)	0.47	0.29	-3.2% (-5.7% to -0.7%)	0.01	0.23
Meat Alternatives (1 oz-eq increase)	3.5% (-8.9% to 15.8%)	0.58		-5.7% (-13.9% to 2.4%)	0.17	
Interaction Term	-3.2% (-7.7% to 1.3%)	0.16		2.5% (-0.626% to 5.7%)	0.11	

	FFQ Data			Food Record Data		
HDL CHOLESTEROL	β^a (95% CI)	p-value	Adj-R^2	β^a (95% CI)	p-value	Adj-R^2
MDEΔ Score (1 serving reduction) [b]	-0.3% (-3.7% to 3.1%)	0.85	0.17	0.9% (-2.4% to 4.1%)	0.59	0.22
Legumes (1 cup-eq increase)	15.5% (-13.3% to 44.3%)	0.29		12.9% (-11.7% to 37.6%)	0.30	
Interaction Term	-8.5% (-17.0% to 0.0%)	0.05		-11.6% (-21.5% to -1.6%)	0.02	
MDEΔ Score (1 serving reduction) [c]	-4.6% (-8.6% to -0.6%)	0.02	0.25	-2.5% (-5.2% to 0.2%)	0.07	0.19
Meat Alternatives (1 oz-eq increase)	-16.4% (-28.9% to -3.8%)	0.01		8.6% (-0.6% to 17.8%)	0.07	
Interaction Term	9.3% (0.8% to 17.8%)	0.03		-3.2% (-6.801% to 0.3%)	0.07	

[a] Adjusting for age, sex, baseline BMI, change in weight, average METs, change in METs, baseline biomarker value, baseline MDE score, baseline calories, change in calories, and number of days on restricted diet.
[b] Excluding two influential outliers, n=92.
[c] Excluding one influential outlier, n=93.

Supplemental Table 4.3. Biomarker Model II with BMI reexamined after removing outliers (n=93).

	FFQ Data			Food Record Data		
BMI	**β [a] (95% CI)**	**p-value**	**Adj-R^2**	**β [a] (95% CI)**	**p-value**	**Adj-R^2**
MDEΔ Score (1 serving reduction)	-0.5% (-1.0% to 0.0%)	0.04	0.16	-0.6% (-1.0% to -0.3%)	0.001*	0.25
Kilocalories (100 kcal decrease)	-0.1% (-0.3% to 0.03%)	0.11		-0.2% (-0.4% to 0.05%)	0.13	
Interaction	-0.01% (-0.09% to 0.07%)	0.80		-0.03% (-0.1% to 0.06%)	0.50	
MDEΔ Score (1 serving reduction)	-0.6% (-1.1% to -0.1%)	0.02	0.20	-0.8% (-1.1% to -0.4%)	0.0001*	0.28
Fish (1 oz increase)	-0.5% (-1.4% to 0.3%)	0.22		0.2% (-0.3% to 0.8%)	0.39	
Interaction Term	0.2% (-0.2% to 0.5%)	0.27		-0.1% (-0.3% to 0.1%)	0.41	
MDEΔ Score (1 serving reduction)	-0.5% (-1.0% to 0.0%)	0.04	0.20	-0.6% (-1.1% to -0.2%)	0.008	0.24
Whole Grain (1 oz-eq increase)	-0.6% (-1.2% to 0.1%)	0.11		-0.2% (-1.2% to 0.8%)	0.71	
Interaction Term	0.07% (-0.3% to 0.4%)	0.69		-0.005% (-0.4% to 0.4%)	0.98	
MDEΔ Score (1 serving reduction)	-0.7% (-1.2% to -0.1%)	0.02	0.17	-1.0% (-1.4% to -0.5%)	<0.0001*	0.28
Refined Grain (1 oz-eq increase)	-0.3% (-1.1% to 0.4%)	0.40		-0.4% (-0.9% to 0.1%)	0.12	
Interaction Term	0.1% (-0.3% to 0.5%)	0.54		0.2% (0.02% to 0.4%)	0.03	
MDEΔ Score (1 serving reduction)	-0.6% (-1.1% to 0.0%)	0.05	0.17	-0.9% (-1.3% to -0.5%)	<0.0001*	0.26
Legumes (1 cup-eq increase)	-4.0% (-9.3% to 1.4%)	0.14		-2.9% (-5.2% to -0.6%)	0.01	
Interaction Term	1.4% (-0.2% to 2.9%)	0.09		1.2% (0.0% to 2.5%)	0.052	
MDEΔ Score (1 serving reduction) [b]	-0.7% (-1.2% to -0.1%)	0.02	0.17	-0.7% (-1.1% to -0.4%)	0.0001*	0.33
Meat Alternatives (1 oz-eq increase)	-1.4% (-3.4% to 0.5%)	0.16		-0.8% (-2.1% to 0.6%)	0.26	
Interaction Term	0.6% (-0.1% to 1.4%)	0.11		0.1% (-0.4% to 0.6%)	0.75	
MDEΔ Score (1 serving reduction)	-0.5% (-1.2% to 0.1%)	0.09	0.15	-0.6% (-1.0% to -0.2%)	0.01	0.24
Nuts & Seeds (1 oz-eq increase)	0.2% (-0.3% to 0.7%)	0.47		-0.03% (-0.4% to 0.3%)	0.87	
Interaction Term	-0.1% (-0.3% to 0.2%)	0.63		-0.02% (-0.1% to 0.1%)	0.66	
MDEΔ Score (1 serving reduction)	-0.8% (-1.4% to -0.3%)	0.001*	0.20	-0.7% (-1.1% to -0.4%)	<0.0001*	0.25
Fruit & Vegetables (1 cup-eq increase)	-0.6% (-1.4% to 0.3%)	0.20		0.6% (-0.2% to 1.5%)	0.16	
Interaction Term	0.3% (-0.03% to 0.6%)	0.08		-0.1% (-0.4% to 0.2%)	0.52	
MDEΔ Score (1 serving reduction)	-0.8% (-1.3% to -0.32%)	0.001*	0.19	-0.6% (-1.0% to -0.25%)	0.002*	0.23
Oil (10 gram increase)	-0.02% (-0.1% to 0.1%)	0.68		-0.08% (-0.6% to 0.4%)	0.75	
Interaction Term	0.02% (-0.002% to 0.05%)	0.07		0.03% (-0.1% to 0.2%)	0.70	
MDEΔ Score (1 serving reduction)	-0.7% (-1.1% to -0.2%)	0.009	0.18	-0.7% (-1.1% to -0.4%)	0.0003*	0.26
Added Sugar (10 gram increase)	0.03% (-0.002% to 0.07%)	0.07		0.4% (-0.16% to 0.9%)	0.17	
Interaction Term	-0.004% (-0.02% to 0.01%)	0.63		-0.06% (-0.3% to 0.2%)	0.58	

[a] Adjusting for age, sex, baseline BMI, average METs, change in METs, baseline MDE score, baseline calories, change in calories, and number of days on restricted diet.

[b] Excluding one additional outlier, n=92.

Supplemental Table 4.4. Comparison of energy-adjusted Pearson correlation coefficients estimated with different FFQs and FRs and/or recalls in this study and other studies.

	WHI [a]	**WHI** [b]	**Willett** [c]		**Block** [d]		**DHQ** [e]		**AHS-2** [f]	
	124-item	*122-item*	*126-item*		*106 item*		*124-item*		*204-item*	
	Women (n=42)	**Women**	**Men**	**Women**	**Men**	**Women**	**Men**	**Women**	**Whites**	**Blacks**
Nutrient	**Men** (n=56)	(n=113)	(n=238)	(n=272)	(n=226)	(n=238)	(n=403)	(n=438)	(n=550)	(n=461)
Kilocalories (males)	0.25	-	0.20	-	0.45	-	0.49	-	-	-
Kilocalories (females)	0.50	0.37	-	0.18	-	0.45	-	0.48	-	-
Kilocalories (all)	0.42	-	-	-	-	-	-	-	0.20	0.07
Total Protein	0.70	0.41	0.58	0.54	0.61	0.53	0.57	0.60	0.29	0.12
Animal Protein	0.88	-	-	-	-	-	-	-	0.76	0.59
Plant Protein	0.76	-	-	-	-	-	-	-	0.57	0.46
Total Fat	0.67	0.58	0.60	0.65	0.55	0.67	0.62	0.66	0.42	0.32
Saturated Fat	0.75	0.56	0.66	0.66	0.67	0.65	0.68	0.66	0.59	0.36
Monounsaturated Fat	0.53	0.57	0.63	0.64	0.54	0.60	0.60	0.62	0.34	0.30
Polyunsaturated Fat	0.41	0.44	0.63	0.47	0.54	0.48	0.60	0.64	0.47	0.32
Total Carbohydrates	0.80	0.63	0.67	0.63	0.64	0.66	0.63	0.69	0.45	0.26
Total Sugars	0.64	-	-	-	-	-	-	-	-	-
Added Sugars	0.81	-	-	-	-	-	-	-	-	-
Fiber	0.68	0.65	0.73	0.68	0.77	0.80	0.80	0.77	0.63	0.56

[a] Present study, Women's Health Initiative FFQ compared with 7-day FR among OCs during Lent, ages 19-73, nutrients energy-adjusted using the nutrient density method.

[b] Women's Health Initiative (WHI) FFQ compared with the average of four 24 hour recalls and four FRs WHI participant subsample, ages 50-79, nutrients energy-adjusted using the residual method (Patterson et al. 1999).

[c] Willett FFQ modified for UK compared with the average of two 7-day FRs, European Prospective Investigation into Cancer UK Norfolk cohort subsample, ages 45-74, nutrients energy-adjusted using the residual method, (McKeown et al. 2001).

[d] Standard Willett FFQ compared with four 24-hour recalls, Eating at America's Table Study (EATS) cohort, ages 20-70, nutrients energy adjusted using the residual method, correlation coefficients are deattenuated (Subar et al. 2001)

[e] Standard Block/NCI FFQ compared with four 24-hour recalls, Eating at America's Table Study (EATS) cohort, ages 20-70, nutrients energy adjusted using the residual method, correlation coefficients are deattenuated (Subar et al. 2001)

[f] Diet and Health Questionnaire (DHQ) compared with four 24-hour recalls, Eating at America's Table Study (EATS) cohort, ages 20-70, nutrients energy adjusted using the residual method, correlation coefficients are deattenuated (Subar et al. 2001)

[g] Adventist Health Study 2 (AHS-2) modified questionnaire compared with the average of three to six 24-hour recalls, AHS-2 participant sub-sample, ages <50-80+, nutrients adjusted using the residual method (Jaceldo-Siegl et al. 2010)

Supplemental Table 4.5. Comparison of energy-adjusted Pearson correlation coefficients estimated with different FFQs and recalls in this study and one other study on food categories.

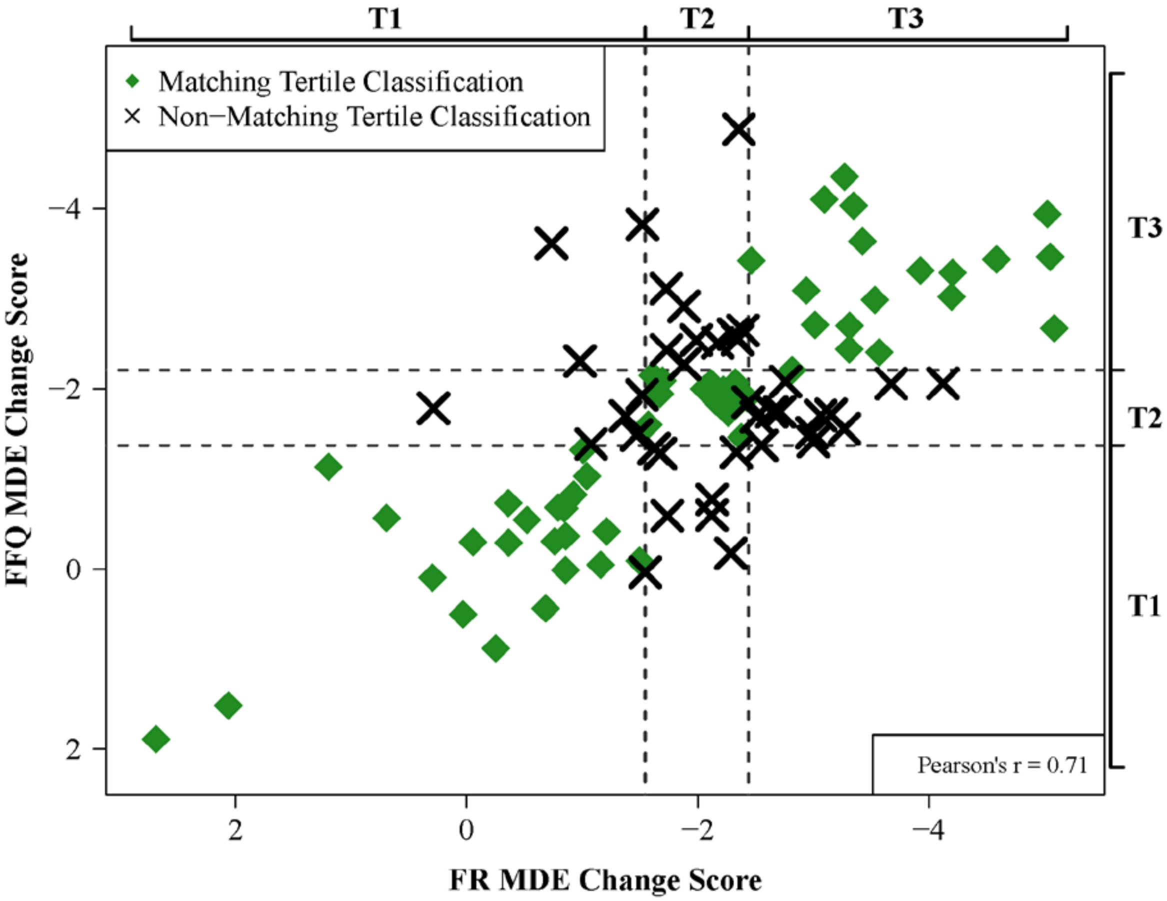
	WHI [a]	DHQ [b]	
	124-item	*124-item*	
Food Component	**Women** (n=42) **Men** (n=56)	**Men** (n=436)	**Women** (n=497)
All Meat (oz)	0.88	-	-
Red Meat (oz)	0.68	0.61	0.58
Poultry (oz)	0.82	0.56	0.50
Processed Meat (oz)	0.88	0.64	0.54
Fish & Shellfish (oz)	0.68	0.60	0.53
Eggs (oz eq)	0.83	0.42	0.45
All Dairy (cup eq)	0.90	0.80	0.76
Milk (cup eq)	0.74	0.78	0.84
Yogurt (cup eq)	0.65	-	-
Cheese (cup eq)	0.80	0.61	0.62
Whole Grain (oz eq)	0.51	0.63	0.59
Refined Grain (oz eq)	0.55	0.61	0.60
Legumes (cup eq)	0.66	0.53	0.59
Soy Products (oz eq)	0.40	-	-
Non-dairy milks (cup)	0.57	-	-
Nuts & Seeds (oz eq)	0.33	0.56	0.51
Fruit (cup eq) [b]	0.66	0.70	0.66
Vegetables (cup eq) [c]	0.53	0.63	0.66
White Potatoes (cup eq)	0.45	0.50	0.52
Discretionary Oil (g) [d]	0.43	0.66	0.65

[a] Present study, Women's Health Initiative FFQ compared with 7-day FR among OCs during Lent, ages 19-73, nutrients energy-adjusted using the nutrient density method.

[b] Diet and Health Questionnaire (DHQ) compared with four 24-hour recalls, Eating at America's Table Study (EATS) cohort, ages 20-70, nutrients energy adjusted using the residual method (Millen et al. 2006)

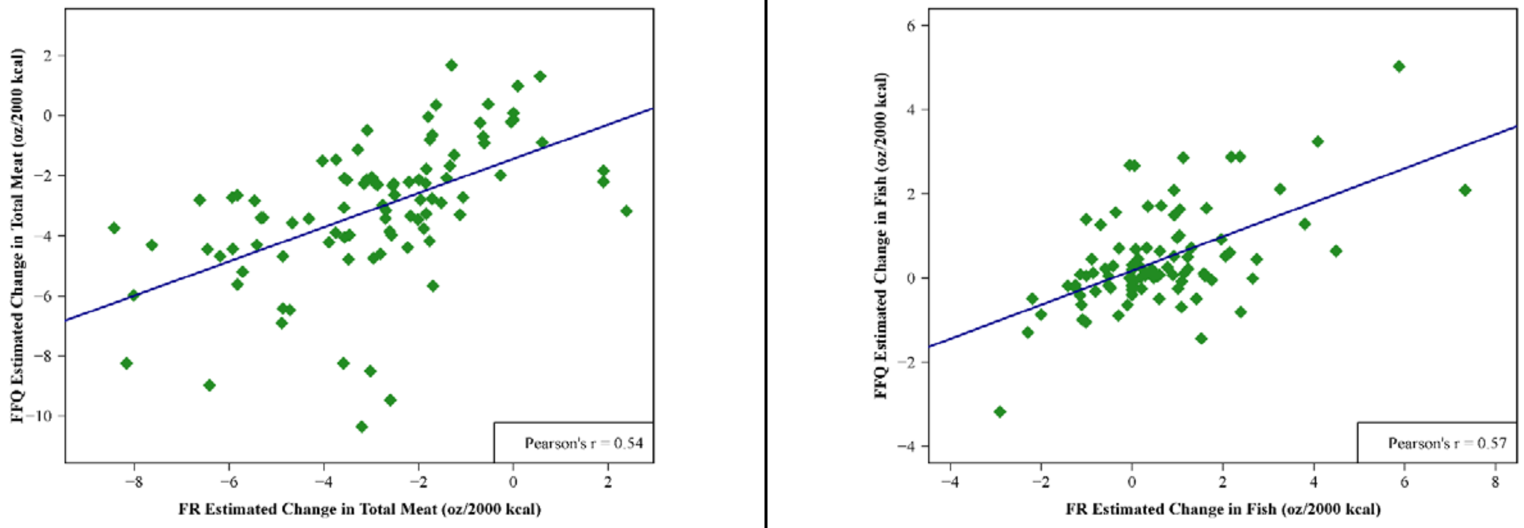
CHAPTER 4 FIGURES

Figure 4.1. Tertile classification by FR versus FFQ MDEΔ Score.



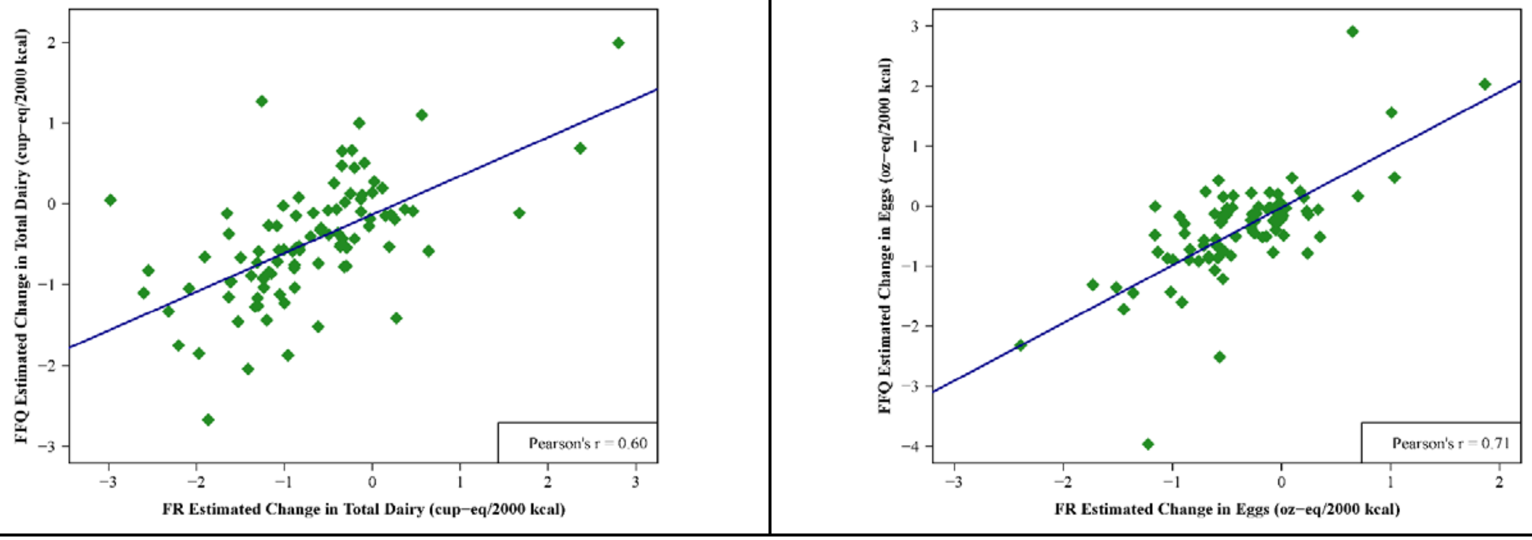
T1=Tertile 1; T2=Tertile 2, T3=Tertile

Figure 4.2. Correlations between FFQ and FR Measurements of Food Intake Densities (n=94).



FFQ and FR Estimated Change in Total Meat

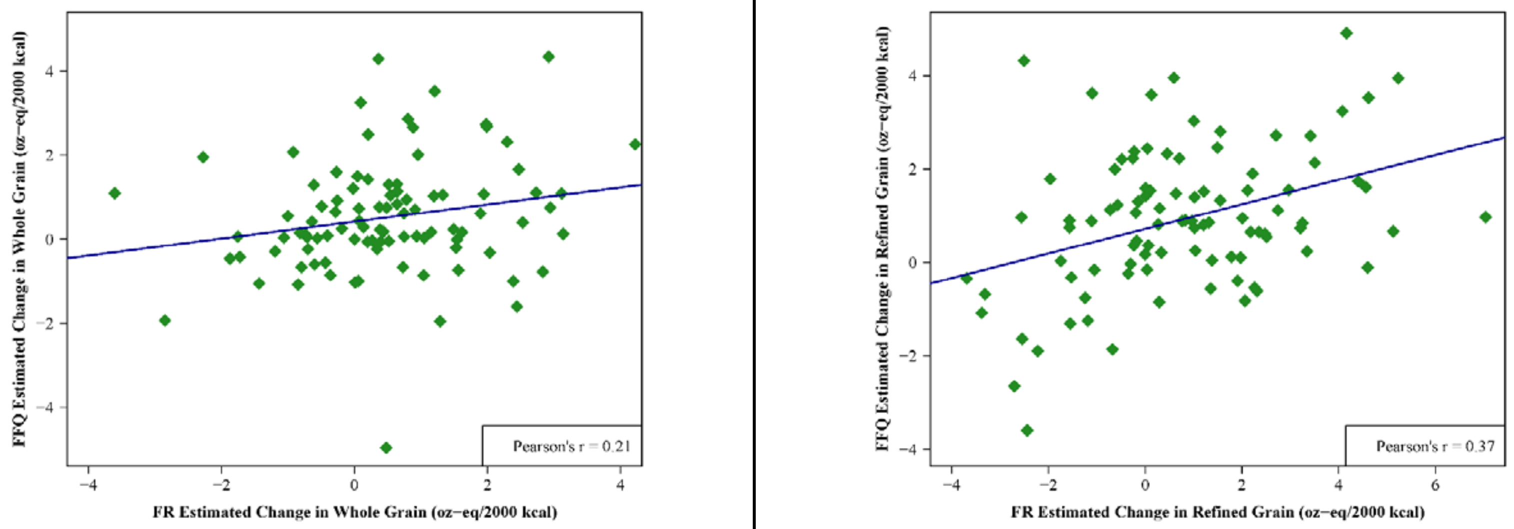
FFQ and FR Estimated Change in Fish and Shellfish



FFQ and FR Estimated Change in Dairy

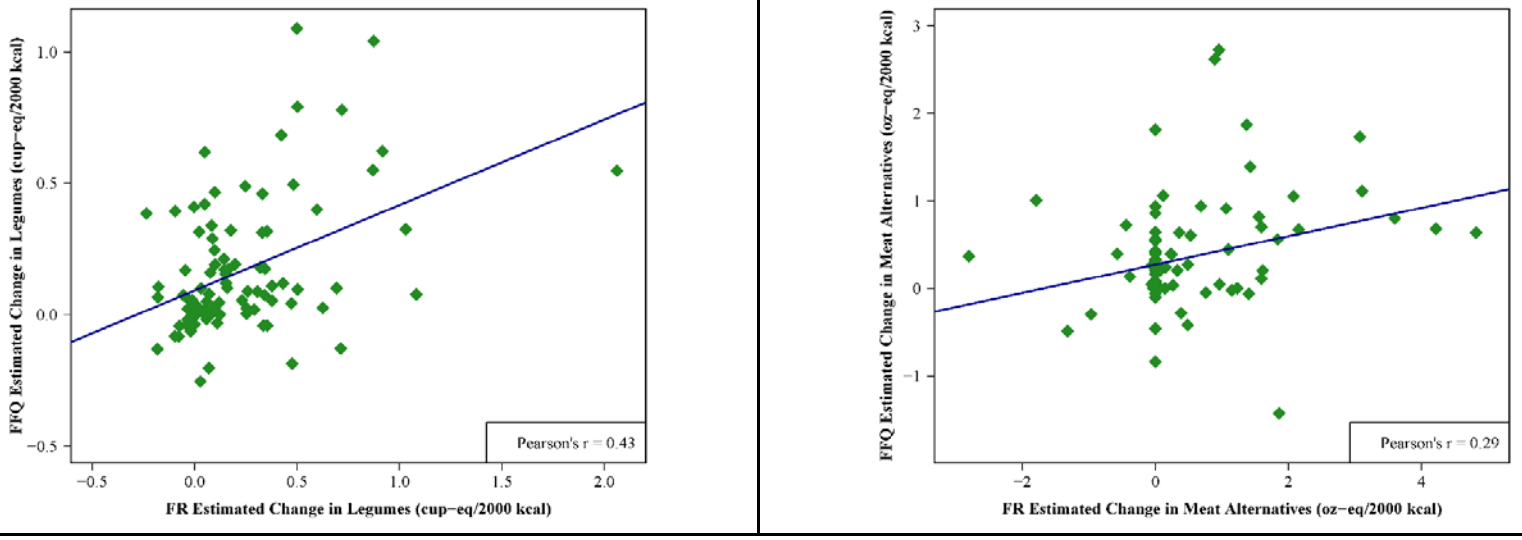
FFQ and FR Estimated Change in Eggs

Figure 4.2 (cont.). Correlations between FFQ and FR Measurements of Food Intake Densities (n=94).



FFQ and FR Estimated Change in Whole Grains

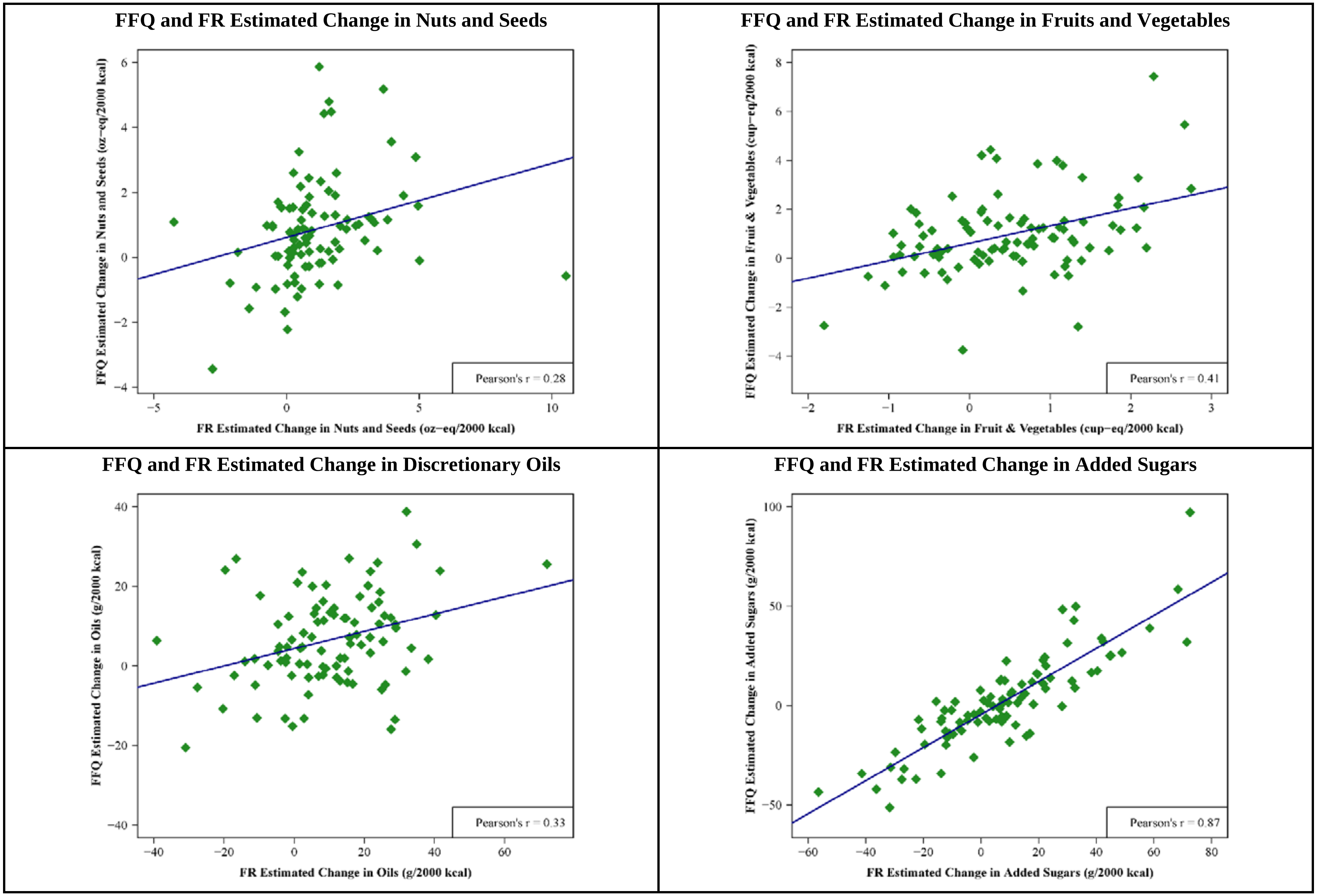
FFQ and FR Estimated Change in Refined Grains



FFQ and FR Estimated Change in Legumes

FFQ and FR Estimated Change in Meat Substitute

Figure 4.2 (cont.). Correlations between FFQ and FR Measurements of Food Intake Densities (n=94).



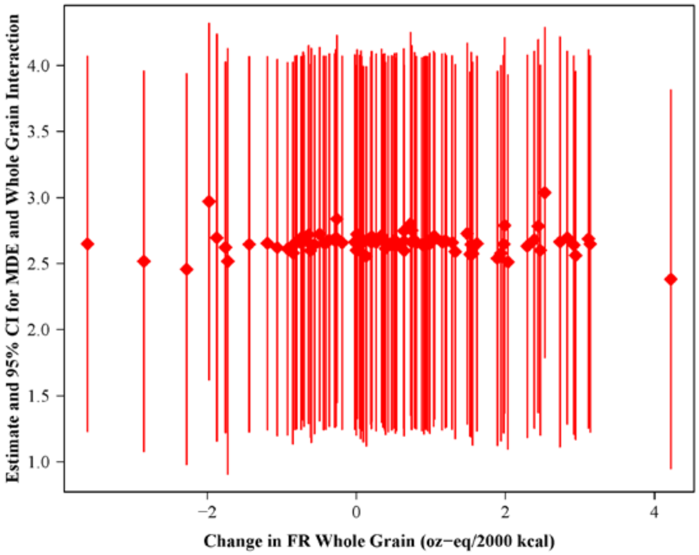
FFQ and FR Estimated Change in Nuts and Seeds

FFQ and FR Estimated Change in Fruits and Vegetables

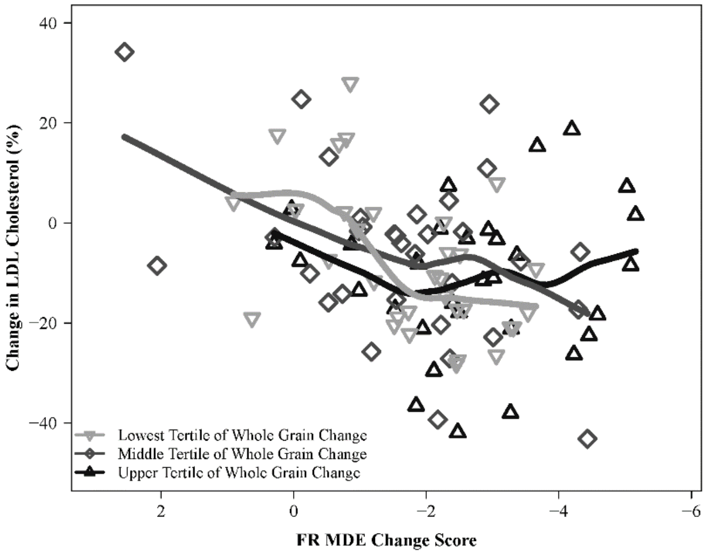
FFQ and FR Estimated Change in Discretionary Oils

FFQ and FR Estimated Change in Added Sugars

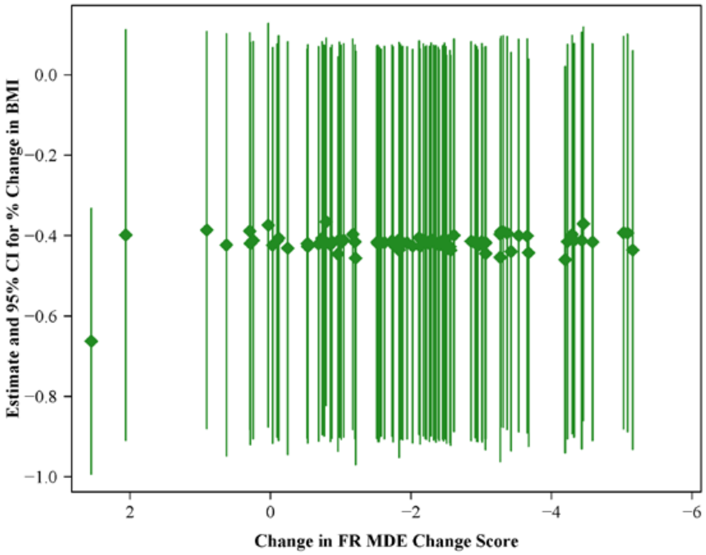
Supplemental Figure 4.1a. Leave-one-out cross-validation for the coefficient for the interaction between FR MDEΔ and shifts in FR whole grain intake in the FR Biomarker Model II for LDL cholesterol.



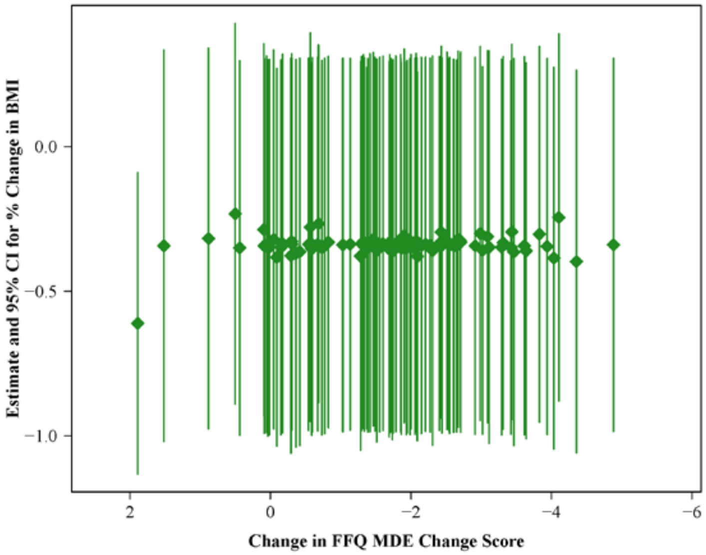
Supplemental Figure 4.1b. Smoothed lowess curves representing the relationship between FR MDEΔ and shifts in total cholesterol across FR-derived tertiles of change in whole grain.



Supplemental Figure 4.2a. Leave-one-out cross-validation for the beta coefficient for the relationship between BMI change and FR MDEΔ score in the FR Biomarker Model II.



Supplemental Figure 4.2b. Leave-one-out cross-validation for the beta coefficient for the relationship between BMI change and FFQ MDEΔ score in the FFQ Biomarker Model II.



CHAPTER 5: LESSONS LEARNED FROM THE LENTEN SEASON STUDY, UNEXPLORED QUESTIONS, AND FUTURE DIRECTIONS

Answered and Unanswered Questions from the Lenten Season Study

This dissertation study developed on the premise that the contrasting perspectives on the role of animal products in health and disease stem, at least in part, from 1) a common failure to consider the broader ecological context and accompanying dietary habits and lifestyle factors that may modify the health effects of any given food or group of foods; 2) the tendency to make comparisons between omnivorous and vegetarian or vegan populations without adequately considering the range of variation within those dietary categories; and 3) the lack of previous research aimed at disentangling the observed effects of restricting or omitting animal products from the effects of concurrent changes in consumption of "healthy" versus "unhealthy" plant-based foods. The objective of the study was to highlight the extent to which even a mostly plant-based diet can contain both "healthy" and "unhealthy" foods and to explore whether different food choices modify the degree to which reductions in animal product consumption result in observable improvements in measures of cardiometabolic health.

Specifically, this study aimed to A) characterize the diets of Orthodox Christians (OCs) in the United States (US) before and during a period of restrictions on meat, dairy, and egg (MDE) products; B) measure short-term changes in common cardiometabolic health biomarkers that occur in relation to those MDE restrictions; and C) test the degree to which shifts in cardiometabolic health biomarkers resulting from MDE restriction depend on concurrent shifts in calories and consumption of different "healthy" and "unhealthy" non-MDE foods. Finally, in recognition that measurement error in dietary intake estimates produced from standard food frequency questionnaires (FFQs) can attenuate diet-disease associations and may be an even greater problem when measuring the transition to a less conventional or more plant-based diet, this study had the supplementary aim of comparing the performance of a standard FFQ to an undocumented 7-day food record (FR) for measuring dietary change; describing diets low in MDE products; and detecting relationships among MDE restriction, concurrent dietary changes, and shifts in health biomarkers.

The key findings from this project are that 1) the OC practice of restricting MDE products during Lent leads to increased consumption of a variety of nutritious plant-based foods (e.g., legumes and nuts/seeds), even if it does not lead to meeting all dietary recommendations on intake of all plant-based foods (e.g., whole grains, fruits, and non-legume vegetables); 2) consumption of added sugar and refined grains remains high for many OCs before and during the Lenten MDE fast; 3) reductions in MDE products are associated with statistically significant reductions in total and LDL cholesterol within 5 to 6 weeks, though some of these reductions are attributed to weight loss; 4) there was no evidence that concurrent changes in calories or any single non-MDE food group modified the association between MDE restrictions and shifts in cholesterol or other health biomarkers; and 5) the standard FFQs appeared to perform similarly to the undocumented 7-day FRs when A) assessing relationships between Lenten MDE reductions and concurrent dietary changes and B) testing the relationships between concurrent dietary changes and shifts in cardiometabolic health biomarkers during the OC MDE Lenten fast.

These study findings corroborate the reports from other studies among OC (Elshorbagy et al. 2017; Papadaki et al. 2008; Sarri et al. 2003) and non-OC populations (Barnard et al. 2015; Wang et al. 2015) showing evidence that avoidance of animal products is associated with reductions in weight and cholesterol. However, it remains unclear if these short-term reductions in cholesterol translate into long-term health benefits. Given the degree to which some OCs continued to consume lower than recommended amounts of “healthy” plant-based foods (e.g., whole grains, fruits, and vegetables) and higher than recommended amounts of “unhealthy” plant-based foods (e.g., refined grains and added sugar), further investigation of the short- and long-term effects of this kind of spiritual MDE fasting is warranted.

There are a number of reasons that could explain why this study did not find the hypothesized interactions between MDE reductions and shifts in healthy or less healthy plant-based foods. For one, as seen in Chapter 2, there was variation in the degree to which OCs increased different plant-based foods, and the changes of any single food may not have been large enough to see a strong effect associated with any single food group. For two, even though many OCs continued to consume more added sugars and refined grains than recommended during Lent, the nutritional density of these foods remained constant and was accompanied by an overall increase in the nutritional density of more nutritious foods. Hence, it perhaps should not be surprising that there was no significant interaction with refined grains or added sugars, as there was little change in those foods relative to the combined change in healthier plant-based foods. For three, as demonstrated in Chapter 4, dietary data is muddled with error, and measurement of dietary change essentially doubles that degree of error, making it difficult to detect associations that may be relatively weak for any single food category. For four, there was considerable variation across individuals not only in dietary changes but also in baseline diet and baseline health biomarkers; this further challenged the ability to identify clear trends in the data. Finally, because of all the issues mentioned above, along with issues of collinearity between correlated food variables, this study was underpowered. A substantially larger sample would be needed to detect potentially small interactions between imprecisely-measured changes in any single plant-based food and a correlated, similarly imprecisely-measured change in MDE products among a heterogeneous group of individuals while adequately controlling for confounding factors and sources of systematic error.

Nonetheless, this study stands as the most thorough quantitative examination known to date of a unique form of MDE fasting, concurrent dietary and nutritional changes, and related shifts in measures of cardiometabolic health experienced by any OC population in the US. It contributes to the limited amount of data on the health implications of OC dietary restrictions as practiced in different areas of the world, and it supports findings from previous studies suggesting that the temporary spiritually-motivated MDE fasts can lead to a reduction in blood lipids. This study is only the second known study to prospectively investigate the health effects of different plant-based foods in MDE-restricted diets (Bloomer et al. 2015) and the first to do so in a free-living population. As such, it demonstrates that, contrary to randomized controlled trials that artificially assign individuals to distinct versions of a vegan diet (Bloomer et al. 2015), the dietary composition of MDE-restricted diets of free-living individuals can vary in so many different ways that such diets cannot be easily categorized as entirely “healthy” or “unhealthy.” Finally, this study is the only known study to compare a standard FFQ with an undocumented 7-day FR for measuring shifts from omnivorous to more plant-based diets and testing relationships between concurrent dietary and health biomarker changes.

Theoretical significance and broader implications

Many early theories in evolutionary anthropology on human diet-disease relationships - and the ones that became popularized in recent years - were based on the notion that humans are best adapted to pre-agricultural diets and that increased consumption of novel foods that appeared with agriculture and later with the industrialization of food production contributed to a decline in longevity and increase in degenerative diseases (Cohen 1989; Cohen and Armelagos 1984; Eaton and Konner 1985; Lindeberg 2010). These theories were valuable for initiating conversations about how evolutionary ecological conditions may have shaped human physiological responses to modern diets and lifestyles. However, evidence of relatively rapid adaptations to consumption of dairy (Ingram et al. 2009; Tishkoff et al. 2006) and increased starch intake (Perry et al. 2007) suggest that humans may be better adapted to at least some aspects of agricultural-based diets than previously thought. Additionally, though anthropological evidence has demonstrated humans' ability to subsist on relatively large amounts of meat and animal fat (Bang et al. 1980; Cordain et al. 2000; Kaplan et al. 2000; Mann et al. 1964), it is important to emphasize that humans are generalists and may be well-adapted to broad variations in the proportions of animal- and plant-based foods (Leonard 2002).

Anthropological theories must also reconcile with epidemiological evidence demonstrating exceptional health and longevity among industrialized populations consuming little to no animal products (Vasto et al. 2012; Willcox et al. 2014). It may be that any potential long-term health consequences (e.g., atherosclerosis and hypercholesterolemia) of increased animal tissue consumption may have traditionally been moderated by the physical activity levels and otherwise high-fiber, antioxidant-rich diets of pre-agricultural populations (Cordain et al. 2002a; Finch and Stanford 2004), by the daily and seasonal variability in consumption of animal products (Benefice et al. 1984; Hill et al. 1984; Hurtado and Hill 1990), or by high pathogen loads (Gurven et al. 2013; Vasunilashorn et al. 2010). In contrast, sedentary lifestyles, low-fiber diets, constant access to nutrient-dense foods, and increased life expectancy in industrialized environments might augment the chances of experiencing health costs in relation to high animal tissue consumption, while consistent access to alternative, plant-based sources of protein and fat may also reduce the relative benefit or need of regularly consuming animal-based foods. Thus, humans may still be attracted to the meat- and fat-rich diets that throughout most of our evolutionary history promoted increased growth and reproductive fitness when faced with regular fluctuations in energy and high extrinsic mortality risk, but those same diets may not be optimal for promoting post-reproductive longevity in the resource-abundant, low pathogen environments of most industrialized regions today. Moving forward, therefore, anthropological theories on diet-disease relationships need to remain flexible to the growing body of cross-disciplinary literature that sheds light on the complexity of these tradeoffs.

Contrary to previous evolutionary perspectives on diet and disease, this project moves beyond identifying specific food categories as ones to which humans are or are not adapted and instead aims to investigate how nutritionally distinct foods and overall dietary patterns might work synergistically or antagonistically with each other and with other lifestyle factors to influence disease processes. At the same time, in contrast to previous epidemiological studies, the focus of this project moves beyond dichotomous comparisons of omnivorous versus plant-based diets or evaluation of isolated nutrients or foods and instead explores the variations within categorized dietary patterns. Hence, this study lays the foundation for new avenues and perspectives in research on the complex relationships between human dietary habits and disease risk.

This study also has implications for where and how the US is investing public health efforts and research dollars. The combined direct and indirect costs of cardiovascular disease and type 2 diabetes have been rising steadily in the US, recently reaching $800 billion/year and expected to increase dramatically in the next two decades (American Diabetes Association 2013; American Heart Association and American Stroke Association 2017). We know that cardiometabolic diseases could largely be preventable through diet and lifestyle interventions (Danaei et al. 2009; Hu 2011), and this study demonstrated that even short-term dietary modifications can influence well-established markers of cardiometabolic health. The problem is that oversimplified interpretations of the research findings and a lack of appreciation for nuance has led to competing advice on dietary approaches for preventing, managing, and reversing disease and, hence, reduced confidence in national dietary guidelines. Further investments need to be directed toward designing and carrying out studies that, like this one, attempt to investigate if and under which accompanying dietary, lifestyle, and physiological circumstances MDE restriction is useful for improving cardiometabolic health. These more comprehensive approaches are needed to reach a more informed and science-based consensus on appropriate dietary guidelines that, perhaps, should leave room for personalized nutritional strategies for individuals at different stages of life with different baseline diets, activity levels, lifestyles, and pre-existing conditions.

Finally, this study may also provide information for the OC communities on the potential health implications of their dietary traditions and insight on ways to continue this tradition in a manner that optimizes physical, as well as spiritual, well-being. Even though this study was unable to show a differential effect of MDE reduction on health biomarkers according to changes in consumption of “healthy” or “unhealthy” replacement foods, it draws attention to the tendency of some OCs to consistently consume excess “unhealthy” plant-based foods and inadequate amounts of some “healthy” plant-based foods during their periodic MDE fasts. Though the OC Lenten MDE fast is more about exercising willpower and self-discipline for the sake of improving spiritual rather than physiological health, it may be worth considering the value that the MDE fast can have for improving both aspects of health and well-being and the ways in which food choices while on the MDE fast may have the potential to accentuate or attenuate the overall benefits of the MDE fasting regimen.

Study limitations

This project was a humbling lesson in why the nutritional literature is as flawed and inconclusive as it is. Every study is, like this one, limited by in what it can accomplish, how many participants it can recruit, how much and what kind of data it can collect, and how robust of an analysis it can perform. One of the major limitations of this study was the inadequate sample size combined with the lack of a larger control group of individuals who consistently consumed typical amounts of MDE products before and during Lent. Consequently, this study was underpowered and unable to adequately measure the degree of health biomarker shifts that could be attributable to the MDE fast as opposed to other hidden time effects causing changes in eating or behavior patterns (e.g., changes in eating habits resulting from being a participant in a study or from seasonal transitions). As discussed extensively in each chapter, another limitation was the use of dietary measures that either A) relied on long-term memory and captured a limited number of plant-based foods (i.e., the standard FFQ) or B) required more detail than many participants provided, were likely to modify participant behavior, and only captured diet within short-time frame before and during Lent (i.e., the undocumented 7-day FR). A third important limitation of these data are the inter-assay variation of the point-of-care blood lipid and glucose measures (coefficients of variation ranging from 2.4% to 9.7% and the intra- ranging from 5.0 to 10.5%) and inter-assay variation in the C-reactive protein measures (intra-assay coefficients of variation ranging from 5.0 to 10.5%; inter-assay coefficients of variation ranging from 7.7 to 16.7%). This much noise in the assay, combined with normal day-to-day variation in blood lipids, glucose, and CRP, makes it difficult to identify a clear trend in biomarker changes, hence, contributing to the low statistical power to detect associations. A fourth limitation was the use of self-report data for measuring physical activities levels and changes in physical activity. Self-report physical activity data suffers from the same kinds of cognitive recall challenges and social desirability bias as dietary recall data (Adams et al. 2005; Troiano et al. 2008). Research demonstrating that physical activity can, independent of diet and weight loss, affect lipid and glucose metabolism (Gaesser et al. 2011; Ross and Janiszewski 2008), suggests that it could be important to have a better measure of physical activity (e.g., through the use of activity monitors) for which to control in the regression models and, given more statistical power, include as another potential effect modifier.

A fifth major limitation is that the statistical models tested only linear main and interactive relationships among dietary and biomarker shifts. There is some suggestion that many plant-based foods, dairy, and eggs may have curvilinear relationships with all-cause mortality (Schwingshackl et al. 2017), for example. Thus, it is quite possible that replacing MDE products with whole grains, legumes, nuts, fruits, or vegetables may only offer an increased health benefit up to a certain threshold. Again, a larger sample size would be needed to reliably assess the possibility of a more complicated interaction between MDE reductions and concurrent dietary shifts. Also related to the statistical models, a sixth major limitation of this study was the issue of multicollinearity in models that included measures of shifts in plant-based foods, which were correlated with the MDEΔ score. Multicollinearity makes it difficult to obtain reliable coefficients for the effect of MDE restriction independent of concurrent dietary shifts. Finally, an area in which this study could be criticized for being overly simplistic was in the treatment of MDE products as a single composite score. Even the attempt to explore the degree to which the separate MDE components explained the observed relationships between MDE restriction and blood lipids did not account for the potentially different effects of reducing less healthy MDE items, such as processed meat, cheese, or ice cream, as opposed to the healthier MDE items, such as poultry, eggs, milk, or yogurt.

Overall, this study could have been improved with a larger sample size; a more distinct control group; the use of multiple 24-hour recalls (instead of FRs) in combination with FFQs in each collection period; venous blood draws samples sent to an expert lab to test more biomarkers, directly measure LDL and its subcomponents, and have broader limits of detection than were available for the point-of-care device; the use of activity monitors; an exploration of nonlinear relationships between dietary shifts and biomarker changes; and an examination of the effects of reducing different kinds of MDE products.

There are also issues of generalizability that should be considered when discussing the implications of this study's findings. Importantly, this study omitted a large portion of the current US-residing OC population by excluding individuals not born or raised in the US or Canada. While this exclusion criterion helped remove what might otherwise have been an additional source of variation, it means that this study cannot necessarily speak to the Lenten dietary and lifestyle changes of that segment of the US OC population. Immigrant OCs may very have different dietary patterns before and during Lent; any distinct early childhood factors may also lead to some immigrant OCs having different cardiometabolic risk factors and cardiometabolic responses to dietary changes (Lillycrop and Burdge 2012; McDade et al. 2009; Victora et al. 2008). Additionally, it may be important to consider how the individuals who were willing to and had the time to invest in participating in this relatively demanding study may differ from the broader OC population. It is possible that individuals that are willing to spend time tracking their diet and scheduling time for health assessments may also be more likely to spend time shopping for and preparing healthy meals and engaging in other health-promoting activities. Hence, this study may not have captured the full range of variability in OC Lenten MDE-restricted diets that might have been captured had it been able to track the diets of individuals with more limited time or less interest in the health component of the Lenten practice.

Other caveats and unexplored questions

The goal of this dissertation project was to highlight the need to at least consider the complex interactions in diet-disease relationships, even if they cannot all be modeled in any single study. Yet the design of this study also necessarily required compromises that ultimately limit the conclusions that can be drawn for the study findings. For instance, the composite MDEΔ score was created to serve as a proxy measure of overall adherence to the unique OC Lenten guidelines on MDE restriction, as well as the need to avoid too many comparisons with separate MDE components when statistical power was already limited. Consequently, this study is unable to speak to how the effects of the OC MDE fast may differ by baseline consumption and degree of change in consumption of different kinds of MDE products.

Similarly, the choice to look at the effects of dietary changes on LDL and HDL cholesterol separately rather than as a ratio or rather than just looking at the effects on non-HDL cholesterol were made for the sake of comparison with other studies, even though cholesterol ratios and non-HDL cholesterol may be more informative about cardiometabolic disease risk (Mensink et al. 2003; Ridker 2014; Siri and Krauss 2005). Furthermore, the use of a point-of-care device to measure cholesterol levels prevented the measurement of LDL particle number and density, which may also be more important than total LDL cholesterol in the pathogenesis of atherosclerosis (Hirayama and Miida 2012; Ridker 2014; Verhoye and Langlois Michel 2009).

Importantly, in order to be prudent about the number of comparisons being made in this study, it did not examine the health effects other lifestyle factors that may have changed for OCs during Lent and could influence health biomarkers independently of MDE restriction. Specifically, the Lenten OC practice for many OCs is more than a typical dietary regimen; as part of the practice of being more mindful and less consumed by earthly concerns, some OCs might restrict when they eat and/or the number of meals they consume, which may result in more frequent extended periods of time in between meals, particularly during days in Lent when there are extra evening services (Bethancourt unpublished). These additional practices set the Lenten dietary restrictions apart from the standard vegetarian or vegan dietary habits of non-OCs and could on their own lead to reductions in weight and cholesterol, independently of changes in food composition or caloric deficit (St-Onge et al. 2017; Stote et al. 2007). Another important question that deserves attention, therefore, is whether, after controlling for MDE restrictions, reductions in the number of meals and shifts in eating windows influence the health biomarkers of OCs during Lent.

Additionally, Lent is described in the OC church as a period of contemplation and reflection. For that reason, some OCs also reported that apart from the dietary restrictions, they often restrict various distractions during Lent, such as watching TV or checking social media. This form of increased mindfulness may radiate to other health-related behaviors as well. For example, some research suggests that willpower is like a muscle that when exercised in one area of life can become stronger in other areas of life (McGonigal 2012). Thus, the periodic OC practice of self-discipline and delayed gratification may help exercise the willpower muscle when it comes to removing MDE products, and this could with time radiate to a greater degree of willpower for restricting other foods or habits that may be detrimental to health. Indeed, some convert OCs reported feeling that since initiating the OC fasting practices they ate more healthfully and were more open to choosing meatless meals even outside of the fasting periods. All of these ideas support the potential merit of investigating how different forms of self-discipline during Lent may affect long-term health-related behaviors and influence not only physical health but perhaps also mental and emotional health and/or resilience to stress.

Finally, while on one hand making the case for the need to better address the complexities of diet-disease associations, the challenges and limitations of this study also demonstrated some of the reasons why few investigators have attempted to consider all the different sources of effect modification in any given diet-disease relationship. There are too many potential modifiers and confounders, and with diet being so variable and difficult to measure, few studies have the power to adequately explore all of the possible relationships. Even if this dissertation project had been conducted perfectly, it still would have been limited in the conclusions it could draw due to simplistic models that did not account for the many other sources of variation in how individuals respond to MDE reduction and concurrent changes in plant-based foods. Such sources include differences in food preparation methods (Liu et al. 2018; Uribarri et al. 2010), eating windows (Longo and Panda 2016; St-Onge et al. 2017), gut microbes (Tilg and Kaser 2011; Zeevi et al. 2015), patterns of stress (Anagnostis et al. 2009; Rosmond et al. 1998), sleep quality and duration (Mullington et al. 2009; Spiegel et al. 2009), and genetic and epigenetic factors that shape metabolic and inflammatory responses to food (Roberts 2015; Victora et al. 2008; Wadhwa et al. 2009). These are important sources of variation that could have varied across participants in this study and, at least in the case of eating windows, stress, and sleep quality, could have changed to some degree during the OC Lenten MDE fast. More research is needed, therefore, to fully understand the complex interactions among different "healthy" and "unhealthy" foods of both plant and animal origin, as well as interactions among different dietary choices and cooking and eating patterns, the gut microbiome, stress factors, sleep patterns, and genetic and epigenetic factors.

Future directions

Given the staggering economic burden of diet and lifestyle-related diseases in the US and worldwide (Bloom et al. 2012), failing to invest in further research on the most effective dietary and lifestyle interventions for the prevention and management of these diseases would have enormous economic and public health consequences. Regardless of any limitations and caveats of studying dietary habits of OCs and others, efforts to better understand the health implications of different foods and food combinations and their effects across different ecological contexts need to persevere. The journey toward a more comprehensive and nuanced understanding of diet-disease relationships is itself an evolutionary process requiring variation in research questions and study designs, replication of study findings, and selection of the most theoretically sound hypotheses to continue examining from different angles or new approaches. Fortunately, there are many exciting avenues for achieving a more nuanced understanding of diet-disease relationships and supporting efforts to develop personalized and context-specific dietary interventions for preventing, managing, or even reversing chronic degenerative diseases in the modern era.

Much could be learned from continuing to study the periodic dietary restrictions and eating patterns of OCs or modeling intervention studies based on their annual fasting practices. It would be worth pursuing a larger version of the study conducted for this dissertation that would have greater statistical power to test the same hypotheses tested herein. As suggested above, such a study should aim to recruit a larger and distinct control group of omnivores who do not change their diet during Lent but are otherwise similar in lifestyle, baseline health, and baseline diet as the OCs who do restrict MDE products during Lent. Such a study should use multiple 24-hour recalls in each time period combined with FFQ data and utilize new modeling strategies for reducing the effects of within-person variation (Dodd et al. 2006; Haubrock et al. 2011; Kipnis et al. 2009). Such a study would also, ideally, incorporate additional biomarkers that may provide further information on cardiometabolic health, including LDL particle number and density (Brunzell et al. 2008; Hirayama and Miida 2012), apolipoprotein B (Brunzell et al. 2008; The Emerging Risk Factors Collaboration 2012), and area-under-the-curve (AUC) glucose and insulin in response to standardized mixed meals or glucose. It may also be worth incorporating markers that are associated with cancer risk, such as IGF-I, adiponectin, and other cytokines (Hursting et al. 2012; Levine et al. 2014; Wei et al. 2016) into future studies of OC Lenten practices.

In addition to exploring the questions about the varying health effects of different plant-based foods as MDE replacements, it would be valuable to also explore the long-term health effects of the OC Lenten practice, combined with their bi-weekly restriction of MDE products, the 40-day MDE restriction before Christmas, and the two weeks of MDE restriction in August. In other words, it would be helpful to investigate the degree to which part-time vegetarianism/veganism might be a health-promoting alternative to full-time vegetarianism/veganism for those who may wish to manage or prevent disease but are not inclined to give up MDE products permanently. This research question would require a multi-year prospective study, and it may be helpful to explore changes that occur not only when transition into MDE restriction periods but also when transitioning out of them.

This study also motivates the design of more controlled trials to more reliably assess the effects of MDE products on health within different dietary and lifestyle contexts. For instance, more randomized controlled trials that compare the health effects of restricted versus unrestricted vegan diets, like the one conducted by Bloomer and colleagues (Bloomer et al. 2015) but with investigation into different foods consumed in each pattern, would be helpful. Additionally, no known published studies have yet compared different versions of whole foods diets that contain varying amounts of MDE products (e.g., whole foods Mediterranean-style versus vegetarian/vegan diets). Such a comparison in both healthy individuals and individuals with existing cardiometabolic ailments would be valuable for answering the question of whether MDE products are actually harmful to health when in their minimally processed form and included in an otherwise high-fiber, whole foods diet. Along similar lines, conducting more trials that test the health effects of lean meats added to whole foods diets that do and do not include grains, legumes, and dairy, such as the study conducted by Lindeberg and colleagues (Lindeberg et al. 2007), are needed to address debates about whether the animal products or the more evolutionarily recent grain-based foods, even when minimally processed, are the greater culprits for our contemporary disease burden (Cordain 1999; Cordain et al. 2005; Turner and Thompson 2013). Further debates regarding the role of exercise in protecting heavy meat-eating societies from cardiometabolic diseases (Gurven et al. 2013; Pontzer et al. 2012) should also be addressed through intervention studies that involve healthy omnivorous diets with and without an exercise and physical activity program. Similarly, given the evidence that caloric restriction, intermittent fasting, and time-restricted feeding may have beneficial impacts on health regardless of dietary composition (Longo and Panda 2016; St-Onge et al. 2017), it would be valuable to investigate if the effects of different calorie- or time-restricted eating regimes might differ when various MDE products are included or excluded from the diet. Also, to examine the degree to which any detrimental effects of meat consumption may depend on their fatty acid composition (Cordain et al. 2002b; Pereira and Vicente 2012), cooking temperatures (Liu et al. 2018; Uribarri et al. 2010), or today's constant access to meat, studies should compare the health effects of grain-fed versus grass-fed meat and dairy products; stewed meats versus meats cooked at high temperatures; and overall frequency (independent of amount) of meat consumption. Furthermore, a growing body of research demonstrates that the diet can influence the gut microbiome, which may in turn affect glucose responses to food, fat storage, and expression if inflammatory cytokines (Bäckhed et al. 2004; Tilg and Kaser 2011; Turnbaugh et al. 2006; Zeevi et al.). Hopefully, future studies will also explore how the gut microbiome is impacted by healthy omnivorous versus plant-based diets and how the gut microbiome in turn influences the health-related responses to different versions of these dietary patterns.

Of course, a major challenge to addressing the chronic disease burden is motivating people to adopt and maintain healthier dietary and lifestyle habits. This is again where OCs could provide an excellent model in how social and community support may help motivate otherwise reluctant individuals to initiate and sustain new dietary regimens. Though the OC practice is about spiritual and not physical health, one major advantage to taking on a health-promoting dietary and lifestyle practice as part of Lent is that individuals are provided with a sense of camaraderie and encouragement from their community to persevere through what may be a relatively large and challenging dietary transition. This is an asset that many individuals seeking to modify their diet for health reasons seldom have. Thus, another potential avenue of research would be to study how individuals' consumption patterns change when they have greater community support.

Conclusions

The effects of diet on cardiometabolic health are complicated. Continued cross-disciplinary dialogue will be necessary for refining our understanding of how variation within broader dietary categories impacts the health of individuals with varying lifestyles and physiologies living in distinct ecological settings. Evolutionary theory helps provide important clues about the kinds of diets, lifestyles, and environments that shaped modern human physiological and neurobiological responses to food. Anthropological research with extant hunter-gatherer, pastoralists, and other subsistence-based populations offer context to the diet-related disease burden currently faced by industrialized populations, as well as insight on which aspects of modern, industrialized diets, lifestyles, and environments might be less conducive to health and longevity than others. Epidemiological research provides solid methods for designing and carrying out observational studies and clinical trials to test hypotheses and help quantify the relative risk or benefit of consuming a given food or diet.

This project aimed to unite theories and methods from these distinct scholarly disciplines and take advantage of the unique spiritually-motivated dietary practice of OCs in the US in order to A) examine the food choices made by a free-living population whose motivations for giving up MDE products is not directly related to a need or desire to improve physical health and B) investigate whether the effects of MDE restriction on cardiometabolic health biomarkers depends on concurrent shifts in calories and intake of “healthy” or “unhealthy” non-MDE foods. In this study sample, both FFQ and undocumented FR data suggested that MDE restriction during the OC Lenten period was associated with increases in some “healthy” plant-based foods (e.g., legumes and nuts/seeds) but with no improvements in the likelihood of consuming adequate fruits and vegetables or limiting refined grains and added sugars to recommended thresholds. Significant reductions in total and LDL cholesterol that were only partially attributable to small degrees of weight loss were observed in relation to both FFQ- and FR-derived measures of MDE restrictions during Lent. The data collected from this study sample provided no evidence that MDE restriction was associated with shifts in glucose, insulin, or C-reactive protein or that changes in calories or any single “healthy” or “unhealthy” non-MDE food modified the association between MDE restrictions and blood lipid reductions. Additional research with adequately powered sample sizes is needed to further investigate if and how different plant-sourced dietary choices might influence the degree to which either short- or long-term periods of MDE restriction results in improved cardiometabolic health markers and which MDE components may have the greatest impact on such improvements. In the meantime, there is good reason to believe that replacing MDE products with refined grain products and added sugars will not produce the same beneficial change in cardiometabolic health markers as replacing MDE products with whole, minimally processed grains, legumes, nuts and seeds, and fruits and vegetables. This study calls for greater attention to be given to these and other sources of variation in health responses to plant-based diets, and it motivates further examination of the role of different kinds of animal products in health and disease trajectories.

Importantly, neither anthropological, epidemiological, nor any other isolated fields of study provide, on their own, a complete picture of why humans in the modern era are facing such a high chronic disease burden or which dietary factor(s) are most responsible for the common nutrition-related noncommunicable diseases ailing much of the world’s population. Together, however, research from across disciplines can help advance our understanding of the intricacies of how diet shapes health throughout the life course and can inform the development of comprehensive solutions to curb the growing prevalence of diet- and lifestyle-related morbidity and mortality.

REFERENCES

Abete I, Romaguera D, Vieira AR, Lopez de Munain A, and Norat T. 2014. Association between total, processed, red and white meat consumption and all-cause, CVD and IHD mortality: a meta-analysis of cohort studies. British Journal of Nutrition 112(5):762-775.

Adams SA, Matthews CE, Ebbeling CB, Moore CG, Cunningham JE, Fulton J, and Hebert JR. 2005. The Effect of Social Desirability and Social Approval on Self-Reports of Physical Activity. American Journal of Epidemiology 161(4):389-398.

Aeberli I, Gerber PA, Hochuli M, Kohler S, Haile SR, Gouni-Berthold I, Berthold HK, Spinas GA, and Berneis K. 2011. Low to moderate sugar-sweetened beverage consumption impairs glucose and lipid metabolism and promotes inflammation in healthy young men: a randomized controlled trial. The American Journal of Clinical Nutrition 94(2):479-485.

Afshin A, Micha R, Khatibzadeh S, and Mozaffarian D. 2014. Consumption of nuts and legumes and risk of incident ischemic heart disease, stroke, and diabetes: a systematic review and meta-analysis. The American Journal of Clinical Nutrition 100(1):278-288.

Aiello LC, and Wells JC. 2002. Energetics and the evolution of the genus Homo. Annual Review of Anthropology 31(1):323-338.

Aiello LC, and Wheeler P. 1995. The Expensive-Tissue Hypothesis: The Brain and the Digestive System in Human and Primate Evolution. Current Anthropology 36(2):199-221.

Ainsworth BE, Haskell WL, Herrmann SD, Meckes N, Bassett DRJ, Tudor-Locke C, Greer JL, Vezina J, Whitt-Glover MC, and Leon AS. 2011. 2011 Compendium of Physical Activities: A Second Update of Codes and MET Values. Medicine & Science in Sports & Exercise 43(8):1575-1581.

American Diabetes Association. 2010. Diagnosis and Classification of Diabetes Mellitus. Diabetes Care 33(Suppl 1):S62-S69.

American Diabetes Association. 2013. Economic Costs of Diabetes in the U.S. in 2012. Diabetes Care 36(4):1033-1046.

American Heart Association and American Stroke Association. 2017. Cardiovascular disease: a costly burden for America. Projections through 2035.

Anagnostis P, Athyros VG, Tziomalos K, Karagiannis A, and Mikhailidis DP. 2009. The Pathogenetic Role of Cortisol in the Metabolic Syndrome: A Hypothesis. The Journal of Clinical Endocrinology & Metabolism 94(8):2692-2701.

Appleby PN, Crowe FL, Bradbury KE, Travis RC, and Key TJ. 2016. Mortality in vegetarians and comparable nonvegetarians in the United Kingdom. The American Journal of Clinical Nutrition 103(1):218-230.

Aune D, Keum N, Giovannucci E, Fadnes LT, Boffetta P, Greenwood DC, Tonstad S, Vatten LJ, Riboli E, and Norat T. 2016a. Nut consumption and risk of cardiovascular disease, total cancer, all-cause and cause-specific mortality: a systematic review and dose-response meta-analysis of prospective studies. BMC Medicine 14(1):207.

Aune D, Keum N, Giovannucci E, Fadnes LT, Boffetta P, Greenwood DC, Tonstad S, Vatten LJ, Riboli E, and Norat T. 2016b. Whole grain consumption and risk of cardiovascular disease, cancer, and all cause and cause specific mortality: systematic review and dose-response meta-analysis of prospective studies. BMJ 353.

Aune D, Norat T, Romundstad P, and Vatten LJ. 2013a. Dairy products and the risk of type 2 diabetes: a systematic review and dose-response meta-analysis of cohort studies. The American Journal of Clinical Nutrition.

Aune D, Norat T, Romundstad P, and Vatten LJ. 2013b. Whole grain and refined grain consumption and the risk of type 2 diabetes: a systematic review and dose–response meta-analysis of cohort studies. European Journal of Epidemiology 28(11):845-858.

Aune D, Ursin G, and Veierod MB. 2009. Meat consumption and the risk of type 2 diabetes: a systematic review and meta-analysis of cohort studies. Diabetologia 52(11):2277-2287.

Bäckhed F, Ding H, Wang T, Hooper LV, Koh GY, Nagy A, Semenkovich CF, and Gordon JI. 2004. The gut microbiota as an environmental factor that regulates fat storage. Proceedings of the National Academy of Sciences of the United States of America 101(44):15718-15723.

Banel DK, and Hu FB. 2009. Effects of walnut consumption on blood lipids and other cardiovascular risk factors: a meta-analysis and systematic review. The American Journal of Clinical Nutrition 90(1):56-63.

Bang HO, Dyerberg J, and Nielsen A. 1971. Plasma Lipid and Lipoprotein Pattern in Greenlandic West-Coast Eskimos. The Lancet 297(7710):1143-1146.

Bang HO, Dyerberg J, and Sinclair HM. 1980. The composition of the Eskimo food in north western Greenland. The American Journal of Clinical Nutrition 33(12):2657-2661.

Barnard ND, Cohen J, Jenkins DJ, Turner-McGrievy G, Gloede L, Green A, and Ferdowsian H. 2009a. A low-fat vegan diet and a conventional diabetes diet in the treatment of type 2 diabetes: a randomized, controlled, 74-wk clinical trial. The American Journal of Clinical Nutrition 89(5):1588S-1596S.

Barnard ND, Cohen J, Jenkins DJA, Turner-McGrievy G, Gloede L, Jaster B, Seidl K, Green AA, and Talpers S. 2006. A Low-Fat Vegan Diet Improves Glycemic Control and Cardiovascular Risk Factors in a Randomized Clinical Trial in Individuals With Type 2 Diabetes. Diabetes Care 29(8):1777-1783.

Barnard ND, Gloede L, Cohen J, Jenkins DJA, Turner-McGrievy G, Green AA, and Ferdowsian H. 2009b. A Low-Fat Vegan Diet Elicits Greater Macronutrient Changes, but Is Comparable in Adherence and Acceptability, Compared with a More Conventional Diabetes Diet among Individuals with Type 2 Diabetes. Journal of the American Dietetic Association 109(2):263-272.

Barnard ND, Levin SM, and Yokoyama Y. 2015. A Systematic Review and Meta-Analysis of Changes in Body Weight in Clinical Trials of Vegetarian Diets. Journal of the Academy of Nutrition and Dietetics 115(6):954-969.

Barnard ND, Scialli AR, Bertron P, Hurlock D, Edmonds K, and Talev L. 2000. Effectiveness of a low-fat vegetarian diet in altering serum lipids in healthy premenopausal women. The American Journal of Cardiology 85(8):969-972.

Barnard ND, Scialli AR, Turner-McGrievy G, Lanou AJ, and Glass J. 2005. The effects of a low-fat, plant-based dietary intervention on body weight, metabolism, and insulin sensitivity. The American Journal of Medicine 118(9):991-997.

Bazzano LA, Thompson AM, Tees MT, Nguyen CH, and Winham DM. 2011. Non-soy legume consumption lowers cholesterol levels: A meta-analysis of randomized controlled trials. Nutrition, Metabolism and Cardiovascular Diseases 21(2):94-103.

Beauchesne-Rondeau É, Gascon A, Bergeron J, and Jacques H. 2003. Plasma lipids and lipoproteins in hypercholesterolemic men fed a lipid-lowering diet containing lean beef, lean fish, or poultry. The American Journal of Clinical Nutrition 77(3):587-593.

Becerra-Tomás N, Díaz-López A, Rosique-Esteban N, Ros E, Buil-Cosiales P, Corella D, Estruch R, Fitó M, Serra-Majem L, Arós F et al. . 2017. Legume consumption is inversely associated with type 2 diabetes incidence in adults: A prospective assessment from the PREDIMED study. Clinical Nutrition.

Bedford JL, and Barr SI. 2005. Diets and selected lifestyle practices of self-defined adult vegetarians from a population-based sample suggest they are more 'health conscious'. International Journal of Behavioral Nutrition and Physical Activity 2(1):4.

Benefice E, Chevassus-Agnes S, and Barral H. 1984. Nutritional situation and seasonal variations for pastoralist populations of the Sahel (Senegalese Ferlo). Ecology of Food and Nutrition 14(3):229-247.

Benjamin EJ, Blaha MJ, Chiuve SE, Cushman M, Das SR, Deo R, de Ferranti SD, Floyd J, Fornage M, Gillespie C et al. . 2017. Heart Disease and Stroke Statistics-2017 Update: A Report From the American Heart Association. Circulation 135(10):e146-e603.

Berkow SE, and Barnard ND. 2005. Blood pressure regulation and vegetarian diets. Nutr Rev 63(1):1-8.

Bethancourt HJ. unpublished. Orthodox Christian fasting in a modern context: a mixed-methods pilot study conducted in 2013-2014.

Bingham SA, Luben R, Welch A, Wareham N, Khaw K-T, and Day N. 2003. Are imprecise methods obscuring a relation between fat and breast cancer? The Lancet 362(9379):212-214.

Bloom D, Cafiero E, Jané-Llopis E, Abrahams-Gessel S, Bloom L, Fathima S, Feigl A, Gaziano T, Hamandi A, and Mowafi M. 2012. The global economic burden of noncommunicable diseases. Program on the Global Demography of Aging.

Bloomer R, Gunnels T, and Schriefer J. 2015. Comparison of a Restricted and Unrestricted Vegan Diet Plan with a Restricted Omnivorous Diet Plan on Health-Specific Measures. Healthcare 3(3):544.

Bloomer RJ, Kabir MM, Canale RE, Trepanowski JF, Marshall KE, Farney TM, and Hammond KG. 2010. Effect of a 21 day Daniel Fast on metabolic and cardiovascular disease risk factors in men and women. Lipids in Health and Disease 9(1):94.

Bloomfield HE, Koeller E, Greer N, MacDonald R, Kane R, and Wilt TJ. 2016. Effects on health outcomes of a mediterranean diet with no restriction on fat intake: A systematic review and meta-analysis. Annals of Internal Medicine 165(7):491-500.

Bocquet-Appel J-P. 2011a. The agricultural demographic transition during and after the agriculture inventions. Current Anthropology 52(S4):S497-S510.

Bocquet-Appel J-P. 2011b. When the world's population took off: The springboard of the Neolithic demographic transition. Science 333(6042):560-561.

Bocquet-Appel J-P, and Naji S. 2006. Testing the hypothesis of a worldwide Neolithic demographic transition: Corroboration from American cemeteries. Current Anthropology 47(2):341-365.

Boers I, Muskiet FA, Berkelaar E, Schut E, Penders R, Hoenderdos K, Wichers HJ, and Jong MC. 2014. Favourable effects of consuming a Palaeolithic-type diet on characteristics of the metabolic syndrome: a randomized controlled pilot-study. Lipids in Health and Disease 13(1):160.

Bogaty P, Dagenais GR, Joseph L, Boyer L, Leblanc A, Bélisle P, and Brophy JM. 2013. Time variability of C-reactive protein: Implications for clinical risk stratification. PLoS One 8(4):e60759.

Boldsen JL, and Milner GR. 2012. An epidemiological approach to paleopathology. In: Grauer AL, editor. A companion to paleopathology. Chichester, West Sussex ; Malden, MA: Chichester, West Sussex ; Malden, MA : Wiley-Blackwell.

Bookstein L, Gidding SS, Donovan M, and Smith FA. 1990. Day-to-day variability of serum cholesterol, triglyceride, and high-density lipoprotein cholesterol levels. Arch Intern Med 150:1653-1657.

Bowman SA, Friday JE, and Moshfegh AJ. 2008. MyPyramid Equivalents Database, 2.0 for USDA survey foods, 2003-2004: documentation and user guide. US Department of Agriculture.

Bradbury KE, Crowe FL, Appleby PN, Schmidt JA, Travis RC, and Key TJ. 2014. Serum concentrations of cholesterol, apolipoprotein A-I and apolipoprotein B in a total of 1694 meat-eaters, fish-eaters, vegetarians and vegans. Eur J Clin Nutr 68(2):178-183.

Braun DR, Harris JWK, McCoy JT, Levin NE, Herries AIR, Bamford MK, Bishop LC, Richmond BG, and Kibunjia M. 2010. Early hominin diet included diverse terrestrial and aquatic animals 1.95 Ma in East Turkana, Kenya. Proc Natl Acad Sci U S A Proceedings of the National Academy of Sciences of the United States of America 107(22):10002-10007.

Brindle E, Fujita M, Shofer J, and O'Connor KA. 2010. Serum, plasma, and dried blood spot high-sensitivity C-reactive protein enzyme immunoassay for population research. Journal of Immunological Methods 362(1–2):112-120.

Brown JE, Buzzard IM, Jacobs DR, Hannan PJ, Kushi LH, Barosso GM, and Schmid LA. 1996. A food frequency questionnaire can detect pregnancy-related changes in diet. Journal of the American Dietetic Association 96(3):262-266.

Brunzell JD, Davidson M, Furberg CD, Goldberg RB, Howard BV, Stein JH, and Witztum JL. 2008. Lipoprotein Management in Patients With Cardiometabolic Risk. Consensus statement from the American Diabetes Association and the American College of Cardiology Foundation 31(4):811-822.

Bunn H. 2007. Meat made us human. In: Ungar PS, editor. Evolution of the Human Diet: the Known, the Unknown, and the Unknowable. New York: Oxford University Press. p 191-211.

Buzzard IM, Faucett CL, Jeffery RW, McBane L, McGovern P, Baxter JS, Shapiro AC, Blackburn GL, Chlebowski RT, Elashoff RM et al. . 1996. Monitoring dietary change in a low-fat diet intervention study: Advantages of using 24-hour dietary recalls vs food records. Journal of the American Dietetic Association 96(6):574-579.

Calder PC. 2011. Fatty acids and inflammation: The cutting edge between food and pharma. European Journal of Pharmacology 668:S50-S58.

Calder PC. 2017. New evidence that omega-3 fatty acids have a role in primary prevention of coronary heart disease. Journal of Public Health and Emergency 1(2).

Carlsen S, Hyltoft Petersen P, Skeie S, Skadberg Ø, and Sandberg S. 2011. Within-subject biological variation of glucose and HbA1c in healthy persons and in type 1 diabetes patients. Clinical Chemistry and Laboratory Medicine. p 1501.

Carter P, Gray LJ, Troughton J, Khunti K, and Davies MJ. 2010. Fruit and vegetable intake and incidence of type 2 diabetes mellitus: systematic review and meta-analysis. British Medical Journal 341.

Chacko George G, Milani TJ, Hanss-Nuss H, Kim M, and Freeland-Graves JH. 2004. Development and validation of a semi-quantitative food frequency questionnaire for young adult women in the southwestern United States. Nutrition Research 24(1):29-43.

Chen GC, Lv DB, Pang Z, and Liu QF. 2013. Red and processed meat consumption and risk of stroke: a meta-analysis of prospective cohort studies. European Journal of Clinical Nutrition 67(1):91-95.

Chen M, Sun Q, Giovannucci E, Mozaffarian D, Manson JE, Willett WC, and Hu FB. 2014. Dairy consumption and risk of type 2 diabetes: 3 cohorts of US adults and an updated meta-analysis. BMC Medicine 12(1):215.

Chiu THT, Huang H-Y, Chen K-J, Wu Y-R, Chiu JPC, Li Y-H, Chiu BCH, Lin C-L, and Lin M-N. 2014. Relative validity and reproducibility of a quantitative FFQ for assessing nutrient intakes of vegetarians in Taiwan. Public Health Nutrition 17(7):1459-1466.

Cholesterol Treatment Trialists' (CTT) Collaborators. 2012. The effects of lowering LDL cholesterol with statin therapy in people at low risk of vascular disease: meta-analysis of individual data from 27 randomised trials. The Lancet 380(9841):581-590.

Cohen MN. 1989. Health and the Rise of Civilization. New Haven: Yale University Press.

Cohen MN. 1997. Does paleopathology measure community health. A rebuttal of "The osteological paradox" and its implications for world history. In: Paine RR, editor. Integrating archaeological demography : multidisciplinary approaches to prehistoric population. Carbondale, Ill.: Center for Archaeological Investigations, Southern Illinois University at Carbondale. p 242-260.

Cohen MN, and Armelagos GJ. 1984. Paleopathology at the Origins of Agriculture. New York: Academic Press.

Cohen MN, and Crane-Kramer GMM. 2007. Ancient Health: Skeletal Indicators of Agricultural and Economic Intensification. Gainesville: University Press of Florida.

Cooper AJ, Sharp SJ, Lentjes MAH, Luben RN, Khaw K-T, Wareham NJ, and Forouhi NG. 2012. A Prospective Study of the Association Between Quantity and Variety of Fruit and Vegetable Intake and Incident Type 2 Diabetes. Diabetes Care 35(6):1293-1300.

Cordain L. 1999. Cereal grains: humanity's double-edged sword. World Review of Nutrition and Dietetics 84:19-19.

Cordain L, Eaton SB, Brand Miller J, Mann N, and Hill K. 2002a. The paradoxical nature of hunter-gatherer diets: meat-based, yet non-atherogenic. European Journal of Clinical Nutrition 56(3):S42-S52.

Cordain L, Eaton SB, Sebastian A, Mann N, Lindeberg S, Watkins BA, O'Keefe JH, and Brand-Miller J. 2005. Origins and evolution of the Western diet: health implications for the 21st century. The American Journal of Clinical Nutrition 81(2):341-354.

Cordain L, Miller JB, Eaton SB, Mann N, Holt SH, and Speth JD. 2000. Plant-animal subsistence ratios and macronutrient energy estimations in worldwide hunter-gatherer diets. The American Journal of Clinical Nutrition 71(3):682-692.

Cordain L, Watkins BA, Florant G, Kelher M, Rogers L, and Li Y. 2002b. Fatty acid analysis of wild ruminant tissues: evolutionary implications for reducing diet-related chronic disease. European Journal of Clinical Nutrition 56(3):181-191.

Cordain L, Watkins BA, and Mann NJ. 2001. Fatty acid composition and energy density of foods available to African hominids. Nutrition and fitness: Metabolic studies in health and disease: Karger Publishers. p 144-161.

Craig WJ. 2009. Health effects of vegan diets. The American Journal of Clinical Nutrition 89(5):1627S-1633S.

Craig WJ. 2010. Nutrition Concerns and Health Effects of Vegetarian Diets. Nutrition in Clinical Practice 25(6):613-620.

Craig WJ, Mangels AR, and American Dietetic A. 2009. Position of the American Dietetic Association: vegetarian diets. Journal of the American Dietetic Association 109(7):1266-1282.

Crowe FL, Appleby PN, Travis RC, and Key TJ. 2013. Risk of hospitalization or death from ischemic heart disease among British vegetarians and nonvegetarians: results from the EPIC-Oxford cohort study. The American Journal of Clinical Nutrition 97(3):597-603.

Dahm CC, Keogh RH, Spencer EA, Greenwood DC, Key TJ, Fentiman IS, Shipley MJ, Brunner EJ, Cade JE, Burley VJ et al. . 2010. Dietary Fiber and Colorectal Cancer Risk: A Nested Case–Control Study Using Food Diaries. JNCI: Journal of the National Cancer Institute 102(9):614-626.

Dall TM, Yang W, Halder P, Pang B, Massoudi M, Wintfeld N, Semilla AP, Franz J, and Hogan PF. 2014. The Economic Burden of Elevated Blood Glucose Levels in 2012: Diagnosed and Undiagnosed Diabetes, Gestational Diabetes Mellitus, and Prediabetes. Diabetes Care 37(12):3172-3179.

Danaei G, Ding EL, Mozaffarian D, Taylor B, Rehm J, Murray CJ, and Ezzati M. 2009. The preventable causes of death in the United States: comparative risk assessment of dietary, lifestyle, and metabolic risk factors. PLOS Medicine 6(4):e1000058.

Dansinger ML, Gleason J, Griffith JL, Selker HP, and Schaefer EJ. 2005. Comparison of the Atkins, Ornish, Weight Watchers, and Zone diets for weight loss and heart disease risk reduction: A randomized trial. JAMA 293(1):43-53.

Dauchet L, Amouyel P, and Dallongeville J. 2009. Fruits, vegetables and coronary heart disease. Nature Reviews Cardiology 6(9):599-608.

Dauchet L, Amouyel P, Hercberg S, and Dallongeville J. 2006. Fruit and vegetable consumption and risk of coronary heart disease: A meta-analysis of cohort studies. The Journal of Nutrition 136(10):2588-2593.

Davidson MH, Hunninghake D, Maki KC, Kwiterovich POJ, and Kafonek S. 1999. Comparison of the effects of lean red meat vs lean white meat on serum lipid levels among free-living persons with hypercholesterolemia: A long-term, randomized clinical trial. Archives of Internal Medicine 159(12):1331-1338.

Day NE, McKeown N, Wong MY, Welch A, and Bingham S. 2001. Epidemiological assessment of diet: a comparison of a 7-day diary with a food frequency questionnaire using urinary markers of nitrogen, potassium and sodium. International Journal of Epidemiology 30(2):309-317.

de Goede J, Geleijnse JM, Ding EL, and Soedamah-Muthu SS. 2015. Effect of cheese consumption on blood lipids: a systematic review and meta-analysis of randomized controlled trials. Nutrition Reviews 73(5):259-275.

de Souza RJ, Mente A, Maroleanu A, Cozma AI, Ha V, Kishibe T, Uleryk E, Budylowski P, Schünemann H, Beyene J et al. . 2015. Intake of saturated and trans unsaturated fatty acids and risk of all cause mortality, cardiovascular disease, and type 2 diabetes: Systematic review and meta-analysis of observational studies. British Medical Journal 351.

Dehghan M, and Merchant AT. 2008. Is bioelectrical impedance accurate for use in large epidemiological studies? Nutrition Journal 7(1):26.

Demacker PNM, Schade RWB, Jansen RTP, and Van 't Laar A. Intra-individual variation of serum cholesterol, triglycerides and high density lipoprotein cholesterol in normal humans. Atherosclerosis 45(3):259-266.

deMenocal PB. 2004. African climate change and faunal evolution during the Pliocene–Pleistocene. Earth and Planetary Science Letters 220(1–2):3-24.

Després J-P, Lamarche B, Mauriège P, Cantin B, Dagenais GR, Moorjani S, and Lupien P-J. 1996. Hyperinsulinemia as an Independent Risk Factor for Ischemic Heart Disease. New England Journal of Medicine 334(15):952-958.

DeWitte SN, and Stojanowski CM. 2015. The Osteological Paradox 20 Years Later: Past Perspectives, Future Directions. Journal of Archaeological Research 23(4):397-450.

DeWitte SN, and Wood JW. 2008. Selectivity of Black Death mortality with respect to preexisting health. Proceedings of the National Academy of Sciences 105(5):1436-1441.

Dinu M, Abbate R, Gensini GF, Casini A, and Sofi F. 2017. Vegetarian, vegan diets and multiple health outcomes: A systematic review with meta-analysis of observational studies. Critical Reviews in Food Science and Nutrition 57(17):3640-3649.

Dodd KW, Guenther PM, Freedman LS, Subar AF, Kipnis V, Midthune D, Tooze JA, and Krebs-Smith SM. 2006. Statistical Methods for Estimating Usual Intake of Nutrients and Foods: A Review of the Theory. Journal of the American Dietetic Association 106(10):1640-1650.

Dominguez LJ, Bes-Rastrollo M, Basterra-Gortari FJ, Gea A, Barbagallo M, and Martínez-González MA. 2017. Should we recommend reductions in saturated fat intake or in red/processed meat consumption? The SUN prospective cohort study. Clinical Nutrition.

Dyerberg J, Bang HO, and Hjørne N. 1975. Fatty acid composition of the plasma lipids in Greenland Eskimos. The American Journal of Clinical Nutrition 28(9):958-966.

Dyett P, Rajaram S, Haddad E, and Sabate J. 2014. Evaluation of a Validated Food Frequency Questionnaire for Self-Defined Vegans in the United States. Nutrients 6(7):2523.

Dyett PA, Sabaté J, Haddad E, Rajaram S, and Shavlik D. 2013. Vegan lifestyle behaviors. An exploration of congruence with health-related beliefs and assessed health indices. Appetite 67:119-124.

Eaton SB, and Konner M. 1985. Paleolithic nutrition: A consideration of its nature and current implications. New England Journal of Medicine 312(5):283-289.

Eaton SB, Konner M, and Shostak M. 1988. Stone agers in the fast lane: Chronic degenerative diseases in evolutionary perspective. The American Journal of Medicine 84(4):739-749.

Elshorbagy A, Jerneren F, Basta M, Basta C, Turner C, Khaled M, and Refsum H. 2017. Amino acid changes during transition to a vegan diet supplemented with fish in healthy humans. European Journal of Nutrition 56(5):1953-1962.

Esposito K, Maiorino MI, Bellastella G, Chiodini P, Panagiotakos D, and Giugliano D. 2015. A journey into a Mediterranean diet and type 2 diabetes: A systematic review with meta-analyses. BMJ Open 5(8).

Estruch R, Ros E, Salas-Salvadó J, Covas M-I, Corella D, Arós F, Gómez-Gracia E, Ruiz-Gutiérrez V, Fiol M, Lapetra J et al. . 2013. Primary prevention of cardiovascular disease with a Mediterranean diet. New England Journal of Medicine 368(14):1279-1290.

Faghihnia N, Tsimikas S, Miller ER, Witztum JL, and Krauss RM. 2010. Changes in lipoprotein(a), oxidized phospholipids, and LDL subclasses with a low-fat high-carbohydrate diet. J Lipid Res 51(11):3324-3330.

Farley TA, Dalal MA, Mostashari F, and Frieden TR. 2010. Deaths preventable in the U.S. By improvements in use of clinical preventive services. American Journal of Preventive Medicine 38(6):600-609.

Ferdowsian HR, and Barnard ND. 2009. Effects of plant-based diets on plasma lipids. The American Journal of Cardiology 104(7):947-956.

Finch CE, and Stanford CB. 2004. Meat-adaptive genes and the evolution of slower aging in humans. Quarterly Review of Biology 79(1):3-50.

Flegal KM, Carroll MD, Kit BK, and Ogden CL. 2012. Prevalence of obesity and trends in the distribution of body mass index among us adults, 1999-2010. JAMA 307(5):491-497.

Fodor JG, Helis E, Yazdekhasti N, and Vohnout B. 2014. "Fishing" for the origins of the "Eskimos and heart disease" story: Facts or wishful thinking? Canadian Journal of Cardiology 30(8):864-868.

Fogelholm M, Kanerva N, and Männistö S. 2015. Association between red and processed meat consumption and chronic diseases: the confounding role of other dietary factors. European Journal of Clinical Nutrition 69:1060.

Fontana L, Meyer TE, Klein S, and Holloszy JO. 2004. Long-term calorie restriction is highly effective in reducing the risk for atherosclerosis in humans. Proceedings of the National Academy of Sciences of the United States of America 101(17):6659-6663.

Fontana L, Villareal DT, Weiss EP, Racette SB, Steger-May K, Klein S, and Holloszy JO. 2007. Calorie restriction or exercise: effects on coronary heart disease risk factors. A randomized, controlled trial. American Journal of Physiology - Endocrinology and Metabolism 293(1):E197-E202.

Forouzanfar MH, Alexander L, Anderson HR, Bachman VF, Biryukov S, Brauer M, Burnett R, Casey D, Coates MM, Cohen A et al. . 2015. Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks in 188 countries, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013. The Lancet 386(10010):2287-2323.

Foster GD, Wyatt HR, Hill JO, Makris AP, Rosenbaum DL, Brill C, Stein RI, Mohammed BS, Miller B, Rader DJ et al. . 2010. Weight and Metabolic Outcomes After 2 Years on a Low-Carbohydrate Versus Low-Fat Diet: A Randomized Trial. Annals of Internal Medicine 153(3):147-157.

Franz MJ. 2006. Medical Nutrition Therapy for Diabetes. In: Wilson T, Temple NJ, and Jacobs DR, editors. Nutritional Health: Strategies for Disease Prevention. Second ed. Totowa, NJ: Humana Press. p 49-75.

Fraser G, Katuli S, Anousheh R, Knutsen S, Herring P, and Fan J. 2015a. Vegetarian diets and cardiovascular risk factors in black members of the Adventist Health Study-2. Public Health Nutrition 18(3):537-545.

Fraser GE. 1999. Associations between diet and cancer, ischemic heart disease, and all-cause mortality in non-Hispanic white California Seventh-day Adventists. The American Journal of Clinical Nutrition 70(3):532s-538s.

Fraser GE. 2009. Vegetarian diets: what do we know of their effects on common chronic diseases? The American Journal of Clinical Nutrition 89(5):1607S-1612S.

Fraser GE, Orlich MJ, and Jaceldo-Siegl K. 2015b. Studies of chronic disease in Seventh-day Adventists. International Journal of Cardiology 184:573.

Frassetto LA, Schloetter M, Mietus-Synder M, Morris R, and Sebastian A. 2009. Metabolic and physiologic improvements from consuming a paleolithic, hunter-gatherer type diet. European Journal of Clinical Nutrition 63(8):947-955.

Freedman LS, Commins JM, Moler JE, Arab L, Baer DJ, Kipnis V, Midthune D, Moshfegh AJ, Neuhouser ML, Prentice RL et al. . 2014. Pooled Results From 5 Validation Studies of Dietary Self-Report Instruments Using Recovery Biomarkers for Energy and Protein Intake. American Journal of Epidemiology 180(2):172-188.

Freedman LS, Potischman N, Kipnis V, Midthune D, Schatzkin A, Thompson FE, Troiano RP, Prentice R, Patterson R, Carroll R et al. . 2006. A comparison of two dietary instruments for evaluating the fat–breast cancer relationship. International Journal of Epidemiology 35(4):1011-1021.

Freedman LS, Schatzkin A, Midthune D, and Kipnis V. 2011. Dealing with dietary measurement error in nutritional cohort studies. J Natl Cancer Inst 103(14):1086-1092.

Freedman LS, Schatzkin A, Thiebaut AC, Potischman N, Subar AF, Thompson FE, and Kipnis V. 2007. Abandon neither the food frequency questionnaire nor the dietary fat-breast cancer hypothesis. Cancer Epidemiology and Prevention Biomarkers 16(6):1321-1322.

Fretts AM, Howard BV, McKnight B, Duncan GE, Beresford SA, Mete M, Eilat-Adar S, Zhang Y, and Siscovick DS. 2012. Associations of processed meat and unprocessed red meat intake with incident diabetes: the Strong Heart Family Study. The American Journal of Clinical Nutrition 95(3):752-758.

Friedewald WT, Levy RI, and Fredrickson DS. 1972. Estimation of the concentration of low-density lipoprotein cholesterol in plasma, without use of the preparative ultracentrifuge. Clinical Chemistry 18(6):499.

Gaddi A, Ciarrocchi A, Matteucci A, Rimondi S, Ravaglia G, Descovich GC, and Sirtori CR. 1991. Dietary treatment for familial hypercholesterolemia--differential effects of dietary soy protein according to the apolipoprotein E phenotypes. The American Journal of Clinical Nutrition 53(5):1191-1196.

Gaesser GA, Angadi SS, and Sawyer BJ. 2011. Exercise and diet, independent of weight loss, improve cardiometabolic risk profile in overweight and obese individuals. The Physician and Sportsmedicine 39(2):87-97.

Gage TB. 2005. Are modern environments really bad for us? Revisiting the demographic and epidemiologic transitions. American journal of physical anthropology 128(S41):96-117.

Gage TB, and DeWitte SN. 2009. What do we know about the agricultural demographic transition? Current Anthropology 50(5):649-655.

Gallagher D, Heymsfield SB, Heo M, Jebb SA, Murgatroyd PR, and Sakamoto Y. 2000. Healthy percentage body fat ranges: an approach for developing guidelines based on body mass index. The American Journal of Clinical Nutrition 72(3):694-701.

Gan Y, Tong X, Li L, Cao S, Yin X, Gao C, Herath C, Li W, Jin Z, Chen Y et al. . 2015. Consumption of fruit and vegetable and risk of coronary heart disease: A meta-analysis of prospective cohort studies. International Journal of Cardiology 183:129-137.

Gardner CD, Coulston A, Chatterjee L, Rigby A, Spiller G, and Farquhar JW. 2005. The effect of a plant-based diet on plasma lipids in hypercholesterolemic adults: A randomized trial. Annals of Internal Medicine 142(9):725-733.

Gardner CD, Kiazand A, Alhassan S, and et al. 2007. Comparison of the Atkins, Zone, Ornish, and Learn diets for change in weight and related risk factors among overweight premenopausal women: The A to L weight loss study: A randomized trial. JAMA 297(9):969-977.

Gayoso-Diz P, Otero-González A, Rodriguez-Alvarez MX, Gude F, García F, De Francisco A, and Quintela AG. 2013. Insulin resistance (HOMA-IR) cut-off values and the metabolic syndrome in a general adult population: effect of gender and age: EPIRCE cross-sectional study. BMC Endocrine Disorders 13(1):47.

Gebauer SK, Psota TL, Harris WS, and Kris-Etherton PM. 2006. n−3 Fatty acid dietary recommendations and food sources to achieve essentiality and cardiovascular benefits. The American Journal of Clinical Nutrition 83(6):S1526-1535S.

Geiker NRW, Larsen ML, Dyerberg J, Stender S, and Astrup A. 2017. Egg consumption, cardiovascular diseases and type 2 diabetes. Eur J Clin Nutr.

Genoni A, Lyons-Wall P, Lo J, and Devine A. 2016. Cardiovascular, Metabolic Effects and Dietary Composition of Ad-Libitum Paleolithic vs. Australian Guide to Healthy Eating Diets: A 4-Week Randomised Trial. Nutrients 8(5):314.

Gialamas A, Laurence CO, Yelland LN, Tideman P, Worley P, Shephard MD, Tirimacco R, Willson KJ, Ryan P, Gill J et al. . 2010. Assessing agreement between point of care and laboratory results for lipid testing from a clinical perspective. Clinical Biochemistry 43(4–5):515-518.

Gijsbers L, Ding EL, Malik VS, de Goede J, Geleijnse JM, and Soedamah-Muthu SS. 2016. Consumption of dairy foods and diabetes incidence: a dose-response meta-analysis of observational studies. The American Journal of Clinical Nutrition 103(4):1111-1124.

Gilsing AMJ, Crowe FL, Lloyd-Wright Z, Sanders TAB, Appleby PN, Allen NE, and Key TJ. 2010. Serum concentrations of vitamin B12 and folate in British male omnivores, vegetarians and vegans: results from a cross-sectional analysis of the EPIC-Oxford cohort study. Eur J Clin Nutr 64(9):933-939.

Goris AH, Westerterp-Plantenga MS, and Westerterp KR. 2000. Undereating and underrecording of habitual food intake in obese men: selective underreporting of fat intake. The American Journal of Clinical Nutrition 71(1):130-134.

Grotto D, and Zied E. 2010. The standard American diet and its relationship to the health status of Americans. Nutrition in Clinical Practice 25(6):603-612.

Grundy SM, Cleeman JI, Merz CNB, Brewer HB, Clark LT, Hunninghake DB, Pasternak RC, Smith SC, and Stone NJ. 2004. Implications of Recent Clinical Trials for the National Cholesterol Education Program Adult Treatment Panel III Guidelines. Circulation 110(2):227-239.

Guariguata L, Whiting DR, Hambleton I, Beagley J, Linnenkamp U, and Shaw JE. 2014. Global estimates of diabetes prevalence for 2013 and projections for 2035. Diabetes Research and Clinical Practice 103(2):137-149.

Guenther PM, Casavale KO, Reedy J, Kirkpatrick SI, Hiza HA, Kuczynski KJ, Kahle LL, and Krebs-Smith SM. 2013. Update of the Healthy Eating Index: HEI-2010. Journal of the Academy of Nutrition and Dietetics 113(4):569-580.

Guenther PM, Kirkpatrick SI, Reedy J, Krebs-Smith SM, Buckman DW, Dodd KW, Casavale KO, and Carroll RJ. 2014. The Healthy Eating Index-2010 is a valid and reliable measure of diet quality according to the 2010 Dietary Guidelines for Americans. The Journal of Nutrition 144(3):399-407.

Guo J, Astrup A, Lovegrove JA, Gijsbers L, Givens DI, and Soedamah-Muthu SS. 2017. Milk and dairy consumption and risk of cardiovascular diseases and all-cause mortality: Dose–response meta-analysis of prospective cohort studies. European Journal of Epidemiology 32(4):269-287.

Gurven M, Jaeggi AV, Kaplan H, and Cummings D. 2013. Physical Activity and Modernization among Bolivian Amerindians. PLoS One 8(1):e55679.

Gurven MD, Trumble BC, Stieglitz J, Blackwell AD, Michalik DE, Finch CE, and Kaplan HS. 2016. Cardiovascular disease and type 2 diabetes in evolutionary perspective: A critical role for helminths? Evolution, Medicine, and Public Health 2016(1):338-357.

Ha V, Sievenpiper JL, de Souza RJ, Jayalath VH, Mirrahimi A, Agarwal A, Chiavaroli L, Mejia SB, Sacks FM, Di Buono M et al. . 2014. Effect of dietary pulse intake on established therapeutic lipid targets for cardiovascular risk reduction: A systematic review and meta-analysis of randomized controlled trials. Canadian Medical Association Journal 186(8):E252-E262.

Haddad EH, and Tanzman JS. 2003. What do vegetarians in the United States eat? The American Journal of Clinical Nutrition 78(3):626S-632S.

Haubrock J, Nöthlings U, Volatier J-L, Dekkers A, Ocké M, Harttig U, Illner A-K, Knüppel S, Andersen LF, Boeing H et al. . 2011. Estimating Usual Food Intake Distributions by Using the Multiple Source Method in the EPIC-Potsdam Calibration Study. The Journal of Nutrition 141(5):914-920.

Hawkes K, O'Connell JF, and Blurton Jones NG. 2001. Hadza meat sharing. Evolution and Human Behavior 22(2):113-142.

He FJ, Nowson CA, Lucas M, and MacGregor GA. 2007. Increased consumption of fruit and vegetables is related to a reduced risk of coronary heart disease: Meta-analysis of cohort studies. Journal of Human Hypertension 21(9):717-728.

He K, Song Y, Daviglus ML, Liu K, Van Horn L, Dyer AR, and Greenland P. 2004. Accumulated evidence on fish consumption and coronary heart disease mortality: A meta-analysis of cohort studies. Circulation 109(22):2705-2711.

Hebert JR, Ebbeling CB, Matthews CE, Hurley TG, Ma Y, Druker S, and Clemow L. 2002. Systematic errors in middle-aged women's estimates of energy intake: Comparing three self-report measures to total energy expenditure from doubly labeled water. Annals of Epidemiology 12(8):577-586.

Hebert JR, Hurley TG, Peterson KE, Resnicow K, Thompson FE, Yaroch AL, Ehlers M, Midthune D, Williams GC, Greene GW et al. . 2008. Social desirability trait influences on self-reported dietary measures among diverse participants in a multicenter multiple risk factor trial. The Journal of Nutrition 138(1):226S-234S.

Henry AG, Brooks AS, and Piperno DR. 2011. Microfossils in calculus demonstrate consumption of plants and cooked foods in Neanderthal diets (Shanidar III, Iraq; Spy I and II, Belgium). Proceedings of the National Academy of Sciences 108(2):486-491.

Hill K, Hawkes K, Hurtado M, and Kaplan H. 1984. Seasonal variance in the diet of Ache hunter-gatherers in Eastern Paraguay. Human Ecology 12(2):101-135.

Hirayama S, and Miida T. 2012. Small dense LDL: An emerging risk factor for cardiovascular disease. Clinica Chimica Acta 414:215-224.

Holden JM, Lemar LE, and Exler J. 2008. Vitamin D in foods: development of the US Department of Agriculture database. The American Journal of Clinical Nutrition 87(4):1092S-1096S.

Hollænder PL, Ross AB, and Kristensen M. 2015. Whole-grain and blood lipid changes in apparently healthy adults: a systematic review and meta-analysis of randomized controlled studies. The American Journal of Clinical Nutrition.

Hooper L, Martin N, Abdelhamid A, and Davey Smith G. 2015. Reduction in saturated fat intake for cardiovascular disease. Cochrane Database Syst Rev(6):Cd011737.

Hu FB. 2011. Globalization of Diabetes: The role of diet, lifestyle, and genes. Diabetes Care 34(6):1249-1257.

Hu FB, Rimm E, Smith-Warner SA, Feskanich D, Stampfer MJ, Ascherio A, Sampson L, and Willett WC. 1999. Reproducibility and validity of dietary patterns assessed with a food-frequency questionnaire. The American Journal of Clinical Nutrition 69(2):243-249.

Huang T, Yang B, Zheng J, Li G, Wahlqvist ML, and Li D. 2012. Cardiovascular disease mortality and cancer incidence in vegetarians: a meta-analysis and systematic review. Ann Nutr Metab 60(4):233-240.

Hursting SD, DiGiovanni J, Dannenberg AJ, Azrad M, LeRoith D, Demark-Wahnefried W, Kakarala M, Brodie A, and Berger NA. 2012. Obesity, Energy Balance, and Cancer: New Opportunities for Prevention. Cancer Prevention Research 5(11):1260-1272.

Hurtado AM, and Hill KR. 1990. Seasonality in a foraging society: variation in diet, work effort, fertility, and sexual division of labor among the Hiwi of Venezuela. Journal of Anthropological Research 46(3):293-346.

Huth PJ, and Park KM. 2012. Influence of dairy product and milk fat consumption on cardiovascular disease risk: A review of the evidence. Advances in Nutrition 3(3):266-285.

Ingram CJ, Mulcare CA, Itan Y, Thomas MG, and Swallow DM. 2009. Lactose digestion and the evolutionary genetics of lactase persistence. Human Genetics 124(6):579-591.

Jaacks LM, Kapoor D, Singh K, Narayan KMV, Ali MK, Kadir MM, Mohan V, Tandon N, and Prabhakaran D. 2016. Vegetarianism and cardiometabolic disease risk factors: Differences between South Asian and US adults. Nutrition 32(9):975-984.

Jaceldo-Siegl K, Knutsen SF, Sabaté J, Beeson WL, Chan J, Herring RP, Butler TL, Haddad E, Bennett H, Montgomery S et al. . 2010. Validation of nutrient intake using an FFQ and repeated 24 h recalls in black and white subjects of the Adventist Health Study-2 (AHS-2). Public Health Nutrition 13(6):812-819.

Jakobsen MU, Dethlefsen C, Joensen AM, Stegger J, Tjønneland A, Schmidt EB, and Overvad K. 2010. Intake of carbohydrates compared with intake of saturated fatty acids and risk of myocardial infarction: importance of the glycemic index. The American Journal of Clinical Nutrition 91(6):1764-1768.

Jakobsen MU, O'Reilly EJ, Heitmann BL, Pereira MA, Bälter K, Fraser GE, Goldbourt U, Hallmans G, Knekt P, Liu S et al. . 2009. Major types of dietary fat and risk of coronary heart disease: A pooled analysis of 11 cohort studies. The American Journal of Clinical Nutrition 89(5):1425-1432.

Janssen M, Busch C, Rödiger M, and Hamm U. 2016. Motives of consumers following a vegan diet and their attitudes towards animal agriculture. Appetite 105(Supplement C):643-651.

Jenkins DA, Kendall CC, Marchie A, and et al. 2003. Effects of a dietary portfolio of cholesterol-lowering foods vs lovastatin on serum lipids and c-reactive protein. JAMA 290(4):502-510.

Jenkins DJA, Popovich DG, Kendall CWC, Vidgen E, Tariq N, Ransom TPP, Wolever TMS, Vuksan V, Mehling CC, Boctor DL et al. . 1997. Effect of a diet high in vegetables, fruit, and nuts on serum lipids. Metabolism 46(5):530-537.

Jönsson T, Granfeldt Y, Ahrén B, Branell U-C, Pålsson G, Hansson A, Söderström M, and Lindeberg S. 2009a. Beneficial effects of a Paleolithic diet on cardiovascular risk factors in type 2 diabetes: a randomized cross-over pilot study. Cardiovascular Diabetology 8:35-35.

Jönsson T, Granfeldt Y, Ahrén B, Branell UC, Pålsson G, Hansson A, Söderström M, and Lindeberg S. 2009b. Beneficial effects of a Paleolithic diet on cardiovascular risk factors in type 2 diabetes: a randomized cross-over pilot study. Cardiovascular Diabetology 8:35.

Kahleova H, Levin S, and Barnard N. 2017. Cardio-Metabolic Benefits of Plant-Based Diets. Nutrients 9(8):848.

Kahleova H, Matoulek M, Malinska H, Oliyarnik O, Kazdova L, Neskudla T, Skoch A, Hajek M, Hill M, Kahle M et al. . 2011. Vegetarian diet improves insulin resistance and oxidative stress markers more than conventional diet in subjects with Type 2 diabetes. Diabetic Medicine 28(5):549-559.

Kaplan H, Hill K, Lancaster J, and Hurtado AM. 2000. A theory of human life history evolution: Diet, intelligence, and longevity. Evolutionary Anthropology: Issues, News, and Reviews 9(4):156-185.

Kaplan H, Thompson RC, Trumble BC, Wann LS, Allam AH, Beheim B, Frohlich B, Sutherland ML, Sutherland JD, Stieglitz J et al. . 2017. Coronary atherosclerosis in indigenous South American Tsimane: a cross-sectional cohort study. The Lancet 389(10080):1730-1739.

Kappeler R, Eichholzer M, and Rohrmann S. 2013. Meat consumption and diet quality and mortality in NHANES III. European Journal of Clinical Nutrition 67:598.

Karras SN, Persynaki A, Petroczi A, Barkans E, Mulrooney H, Kypraiou M, Tzotzas T, Tziomalos K, Kotsa K, Tsioudas AA et al. . 2017. Health benefits and consequences of the Eastern Orthodox fasting in monks of Mount Athos: a cross-sectional study. Eur J Clin Nutr 71(6):743-749.

Key TJ, Fraser GE, Thorogood M, Appleby PN, Beral V, Reeves G, Burr ML, Chang-Claude J, Frentzel-Beyme R, Kuzma JW et al. . 1999. Mortality in vegetarians and nonvegetarians: detailed findings from a collaborative analysis of 5 prospective studies. The American Journal of Clinical Nutrition 70(3):516s-524s.

Kipnis V, Carroll RJ, Freedman LS, and Li L. 1999. Implications of a new dietary measurement error model for estimation of relative risk: Application to four calibration studies. American Journal of Epidemiology 150(6):642-651.

Kipnis V, Midthune D, Buckman DW, Dodd KW, Guenther PM, Krebs-Smith SM, Subar AF, Tooze JA, Carroll RJ, and Freedman LS. 2009. Modeling data with excess zeros and measurement error: Application to evaluating relationships between episodically consumed foods and health outcomes. Biometrics 65(4):1003-1010.

Kipnis V, Midthune D, Freedman LS, Bingham S, Schatzkin A, Subar A, and Carroll RJ. 2001. Empirical Evidence of Correlated Biases in Dietary Assessment Instruments and Its Implications. American Journal of Epidemiology 153(4):394-403.

Kipnis V, Subar AF, Midthune D, Freedman LS, Ballard-Barbash R, Troiano RP, Bingham S, Schoeller DA, Schatzkin A, and Carroll RJ. 2003. Structure of dietary measurement error: Results of the OPEN biomarker study. American Journal of Epidemiology 158(1):14-21; Discussion 22-16.

Kohl H, Blair S, Paffenbarger R, Macera C, and Kronenfeld J. 1997. The aerobics center longitudinal study physical activity questionnaire. Med Sci Sports Exerc 29(Suppl 6):S10-S14.

Kohl HW, Blair SN, Paffenbarger RS, Macera CA, and Kronenfeld JJ. 1988. A mail survey of physical activity habits as related to measured physical fitness. American Journal of Epidemiology 127(6):1228-1239.

Kratz M, Baars T, and Guyenet S. 2013. The relationship between high-fat dairy consumption and obesity, cardiovascular, and metabolic disease. European Journal of Nutrition 52(1):1-24.

Krebs-Smith SM, Guenther PM, Subar AF, Kirkpatrick SI, and Dodd KW. 2010. Americans do not meet federal dietary recommendations. The Journal of Nutrition 140(10):1832-1838.

Krindatch AD. 2011. Atlas of American Orthodox Christian Churches. Brookline, MA: Holy Cross Orthodox Press.

Kristal AR, Beresford S, and Lazovich D. 1994. Assessing change in diet-intervention research. The American Journal of Clinical Nutrition 59(1):185S-189S.

Kristal AR, Peters U, and Potter JD. 2005. Is it time to abandon the food frequency questionnaire? Cancer Epidemiology Biomarkers and Prevention 14(12):2826-2828.

Kristal AR, and Potter JD. 2006. Not the time to abandon the food frequency questionnaire: counterpoint. Cancer Epidemiology Biomarkers and Prevention 15(10):1759.

Kwan ML, Kushi LH, Song J, Timperi AW, Boynton AM, Johnson KM, Standley J, and Kristal AR. 2010. A practical method for collecting food record data in a prospective cohort study of breast cancer survivors. American Journal of Epidemiology 172(11):1315-1323.

Kwok CS, Mamas MA, and Loke YK. 2015. Vegetarian diets and Adventists. International Journal of Cardiology 190:383.

Kwok CS, Umar S, Myint PK, Mamas MA, and Loke YK. 2014. Vegetarian diet, Seventh Day Adventists and risk of cardiovascular mortality: A systematic review and meta-analysis. International Journal of Cardiology 176(3):680-686.

Lajous M, Tondeur L, Fagherazzi G, de Lauzon-Guillain B, Boutron-Ruaualt M-C, and Clavel-Chapelon F. 2012. Processed and unprocessed red meat consumption and incident type 2 diabetes among French women. Diabetes Care 35(1):128-130.

Lambert Patricia M. 2009. Health versus fitness: Competing themes in the origins and spread of agriculture? Current Anthropology 50(5):603-608.

Larsen CS. 1995. Biological changes in human populations with agriculture. Annual Review of Anthropology 24(1):185-213.

Larsen CS. 2006. The agricultural revolution as environmental catastrophe: Implications for health and lifestyle in the Holocene. Quaternary International 150(1):12-20.

Larsson SC, and Orsini N. 2014. Red Meat and Processed Meat Consumption and All-Cause Mortality: A Meta-Analysis. American Journal of Epidemiology 179(3):282-289.

Leenders M, Boshuizen HC, Ferrari P, Siersema PD, Overvad K, Tjønneland A, Olsen A, Boutron-Ruault M-C, Dossus L, Dartois L et al. . 2014. Fruit and vegetable intake and cause-specific mortality in the EPIC study. European Journal of Epidemiology 29(9):639-652.

Leitzmann C. 2014. Vegetarian nutrition: past, present, future. The American Journal of Clinical Nutrition 100(Supplement 1):496S-502S.

Leonard WR. 2002. Food for thought. Scientific American 287(6).

Leonard WR, Crawford MH, Comuzzie AG, and Sukernik RI. 1994. Correlates of low serum lipid levels among the Evenki herders of Siberia. Am J Hum Biol 6(3):329-338.

Leonard WR, Snodgrass JJ, and Robertson ML. 2007. Effects of brain evolution on human nutrition and metabolism. Annu Rev Nutr 27:311-327.

Levine ME, Suarez JA, Brandhorst S, Balasubramanian P, Cheng C-W, Madia F, Fontana L, Mirisola MG, Guevara-Aguirre J, Wan J et al. . 2014. Low protein intake is associated with a major reduction in IGF-1, cancer, and overall mortality in the 65 and younger but not older population. Cell metabolism 19(3):407-417.

Ley SH, Hamdy O, Mohan V, and Hu FB. 2014. Prevention and management of type 2 diabetes: dietary components and nutritional strategies. The Lancet 383(9933):1999-2007.

Li M, Fan Y, Zhang X, Hou W, and Tang Z. 2014. Fruit and vegetable intake and risk of type 2 diabetes mellitus: meta-analysis of prospective cohort studies. BMJ Open 4(11).

Li Y, Hruby A, Bernstein AM, Ley SH, Wang DD, Chiuve SE, Sampson L, Rexrode KM, Rimm EB, Willett WC et al. . 2015. Saturated fats compared with unsaturated fats and sources of carbohydrates in relation to risk of coronary heart disease: A prospective cohort study. Journal of the American College of Cardiology 66(14):1538-1548.

Lillycrop KA, and Burdge GC. 2012. Epigenetic mechanisms linking early nutrition to long term health. Best Practice and Research Clinical Endocrinology and Metabolism 26(5):667-676.

Lim SS, Vos T, Flaxman AD, Danaei G, Shibuya K, Adair-Rohani H, Amann M, Anderson HR, Andrews KG, and Aryee M. 2013. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. The Lancet 380(9859):2224-2260.

Lindeberg S. 2010. Food and Western Disease Health and Nutrition from an Evolutionary Perspective. Oxford; Ames, Iowa: Wiley-Blackwell.

Lindeberg S, Berntorp E, Nilsson-Ehle P, Terént A, and Vessby B. 1997. Age relations of cardiovascular risk factors in a traditional Melanesian society: the Kitava Study. The American Journal of Clinical Nutrition 66(4):845-852.

Lindeberg S, Jönsson T, Granfeldt Y, Borgstrand E, Soffman J, Sjöström K, and Ahren B. 2007. A Palaeolithic diet improves glucose tolerance more than a Mediterranean-like diet in individuals with ischaemic heart disease. Diabetologia 50(9):1795-1807.

Liu G, Zong G, Wu K, Hu Y, Li Y, Willett WC, Eisenberg DM, Hu FB, and Sun Q. 2018. Meat cooking methods and risk of type 2 diabetes: Results from three prospective cohort studies. Diabetes Care.

Liyanage T, Ninomiya T, Wang A, Neal B, Jun M, Wong MG, Jardine M, Hillis GS, and Perkovic V. 2016. Effects of the mediterranean diet on cardiovascular outcomes—A systematic review and meta-analysis. PLoS One 11(8):e0159252.

Lock K, Pomerleau J, Causer L, Altmann DR, and McKee M. 2005. The global burden of disease attributable to low consumption of fruit and vegetables: implications for the global strategy on diet. Bulletin of the World Health Organization 83(2):100.

Longo VD, and Panda S. 2016. Fasting, circadian rhythms, and time-restricted feeding in healthy lifespan. Cell metabolism 23(6):1048-1059.

Lopez-Miranda J, Ordovas JM, Mata P, Lichtenstein AH, Clevidence B, Judd JT, and Schaefer EJ. 1994. Effect of apolipoprotein E phenotype on diet-induced lowering of plasma low density lipoprotein cholesterol. J Lipid Res 35(11):1965-1975.

Lovegrove JA, and Givens DI. 2016. Dairy food products: good or bad for cardiometabolic disease? Nutrition Research Reviews 29(2):249-267.

Luo C, Zhang Y, Ding Y, Shan Z, Chen S, Yu M, Hu FB, and Liu L. 2014. Nut consumption and risk of type 2 diabetes, cardiovascular disease, and all-cause mortality: A systematic review and meta-analysis. The American Journal of Clinical Nutrition 100(1):256-269.

Malik VS, Popkin BM, Bray GA, Després J-P, Willett WC, and Hu FB. 2010. Sugar-Sweetened Beverages and Risk of Metabolic Syndrome and Type 2 Diabetes. A meta-analysis 33(11):2477-2483.

Manheimer EW, van Zuuren EJ, Fedorowicz Z, and Pijl H. 2015. Paleolithic nutrition for metabolic syndrome: systematic review and meta-analysis. The American Journal of Clinical Nutrition 102(4).

Mann G, Shaffer R, and Rich A. 1965. Physical Fitness and Immunity to Heart-Disease in Masai. The Lancet 286(7426):1308-1310.

Mann GV, Shaffer RD, Anderson RS, Sandstead HH, Prendergast H, Mann JC, Rose S, Powell-Jackson J, Moitanik S, Ol Monah J et al. . 1964. Cardiovascular disease in the Masai. Journal of Atherosclerosis Research 4(4):289-312.

Mann GV, Spoerry A, Gary M, and Jarashow D. 1972. Atherosclerosis in the Masai. American Journal of Epidemiology 95(1):26-37.

Marcovina S, Bowsher RR, Miller WG, Staten M, Myers G, Caudill SP, Campbell SE, and Steffes MW. 2007. Standardization of insulin immunoassays: Report of the American Diabetes Association Workgroup. Clinical Chemistry 53(4):711-716.

Matthews DR, Hosker JP, Rudenski AS, Naylor BA, Treacher DF, and Turner RC. 1985. Homeostasis model assessment: insulin resistance and β-cell function from fasting plasma glucose and insulin concentrations in man. Diabetologia 28(7):412-419.

Mattson MP, Longo VD, and Harvie M. 2017. Impact of intermittent fasting on health and disease processes. Ageing Research Reviews 39:46-58.

McAuley KA, Williams SM, Mann JI, Walker RJ, Lewis-Barned NJ, Temple LA, and Duncan AW. 2001. Diagnosing Insulin Resistance in the General Population. Diabetes Care 24(3):460-464.

McDade TW, Rutherford JN, Adair L, and Kuzawa C. 2009. Population differences in associations between C-reactive protein concentration and adiposity: comparison of young adults in the Philippines and the United States. The American Journal of Clinical Nutrition 89(4):1237-1245.

McEvoy CT, Temple N, and Woodside JV. 2012. Vegetarian diets, low-meat diets and health: A review. Public Health Nutrition 15(12):2287-2294.

McGonigal K. 2012. The willpower instinct: How self-control works, why it matters, and what you can do to get more of it. New York: Avery.

McKeown NM, Day NE, Welch AA, Runswick SA, Luben RN, Mulligan AA, McTaggart A, and Bingham SA. 2001. Use of biological markers to validate self-reported dietary intake in a random sample of the European Prospective Investigation into Cancer United Kingdom Norfolk cohort. The American Journal of Clinical Nutrition 74(2):188-196.

Melamed Y, Kislev ME, Geffen E, Lev-Yadun S, and Goren-Inbar N. 2016. The plant component of an Acheulian diet at Gesher Benot Ya‘aqov, Israel. Proceedings of the National Academy of Sciences 113(51):14674-14679.

Melina V, Craig W, and Levin S. 2016. Position of the Academy of Nutrition and Dietetics: Vegetarian Diets. Journal of the Academy of Nutrition and Dietetics 116(12):1970-1980.

Mellberg C, Sandberg S, Ryberg M, Eriksson M, Brage S, Larsson C, Olsson T, and Lindahl B. 2014. Long-term effects of a Palaeolithic-type diet in obese postmenopausal women: a two-year randomized trial. European Journal of Clinical Nutrition 68(3):350-357.

Mensink RP, Zock PL, Kester AD, and Katan MB. 2003. Effects of dietary fatty acids and carbohydrates on the ratio of serum total to HDL cholesterol and on serum lipids and apolipoproteins: a meta-analysis of 60 controlled trials. The American Journal of Clinical Nutrition 77(5):1146-1155.

Mercader J. 2009. Mozambican grass seed consumption during the Middle Stone Age. Science 326(5960):1680-1683.

Messina V. 2014. Nutritional and health benefits of dried beans. The American Journal of Clinical Nutrition 100(Supplement 1):437S-442S.

Micha R, Khatibzadeh S, Shi P, Andrews KG, Engell RE, and Mozaffarian D. 2015. Global, regional and national consumption of major food groups in 1990 and 2010: a systematic analysis including 266 country-specific nutrition surveys worldwide. BMJ Open 5(9).

Micha R, Michas G, and Mozaffarian D. 2012. Unprocessed red and processed meats and risk of coronary artery disease and type 2 diabetes – An updated review of the evidence. Current Atherosclerosis Reports 14(6):515-524.

Micha R, Peñalvo JL, Cudhea F, Imamura F, Rehm CD, and Mozaffarian D. 2017. Association between dietary factors and mortality from heart disease, stroke, and type 2 diabetes in the united states. JAMA 317(9):912-924.

Micha R, Wallace SK, and Mozaffarian D. 2010. Red and processed meat consumption and risk of incident coronary heart disease, stroke, and diabetes mellitus. A systematic review and meta-analysis. Circulation.

Michas G, Micha R, and Zampelas A. 2014. Dietary fats and cardiovascular disease: Putting together the pieces of a complicated puzzle. Atherosclerosis 234(2):320-328.

Mielke MM, Zandi PP, Sjögren M, Gustafson D, Östling S, Steen B, and Skoog I. 2005. High total cholesterol levels in late life associated with a reduced risk of dementia. Neurology 64(10):1689-1695.

Mihrshahi S, Ding D, Gale J, Allman-Farinelli M, Banks E, and Bauman AE. 2017. Vegetarian diet and all-cause mortality: Evidence from a large population-based Australian cohort - the 45 and Up Study. Preventive Medicine 97:1-7.

Millen AE, Midthune D, Thompson FE, Kipnis V, and Subar AF. 2006. The National Cancer Institute Diet History Questionnaire: Validation of Pyramid Food Servings. American Journal of Epidemiology 163(3):279-288.

Miller M, Stone NJ, Ballantyne C, Bittner V, Criqui MH, Ginsberg HN, Goldberg AC, Howard WJ, Jacobson MS, Kris-Etherton PM et al. . 2011. Triglycerides and Cardiovascular Disease. A Scientific Statement From the American Heart Association 123(20):2292-2333.

Milton K. 2000. Hunter-gatherer diets: A different perspective. The American Journal of Clinical Nutrition 71(3):665-667.

Milton K. 2003. The critical role played by animal source foods in human (Homo) evolution. The Journal of Nutrition 133(11):3886S-3892S.

Mishra S, Xu J, Agarwal U, Gonzales J, Levin S, and Barnard ND. 2013. A multicenter randomized controlled trial of a plant-based nutrition program to reduce body weight and cardiovascular risk in the corporate setting: the GEICO study. Eur J Clin Nutr 67(7):718-724.

Mogadam M, Ahmed SW, Mensch AH, and Godwin ID. 1990. Within-person fluctuations of serum cholesterol and lipoproteins. Archives of Internal Medicine 150(8):1645-1648.

Mokdad AH, Marks JS, Stroup DF, and Gerberding JL. 2004. Actual causes of death in the United States, 2000. Journal of the American Medical Association 291(10):1238-1245.

Moore LV, and Thompson FE. 2015. Adults Meeting Fruit and Vegetable Intake Recommendations - United States, 2013. MMWR Morbidity and mortality weekly report 64(26):709-713.

Mora S, Otvos JD, Rifai N, Rosenson RS, Buring JE, and Ridker PM. 2009. Lipoprotein Particle Profiles by Nuclear Magnetic Resonance Compared With Standard Lipids and Apolipoproteins in Predicting Incident Cardiovascular Disease in Women. Circulation 119(7):931-939.

Morcos NY, Seoudi DM, Kamel I, and Youssef MM. 2013. Effect of Coptic Orthodox Christian church fasting on healthy and diabetic subjects. International Journal of Nutrition, Pharmacology, Neurological Diseases 3(4):375.

Morgan RE, Palinkas LA, Barrett-Connor EL, and Wingard DL. 1993. Plasma cholesterol and depressive symptoms in older men. The Lancet 341(8837):75-79.

Most J, Tosti V, Redman LM, and Fontana L. 2017. Calorie restriction in humans: An update. Ageing Research Reviews 39(Supplement C):36-45.

Motamed N, Miresmail SJH, Rabiee B, Keyvani H, Farahani B, Maadi M, and Zamani F. 2016. Optimal cutoff points for HOMA-IR and QUICKI in the diagnosis of metabolic syndrome and non-alcoholic fatty liver disease: A population based study. Journal of Diabetes and its Complications 30(2):269-274.

Mozaffarian D. 2016. Dietary and policy priorities for cardiovascular disease, diabetes, and obesity: A Comprehensive Review. Circulation 133(2):187-225.

Mozaffarian D, Hao T, Rimm EB, Willett WC, and Hu FB. 2011. Changes in Diet and Lifestyle and Long-Term Weight Gain in Women and Men. New England Journal of Medicine 364(25):2392-2404.

Mozaffarian D, Micha R, and Wallace S. 2010. Effects on coronary heart disease of increasing polyunsaturated fat in place of saturated fat: A systematic review and meta-analysis of randomized controlled trials. PLOS Medicine 7(3):e1000252.

Mullington JM, Haack M, Toth M, Serrador JM, and Meier-Ewert HK. 2009. Cardiovascular, Inflammatory, and Metabolic Consequences of Sleep Deprivation. Progress in Cardiovascular Diseases 51(4):294-302.

Murphy SP, and Allen LH. 2003. Nutritional importance of animal source foods. The Journal of Nutrition 133(11):3932S-3935S.

Myers GL, Rifai N, Tracy RP, Roberts WL, Alexander RW, Biasucci LM, Catravas JD, Cole TG, Cooper GR, Khan BV et al. . 2004. CDC/AHA Workshop on Markers of Inflammation and Cardiovascular Disease. Application to Clinical and Public Health Practice: Report From the Laboratory Science Discussion Group 110(25):e545-e549.

NASR. Nutrition Assessment. Nutritional Assessment Shared Resource (NASR), Fred Hutchinson Cancer Research Center, available at http://sharedresources.fhcrc.org/core-facilities/nutrition-assessment.

National Institutes of Health. 1998. Clinical guidelines on the identification, evaluation, and treatment of overweight and obesity in adults - the evidence report. . In: National Heart LaBI, editor. NIH Publication. Bethesda, MD. p 228.

Nayor M, and Vasan RS. 2016. Recent Update to the US Cholesterol Treatment Guidelines. A Comparison With International Guidelines 133(18):1795-1806.

NCEP. 2002. Third Report of the National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III) Final Report. Circulation 106(25):3143-3143.

Neuhouser ML, Tinker L, Shaw PA, Schoeller D, Bingham SA, Horn LV, Beresford SAA, Caan B, Thomson C, Satterfield S et al. . 2008. Use of recovery biomarkers to calibrate nutrient consumption self-reports in the Women's Health Initiative. American Journal of Epidemiology 167(10):1247-1259.

Neumann CG, Murphy SP, Gewa C, Grillenberger M, and Bwibo NO. 2007. Meat supplementation improves growth, cognitive, and behavioral outcomes in Kenyan children. The Journal of Nutrition 137(4):1119-1123.

Nieves JW. 2013. Skeletal effects of nutrients and nutraceuticals, beyond calcium and vitamin D. Osteoporosis International 24(3):771-786.

Nordmann AJ, Suter-Zimmermann K, Bucher HC, Shai I, Tuttle KR, Estruch R, and Briel M. 2011. Meta-analysis comparing mediterranean to low-fat diets for modification of cardiovascular risk factors. American Journal of Medicine 124(9):841-851.

Nutrition Coordinating Center: University of Minnesota. 2015. Nutrient Data System for Research.

O'Keefe JH, Cordain L, Harris WH, Moe RM, and Vogel R. 2004. Optimal low-density lipoprotein is 50 to 70 mg/dl: Lower is better and physiologically normal. J Am Coll Cardiol 43(11):2142-2146.

O'Keefe JH, Vogel R, Lavie CJ, and Cordain L. 2011. Exercise like a hunter-gatherer: a prescription for organic physical fitness. Progress in Cardiovascular Diseases 53(6):471-479.

O’Connell J, Hawkes K, and Blurton Jones N. 2002. Meat-eating, grandmothering, and the evolution of early human diets. In: Ungar PS, and Teaford MF, editors. Human Diet: Its Origin and Evolution. Westport, Connecticut: Bergin & Garvey. p 61-76.

O’Connell JF, Hawkes K, and Blurton Jones NG. 1999. Grandmothering and the evolution of *Homo erectus*. J Hum Evol 36(5):461-485.

Oeppen J, and Vaupel JW. 2002. Broken Limits to Life Expectancy. Science 296(5570):1029-1031.

Omran AR. 1998. The epidemiologic transition theory revisited thirty years later. World Health Statistics Quarterly 51(1).

Onder G, Landi F, Volpato S, Fellin R, Carbonin P, Gambassi G, and Bernabei R. Serum cholesterol levels and in-hospital mortality in the elderly. The American Journal of Medicine 115(4):265-271.

Oreopoulos A, Ezekowitz JA, McAlister FA, Kalantar-Zadeh K, Fonarow GC, Norris CM, Johnson JA, and Padwal RS. 2010. Association between direct measures of body composition and prognostic factors in chronic heart failure. Mayo Clinic Proceedings 85(7):609-617.

Orlich MJ, Jaceldo-Siegl K, Sabaté J, Fan J, Singh PN, and Fraser GE. 2014. Patterns of food consumption among vegetarians and non-vegetarians. British Journal of Nutrition 112(10):1644-1653.

Orlich MJ, Singh PN, Sabaté J, Jaceldo-Siegl K, Fan J, Knutsen S, Beeson WL, and Fraser GE. 2013. Vegetarian dietary patterns and mortality in Adventist Health Study 2. JAMA Internal Medicine:1-8.

Otten J, Stomby A, Waling M, Isaksson A, Tellström A, Lundin-Olsson L, Brage S, Ryberg M, Svensson M, and Olsson T. 2017. Benefits of a Paleolithic diet with and without supervised exercise on fat mass, insulin sensitivity, and glycemic control: a randomized controlled trial in individuals with type 2 diabetes. Diabetes/Metabolism Research and Reviews 33(1):e2828.

Pan A, PhD, Sun Q, Md, ScD, Bernstein AM, Md, ScD, and et al. 2012a. Red meat consumption and mortality: Results from 2 prospective cohort studies. Archives of Internal Medicine 172(7):555-563.

Pan A, Sun Q, Bernstein AM, Schulze MB, Manson JE, Stampfer MJ, Willett WC, and Hu FB. 2012b. Red meat consumption and mortality: results from 2 prospective cohort studies. Archives of Internal Medicine 172(7):555-563.

Pan A, Sun Q, Bernstein AM, Schulze MB, Manson JE, Willett WC, and Hu FB. 2011. Red meat consumption and risk of type 2 diabetes: 3 cohorts of US adults and an updated meta-analysis. The American Journal of Clinical Nutrition 94(4):1088-1096.

Papadaki A, Valsta LM, Lampi AM, Peñalvo J, Adlercreutz H, Vardavas C, and Kafatos A. 2011. Differences in nutrient intake during a Greek Orthodox Christian fasting and non-fasting week, as assessed by a food composition database and chemical analyses of 7-day weighed food samples. Journal of Food Composition and Analysis 24(1):22-28.

Papadaki A, Vardavas C, Hatzis C, and Kafatos A. 2008. Calcium, nutrient and food intake of Greek Orthodox Christian monks during a fasting and non-fasting week. Public Health Nutrition 11(10):1022-1029.

Pastore RL, Brooks JT, and Carbone JW. 2015. Paleolithic nutrition improves plasma lipid concentrations of hypercholesterolemic adults to a greater extent than traditional heart-healthy dietary recommendations. Nutrition Research 35(6):474-479.

Patterson RE, Kristal AR, Tinker LF, Carter RA, Bolton MP, and Agurs-Collins T. 1999. Measurement Characteristics of the Women’s Health Initiative Food Frequency Questionnaire. Annals of Epidemiology 9(3):178-187.

Pawlak R. 2014. Inadequate vitamin B-12 intake may be a problem not just for a small number of adventist vegans. Journal of the Academy of Nutrition and Dietetics 114(2):197.

Pawlak R. 2015. Is vitamin B12 deficiency a risk factor for cardiovascular disease in vegetarians? American Journal of Preventive Medicine 48(6):e11-e26.

Pereira MA, Jacobs DR, Pins JJ, Raatz SK, Gross MD, Slavin JL, and Seaquist ER. 2002. Effect of whole grains on insulin sensitivity in overweight hyperinsulinemic adults. The American Journal of Clinical Nutrition 75(5):848-855.

Pereira PMdCC, and Vicente AFdRB. 2012. Meat nutritional composition and nutritive role in the human diet. Meat Science 93(3):586-592.

Perry GH, Dominy NJ, Claw KG, Lee AS, Fiegler H, Redon R, Werner J, Villanea FA, Mountain JL, and Misra R. 2007. Diet and the evolution of human amylase gene copy number variation. Nature Genetics 39(10):1256-1260.

Pettersen BJ, Anousheh R, Fan J, Jaceldo-Siegl K, and Fraser GE. 2012. Vegetarian diets and blood pressure among white subjects: results from the Adventist Health Study-2 (AHS-2). Public Health Nutrition 15(10):1909.

Pimpin L, Wu JHY, Haskelberg H, Del Gobbo L, and Mozaffarian D. 2016. Is butter back? A systematic review and meta-analysis of butter consumption and risk of cardiovascular disease, diabetes, and total mortality. PLoS One 11(6):e0158118.

Piperno DR, Weiss E, Holst I, and Nadel D. 2004. Processing of wild cereal grains in the Upper Palaeolithic revealed by starch grain analysis. Nature 430(7000):670-673.

Pletcher MJ, Lazar L, Bibbins-Domingo K, and et al. 2009. Comparing impact and cost-effectiveness of primary prevention strategies for lipid-lowering. Annals of Internal Medicine 150(4):243-254.

Pluciennik M, and Zvelebil M. 2009. The Origins and Spread of Agriculture. In: Bentley RA, Chippindale C, and Maschner HDG, editors. Handbook of Archaeological Theories: AltaMira Press.

Pontzer H, Raichlen DA, Wood BM, Mabulla AZP, Racette SB, and Marlowe FW. 2012. Hunter-gatherer energetics and human obesity. PLoS One 7(7):e40503.

Poulain M, Herm A, and Pes G. 2013. The Blue Zones: Areas of exceptional longevity around the world. Vienna Yearbook of Population Research 11:87-108.

Prentice RL, Mossavar-Rahmani Y, Huang Y, Van Horn L, Beresford SAA, Caan B, Tinker L, Schoeller D, Bingham S, Eaton CB et al. . 2011. Evaluation and Comparison of Food Records, Recalls, and Frequencies for Energy and Protein Assessment by Using Recovery Biomarkers. American Journal of Epidemiology 174(5):591-603.

Price TD, and Bar-Yosef O. 2011. The Origins of Agriculture: New Data, New Ideas: An Introduction to Supplement 4. Current Anthropology 52(S4):S163-S174.

Price TD, and Gebauer AB. 1995. Last hunters, first farmers : new perspectives on the prehistoric transition to agriculture. Santa Fe, N.M.: School of American Research Press : Distributed by the University of Washington Press.

Rader DJ, and Hovingh GK. 2014. HDL and cardiovascular disease. The Lancet 384(9943):618-625.

Radnitz C, Beezhold B, and DiMatteo J. 2015. Investigation of lifestyle choices of individuals following a vegan diet for health and ethical reasons. Appetite 90:31-36.

Ramdath D, Renwick S, and Duncan AM. 2016. The Role of Pulses in the Dietary Management of Diabetes. Canadian Journal of Diabetes 40(4):355-363.

Rebro SM, Patterson RE, Kristal AR, and Cheney CL. 1998. The effect of keeping food records on eating patterns. Journal of the American Dietetic Association 98(10):1163-1165.

Reed KE. 1997. Early hominid evolution and ecological change through the African Plio-Pleistocene. J Hum Evol 32(2–3):289-322.

Reedy J, Krebs-Smith SM, Miller PE, Liese AD, Kahle LL, Park Y, and Subar AF. 2014. Higher diet quality is associated with decreased risk of all-cause, cardiovascular disease, and cancer mortality among older adults. J Nutr 144(6):881-889.

Rees K, Hartley L, Flowers N, Clarke A, Hooper L, Thorogood M, and Stranges S. 2013. 'Mediterranean' dietary pattern for the primary prevention of cardiovascular disease. Cochrane Database of Systematic Reviews(8).

Reynolds K, Chin A, Lees KA, Nguyen A, Bujnowski D, and He J. 2006. A meta-analysis of the effect of soy protein supplementation on serum lipids. The American Journal of Cardiology 98(5):633-640.

Ridker PM. 2014. LDL cholesterol: controversies and future therapeutic directions. The Lancet 384(9943):607-617.

Rizzo G, Laganà AS, Rapisarda AMC, La Ferrera GMG, Buscema M, Rossetti P, Nigro A, Muscia V, Valenti G, Sapia F et al. . 2016. Vitamin B12 among vegetarians: Status, assessment and supplementation. Nutrients 8(12):767.

Rizzo NS, Jaceldo-Siegl K, Sabate J, and Fraser GE. 2013. Nutrient profiles of vegetarian and nonvegetarian dietary patterns. Journal of the Academy of Nutrition and Dietetics 113(12):1610-1619.

Rizzo NS, Sabaté J, Jaceldo-Siegl K, and Fraser GE. 2011. Vegetarian dietary patterns are associated with a lower risk of metabolic syndrome. The Adventist Health Study 2 34(5):1225-1227.

Roberts R. 2015. A genetic basis for coronary artery disease. Trends in Cardiovascular Medicine 25(3):171-178.

Rohrmann S, Overvad K, Bueno-de-Mesquita HB, Jakobsen MU, Egeberg R, Tjønneland A, Nailler L, Boutron-Ruault M-C, Clavel-Chapelon F, Krogh V et al. . 2013. Meat consumption and mortality - results from the European Prospective Investigation into Cancer and Nutrition. BMC Medicine 11(1):63.

Rong Y, Chen L, Zhu T, Song Y, Yu M, Shan Z, Sands A, Hu FB, and Liu L. 2013. Egg consumption and risk of coronary heart disease and stroke: dose-response meta-analysis of prospective cohort studies. BMJ : British Medical Journal 346.

Rosell M, Appleby P, Spencer E, and Key T. 2006. Weight gain over 5 years in 21,966 meat-eating, fish-eating, vegetarian, and vegan men and women in EPIC-Oxford. Int J Obes 30(9):1389-1396.

Rosinger A, Carroll MD, Lacher D, and Ogden C. 2017. Trends in total cholesterol, triglycerides, and low-density lipoprotein in us adults, 1999-2014. JAMA Cardiology 2(3):339-341.

Rosmond R, Dallman MF, and Björntorp P. 1998. Stress-Related Cortisol Secretion in Men: Relationships with Abdominal Obesity and Endocrine, Metabolic and Hemodynamic Abnormalities1. The Journal of Clinical Endocrinology & Metabolism 83(6):1853-1859.

Ross R, and Janiszewski PM. 2008. Is weight loss the optimal target for obesity-related cardiovascular disease risk reduction? Canadian Journal of Cardiology 24:25D-31D.

Sabaté J, Oda K, and Ros E. 2010. Nut consumption and blood lipid levels: A pooled analysis of 25 intervention trials. Archives of Internal Medicine 170(9):821-827.

Sacks FM, and Katan M. 2002. Randomized clinical trials on the effects of dietary fat and carbohydrate on plasma lipoproteins and cardiovascular disease. The American Journal of Medicine 113(9, Supplement 2):13-24.

Sacks FM, Lichtenstein AH, Wu JHY, Appel LJ, Creager MA, Kris-Etherton PM, Miller M, Rimm EB, Rudel LL, Robinson JG et al. . 2017. Dietary Fats and Cardiovascular Disease: A Presidential Advisory From the American Heart Association. Circulation 136(3):e1-e23.

Salas-Salvadó J, Bulló M, Pérez-Heras A, and Ros E. 2006. Dietary fibre, nuts and cardiovascular diseases. British Journal of Nutrition 96(S2):S45-S51.

Salvini S, Hunter DJ, Sampson L, Stampfer MJ, Colditz GA, Rosner B, and Willett WC. 1989. Food-based validation of a dietary questionnaire: The effects of week-to-week variation in food consumption. International Journal of Epidemiology 18(4):858-867.

Sarkkinen E, Korhonen M, Erkkilä A, Ebeling T, and Uusitupa M. 1998. Effect of apolipoprotein E polymorphism on serum lipid response to the separate modification of dietary fat and dietary cholesterol. The American Journal of Clinical Nutrition 68(6):1215-1222.

Sarri KO, Linardakis MK, Bervanaki FN, Tzanakis NE, and Kafatos AG. 2004. Greek Orthodox fasting rituals: a hidden characteristic of the Mediterranean diet of Crete. British Journal of Nutrition 92(2):277-284.

Sarri KO, Tzanakis NE, Linardakis MK, Mamalakis GD, and Kafatos AG. 2003. Effects of Greek Orthodox Christian Church fasting on serum lipids and obesity. BMC Public Health 3(1):16.

Satija A, Bhupathiraju SN, Rimm EB, Spiegelman D, Chiuve SE, Borgi L, Willett WC, Manson JE, Sun Q, and Hu FB. 2016. Plant-based dietary patterns and incidence of type 2 diabetes in us men and women: Results from three prospective cohort studies. PLoS Med 13(6):e1002039.

Satija A, Bhupathiraju SN, Spiegelman D, Chiuve SE, Manson JE, Willett W, Rexrode KM, Rimm EB, and Hu FB. 2017. Healthful and unhealthful plant-based diets and the risk of coronary heart disease in U.S. adults. J Am Coll Cardiol 70(4):411-422.

Satija A, and Hu FB. 2018. Plant-based diets and cardiovascular health. Trends in Cardiovascular Medicine.

Schaible UE, and Kaufmann SHE. 2007. Malnutrition and infection: Complex mechanisms and global impacts. PLoS Med 4(5):e115.

Schakel SF. 2001. Maintaining a nutrient database in a changing marketplace: Keeping pace with changing food products—A research perspective. Journal of Food Composition and Analysis 14(3):315-322.

Schakel SF, Buzzard IM, and Gebhardt SE. 1997. Procedures for estimating nutrient values for food composition databases. Journal of Food Composition and Analysis 10(2):102-114.

Schakel SF, Sievert YA, and Buzzard IM. 1988. Sources of data for developing and maintaining a nutrient database. J Am Diet Assoc 88(10):1268-1271.

Schatzkin A, Kipnis V, Carroll RJ, Midthune D, Subar AF, Bingham S, Schoeller DA, Troiano RP, and Freedman LS. 2003. A comparison of a food frequency questionnaire with a 24-hour recall for use in an epidemiological cohort study: results from the biomarker-based Observing Protein and Energy Nutrition (OPEN) study. International Journal of Epidemiology 32(6):1054-1062.

Schwingshackl L, Schwedhelm C, Hoffmann G, Lampousi A-M, Knüppel S, Iqbal K, Bechthold A, Schlesinger S, and Boeing H. 2017. Food groups and risk of all-cause mortality: a systematic review and meta-analysis of prospective studies. The American Journal of Clinical Nutrition 105(6):1462-1473.

Shang P-H, Shu Z, Wang Y-F, Li N, Du S-M, Sun F, Xia Y-Y, and Zhan S-Y. 2011. Veganism does not reduce the risk of the metabolic syndrome in a Taiwanese cohort. Asia Pacific journal of clinical nutrition 20(3):404-410.

Shell-Duncan B. 1995. Impact of seasonal variation in food availability and disease stress on the health status of nomadic Turkana children: a longitudinal analysis of morbidity, immunity, and nutritional status. American Journal of Human Biology 7(3):339-355.

Shemesh T, Rowley KG, Shephard M, Piers LS, and O'Dea K. 2006. Agreement between laboratory results and on-site pathology testing using Bayer DCA2000+ and Cholestech LDX point-of-care methods in remote Australian Aboriginal communities. Clinica Chimica Acta 367(1–2):69-76.

Shin JY, Kim JY, Kang HT, Han KH, and Shim JY. 2015. Effect of fruits and vegetables on metabolic syndrome: a systematic review and meta-analysis of randomized controlled trials. International Journal of Food Sciences and Nutrition 66(4):416-425.

Shin JY, Xun P, Nakamura Y, and He K. 2013. Egg consumption in relation to risk of cardiovascular disease and diabetes: a systematic review and meta-analysis. The American Journal of Clinical Nutrition.

Sievenpiper JL, Kendall CWC, Esfahani A, Wong JMW, Carleton AJ, Jiang HY, Bazinet RP, Vidgen E, and Jenkins DJA. 2009. Effect of non-oil-seed pulses on glycaemic control: a systematic review and meta-analysis of randomised controlled experimental trials in people with and without diabetes. Diabetologia 52(8):1479.

Singh PN, Arthur KN, Orlich MJ, James W, Purty A, Job JS, Rajaram S, and Sabaté J. 2014. Global epidemiology of obesity, vegetarian dietary patterns, and noncommunicable disease in Asian Indians. The American Journal of Clinical Nutrition 100(Supplement 1):359S-364S.

Sinha R, Cross AJ, Graubard BI, Leitzmann MF, and Schatzkin A. 2009. Meat intake and mortality: A prospective study of over half a million people. Archives of Internal Medicine 169(6):562-571.

Siri-Tarino PW, Sun Q, Hu FB, and Krauss RM. 2010. Meta-analysis of prospective cohort studies evaluating the association of saturated fat with cardiovascular disease. The American Journal of Clinical Nutrition 91(3):535-546.

Siri PW, and Krauss RM. 2005. Influence of dietary carbohydrate and fat on LDL and HDL particle distributions. Current Atherosclerosis Reports 7(6):455-459.

Snodgrass JJ, Leonard WR, and Robertson ML. 2009. The Energetics of Encephalization in Early Hominids. In: Hublin J-J, and Richards MP, editors. The Evolution of Hominin Diets: Integrating Approaches to the Study of Palaeolithic Subsistence. Dordrecht: Springer Netherlands. p 15-29.

Sobiecki JG, Appleby PN, Bradbury KE, and Key TJ. 2016. High compliance with dietary recommendations in a cohort of meat eaters, fish eaters, vegetarians, and vegans: results from the European Prospective Investigation into Cancer and Nutrition–Oxford study. Nutrition Research 36(5):464-477.

Sofi F, Macchi C, Abbate R, Gensini GF, and Casini A. 2014. Mediterranean diet and health status: an updated meta-analysis and a proposal for a literature-based adherence score. Public Health Nutr 17(12):2769-2782.

Souza RGM, Gomes AC, Naves MMV, and Mota JF. 2015. Nuts and legume seeds for cardiovascular risk reduction: scientific evidence and mechanisms of action. Nutrition Reviews 73(6):335-347.

Spencer C. 1996. The Heretic's Feast: A History Of Vegetarianism. Hanover, NH: Hanover, NH : University Press of New England.

Spencer E, Appleby P, Davey G, and Key T. 2003a. Diet and body mass index in 38,000 EPIC-Oxford meat-eaters, fish-eaters, vegetarians and vegans. International Journal of Obesity 27(6):728-734.

Spencer EA, Appleby PN, Davey GK, and Key TJ. 2003b. Diet and body mass index in 38,000 EPIC-Oxford meat-eaters, fish-eaters, vegetarians and vegans. Int J Obes Relat Metab Disord 27(6):728-734.

Speth JD, and Davis DD. 1976. Seasonal variability in early hominid predation. Science 192(4238):441-445.

Speth JD, and Spielmann KA. 1983. Energy source, protein metabolism, and hunter-gatherer subsistence strategies. Journal of Anthropological Archaeology 2(1):1-31.

Spiegel K, Tasali E, Leproult R, and Van Cauter E. 2009. Effects of poor and short sleep on glucose metabolism and obesity risk. Nat Rev Endocrinol 5(5):253-261.

St-Onge M-P, Ard J, Baskin ML, Chiuve SE, Johnson HM, Kris-Etherton P, and Varady K. 2017. Meal timing and frequency: Implications for cardiovascular disease prevention: A scientific statement from the American Heart Association. Circulation.

St-Onge M-P, Farnworth ER, and Jones PJ. 2000. Consumption of fermented and nonfermented dairy products: effects on cholesterol concentrations and metabolism. The American Journal of Clinical Nutrition 71(3):674-681.

Stanhope KL, Medici V, Bremer AA, Lee V, Lam HD, Nunez MV, Chen GX, Keim NL, and Havel PJ. 2015. A dose-response study of consuming high-fructose corn syrup–sweetened beverages on lipid/lipoprotein risk factors for cardiovascular disease in young adults. The American Journal of Clinical Nutrition.

Stone NJ, Robinson J, Lichtenstein AH, Merz CNB, Blum CB, Eckel RH, Goldberg AC, Gordon D, Levy D, Lloyd-Jones DM et al. . 2013. 2013 ACC/AHA Guideline on the Treatment of Blood Cholesterol to Reduce Atherosclerotic Cardiovascular Risk in Adults. A Report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines.

Stote KS, Baer DJ, Spears K, Paul DR, Harris GK, Rumpler WV, Strycula P, Najjar SS, Ferrucci L, and Ingram DK. 2007. A controlled trial of reduced meal frequency without caloric restriction in healthy, normal-weight, middle-aged adults. The American Journal of Clinical Nutrition 85(4):981-988.

Subar AF, Thompson FE, Kipnis V, Midthune D, Hurwitz P, McNutt S, McIntosh A, and Rosenfeld S. 2001. Comparative Validation of the Block, Willett, and National Cancer Institute Food Frequency Questionnaires The Eating at America's Table Study. American Journal of Epidemiology 154(12):1089-1099.

Te Morenga LA, Howatson AJ, Jones RM, and Mann J. 2014. Dietary sugars and cardiometabolic risk: systematic review and meta-analyses of randomized controlled trials of the effects on blood pressure and lipids. The American Journal of Clinical Nutrition.

The Emerging Risk Factors Collaboration. 2012. Lipid-related markers and cardiovascular disease prediction. JAMA 307(23):2499-2506.

The US Burden of Disease Collaborators. 2018. The state of US health, 1990-2016: Burden of diseases, injuries, and risk factors among us states. JAMA 319(14):1444-1472.

Thompson DL, Thompson WR, Prestridge TJ, Bailey JG, Bean MH, Brown SP, and McDaniel JB. 1991. Effects of hydration and dehydration on body composition analysis: a comparative study of bioelectric impedance analysis and hydrodensitometry. The Journal of sports medicine and physical fitness 31(4):565-570.

Thompson FE, and Subar AF. 2013. Dietary Assessment Methodology. In: Coulston AM, Boushey C, and Ferruzzi MG, editors. Nutrition in the prevention and treatment of disease. 3rd ed. ed. Oxford ; New York: Oxford ; New York : Elsevier/Academic.

Tilg H, and Kaser A. 2011. Gut microbiome, obesity, and metabolic dysfunction. The Journal of Clinical Investigation 121(6):2126-2132.

Tishkoff SA, Reed FA, Ranciaro A, Voight BF, Babbitt CC, Silverman JS, Powell K, Mortensen HM, Hirbo JB, and Osman M. 2006. Convergent adaptation of human lactase persistence in Africa and Europe. Nature Genetics 39(1):31-40.

Tonstad S, Butler T, Yan R, and Fraser GE. 2009. Type of Vegetarian Diet, Body Weight, and Prevalence of Type 2 Diabetes. Diabetes Care 32(5):791-796.

Tonstad S, Stewart K, Oda K, Batech M, Herring RP, and Fraser GE. 2013. Vegetarian diets and incidence of diabetes in the Adventist Health Study-2. Nutrition, Metabolism and Cardiovascular Diseases 23(4):292-299.

Troiano RP, Berrigan D, Dodd KW, Masse LC, Tilert T, and McDowell M. 2008. Physical activity in the United States measured by accelerometer. Medicine and Science in Sports and Exercise 40(1):181.

Turnbaugh PJ, Ley RE, Mahowald MA, Magrini V, Mardis ER, and Gordon JI. 2006. An obesity-associated gut microbiome with increased capacity for energy harvest. Nature 444:1027.

Turner-McGrievy GM, Barnard ND, Scialli AR, and Lanou AJ. 2004. Effects of a low-fat vegan diet and a Step II diet on macro- and micronutrient intakes in overweight postmenopausal women. Nutrition 20(9):738-746.

Turner-McGrievy GM, Davidson CR, Wingard EE, Wilcox S, and Frongillo EA. 2015. Comparative effectiveness of plant-based diets for weight loss: A randomized controlled trial of five different diets. Nutrition 31(2):350-358.

Turner BL, and Thompson AL. 2013. Beyond the Paleolithic prescription: incorporating diversity and flexibility in the study of human diet evolution. Nutrition Reviews 71(8):501-510.

Ungar PS, Grine FE, and Teaford MF. 2006. Diet in early *Homo*: A review of the evidence and a new model of adaptive versatility. Annual Review of Anthropology 35:209-228.

Uribarri J, Woodruff S, Goodman S, Cai W, Chen X, Pyzik R, Yong A, Striker GE, and Vlassara H. 2010. Advanced glycation end products in foods and a practical guide to their reduction in the diet. Journal of the American Dietetic Association 110(6):911-916.e912.

US Burden of Disease Collaborators. 2013. The state of US health, 1990-2010: Burden of diseases, injuries, and risk factors. JAMA 310(6):591-606.

US Department of Health Human Services; US Department of Agriculture. 2015. 2015-2020 Dietary Guidelines for Americans. In: Services UDoHH, editor. 8th Edition ed. Washington, DC.

Vasto S, Rizzo C, and Caruso C. 2012. Centenarians and diet: what they eat in the Western part of Sicily. Immunity & Ageing 9(1):10.

Vasunilashorn S, Crimmins EM, Kim JK, Winking J, Gurven M, Kaplan H, and Finch CE. 2010. Blood lipids, infection, and inflammatory markers in the Tsimane of Bolivia. American Journal of Human Biology 22(6):731-740.

Vaupel JW. 2010. Biodemography of human ageing. Nature 464(7288):536-542.

Verhoye E, and Langlois Michel R. 2009. Circulating oxidized low-density lipoprotein: a biomarker of atherosclerosis and cardiovascular risk? Clinical Chemistry and Laboratory Medicine. p 128.

Victora CG, Adair L, Fall C, Hallal PC, Martorell R, Richter L, and Sachdev HS. 2008. Maternal and child undernutrition: consequences for adult health and human capital. The Lancet 371(9609):340-357.

Vuckovic N, Ritenbaugh C, Taren DL, and Tobar M. 2000. A Qualitative Study of Participants' Experiences with Dietary Assessment. Journal of the American Dietetic Association 100(9):1023-1028.

Wadhwa PD, Buss C, Entringer S, and Swanson JM. 2009. Developmental origins of health and disease: Brief history of the approach and current focus on epigenetic mechanisms. Seminars in reproductive medicine 27(5):358-368.

Wang DD, Leung CW, Li Y, and et al. 2014a. Trends in dietary quality among adults in the united states, 1999 through 2010. Supplemental material. JAMA Internal Medicine 174(10):1587-1595.

Wang F, Zheng J, Yang B, Jiang J, Fu Y, and Li D. 2015. Effects of Vegetarian Diets on Blood Lipids: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. Journal of the American Heart Association: Cardiovascular and Cerebrovascular Disease 4(10):e002408.

Wang X, Lin X, Ouyang YY, Liu J, Zhao G, Pan A, and Hu FB. 2016. Red and processed meat consumption and mortality: dose–response meta-analysis of prospective cohort studies. Public Health Nutrition 19(5):893-905.

Wang X, Ouyang Y, Liu J, Zhu M, Zhao G, Bao W, and Hu FB. 2014b. Fruit and vegetable consumption and mortality from all causes, cardiovascular disease, and cancer: systematic review and dose-response meta-analysis of prospective cohort studies. BMJ : British Medical Journal 349.

Ware K. 1977. The meaning of the great fast. The Lenten Triodion. South Canaan, PA: St. Tikhon's Seminary Press. p 13-37.

Wei M, Brandhorst S, Shelehchi M, Mirzaei H, Cheng CW, Budniak J, Groshen S, Mack WJ, Guen E, Di Biase S et al. . 2017. Fasting-mimicking diet and markers/risk factors for aging, diabetes, cancer, and cardiovascular disease. Science Translational Medicine 9(377).

Wei T, Ye P, Peng X, Wu L-L, and Yu G-Y. 2016. Circulating adiponectin levels in various malignancies: an updated meta-analysis of 107 studies. Oncotarget 7(30):48671-48691.

Widjaja A, Morris RJ, Levy JC, Frayn KN, Manley SE, and Turner RC. 1999. Within- and between-subject variation in commonly measured anthropometric and biochemical variables. Clin Chem 45(4):561-566.

Willcox DC, Scapagnini G, and Willcox BJ. 2014. Healthy aging diets other than the Mediterranean: A focus on the Okinawan diet. Mechanisms of Ageing and Development 136-137:148-162.

Willcox DC, Willcox BJ, Todoriki H, and Suzuki M. 2009. The Okinawan Diet: Health Implications of a Low-Calorie, Nutrient-Dense, Antioxidant-Rich Dietary Pattern Low in Glycemic Load. Journal of the American College of Nutrition 28(sup4):500S-516S.

Willett W. 2001a. Commentary: Dietary diaries versus food frequency questionnaires-a case of undigestible data. Int J Epidemiol 30(2):317-319.

Willett W. 2001b. Invited Commentary: A Further Look at Dietary Questionnaire Validation. American Journal of Epidemiology 154(12):1100-1102.

Willett W. 2013. Nutritional Epidemiology. Oxford; New York: Oxford University Press.

Willett WC. 2012. Dietary fats and coronary heart disease. Journal of Internal Medicine 272(1):13-24.

Willett WC, Howe GR, and Kushi LH. 1997. Adjustment for total energy intake in epidemiologic studies. The American Journal of Clinical Nutrition 65(4):1220S-1228S.

Willett WC, and Hu FB. 2006. Not the time to abandon the food frequency questionnaire: Point. Cancer Epidemiology Biomarkers and Prevention 15(10):1757-1758.

Willett WC, and Hu FB. 2007. The food frequency questionnaire. Cancer Epidemiology Biomarkers and Prevention 16(1):182-183.

Willett WC, Sacks F, Trichopoulou A, Drescher G, Ferro-Luzzi A, Helsing E, and Trichopoulos D. 1995. Mediterranean diet pyramid: A cultural model for healthy eating. The American Journal of Clinical Nutrition 61(6):1402S-1406S.

Wood JW, Milner GR, Harpending HC, and Weiss KM. 1992. The osteological paradox: problems of inferring prehistoric health from skeletal samples. Current Anthropology 33(4):343-370.

Wrangham R. 2017. Control of fire in the Paleolithic: Evaluating the cooking hypothesis. Current Anthropology 0(0):S000-S000.

Wrangham R, and Conklin-Brittain N. 2003. Cooking as a biological trait. Comparative Biochemistry and Physiology, Part A 136(1):35-46.

Wrangham RW, Jones JH, Laden G, Pilbeam D, and Conklin-Brittain N. 1999. The raw and the stolen: Cooking and the ecology of human origins. Current Anthropology 40(5):567-594.

Wright N, Wilson L, Smith M, Duncan B, and McHugh P. 2017. The BROAD study: A randomised controlled trial using a whole food plant-based diet in the community for obesity, ischaemic heart disease or diabetes. Nutrition & Diabetes 7:e256.

Yang Q, Cogswell ME, Flanders W, and et al. 2012. Trends in cardiovascular health metrics and associations with all-cause and cvd mortality among us adults. JAMA 307(12):1273-1283.

Yang Q, Zhang Z, Gregg EW, Flanders W, Merritt R, and Hu FB. 2014. Added sugar intake and cardiovascular diseases mortality among us adults. JAMA Internal Medicine 174(4):516-524.

Yokoyama Y, Barnard ND, Levin SM, and Watanabe M. 2014. Vegetarian diets and glycemic control in diabetes: a systematic review and meta-analysis. Cardiovascular Diagnosis and Therapy 4(5):373-382.

Yokoyama Y, Levin SM, and Barnard ND. 2017. Association between plant-based diets and plasma lipids: a systematic review and meta-analysis. Nutrition Reviews.

Zeevi D, Korem T, Zmora N, Israeli D, Rothschild D, Weinberger A, Ben-Yacov O, Lador D, Avnit-Sagi T, Lotan-Pompan M et al. . 2015. Personalized nutrition by prediction of glycemic responses. Cell 163(5):1079-1094.

Zhang L, Qin L-Q, Liu A-P, and Wang P-Y. 2010. Prevalence of risk factors for cardiovascular disease and their associations with diet and physical activity in suburban Beijing, China. Journal of Epidemiology 20(3):237-243.

Zhang X, Shu X-O, Xiang Y-B, Yang G, Li H, Gao J, Cai H, Gao Y-T, and Zheng W. 2011. Cruciferous vegetable consumption is associated with a reduced risk of total and cardiovascular disease mortality. The American Journal of Clinical Nutrition.

Zhang Z, Ma G, Chen S, Li Z, Xia E, Sun Y, Yang F, Zheng L, and Feng X. 2013. Comparison of plasma triacylglycerol levels in vegetarians and omnivores: A meta-analysis. Nutrition 29(2):426-430.