DIET QUALITY AND MICRONUTRIENT INTAKE IN LONG-TERM WEIGHT LOSS MAINTAINERS

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ABSTRACT

Diet Quality and Micronutrient Intake in Long-Term Weight Loss Maintainers

Rebecca W. Pascual

Objective: This study's purpose was to examine dietary quality, macronutrient intake, and micronutrient adequacy among long term weight loss maintainers (WLM) in a commercial weight management program.

Methods: Participants were 1,207 WLM in WW (formerly Weight Watchers) who had maintained a 9.1 kg or greater weight loss (29.7 kg on average) for 3.4 years, and had an average BMI of 28.3 kg/m^2. A control group of weight stable adults with obesity (Controls; N=102) had a BMI of 41.1 kg/m^2 and 2.3 kg or less weight change over the previous five years.

Results: WLM vs. Controls had a 10.1 point higher HEI-2015 score (70.2 [69.7 - 70.7] vs 60.1 [58.4 - 61.8], respectively; p=0.0001) in analyses that adjusted for group difference in demographic factors. WLM versus Controls had a significantly higher average percentage of calories from carbohydrates (50.3% [49.7 - 50.8] vs 46.7% [44.8 - 48.7], respectively; p=0.0001) and protein (18.2% [18.0-18.5] vs 15.9% [15.1-16.6], respectively; p=0.0001) and lower percentage of calories from fat (32.3% [31.9-32.8] vs 37.4% [35.8-38.9], respectively; p=0.0001). Examining micronutrients, WLM had significantly higher odds for meeting the EAR for copper (OR=5.8 [2.6-13.1]; p=0.0001), magnesium (OR=2.9 [1.8-4.7]; p=0.0001), potassium (OR=4.7 [1.4-16.5]; p=0.015), vitamin A (OR=2.8 [1.7-4.8]; p=0.0001), thiamin (OR=2.3 [1.3-4.1]; p=0.003), riboflavin

(OR=6.5 [2.2-19.3]; p=0.001), vitamin B6 (OR=2.91 [1.6-5.2]; p=0.0001), vitamin C (OR=5.0 [2.8-8.8]; p=0.0001), folate (OR=2.2 [1.3-3.7]; p=0.003), and vitamin E (OR=1.8 [1.1-2.8]; p=0.014) and didn't differ in calcium (OR=1.15 [0.7-1.7]; p=0.823), iron (OR=1.9 [0.8-4.6]; p=0.151), phosphorus (OR=2.0 [0.9-4.5]; p=0.101), selenium (OR=1.6 [0.6-3.8]; p=0.332), zinc (OR=1.7 [0.9-3.0]; p=0.095), niacin (B3) (OR=1.9 [0.8-4.1]; p=0.136), vitamin B12 (OR=1.2 [0.5-2.8]; p=0.625), and vitamin D (OR=1.5 [0.9-2.4]; p=0.09).

Conclusions: In a widely available commercial program, WLM consumed a healthier and more micronutrient rich diet than adults who were weight stable with obesity. Future research is needed to examine whether improved micronutrient status among WLM reduces risk of chronic disease.

Keywords: weight loss, weight loss maintenance, micronutrient intake, micronutrient deficiency, macronutrient intake, healthy eating index, estimated average requirement, and obesity.

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ABBREVIATIONS

AI	Adequate Intake
BMI	Body mass index
CVD	Cardiovascular Disease
DHQ	Dietary Health Questionnaire
DRI	Dietary Reference Intakes
EAR	Estimated Average Requirement
FFQ	Food Frequency Questionnaire
FNB	Food and Nutrition Board
HbA1C	Hemoglobin A1C
HEI	Healthy Eating Index
IOM	Institute of Medicine
kcal	Kilocalorie(s)
kg	Kilogram(s)
lbs.	Pounds
LDL	Low Density Lipoprotein
MUFA	Monounsaturated Fatty Acids
NHANES	National Health and Nutrition Examination Survey
NWCR	National Weight Control Registry
OR	Odds Ratio
PA	Physical Activity
PUFA	Polyunsaturated Fatty Acids
RCT	Randomized Control Trial
RDA	Recommended Daily Allowance
SFA	Saturated Fatty Acids
T2DM	Type 2 Diabetes Mellitus
UL	Tolerable Upper Intake Level
WLM	Weight Loss Maintainers

WW	Weight Watchers
WWS	Weight Watchers Success Registry

Chapter 1

INTRODUCTION AND LITERATURE REVIEW

In the US, poor diet quality is the largest risk factor for death accounting for nearly 530,000 deaths in 2016, followed by tobacco use, high systolic blood pressure, and 390,000 deaths from high body mass index (BMI). The majority of deaths from dietary risk factors were the result of cardiovascular disease (CVD) (83.4%) followed by neoplasms, diabetes, and urogenital, blood, and endocrine diseases. In addition to mortality, after tobacco use, high BMI was ranked second and dietary risks were ranked as the third highest risk factor for disability-adjusted life-years which is the sum of years of lost life and years lived with disability (Mokdad et al., 2018). Overall, poor diet quality and obesity are critical risk factors for the development of not only disability, but death in the US.

The prevalence of US adults with obesity has been consistently rising since the 1980s. Recent studies, based on National Health and Nutrition Examination Survey (NHANES) data evaluating the trends in the prevalence of obesity, estimate a rising significant linear trend with 33.7% of US adults with obesity between 2007-2008 and 39.6% between 2015-2016 (Hales, Fryar, Carroll, Freedman, & Ogden, 2018). Increased CVD, diabetes, some cancers, and poor health-related quality of life are associated with obesity (Mokdad et al., 2018). In general, research has focused on obesity as a significant risk factor for the development of chronic diseases however, there is also a strong association between micronutrient deficiency and obesity. Although causality has not been determined, individuals with obesity have been shown to have lower serum concentrations of vitamins and minerals compared to individuals with normal weight (García, Long, & Rosado, 2009). An analysis of NHANES III data of US adults found a strong association between adults who are overweight or obese and higher odds of low serum levels of micronutrients compared to adults with normal weight (Kimmons, Blanck, Tohill, Zhang, & Khan, 2006). There are multiple proposed reasons for this disparity such as differences in dietary intake, nutrient absorption and excretion, storage or sequestration of nutrients by adipose tissue, and increased physiological requirements due to oxidative stress (Furukawa et al., 2004; Johnson, 2005; Ledikwe et al., 2006; Patrini, Griziotti, & Ricciardi, 2004; Wortsman, Matsuoka, Chen, Lu, & Holick, 2000). Overall, weight loss has been shown to be beneficial in reducing the risk or slowing the progression of chronic diseases, however it is unclear whether individuals with successful weight loss maintenance have higher dietary micronutrient intake compared to individuals with obesity therefore conveying further health benefits of a more nutrient dense diet.

BMI is used as a proxy for estimating body adiposity and is defined as weight in kg divided by height in meters squared. The generally accepted cut points for the classification of BMI in adults is: less than 18.5 kg/m^2 as underweight, 18.5-24.9 kg/m^2 as normal weight, BMI 25-29.9 kg/m^2 as overweight, and BMI ≥ 30.0 kg/m^2 as obese. Large studies examining the association between BMI and mortality, such as the European Prospective Investigation into Cancer and Nutrition (EPIC), have demonstrated a J-shaped curve with the lowest risk of mortality for men with a BMI of 25.3 kg/m^2 and for women with a BMI of 24.3 kg/m^2 with increased risk of mortality in the underweight

BMI category (BMI < 18.5 kg/m^2) and escalating risk in the upper BMI categories especially above BMI of 28.0 kg/m^2 (Pischon et al., 2008). The authors also found an 85% correlation with BMI and waist circumference for men (P<0.001) and 84% correlation for women (P<0.001). Although BMI does not directly measure visceral fat, BMI is easily measurable in adults and given the high correlation with waist circumference, BMI is used as a proxy for estimating excess body fat.

The development of obesity is generally attributed to an energy imbalance which surpasses physiological needs from a combination of excess caloric intake and a lack of physical activity (PA). Food production has advanced rapidly in the US and most other developed countries with a transformation into an industrialized food system that provides large quantities of highly palatable, energy dense foods that are inexpensive and readily available (Hall, 2018). One food classification method based on the level of industrial food processing is called NOVA which encompasses four categories of food processing: (1) unprocessed/minimally processed which include plant or animal foods with nothing added, (2) processed culinary ingredients which are foods extracted from unprocessed foods like oil and sugar, (3) processed foods which include adding salt, oil or sugar to an unprocessed food, and (4) ultra-processed foods are multi-ingredient industrial formulations and include ready to eat foods like sugar sweetened beverages, snack foods, desserts, instant soups, frozen meals, packaged breads and processed meat like chicken nuggets or cured meats (Monteiro et al., 2018).

Poti et al., (2015) analyzed food and beverage purchases by US households using 2000-2012 Nielsen Homescan Panel to estimate the contribution of highly processed foods, also known as ultra-processed foods, in total food purchasing. Unprocessed or minimally processed food accounted for less than 25% of purchases while highly processed foods accounted for 61% of purchases and these foods had higher levels of saturated fat, sugar, and sodium compared to less processed foods (Poti, Mendez, Ng, & Popkin, 2015). Subsequently, in a review article, Poti et al., (2017) examined five studies using the NOVA classification system and found that in four of the studies higher consumption of ultra-processed foods was associated with significantly increased risk of overweight or obesity (Poti, Braga, & Qin, 2017). In addition, Juul et al., (2018) examined NHANES data from 2005-2014 among US adults and found ultra-processed food consumption is associated with higher risk of having a BMI classified as overweight or obese. The authors reported consumption of total energy of greater than 74.2% from ultra-processed foods versus less than 36.5% of energy from ultra-processed foods was significantly associated ($p<0.001$) with higher BMI, larger waist circumference, and higher odds of BMI in the overweight (25.0-29.9 kg/m^2) or obese (30.0 kg/m^2 or greater) categories (Juul, Martinez-Steele, Parekh, Monteiro, & Chang, 2018).

Hall et al., (2019) studied 20 adults in an inpatient setting and randomly exposed subjects for two weeks to either an unprocessed diet or ultra-processed diet and then switched them to the other diet for two weeks. The researchers found that consumption of ultra-processed diet increased the total calories consumed compared to the unprocessed diet significantly (459 ± 105 kcal/day; $p=0.0003$) despite the diets being matched for energy density, macronutrients, sugar, sodium, and fiber. While they did not find a significant change in the amount of protein consumed based on the diet, subjects had higher intake of carbohydrates (280 ± 54 kcals/day; $p < 0.0001$) and fat (230 ± 53 kcals/day; $p=0.0004$) on the ultra-processed diet compared to the unprocessed diet. Overall, subjects while on the ultra-processed diet gained weight (0.9 kg ± 0.3 kg; $p=0.009$) while losing weight when on the unprocessed diet (0.9 kg ± 0.3 kg; $p=0.007$). The authors concluded that higher consumption of ultra-processed foods leads to increased energy intake and weight gain (Hall et al., 2019).

Emerging research has hypothesized that obesity resulting from diets associated with the consumption of excess macronutrients from calorically dense processed foods may simultaneously be associated with consuming insufficient vitamins such as B vitamins (thiamine, vitamin B12, folate), and vitamins A, D, and E (Kaidar-Person, Person, Szomstein, & Rosenthal, 2008a) and minerals magnesium, iron, selenium, chromium, and zinc (Kaidar-Person, Person, Szomstein, & Rosenthal, 2008b). Thiamin is required for oxidative ATP synthesis therefore deficiency is associated with negative metabolic effects especially on major organs which have high metabolic needs. Severe thiamin deficiency can impact both the cardiovascular system and nervous system (Kerns & Gutierrez, 2017). Vitamin B12 is involved in DNA synthesis and mitochondrial function and deficiency is associated with pernicious anemia and nervous system dysfunction such as ataxia and neurological decline (Green et al., 2017). Folate is important in methylation of proteins and DNA synthesis and inadequate levels have been associated with increased risk of CVD and incidence of breast and colon cancer (Kaidar-Person et al., 2008a). Vitamin D is vital in bone health and deficiency is associated with osteomalacia and hyperparathyroidism (Kaidar-Person et al., 2008a).

Vitamins A and E are antioxidants that play a protective role in reducing oxidative damage. Deficiency in antioxidants have been associated with increased oxidation of low density lipoproteins (LDL) which increases the risk of atherosclerosis, and also impairment in glucose metabolism and insulin resistance (Kimmons et al., 2006).

Among minerals, magnesium is a cofactor in over 300 enzymes and important for metabolic activity. Dietary deficiency of magnesium is associated with increased risk of CVD, incidence of diabetes, and lower bone density (Kimmons et al., 2006). Iron is essential for electron transfer reactions and the binding and delivery of oxygen to tissues. Iron deficiency is the most common mineral deficiency and is associated with anemia and impaired thermoregulation, immune function, and mental function (Beard, 2001). Selenium is an important mineral in antioxidant reactions and reducing the generation of oxidative stress and inflammation (Goldhaber, 2003). Selenium deficiency has been associated with CVD and cancer (Kaidar-Person et al., 2008b). Chromium is essential in metabolism of macronutrients (carbohydrate, protein and lipids). Chromium deficiency is associated with impaired glucose tolerance and increased serum levels of insulin (Goldhaber, 2003). According to Ruz et al., (2019), zinc is involved in over 300 enzymes as a constituent or regulatory component and important in the insulin signaling pathway and lipolysis regulation. The authors examined intervention studies and found that among patients with T2D who had zinc deficiency, providing zinc supplementation improved glucose outcomes through a reduction in fasting blood glucose or improved HbA1c levels (Ruz et al., 2019). Overall, adequate intake of vitamins and minerals are essential for health and reduction in the risk for disease.

The first national nutrient recommendations were published in the 1941 with Recommended Daily Allowance (RDA) for eight vitamins and minerals along with protein and energy. The RDA is the intake estimated to meet the requirements of approximately 98% of the population. Revisions to these recommendations were provided by panels of scientists for the Food and Nutrition Board (FNB) of the Institute of Medicine (IOM) (Murphy, Yates, Atkinson, Barr, & Dwyer, 2016). By the 1980s, as more micronutrient focused research had been conducted, the FNB published recommendations for 25 nutrients, mainly targeting nutrients in deficiency diseases.

In 1997, the Dietary Reference Intakes (DRI) for essential nutrients were published based on recommendations by consensus committees composed of scientific experts to help better quantify and convey the scientific research around vitamins, minerals, and macronutrients. According to Murphy, et al., (2016) the DRIs were intended to provide guidelines for labeling, set limits for food fortification, and provide a standard to assess the dietary intake of specific populations. The DRIs are composed of four nutrient-based reference values: Estimated Average Requirement (EAR), Recommended Daily Allowance (RDA), Adequate Intakes (AI), and tolerable Upper Intake Levels (UL). The EAR is the average daily nutrient intake level predicted to meet a healthy individual's daily requirement for one half of the population, and there are often multiple EARs for specific nutrients based on gender or stage of life. The EAR is often used in population studies to examine the prevalence of inadequacy of micronutrients (Murphy et al., 2016). The AI is the estimated average intake for healthy individuals when there is insufficient evidence to establish an EAR or RDA, while the UL is the maximum intake that has been shown to not have likely adverse health effects for most of the population (Murphy et al., 2016).

The dietary micronutrient contribution of food may be altered based on the type of processing used to mechanically or chemically change the food (Weaver et al., 2014). Many processed foods are enriched, that is vitamins and minerals are added back to the food product when lost during processing, while other food products are fortified as vitamins and minerals are added at higher levels than are found in the natural food. Fulgoni et al., (2011) examined NHANES data between 2003-2004 and 2005-2006 for individuals over the age of two and estimated that as result of enrichment and fortification of processed foods, a smaller proportion of the US population has intake below the EAR for vitamins A, C, D, E, thiamin, and folate, and of the minerals calcium, magnesium, and iron than if there were no enrichment and fortification of foods. The estimated rate of deficiency if only naturally occurring micronutrients sources were considered versus including micronutrients from fortification or enrichment revealed the percentage of individuals below the EAR for vitamin A declined from 74% to 45%, thiamin 51% to 6%, folate 88% to 11%, vitamin C 46% to 37%, iron 22% to 7%, vitamin B6 22% to 12%, and zinc 15% to 11% (Fulgoni, Keast, Bailey, & Dwyer, 2011). Therefore enrichment and fortification have reduced the percentage of the population that have intakes below the EAR for many vitamins and minerals, however micronutrient deficiencies in the population still persist.

Agarwal et al., (2015) examined NHANES dietary and supplement intake data between 2001 and 2008 and found high proportions of US adults do not to meet the EAR for several vitamins and minerals despite many foods being fortified or enriched. Deficiency among adults was especially high for vitamins D and E with more than 90% of US adults not meeting the EAR, and 40-60% of adults being classified as deficient for vitamins A, C, calcium and magnesium. Analyses further compared prevalence of deficiency by weight category (normal, overweight, and obese). The percentage of adults with obesity who did not meet the EAR was significantly higher compared to normal weight individuals for vitamins A, C, D, E, calcium, magnesium, potassium and fiber. Dietary supplement use significantly increased micronutrient intakes ($p<0.01$) and decreased the prevalence of inadequacy in supplement users versus non-users (19%-35%, $p<0.01$). Finally, using the HEI-2005 to compare diet quality, normal weight and overweight adults had a significantly higher HEI score compared to adults with obesity (normal weight HEI=51.56 [+/-0.33], overweight HEI=51.56 [+/-0.29] versus 50.21 [+/-0.30] for adults with obesity, $p<0.05$) (Agarwal, Reider, Brooks, & Fulgoni, 2015).

Recent studies have shown an association between the prevalence of micronutrient intake deficiency and poor diet quality. Martinez Steele et al., (2017) analyzed NHANES data from 2009-2010 using 24-hour recall dietary data for individuals over the age of one and created quintiles based on the percentage of energy intake from ultra-processed foods. The lowest quintile averaged 32.6% of calories from ultra-processed foods while the highest quintile averaged 80.7% of calories from ultra-processed foods.   The authors found a positive increasing association between ultra-processed food quintiles and higher intake of carbohydrate, added sugars, and saturated fat. An inverse association was found with increased dietary consumption of ultra-processed foods and lower consumption of protein, fiber, vitamins A, C, D, E and minerals calcium, magnesium, phosphorus, potassium, and zinc. Iron fortification of ultra-processed food is common and did not show an inverse relationship like the other micronutrients. Sodium was above the tolerable Upper Limit (UL) for all quintiles. The authors did not consider any other micronutrients and stated their focus was on the most under-consumed micronutrients and fiber along with the most over consumed nutrients sodium, added sugar and saturated fat in the US population (Martínez Steele, Popkin, Swinburn, & Monteiro, 2017). Overall, recent studies suggest that consumption of ultra-processed foods is associated with increased risk of developing obesity from calorically dense food with excess added sugar and saturated fat, while simultaneously providing lower levels of micronutrients and fiber.

Micronutrient deficiency in the diet has a clear role in the development some diseases such as iron deficiency anemia however, the contribution of micronutrient deficiency in the development of chronic diseases is not well understood (Kelly, Gilman, Kim, & Ilich, 2016). Although obesity and excess adiposity are associated with an increased risk of chronic disease, it is unclear whether micronutrient deficiency contributes to obesity or if obesity causes micronutrient deficiency (García et al., 2009). It has been hypothesized that the increased prevalence of micronutrient deficiencies in adults with obesity may further exacerbate the risk for developing chronic diseases

(Astrup & Bügel, 2018). A considerable number of studies have looked at the efficacy of multivitamin and mineral supplements for the prevention of chronic disease; however this remains controversial given the inconsistency of the results and even possible harm (Blumberg, Bailey, Sesso, & Ulrich, 2018). Although the role of micronutrient status and chronic disease is still unclear, research has shown a strong relationship between the benefits of weight loss and the reduction in the risk of chronic diseases.

Considerable research has been conducted on effective strategies that promote long-term weight loss since excess adiposity is related to increased levels of inflammation in the body and the development of chronic diseases. Fat tissue actively produces adipokines and releases free fatty acids into the blood which contribute to developing hyperlipidemia and insulin resistance which are risk factors for CVD and T2DM (Ryan & Yockey, 2017). Adults with obesity are estimated to have significantly fewer years of major chronic disease-free living compared to individuals with normal weight. For adult men and women between the ages of 40 to 75, adults with class I obesity (BMI 30.0-34.9 kg/m^2) were estimated to have 3 to 4 disease-free years lost compared to adults with normal weight and 7 to 8 disease-free years lost for adults with severe obesity with class II obesity (BMI 35.0-39.9 kg/m^2) or class III obesity (BMI ≥ 40 kg/m^2) (Nyberg et al., 2018).

Ryan & Yockey (2017) examined reductions in comorbidity associated with various levels of weight loss and found weight loss beginning at 3% of body weight is associated with significant improvements in blood glucose measures and triglycerides. Furthermore, weight loss of 5% of body weight reduces the risk of developing chronic diseases such as T2DM and CVD through improved fasting blood glucose, hemoglobin A1c, blood pressure, HDL cholesterol, and triglycerides. In addition, weight loss of 10% or more of body weight has shown even greater benefits for reducing metabolic and cardiovascular risk (Ryan & Yockey, 2017). De las Fuentes et al., (2009) found that average weight loss of 4.1 kg (+/-8.8 kg) during a two-year period among obese subjects was associated with improved carotid intima media thickness and left ventricular diastolic function at 6, 12, and 24 months (de las Fuentes et al., 2009). Overall, weight loss has been shown to improve cardiac function through beneficial changes in cardiovascular structure and function and improved right and left ventricle function among obese adults (Bianchi, 2018).

Metabolic syndrome is a clustering of indicators which is associated with an individual's risk for chronic disease. The five indicators of metabolic health are large waist size, elevated blood pressure, low high-density lipoprotein (HDL), elevated triglycerides, and hyperglycemia. Individuals with three or more indicators out of five are at increased risk of T2DM or CVD (Huang, 2009). Knell et al., (2018) examined the relationship between weight loss maintained for at least one year and reduced risk of metabolic syndrome among US adults aged 20-64 in NHANES data between 2007-2014. Compared to adults with weight loss of less than 5%, adults with the greatest percentage of weight loss had lower odds of having metabolic syndrome with weight loss >20% OR= 0.47 (95%CI: 0.35-0.63) or weight loss of 15%-19.9% OR=0.63 (95%CI: 0.42-0.95). Compared to adults with less than 5% weight loss, weight loss between 10% and 14.9% just missed statistical significance at the 95% level with OR=0.79 (95%CI:

0.61-1.02), however weight loss of 5% - 9.9% OR=0.78 (95%CI: 0.66-0.92) was significantly lower odds for metabolic syndrome (Knell, Li, Pettee Gabriel, & Shuval, 2018). Overall, there is strong evidence that weight loss is associated with better health outcomes in reducing risk for chronic disease.

Significant weight loss of body weight clearly provides improvements in health, however behavioral weight loss interventions tend to demonstrate peak weight loss at about six months and then gradual regain of weight (Dombrowski, Avenell, & Sniehott, 2010). Among individuals who intentionally lose weight, most will regain the weight back (≈80%) however, there are data to suggest that a significant subset of the population can successfully lose and keep the weight off (Wing & Phelan, 2005). In a random digit dial telephone survey of adults in the US conducted by researchers (McGuire, Wing, & Hill, 1999) found that among individuals who had intentionally lost more than 10% of body weight, nearly half had maintained the weight loss for one year and one quarter had maintained their weight loss for five or more years. Overall, the authors found that among individuals who are overweight, 62% have lost 10% or more of their body weight in their lifetime. Among those adults with obesity prior to weight loss, 21% at the time of the survey were ten percent or more below their highest weight (McGuire et al., 1999).

Fildes et al., (2015) estimated the annual probability of an adult with a BMI ≥ 30 kg/m^2 losing 5% of their body weight using electronic health records of primary care doctors in the United Kingdom between 2004 and 2014. The annual probability for a man with BMI 30-34.9 kg/m^2 was 1 in 12 for reducing body weight by 5% and the probability increased to 1 in 5 for each 5-unit increment of BMI to a BMI ≥ 45.0 kg/m^2. Among adult women the probability for BMI 30-34.9 kg/m^2 was 1 in 10 and the probability increased to 1 in 6 for each 5-unit increment of BMI to a BMI ≥ 45.0 kg/m^2. In examining weight loss maintenance, consistent with other research, the authors reported at least 50% of adults who lost at least 5% of their weight regained the lost weight within 2 years. The annual probability was calculated for achieving a normal BMI with an initial BMI from 30-34.9 kg/m^2 was 1 in 210 for men and 1 in 124 for women. Finally, during the 9 year follow up, 14% of men and 15% of women had decreased ≥ 1 BMI category with no increases in BMI indicating they were successfully maintaining their weight loss and not weight cycling (Fildes et al., 2015).

In a six year follow up of adult women who had lost weight in the Nurses' Health Study II Field et al., (2001), estimated the proportion who were able to successfully maintain weight loss. Between 1989 and 1991, 5.5% of women lost between 5-9.9% of weight body weight and 2.8% lost 10% or more of their body weight. During the subsequent four years, from 1991-1995, among those who had had initially lost more than 10%: those with starting BMI ≥ 30 kg/m^2, 54% of the women regained all the weight while, 51% regained all the weight in the group whose BMI was 25.0-29.9 kg/m^2. For those who had had initially lost 5-9.9%: those with starting BMI ≥ 30 kg/m^2, 48% of the women regained all the weight while 39% regained all the weight in the group whose BMI was 25.0-29.9 kg/m^2. Among those with weight loss >5% and BMI ≥ 25 kg/m^2, approximately 20-35% of women were successful at maintaining some portion of weight loss (gained less than 5% of weight back or less than 2.3 kg) between 1991-1995 (Field, Wing, Manson, Spiegelman, & Willett, 2001).

Weight loss maintenance using NHANES data for US adults from 1999-2002 was examined by Weiss et al., (2007). The authors included adults between the ages of 20-84 years with BMI ≥ 25 kg/m^2 who intentionally lost weight and were at least 10% less than their maximum body weight one year prior. Weight regain was defined as weight gain of greater than 5% of body weight in the previous 12 months. The authors found one third had regained more than 5% of their body weight, while 58.9% had maintained their weight loss of at least 5%, and 7.6% had continued to lose weight. The authors found the odds of weight regain increased for individuals who had lost a greater percentage of their initial body weight. The odds of weight regain was 2.8 times higher for those who lost more than 20% of body weight and 1.5 times higher for those who lost 15-20% compared to individuals who had lost 10-15%. Lower odds of weight regain were found among adults who had reached their maximum lifetime weight maintained their weight loss more than ten years compared to 6-10 years of maintenance with odds of 1.6 for regain and even higher odds of 2.1 for individuals who had maintained weight loss for 2-5 years. Other factors associated with weight regain were Mexican American ethnicity, higher average hours of screen time per day, and sedentary lifestyle or PA below 150 minutes per week (Weiss, Galuska, Kettel Khan, Gillespie, & Serdula, 2007).

Another analysis of weight loss strategies used by adults in the US to lose weight was estimated using NHANES data between 2001 and 2006. Nicklas et al., (2012) found that among adults with obesity trying to lose weight, 40% lost at least 5% of their body weight and 20% lost ≥ 10%. Statistically significant strategies for successfully losing ≥ 10% of body weight included eating less fat, exercising more, using prescription weight loss medications, and joining commercial weight loss programs (Nicklas, Huskey, Davis, & Wee, 2012).

Overall, no specific dietary pattern has been associated with being required for weight loss. In a systematic review examining interventions with a dietary component for weight loss maintenance, the authors found that the most effective strategies included a reduction in energy intake, but no single specific dietary pattern was identified as being required (Collins, Morgan, Callister, & Fletcher, 2010). In a systematic review of weight loss maintenance among adults who lost weight with behavioral interventions between 1984 and 2013, Dombrowski et al., (2014), found that interventions that combined diet and PA resulted in significantly lower weight regain among participants compared to controls at 12, 18, and 24 months. The average age of participants was 47.3 years and average BMI before weight loss was 35.2 kg/m^2. For weight loss maintenance for 12 months, 15 studies were meta-analyzed, and interventions showed lower average weight regain of -1.56 kg (95%CI: -2.27 to -0.86 kg) compared to controls. For analysis at 18 months, seven studies were analyzed and the mean difference in weight change was -1.96 kg (95%CI: -2.73 to -1.20 kg). Only two studies were available at 24 and 30 months, with significant lower mean difference -1.48 kg (95%CI: -2.27 to -0.69 kg) at 24 months and -0.85 kg (95% CI: -1.81 to 0.11) at 30 months which was not significant at the 95% level (Dombrowski, Knittle, Avenell, Araújo-Soares, & Sniehotta, 2014).

Long-term significant weight loss strategies have been identified through studies conducted on participants of the National Weight Control Registry (NWCR). This registry is a self-selected group consisting of more than 10,000 adults recruited in the US mainly through newspaper and magazine articles and participants are not compensated. The eligibility criteria include having lost at least 30lbs (13.6 kg) and maintained that weight loss for at least a year. In an observational study conducted in 2014 by Thomas et al., NWCR participants who had enrolled between 1993 and 2000 (n=3,284) were contacted for a 10 year follow up study. The inclusion criteria required that members have completed at least two of the annual follow up questionnaires in the past ten years. The study included 2,886 members and revealed average initial weight loss of 31.3 kg and successful average maintenance of weight loss of 23.8 kg at 5 years (77% of initial weight loss) and 23.1 kg (74% of initial weight loss) at 10 years (Thomas, Bond, Phelan, Hill, & Wing, 2014). Most NWCR members report using both diet and PA to lose weight (89%). There was considerable variation in the dietary strategies employed to maintain weight loss including restricting certain foods (87.6%), limiting quantities (44%), and counting calories (43%), however, no single dietary pattern emerged as most efficacious. The individuals who tended to have better success maintaining their weight loss continued their PA levels and tended to consistently follow their dietary eating plan over days, weekends, and holidays. Individuals who regained weight tended to relax their healthy eating and exercise behaviors (Wing & Phelan, 2005).

To examine macronutrient and micronutrient dietary differences among successful weight losers, Shick et al., (1998) compared dietary intake of NWCR participants to US adults, using data from NHANES III. Nutrient intake was estimated using the Health Habits and History Questionnaire, a food frequency questionnaire (FFQ), which also includes the use of vitamin and mineral supplements. Overall, among the NWCR participants, 80% consumed less than 30% of total calories in their diet from fat. The percent of energy from fat was significantly lower among women and men in the NWCR compared to NHANES III participants (NWCR women 24.3% [8.2] vs NHANES III women 34.9% [14.7], p<0.0001 and NWCR men 23.5% [7.8] vs NHANES III men 33.9% [12.5], p<0.0001). The percentage of energy from carbohydrate was significantly higher among NWCR compared to NHANES III (NWCR women 55.5% [9.3] vs NHANES III women 49.0% [17.2], p<0.0001 and NWCR men 56.2% [8.5] vs NHANES III men 46.9% [17.5], p<0.0001). Also the percentage of energy from protein was significantly higher among NWCR compared to NHANES III (NWCR women 19.2% [3.7] vs NHANES III women 15.8% [7.4], p<0.0001 and NWCR men 18.2% [3.9] vs NHANES III men 15.6% [7.5], p<0.0001). The authors also found that successful female WLM in the NWCR had significantly higher total intake of calcium, vitamin A, and vitamin C compared to adult women in NHANES III data. In examining differences among men, micronutrient intake was significantly higher in the NWCR compared to NHANES III for only vitamin C (Shick et al., 1998).

In an 8-month weight loss trial of postmenopausal women on a low-fat diet, Mueller-Cunningham, Quintana & Kasim-Karakas, (2003) found that participants at the end of the intervention, based on the evaluation of seven day food records, tended to have higher dietary average intake of beta-carotene, vitamin A, D, calcium, iron and folate compared to baseline, however none were statistically significant. Intake of vitamin E was significantly lower at the end of the 8-month trial, likely due to the lower intake of typical vitamin E food sources such as vegetable oil, nuts, and seeds.

Miller et al., (2017) conducted an 18-month weight loss program for adults age fifty-five and older where they randomized participants into three groups consisting of exercise only, diet only, and diet plus exercise groups. They analyzed weight loss and changes in dietary intake of vitamins and minerals. The diet intervention used commercial meal replacement shakes for two meals and then a third meal and snacks that were high in fruits, vegetables and low in fat. The overall findings were that individuals in the diet only group and the diet plus exercise group had significantly higher intakes of vitamins A, E, C, thiamin, niacin, vitamin B6, folate, calcium, iron, and zinc compared to the exercise only group at the end of 18 months (Miller, Beavers, Hamm, Mihalko, & Messier, 2017).

In a systematic review of randomized and non-randomized controlled weight loss trials examining vitamin D status and weight loss, Mallard, Howe & Houghton (2016) concluded that there is some evidence to support an association between improved serum levels of vitamin D and weight loss. Unfortunately, many studies had confounding factors such as sun exposure, seasonality, or supplementation and the authors stated that better designed RCT should be conducted in the future to confirm these findings.

In an analysis of overall diet quality and micronutrient intake Ledikwe et al., (2006) examined cross sectional data of Americans and divided adults by dietary intake based into three energy-density categories: low energy density, medium, and high. Individuals consuming low-energy-density diets had higher intakes of fruits and vegetables and lower intakes of total fat, baked goods, dry snacks, fried potatoes, and regular and low-calorie carbonated soft drinks compared to the high energy density group. Except for dairy products, the low energy density group also ate more food by weight than the high energy density group. The authors found that adults eating low-energy-density diets had the highest consumption of micronutrients such as vitamins A, C, B6, folate, and iron, calcium and potassium (Ledikwe et al., 2006).

FFQs estimate usual dietary intake and may be used to assess the adequacy of specific nutrients in an individual's diet. In a systematic review of dietary assessment methods for vitamins, Henriquez-Sanchez et al., (2009) summarized that FFQ are an acceptable method for assessing vitamin intake. Overall, weighted mean correlation coefficients for FFQs validated by dietary record ranged from 0.41-0.51 for vitamins A, C, D, E, folic acid, B_{12}, B_6, thiamine, riboflavin, and niacin. Mean correlation coefficients were higher (CC=0.52) in studies using FFQ with more than 100 types of foods versus a mean correlation coefficient of 0.47 in studies using FFQs with fewer than 100 food items (Henríquez-Sánchez et al., 2009). The authors recommended using FFQs which have greater than 100 types of foods assessed and also include questions regarding supplement intake to improve the quality of the dietary vitamin intake assessments.

The FFQ requires participants to work from memory and use cognitive reasoning to estimate the frequency of intake of particular foods. In general, FFQs have been shown to have both systematic and random dietary measurement error, which may affect the accuracy of dietary assessment (Kipnis et al., 2003). Using doubly labeled water as a biomarker to assess the accuracy of reported intakes, Subar et al., (2003) found that among men, underreporting of energy intake on FFQs was 31-36% and underreporting of protein intake was 30-34%. While among women, total energy underreporting was 34-38% and underreporting of protein intake was 27-32%. There was also a trend for higher underreporting among those adults with a BMI in the overweight or obese categories compared to those adults in the normal BMI range (less than 25 kg/m^2) for both men and women (Subar et al., 2003). In another study using doubly labeled water, researchers found higher BMI and a weight-loss history of losing 10 lbs. were significant predictors for energy intake underreporting on FFQ by both men and women (Tooze et al., 2004).

Subar et al., (2001) estimated correlations for how well three different FFQs reflected intake over the course of a year relative to dietary intake using periodic 24-hour diet recalls. The three FFQs assessed were the Dietary Health Questionnaire (DHQ), Block, and Willet. Participants over the course of one year completed four 24-hour diet recalls approximately three months apart and then were randomized to complete two FFQs, each one month apart. The authors reported their results were similar to other studies which tend to find correlation coefficients between 0.40 - 0.70. The DHQ correlations among nutrients compared to Block and Willet FFQs were the highest for most nutrients for both men and women. The correlation coefficient for energy in the DHQ for women was 0.48 and 0.49 for men, the correlation coefficient for protein was 0.46 for women and 0.47 for men, and for micronutrients correlation coefficient values ranged from 0.43-0.61 for women and between 0.55-0.66 for men (Subar et al., 2001).

Serra-Majem et al., (2009) conducted a systematic review of dietary assessment methods for minerals, including iron, calcium, selenium, and zinc. The authors found higher weighted mean correlation coefficients for FFQs compared to dietary records for the minerals calcium (CC=0.55), zinc (CC=0.52), and iron (CC=0.49) versus selenium which was lower (CC=0.39). Consistent with other validation studies, the authors found stronger correlations when FFQs included at least 100 or more foods and recommended having questions regarding supplement use in the FFQ. Overall, the authors concluded that using FFQs as a tool for assessing dietary mineral intake is acceptable (Serra-Majem et al., 2009).

The usual dietary information obtained in the DHQ may be used to assess diet quality using a healthy eating index (HEI). The Healthy Eating Index-2015 (HEI-2015) reflects adherence to the U.S. government's recommended *2015-2020 Dietary Guidelines for Americans.* In an evaluation of the properties of the HEI-2015, Reedy et al., (2018) concluded that the HEI-2015 demonstrated both construct validity and reliability as a diet quality measure reflecting the 2015-2020 Dietary Guidelines for Americans (Reedy et al., 2018). The HEI-2015 was used to compile scores for high nutritional quality menus such as the USDA Food Patterns 7-day 2,000 kcal/day sample menu, Dietary Approaches to Stop Hypertension 7-day, 2,000 kcal/day sample menu, the Harvard 7-day 1,700 kcal/day and 2,000 kcal/day sample menus and the American Heart Association 2-day 1,600 kcal and 2,000 kcal/day sample menus. The total scores were consistently high ranging from 87.8 for the Harvard sample menu to 100 for the DASH sample menu indicating that the HEI-2015 index consistently provides high scores for excellent quality sample menus.

To examine the HEI's effectiveness in identifying dietary differences among groups of Americans, Reedy et al., (2018) analyzed NHANES data between groups with known differences. The authors found that smokers had a significantly lower average mean diet quality total score compared to non-smokers (mean score of 59.6 for nonsmokers versus 53.3 for current smokers.) Also, as expected, adults in the youngest group had significantly lower average diet quality scores compared to individuals in the oldest age groups (mean score for youngest group was 55.0 while the oldest group had a mean score of 62.8). Overall, the HEI-2015 demonstrated construct validity in its effectiveness in identifying differences in diet quality between groups (Reedy et al., 2018). In examining individuals, the HEI scoring algorithm allows for the estimation of individual level scores that can be used with regression models (Kirkpatrick et al., 2018). Finally, the HEI has been used for a variety of scientific research purposes including studies examining differences in dietary quality among older rural adults (Savoca et al., 2009).

Overall, the research indicates that successful weight loss may incorporate a variety of potential dietary changes along with increased PA. Weight loss methods vary and whether these dietary changes consistently improve diet quality is unclear. Also, if diet quality is improved during weight loss, little research has been conducted on whether higher diet quality is sustained during weight maintenance. Previous research using earlier versions of the Healthy Eating Index-2005 (HEI-2005), based on *2005 Dietary Guidelines for Americans* and Healthy Eating Index-2010 (HEI-2010), aligned with the *2010 Dietary Guidelines for Americans*, have been employed in several studies to assess diet quality during weight loss interventions and during weight maintenance.

Webber and Lee (2011) measured changes in HEI-2005 scores during a 16 week behavior weight loss program among women who were overweight or with obesity and found an increase in HEI scores between the baseline and at 16 weeks (53.9 [9.9] to 57.4 [10.6], p-value = 0.002). For macronutrients, the only significant change was in the percentage of kcals from protein which increased (15.4% at baseline to 16.6% after 16 weeks, p<0.01). There was no change in the percentage of kcals from carbohydrate (48.7 versus 48.5%, p-value=0.79) and the percentage of kcals from fat fell from 36.1% to 34.9% (p-value=0.07), but was not significant (Webber & Lee, 2011).

Anderson et al., (2016) completed a randomized six month weight loss trial, comparing HEI-2010 scores among breast cancer survivors with overweight or obesity to controls receiving usual care. The diet intervention group had a larger average improvement in their HEI score compared to the usual care group (6.8 points versus only 3.1 points, p=0.09). The authors also found that individuals in the intervention decreased percentage of energy intake from fat (-4.19% [6.49] compared to -1.12% [6.49] in the usual care group p-value=0.01) (Anderson et al., 2016). In another weight loss trial of breast cancer survivors that were overweight or obese, Christifano et al., (2016) compared the HEI-2010 scores in a non-randomized 6 month weight loss trial at baseline and again at six months. The average HEI-2010 score was 51.93 [11.19] and after 6 months increased an average 12.11 points ([14.46] p-value 0.001). The authors also found that greater improvements in HEI-2010 scores between 0 and 6 months were associated with greater weight loss. In addition, the percentage of kcals from fat fell from an average of 36.1% at baseline to 24.1% at 6 months, while the percentage of kcals from carbohydrates rose for 45.9% to 53.0% and percentage of kcals from protein rose from 16.8% to 22.6% (Christifano, Fazzino, Sullivan, & Befort, 2016).

In another randomized six month weight loss trial of adults with BMIs classified as overweight or obese, HEI-2010 scores among individuals receiving either phone based or in person clinic educational sessions followed a reduced calorie diet for six months and then participants were followed until eighteen months. Baseline HEI-2010 scores increased by 20.3[11.9] points on average ($p<0.001$) at six months during the weight loss phase. While the average HEI-2010 scores fell during the weight maintenance phase of 6 to 18 months, they remained significantly higher overall compared to the baseline, with an average increase of 11.3[11.9] points from baseline to 18 months ($p <0.001$) indicating that participants preserved a significant proportion of the positive improvement in diet quality achieved during weight loss into weight maintenance (Ptomey et al., 2016).

Analyzing the diets of Weight Watcher (WW) participants who have successfully lost at least 20 pounds and maintained that weight loss for at least a year provides a unique opportunity further investigate the question of whether weight loss maintenance is associated with improved dietary quality. WW is a commercial weight loss program that utilizes a variety of approaches to aid participants with weight loss, most recently *PointsPlus®,* which is a dietary and physical activity system to promote steady weight loss by encouraging the maintenance of a caloric deficit combined with regular PA. Participants enroll and are provided an allocation of daily points based on their height, weight, activity level and gender. Better quality nutritious foods that are high in fiber while low in saturated fat such as fruits, vegetables, whole grains, lean protein, and nonfat dairy are assigned lower point values, while foods high in saturated fat, sugar, and total calories are assigned higher point values. The WW program emphasizes flexibility and participants are free to allocate their daily and weekly points for a variety of foods they desire; however, eating higher quality nutrient and fiber dense foods while reducing saturated fat intake depletes daily points more slowly, allowing a participant to eat a greater quantity of food. Participants can choose to go to weekly meetings with weigh-ins and counselor led discussions or use the WW Online program alone. In addition, there are online resources (some free and some available for purchase) such as dietary intake and PA trackers (*ActiveLink*: an accelerometer to estimate PA), sample menus, recipes, supplemental materials and coaches to encourage weight loss.

The WW program has been analyzed and compared to other programs in a variety of studies. In a systematic review of RCTs examining commercial weight loss programs at 12 months, WW participants had a 2.6% greater weight loss than controls (Gudzune et al., 2015). In a comparison of commercially available weight loss programs, Truby et al., (2008) completed a controlled weight loss trial assigning participants randomly into Atkins, Slim Fast, WW, or Rosemary Conley's program for two months.   None of the plans were found to result in any dietary micronutrient intake deficiencies, however average intakes of potassium were less than dietary recommendations for all four groups. WW participants significantly reduced their dietary fat intake by 7% [95% CI 5.7, 9.79] and was the only group to have a statically significant increase in fruit and vegetable consumption, although this was equivalent to less than a full (0.79) serving per day. Ma et al., (2007) examined dietary quality of weight loss programs by compiling Alternative Healthy Eating Index (AHEI) scores for Ornish, WW, New Glucose Revolution, South Beach, Zone, and the USDA 2005 Food Guide Pyramid. The AHEI is similar to the HEI, but includes components that were found to be strongly associated with CVD risk reduction in both men and women (McCullough et al., 2002). Ma et al., (2007) scored seven of the dietary components in the AHEI including consumption of vegetables, fruit, nuts and soy protein, ratio of white to red meat, trans fat, cereal fiber, and ratio of PUFA to SFA. The authors found that the Ornish plan scored the highest on the AHEI with 64.6, while WW was second with a score of 57.4. Overall the authors stated that WW plan scored well due to the emphasis on combining low trans-fat with high intake of fruits, vegetables, and whole-grains averaging a total of 34.7 grams of fiber per day (Ma et al., 2007).

Overall, adults with obesity tend to have higher caloric intake, yet are also more likely to be deficient in key micronutrients. It is not clear if this is due to insufficient intake of micronutrients or if there are metabolic affects related to excess adiposity and inflammation that results in low serum levels of vitamins and minerals. Weight loss maintenance has been shown to greatly reduce disease risk, but research has not examined if dietary intake of micronutrients differs among individuals with successful weight loss and individuals who are weight stable and obese.

The primary research aim of this study is to better understand and quantify the dietary intake of successful WW WLM. Analysis will compare the dietary intake of adults using a FFQ who have lost at least 20 pounds in the WW program and have successfully maintained that weight loss for at least one year to the dietary intake of weight stable obese US adults using (1) Heathy Eating Index-2015, (2) analysis of macronutrient content (dietary carbohydrate, fat and protein), and (3) analysis of dietary micronutrient content for meeting the EAR for vitamins and minerals and AI for potassium.

Chapter 2

METHODS

2.1 Participants

The Weight Watchers Success Registry (WWS) is a sample of over 4,000 Weight Watchers (WW) members who have maintained a significant weight loss for at least one year. WW identified US members who were with reported weight loss of at least 20 lbs. and weight maintenance for at least 12 months and emailed these individuals inviting them to participate in an online survey. These individuals are referred to as weight loss maintainers (WLM). Controls are adults with obesity who are weight stable. These individuals were recruited predominantly through Amazon Mechanical Turk along with national advertising channels such as Facebook, ResearchMatch.org, and local channels via the Cal Poly Family Health Research registry. To incentivize participation, individuals who completed the survey through Amazon Mechanical Turk received one month of WW Digital for free.

2.2 Inclusion Criteria

All participants completed an online survey and had to be able to read and write English. The criteria for eligibility to be enrolled within the control group included: living in the US, at least 18 years old, currently have a BMI ≥ 30 kg/m^2 (obese category) and reported weight stability defined as weight within ± 5 lbs. in the previous 5 years before enrollment. All individuals included in this study, both the control group and WWS participants, completed a survey regarding demographic characteristics, weight, a FFQ and questions regarding behavioral factors such PA, sedentary behaviors, eating habits, self-monitoring, cognitive restraint and disinhibition, motivation, and environmental factors. In addition, the WWS participants provided documentation of their successful weight loss, WW program modalities used to lose and maintain weight, difficulty in weight loss maintenance, and the effect of weight loss on their quality of life. Surveys were completed at baseline and again at 12 months. Initial on-line surveys were obtained between March 2018 and February 2019 with subsequent 1 year follow up assessments planned between March 2019 and February 2020.

2.3 Measures

Comparison of the dietary intake between the WLM participants and the weight stable individuals with obesity were based on a FFQ called the Diet History Questionnaire (DHQ-II) from the National Institutes of Health. The DHQ-II was created by the staff at the Risk Factor Assessment Branch of the National Cancer Institute and is free to use for researchers and clinicians. Overall, FFQs reflect usual dietary intake and averages over time rather than precise measurements of daily intake. The DHQ-II assesses dietary intake over the past 12 months for 134 food items and includes questions regarding portion sizes and intake of vitamin, mineral and herbal supplements[1]. Thompson et al., (2002), in an experimental validation study, cited several advantages in the design of the DHQ for enhancing FFQ reporting accuracy. Respondents are first asked about a main type of food such as milk, followed by nested questions about more specific variations regarding alternative forms, frequency, and typical portion sizes to obtain more accurate assessments (Thompson et al., 2002).

[1] https://epi.grants.cancer.gov/dhq2/about/

In this study, the DRI for vitamins were used to determine the proportion of individuals whose diets met the EAR using the EAR cut-point method. The EAR is the appropriate measure to compare the adequacy of intakes between groups (Murphy & Poos, 2002). Vitamins in which an EAR has not been established were excluded. The cut points based on age and sex are listed for each vitamin in Table 1 below.

Table 1: **Vitamin DRIs: EAR Food and Nutrition Board, National Academis of Sciences, Engineering, and Medicine**

		Males		**Females**	
		19–50 y	**> 51 y**	**19–50 y**	**>51 years**
Vit A	(µg/d)[a]	625	625	500	500
Vit C	(mg/d)	75	75	60	60
Vit D	(µg/d)[b]	10	10	10	10
Vit E	(mg/d)[c]	12	12	12	12
Thiamin	(mg/d)	1	1	0.9	0.9
Riboflavin	(mg/d)	1.1	1.1	0.9	0.9
Niacin	(mg/d)[d]	12	12	11	11
Vit B6	(mg/d)	1.1	1.4	1.1	1.3
Folate	(µg/d)[e]	320	320	320	320
Vit B12	(µg/d)	2	2	2	2

Source:
https://www.ncbi.nlm.nih.gov/books/NBK56068/table/summarytables.t1/?report=objectonly

The data in this table was taken from the DRI reports (available at www.nap.edu). An EAR is the average daily nutrient intake level estimated to meet the requirements of half of the healthy individuals in a group. EARs have not been established for Vitamin K, pantothenic acid, biotin choline, chromium, flouride, manganese, potassium, sodium, or chloride.

SOURCES: DRI for Calcium, Phosphorous, Magnesium, Vitamin D, and Fluoride (1997); DRIs for Thiamin, Riboflavin, Niacin, Vitamin B6, Folate, Vitamin B12, Pantothenic Acid, Biotin, and Choline (1998); DRIs for Vitamin C, Vitamin E, Selenium, and Carotenoids (2000); DRIs for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc (2001); DRIs for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids (2002/2005); and Water, Potassium, Sodium, Chloride, and Sulfate (2005); and DRIs for Calcium and Vitamin D (2011). These reports may be accessed via www.nap.edu.

[a] As retinol activity equivalents (RAEs). 1 RAE = 1 µg retinol, 12 µg β-carotene, 24 µg α-carotene, or 24 µg β-cryptoxanthin. The RAE for dietary provitamin A carotenoids is two-fold greater than retinol equivalents (REs), whereas the RAE for preformed vitamin A is the same as RE.

[b] As cholecalciferol. 1 µg cholecalciferol = 40 IU vitamin D. Assumes minimal sun exposure.

[c] As α-tocopherol. α-tocopherol includes RRR-α-tocopherol, the only form of α-tocopherol that occurs naturally in foods, and the 2R-stereoisomeric forms of α-tocopherol (RRR-, RSR-, RRS-, and RSS-α-tocopherol) that occur in fortified foods and supplements. It does not include the 2S-stereoisomeric forms of α-tocopherol (SRR-, SSR-, SRS-, and SSS-α-tocopherol), also found in fortified foods and supplements.

[d] As niacin equivalents (NE). 1 mg of niacin = 60 mg of tryptophan

[e] As dietary folate equivalents (DFE). 1 DFE = 1 µg food folate = 0.6 µg of folic acid from fortified food or as a supplement consumed with food = 0.5 µg of a supplement taken on an empty stomach. In view of evidence linking folate intake with neural tube defects in the fetus, it is recommended that all women capable of becoming pregnant consume 400 µg from supplements or fortified foods in addition to intake of food folate from a varied diet.

In this study, the DRI for minerals were used to determine the proportion of individuals whose diets met the EAR. The cut points based on age and sex are listed for each mineral in the table below. Minerals with an EAR established were included in the analysis and are listed in Table 2 except for molybdenum and iodine because these minerals are not measured in the DHQ-II. In addition, potassium which has an AI was also included since it has been shown in the literature that adults with obesity are more likely to have diets that are deficient in potassium (Agarwal et al., 2015).

Table 2: Mineral DRIs: EAR Food and Nutrition Board, National Academis of Sciences, Engineering, and Medicine

		Males		Females		
		19–70 y	> 70 y	19–30 y	31–50 y	>50
Calcium	(mg/d)	800	1000	800	800	1000
Copper	(µg/d)	700	700	700	700	700
Iodine	(µg/d)	95	95	95	95	95
Iron	(mg/d)	6	6	8.1	8.1	5
Magnesium	(mg/d)	330	330	255	265	265
Phosphorus	(mg/d)	580	580	580	580	580
Potassium[a]	(g/d)	4.7	4.7	4.7	4.7	4.7
Selenium	(µg/d)	45	45	45	45	45
Zinc	(mg/d)	9.4	9.4	6.8	6.8	6.8

Source: https://www.ncbi.nlm.nih.gov/books/NBK56068/table/summarytables.t1/?report=objectonly
[a] Potassium has an AI rather than an EAR established.
The data in this table was taken from the DRI reports (available at www.nap.edu). An EAR is the average daily nutrient intake level estimated to meet the requirements of half of the healthy individuals in a group. EARs have not been established for vitamin K, pantothenic acid, biotin choline, chromium, flouride, manganese, potassium, sodium, or chloride.
SOURCES: *DRIs for Calcium, Phosphorous, Magnesium, Vitamin D, and Fluoride* (1997); *DRIs for Thiamin, Riboflavin, Niacin, Vitamin* B_6*, Folate, Vitamin* B_{12}*, Pantothenic Acid, Biotin, and Choline* (1998); *DRIs for Vitamin C, Vitamin E, Selenium, and Carotenoids* (2000); *DRIs for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc* (2001); *DRIs for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids (2002/2005); and Water, Potassium, Sodium, Chloride, and Sulfate* (2005); and *DRIs for Calcium and Vitamin D* (2011). These reports may be accessed via www.nap.edu.

Since the DHQ-II asks about usual intake over the past year, individuals reporting biologically implausible daily energy intakes were removed from the analysis. The cut points selected for this study were based on previous studies analyzing FFQ data in which individuals who reported implausible daily energy intakes for men of less than 800 kcals per day or more than 4,200 kcals per day and for women with less than 600 kcals per day or more than 3,500 kcals per day were excluded from the analysis (Subar et al., 2001). In this study, 44 individuals were removed for implausible values based on this criteria.

The diet quality of the individuals in the study was assessed using the HEI-2015 which reflects adherence to the U.S. government's recommended *2015-2020 Dietary Guidelines for Americans.* The components for scoring include adequate intake for a total of 13 categories including: total fruits, whole fruits, total vegetables, greens and beans, whole grains, dairy, total protein foods, seafood and plant proteins, fatty acids and moderation in refined grains, sodium, added sugars and saturated fats with a highest possible total score of 100 if all components received maximum scores (Krebs-Smith et al., 2018).

Table 3: HEI-2015

	Total Possible Points	Standard to Maximize Points	Standard for Minimum score of zero
9 Adequacy Components:			
Total Fruits	5	≥0.8 c equivalents/1,000 kcal	No fruit
Whole Fruits	5	≥0.4 c equivalents/1,000 kcal	No whole fruit
Total Vegetables	5	≥1.1 c equivalents/1,000 kcal	No vegetables
Greens and Beans	5	≥0.2 c equivalents/1,000 kcal	No dark green veg/beans/peas
Whole Grains	10	≥1.5 oz equivalents/1,000 kcal	No whole grains
Dairy	10	≥1.3 c equivalents/1,000 kcal	No dairy
Total Protein Foods	5	≥2.5 oz equivalents/1,000 kcal	No protein foods
Seafood & Plant Protein	5	≥0.8 oz equivalents/1,000 kcal	No seafood/plant proteins
Fatty Acids	10	(PUFA+MUFA)/SFA ≥ 2.5	(PUFA+MUFA)/SFA ≤ 1.2
4 Moderation Components:			
Refined Grains	10	≤ 1.8 oz equivalents/1,000 kcal	≥4.3 oz equivalents/1,000 kcal
Sodium	10	≤ 1.1 g/1,000 kcal	≥ 2.0 g/1,000 kcal
Added Sugars	10	≤ 6.5% energy	≥ 26% of energy
Saturated Fats	10	≤ 8% energy	≥ 16% of energy
Maximum Possible Score	100		

Source: Reedy et al., (2018)
PUFA: polyunsaturated fatty acids
MUFA: monounsaturated fatty acids
SFA: saturated fatty acids

2.4 Statistics

Independent t-tests and chi-square analyses were conducted to examine differences among adults who completed the DHQ-II and non-completers of the DHQ-II and differences between WLM and Controls. General linear models (for HEI scores and macronutrients) and logistic regression models (for EAR cutoffs) were used to examine dietary differences between the WLM and Controls on dependent measures, while controlling for demographic characteristics: age, sex, income, education, employment, race, marital status, and maximum lifetime weight (kg). A p-value of less than 0.05 was set to indicate statistical significance. The SPSS (23.0.0) statistical package was used for all analyses.

Chapter 3

RESULTS

3.1 Characteristics of DHQ-II Completers versus Non-Completers

Completion of the DHQ-II was required to analyze the dietary differences among adults with successful long-term WLM with Controls. Table 3 summarizes the characteristics of the 7,538 eligible participants comparing those that completed the DHQ-II and those who did not. Overall, 1,309 or 17.4% of study participants completed the DHQ-II. Among the WLM, 17.7% completed the DHQ-II while 14.1% of the Controls completed the DHQ-II (p= 0.016). The DHQ-II completers compared with non-completers were older (mean[SD]; 55.0[12.5] vs 52.4[12.9] years; p = 0.0001), more likely to currently be in WW (89.6% vs 83.1%; p = 0.0001), had a lower current body weight (78.2[19.0] vs 80.4[19.7] kg; p = 0.0001), had greater weight loss since WW start (25.7[13.2] vs 23.9[12.1] kg; p = 0.0001), attained greater weight lost from maximum weight (28.2[15.7] vs 26.1[15.5] kg; p = 0.0001), had lower current BMI (28.3[6.6] vs 29.0[6.5] kg/m^2; p = 0.001), were less likely to have BMI in obese category (25.7% vs 31.7%; p = 0.0001), were more likely to be Caucasian (94.0% vs 79.7%; p = 0.0001), were less likely to be Hispanic (3.4% vs 4.7%; p = 0.041), and were less likely to be employed (63.3% vs 69.3%; p = 0.0001). The demographic characteristics that did not significantly differ between the DHQ-II completers and non-completers were lifetime maximum weight, weight at start of WW, duration of 9.1 kg loss from WW start weight, income, gender, education and marital status.

Table 4. Characteristics of DHQ-II Completers vs Non-Completers

	DHQ-II Non-Completer N = 6229	DHQ-II Completed N = 1309	P value
Age, years	52.4(12.9)	55.0(12.5)	0.0001
Female, %	91.0%	90.7%	0.691
Group			0.016
WLM	82.3%	17.7%	
Controls	85.9%	14.1%	
Currently in WW, %	83.1%	89.6%	0.0001
Lifetime maximum weight, kg	106.7(23.6)	106.5(23.4)	0.816
Weight at start of WW, kg	101.2(21.3)	100.9(20.9)	0.610
Current weight, kg	80.4(19.7)	78.2(19.0)	0.0001
Weight loss since WW start, kg	23.9(12.1)	25.7(13.2)	0.0001
Duration of 9.1 kg loss from WW start weight, years	3.2(3.5)	3.4(3.0)	0.064
Weight lost from maximum weight, kg	26.1(15.5)	28.2(15.7)	0.0001
Current BMI, kg/m^2	29.0(6.5)	28.3(6.6)	0.001
BMI Categories			0.0001
Obese, %	31.7%	25.7%	
Overweight, %	40.2%	41.8%	
Normal weight, %	28.0%	32.5%	
Underweight, %	0%	0%	
Income (total in family per year)			0.360
< $25,000	6.5%	5.4%	
$25,001-75,000	32.6%	33.4%	
>75,000	60.9%	61.2%	
Race/ethnicity			
White, %	79.7%	94.0%	0.0001
Black, %	3.5%	3.1%	0.543
Hispanic, %	4.7%	3.4%	0.041
Employed, %	69.3%	63.3%	0.0001
College education or more, %	88.3%	89.9%	0.250
Married, %	71.0%	72.7%	0.223

3.2 Characteristics of WLM versus Controls

Demographic characteristics of the 1,309 participants who completed the DHQ-II are presented in Table 4 with a comparison of the WLM and the Controls. The WLM were statistically significantly more likely to be older (mean [SD]; 55.6[12.3] vs 48.6[13.2] years; p = 0.0001), female (91.4% vs 82.4%; p = 0.003), currently in WW (92.2% vs 5.4%; p = 0.0001), had a lower lifetime maximum weight (105.0[22.1] vs 124.5[29.7] kg; p = 0.0001), had lower current weight (75.2[15.2] vs 113.2[24.3] kg; p = 0.0001), attained greater weight lost from maximum weight (29.7[15.0] vs 11.3[13.2] kg; p = 0.0001), had lower current BMI (27.2[5.1] vs 41.1[8.8] kg/m^2; p = 0.0001), had higher total family income>75,000, (64.0% vs 30.7%; p = 0.0001), were more likely to be Caucasian (94.9% vs 84.3%; p = 0.0001), were less likely to be Black (2.2% vs 13.7%; p = 0.0001), were less likely to be employed (62.5% vs 72.5%; p = 0.043), and were more likely to be married (74.2% vs 55.0%; p = 0.0001). The proportion of WLM taking supplements was higher than the Controls (76.6% vs 68.6%; p = 0.069), but this difference is not statically significant. In addition, the demographic characteristics for WLM and Controls did not significantly differ by ethnic group or education level. Finally, the proportion that reported using surgery to control their weight was very low with only seven individuals in the WLM group (0.58%) and one individual in the Control group (0.98%).

Table 5. Characteristics of WLM vs. Controls

	WLM N = 1207	Controls N = 102	P value
Age, years	55.6(12.3)	48.6(13.2)	0.0001
Female, %	91.4%	82.4%	0.003
Currently in WW, %	92.2%	5.4%	0.0001
Lifetime maximum weight, kg	105.0(22.1)	124.5(29.7)	0.0001
Weight at start of WW, kg	100.9(20.9)	not applicable	0.0001
Current weight, kg	75.2(15.2)	113.2(24.3)	0.0001
Weight loss since WW start, kg	25.7(13.2)		
Duration of 9.1 kg loss from WW start weight, years	3.4(3.0)		
Weight lost from maximum weight, kg	29.7(15.0)	11.3(13.2)	0.0001
Current BMI, kg/m^2	27.2(5.1)	41.1(8.8)	0.0001
BMI Categories			
Obese, %	19.4%	100%	0.0001
Overweight, %	45.4%	0%	
Normal weight, %	35.2%	0%	
Underweight, %	0%	0%	
Income (total in family per year)			0.0001
< $25,000	4.3%	16.8%	
$25,001-75,000	31.6%	52.5%	
>75,000	64.0%	30.7%	
Race/ethnicity			
White, %	94.9%	84.3%	0.0001
Black, %	2.2%	13.7%	0.0001
Hispanic, %	3.4%	3.9%	0.773
Employed, %	62.5%	72.5%	0.043
College education or more, %	90.1%	88.2%	0.794
Married, %	74.2%	55.0%	0.0001
Supplement use[a], %	76.6%	68.6%	0.069

[a] Supplement use was defined as the use at least one micronutrient supplement which included either individual micronutrient supplements or supplements which provide multiple vitamins and minerals.

3.3 Group Differences in HEI-2015 and Macronutrients

The total average energy intake in kcals was not significantly different between WLM and Controls in analyses that adjusted for group differences in demographic factors (B=-51.9 [-165.7 to 61.8], respectively; p=0.37). However, WLM had significantly higher average HEI scores compared with Controls (70.2 [69.7 - 70.7] vs 60.1 [58.4 - 61.8], respectively; p=0.0001) in analyses that adjusted for group differences in demographic factors (Figure 1). The HEI score was 10.1 points [8.3 to 11.9] higher on average for WLM than Controls.

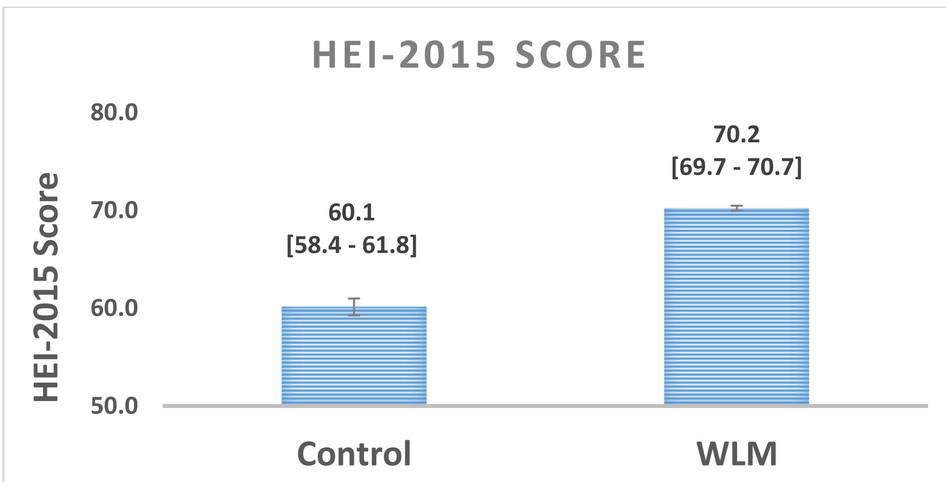
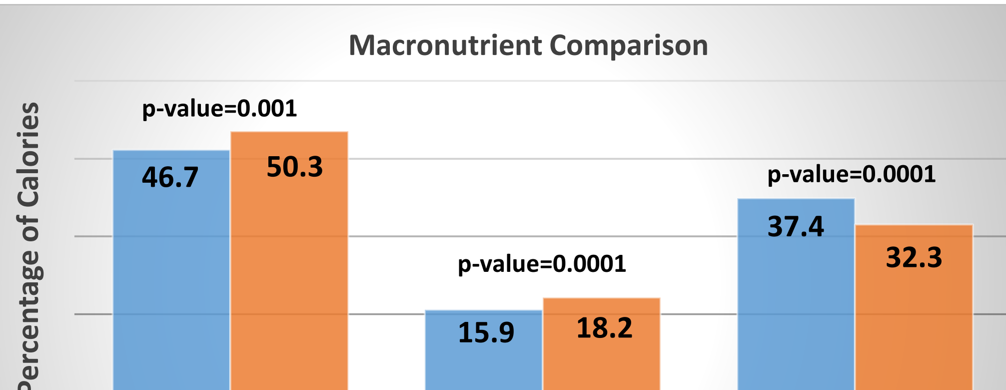


Figure 1: HEI-2015 Score for Controls and WLM

The percentage of calories from the macronutrients in the diet (carbohydrate, protein and fat) also differed significantly between the WLM and the Controls (Figure 2). WLM had a significantly higher average percentage of calories from carbohydrates compared with Controls (50.3% [49.7 - 50.8] vs 46.7% [44.8 - 48.7], respectively; p=0.0001). The percentage of calories from carbohydrate was 3.6 percentage points [1.5 to 5.6] higher on average for WLM compared to Controls. WLM also had higher average percentage of calories from protein compared with Controls (18.2% [18.0-18.5] vs 15.9% [15.1-16.6], respectively; p=0.0001). The percentage of calories from protein was 2.4 percentage points [1.6 to 3.1] higher on average for WLM than Controls. Conversely, WLM had significantly lower average percentage of calories from fat compared to Controls (32.3% [31.9-32.8] vs 37.4% [35.8-38.9], respectively; p=0.0001). The percentage of calories in the diet from fat was 5.0 percentage points [3.4 to 6.7] lower on average for the WLM compared to Controls.



	Carbohydrate %	Protein %	Fat %
Control	46.7	15.9	37.4
WLM	50.3	18.2	32.3

Figure 2: Macronutrient Comparison for Controls and WLM

3.4 Group Differences in Proportion Meeting EAR for Micronutrients

Examining the proportion of WLM and Controls who met the EAR based on age and sex for individual micronutrients while adjusting for group differences in demographic factors, revealed many significant differences between the two groups (Tables 5 and 6). WLM from dietary sources alone were significantly more likely to meet the EAR for copper, magnesium, potassium, vitamin A, thiamin, riboflavin, vitamin B6, vitamin C and folate compared to Controls. WLM had 7.6 times higher odds for meeting the EAR for copper (OR=7.6 [95%CI 3.7-15.3]; p=0.0001), magnesium (OR=1.7 [1.1-2.7]; p=0.017), potassium (OR=6.8 [1.5-30.5]; p=0.012), vitamin A (OR= 2.3 [1.4-3.7]; p=0.001), thiamin (OR= 1.7 [1.1-2.8]; p=0.026), riboflavin (OR=5.3 [2.1-13.5]; p=0.0001), vitamin B6 (OR=2.3 [1.4-3.7]; p=0.001), vitamin C (OR=4.3 [2.6-7.0]; p=0.0001), and folate (OR=1.7 [1.1-2.7]; p=0.020.) There was a trend with greater supplement intake among WLM vs. Controls (Table 4). However, analysis of group differences in micronutrient intake from diet AND supplements revealed similar findings with the exception that the inclusion of supplement intake revealed a significant group difference with a higher proportion of WLM compared to controls meeting the EAR for vitamin E. Similar to analyses of intake from diet alone, in analyses of intake from food and supplements, a significantly higher proportion of WLM compared to Controls met the EAR for copper, magnesium, potassium, vitamin A, thiamin, riboflavin, vitamin B6, vitamin C, folate, and vitamin E. WLM had 5.8 times higher odds for meeting the EAR for copper (OR=5.8 [2.6-13.1]; p=0.0001), magnesium (OR=2.9 [1.8-4.7]; p=0.0001), potassium (OR=4.7 [1.4-16.5]; p=0.015), vitamin A (OR=2.8 [1.7-4.8]; p=0.0001), thiamin

(OR=2.3 [1.3-4.1]; p=0.003), riboflavin (OR=6.5 [2.2-19.3]; p=0.001), vitamin B6 (OR=2.91 [1.6-5.2]; p=0.0001), vitamin C (OR=5.0 [2.8-8.8]; p=0.0001), folate (OR=2.2 [1.3-3.7]; p=0.003), and vitamin E (OR=1.8 [1.1-2.8]; p=0.014).

Table 6. Proportion of WLM and Controls Meeting the EAR (based on Age and Sex) for Minerals

		% Met EAR			
		Control (N=102)	**WLM** (N=1207)	**Chi-square[a]** P-value	**Odds Ratio[b]** 95% CI
Calcium	Diet	42.2%	32.1%	0.037*	0.92 (0.58 - 1.47); p=0.726
	Diet+Suppl	56.9%	54.4%	0.636	1.05 (0.67 - 1.65); p=0.823
Copper	Diet	81.4%	96.2%	0.0001*	7.56 (3.74 - 15.32); p=0.0001*
	Diet+Suppl	87.3%	97.2%	0.0001*	5.84 (2.60 - 13.11); p=0.0001*
Iron	Diet	75.5%	78.1%	0.537	1.47 (0.86 - 2.51); p=0.159
	Diet+Suppl	91.2%	96.3%	0.013*	1.91 (0.79 - 4.62); p=0.151
Magnesium	Diet	49.0%	62.1%	0.010*	1.73 (1.10 - 2.72); p=0.017*
	Diet+Suppl	61.8%	81.4%	0.0001*	2.87 (1.77 - 4.65); p=0.0001*
Phosphorus	Diet	89.2%	93.5%	0.096	1.54 (0.72 - 3.32); p=0.269
	Diet+Suppl	90.2%	95.6%	0.014*	1.97 (0.88 - 4.45); p=0.101
Potassium [c]	Diet	2.0%	9.6%	0.010*	6.83 (1.53 - 30.48); p=0.012*
	Diet+Suppl	2.9%	10.1%	0.018*	4.72 (1.35 - 16.47); p=0.015*
Selenium	Diet	90.2%	91.6%	0.617	1.14 (0.53 - 2.48); p=0.739
	Diet+Suppl	92.2%	95.6%	0.112	1.56 (0.64 - 3.81); p=0.332
Zinc	Diet	70.6%	72.9%	0.613	1.21 (0.74 - 2.00); p=0.447
	Diet+Suppl	81.4%	87.3%	0.088	1.66 (0.92 - 3.01); p=0.095

[a] Proportions were unadjusted.

[b] Odds ratio adjusted for group, age, sex, employment, education, marital status, race, income, and maximum weight in kg.

[c] Potassium only has an AI, not an EAR

Table 7. Proportion of WLM and Controls Meeting the EAR (based on Age and Sex) for Vitamins

		% Met EAR			
		Control	WLM	Chi-square[a]	Odds Ratio[b]
		(N=102)	(N=1207)	P-value	95% CI
Vitamin A	Diet	48.0%	71.4%	0.0001*	2.28 (1.42 - 3.66); p=0.001*
	Diet+Suppl	69.6%	85.9%	0.0001*	2.82 (1.68 - 4.75); p=0.0001*
Thiamin (B1)	Diet	64.7%	73.9%	0.044*	1.72 (1.07 - 2.78); p=0.026*
	Diet+Suppl	77.5%	88.1%	0.002*	2.33 (1.33 - 4.09); p=0.003*
Riboflavin (B2)	Diet	89.2%	98.0%	0.0001*	5.33 (2.11 - 13.5); p=0.0001*
	Diet+Suppl	92.2%	99.0%	0.0001*	6.54 (2.21 - 19.34); p=0.001*
Niacin (B3)	Diet	82.4%	87.4%	0.145	1.64 (0.90 - 2.98); p=0.110
	Diet+Suppl	90.2%	94.7%	0.059	1.85 (0.82 - 4.14); p=0.136
Vitamin B6	Diet	65.7%	76.6%	0.014*	2.29 (1.41 - 3.73); p=0.001*
	Diet+Suppl	79.4%	88.9%	0.004*	2.91 (1.61 - 5.24); p=0.0001*
Vitamin B12	Diet	85.3%	86.6%	0.716	1.12 (0.58 - 2.13); p=0.741
	Diet+Suppl	92.2%	93.5%	0.613	1.23 (0.53 - 2.84); p=0.625
Vitamin C	Diet	56.9%	85.3%	0.0001*	4.29 (2.63 - 7.00); p=0.0001*
	Diet+Suppl	71.6%	92.7%	0.0001*	4.97 (2.80 - 8.80); p=0.0001*
Vitamin D	Diet	4.9%	5.3%	0.862	1.22 (0.44 - 3.44); p=0.704
	Diet+Suppl	42.2%	54.0%	0.021*	1.49 (0.94 - 2.35); p=0.090
Vitamin E	Diet	11.8%	11.1%	0.838	0.87 (0.44 - 1.72); p=0.680
	Diet+Suppl	46.1%	61.2%	0.003*	1.76 (1.12 - 2.77); p=0.014*
Folate	Diet	53.9%	63.6%	0.051	1.72 (1.09 - 2.72); p=0.020*
	Diet+Suppl	70.6%	83.1%	0.002*	2.20 (1.32 - 3.68); p=0.003*

[a] Proportions were unadjusted.

[b] Odds ratio adjusted for group, age, sex, employment, education, marital status, race, income, and maximum weight in kg.

For all micronutrients and among both WLM and Controls, the inclusion of supplement use resulted in increasing the unadjusted proportions of individuals meeting the EAR compared to diet alone. In Tables 6 and 7 this was especially apparent for meeting the EAR for vitamin D (WLM diet only: 5.3% to diet plus supplements: 54.0%

and Controls 4.2% to 42.2%), vitamin E (WLM 11.1% to 61.2% and Controls 11.8% to 46.1%), calcium (WLM 32.1% to 54.4% Controls 42.2% to 56.9%), and iron (WLM 78.1% to 96.3% and Controls 75.5% to 91.2%).

3.5 Demographic Correlates

Independent of group, we examined relationships between demographic factors and HEI scores, macronutrients, and odds of meeting the EARs for micronutrients from diet plus supplements. Among the covariates, age was only the significant demographic factor related to the HEI scores unadjusted B = 0.096 [95%CI, 0.052, 0.139]; p=0.0001). In addition, older adults had higher percentage of calories from carbohydrates unadjusted B = 0.001 [95%CI, 0.000, 0.001]; p=0.0001) and protein unadjusted B = 0.000 [95%CI, 0.000, 0.001]; p=0.001) and lower percentage calories from fat B = -0.001 [95%CI, -0.001, 0.000]; p=0.002). Older adults also had higher odds of meeting the EAR for iron, vitamin C, and vitamin D (ORs ranged from 1.01-1.10) and lower odds of meeting the EAR for calcium (OR= 0.99 [0.98-0.99]). Men had higher odds for meeting the EAR for potassium, thiamin, niacin, vitamin B6, and vitamin B12 (OR ranged from 1.13-68.86) but lower odds of meeting the EAR for magnesium (OR=0.62 [0.38-0.99] and folate (OR=0.99 [0.98-0.99]). Being employed was associated with significantly lower odds of meeting the EAR for selenium, vitamins A, B6, D, and E (OR ranged from 0.44-0.69). Being married was related to significantly higher odds of meeting the EAR for potassium (OR 1.85 [1.05-3.26]). Having lower income was related to significantly lower odds of meeting the EAR for phosphorus, selenium, vitamin A, and niacin (OR ranged from 0.037-0.34). Higher lifetime maximum weight in kg was associated with higher percentage of calories from carbohydrates and protein, and increased odds for meeting EAR for magnesium, potassium, zinc, niacin, vitamin A (OR ranged from 1.01–1.013). Education and race were not found to be significant factors in the odds of meeting the micronutrient EARs.

Chapter 4

Discussion

This study used a validated diet history questionnaire to compare dietary quality, macronutrient content, and micronutrient adequacy of adult long-term WLM in a commercial weight loss program (WW) compared to Controls. The dietary analysis revealed WLM consumed a diet with higher average HEI scores and with a higher percentage of calories from carbohydrates and protein than Controls, and a lower percentage of calories from fat. In addition, a higher proportion of WLM than Controls met the EAR average daily requirement (EAR) from diet and supplement intake for ten out of eighteen micronutrients analyzed; vitamin A, thiamin, riboflavin, vitamin B6, vitamin C, vitamin E, folate, copper, magnesium, and potassium. These results indicate that WLM engaged in healthier eating dietary patterns than Controls which was reflected in improved diet quality and micronutrient density.

4.1 HEI Scores

The WLM had significantly higher average HEI scores compared with Controls (70.2 [69.7 - 70.7] vs 60.1 [58.4 - 61.8], respectively; p=0.0001) representing a 10 point difference in analyses that adjusted for group differences in demographic factors. The HEI-2015 reflects adherence to the U.S. government's recommended *2015-2020 Dietary Guidelines for Americans* and demonstrated both construct validity and reliability as a diet quality measure between groups (Reedy et al., 2018). The HEI includes 9 adequacy factors related to intake of foods such as fruits, vegetables, and whole grains, and 4 moderation components for refined grains, sodium, added sugar, and saturated fat.

Overall, diets with more highly processed foods have lower total HEI scores because they are higher in added sodium, sugar, and saturated fats. Thus, findings suggest that WLM likely consumed a diet with fewer processed foods than Controls, although this wasn't directly examined in the current study.

The WW program encourages healthy eating consistent with the HEI. Also, the higher WLM average HEI scores in this study were consistent with research that ranked popular weight loss diets using an alternative HEI and found that WW ranked second (score of 57.4), behind the Dean Ornish plan (score of 64.6), for having a high HEI score (Ma et al., 2007). Randomized trials have also examined HEI scores before and after a weight loss intervention targeting balanced nutrition and healthy eating, however few have examined whether improvements in the HEI were sustained long-term. Overall, significant increases in HEI scores ranging from 3.5 points to 20.3 points have been found in weight loss interventions lasting from 4 to 6 months (Anderson et al., 2016; Christifano et al., 2016; Ptomey et al., 2016; Webber & Lee, 2011). Only one study continued to measure HEI-2010 scores during 12 months of weight maintenance after a weight loss intervention (baseline= 46.6 ± 8.9; 6 month= 66.6 ± 9.4; 12 month= 58.0 ± 10.1; 18 month= 57.7 ± 10.6; $p<0.001$) and found that after an initial increase in HEI from baseline to 6 months (20.3[11.9] points, $p<0.001$), HEI scores moderated to an increase from baseline to 18 months (11.3 [11.9] points, $p<0.001$) indicating that among WLM, there was a strong net positive increase in HEI scores during maintenance compared to baseline (Ptomey et al., 2016). The WLM in the current study had maintained weight loss for 3.4 years on average, suggesting that improved HEI scores were maintained among WLM. However, prospective research would be needed to examine changes in HEI from initiation of WW program through later, long-term follow-up to determine whether HEI improvement with initial weight loss in WW is fully sustained long-term or if there is a moderating effect during weight maintenance.

4.2 Macronutrient Composition

WLM had a significantly higher average percentage of calories from carbohydrates and protein compared with Controls (carbohydrate: 50.3% vs 46.7% and protein: 18.2% vs 15.9%, respectively; p=0.0001) and a significantly lower average percentage of calories from fat (32.3% vs 37.4%, respectively; p=0.0001). These results are consistent with analysis of commercially available weight loss programs which found WW participants during an 8 week weight loss program significantly reduced their dietary fat intake from 36% of total calories to 29% while increasing fruit and vegetable consumption (Truby et al., 2008). Similarly, analysis of long-term WLM in the NWCR also showed that both women and men had significantly lower percentage of total calories from fat compared to NHANES III adults (women: 24.3% vs 34.9% respectively and men: 23.5% vs 33.9% respectively) and higher percentage total calories from carbohydrate (women: 55.5% vs 49.0% and men: 56.2% vs 46.9%) and protein (women: 19.2% vs 15.8% and men: 18.2% vs 15.6%) (Shick et al., 1998). For the WLM in WW in the current study, the percentage of calories from fat in the diet was considerably higher than what was reported among NWCR WLM adults enrolled between 1993-1997 (32.3% vs 24.3%), but lower than reported by NHANES III 1988-1994 (34.9%). Differences may reflect the years in which these studies were completed, as lower-fat diets were more popular when the NWCR first published. From 1995 to 2003, the percentage of calories from fat increased (23.8% to 29.4%) among NWCR WLM as higher fat diets increased in popularity (Phelan, Wyatt, Hill, & Wing, 2006). In a systematic review of determinants of weight loss maintenance, the only macronutrient that was predictive of successful weight maintenance was a decrease in fat intake, while intake of carbohydrate or protein failed to show conclusive evidence. Research suggests that a variety of diets that promote a reduction energy intake through a decrease in unhealthy foods may successfully promote long-term weight maintenance (Varkevisser, van Stralen, Kroeze, Ket, & Steenhuis, 2018). Overall, the *2015-2020 Dietary Guidelines for Americans* recommend that the percentage of calories from fat in the diet range from 20-35% of total calories, consistent with the range of calories from fat reported among WLM in the current and other studies. Of note, the Control group exceeded this recommended range (37.4% of calories from fat). Research has found that high energy density diets with average percentage of calories from fat of 37.0% for males and 36.4% for women, were associated with lower diet quality and lower average intake of vitamins A, C, B-6, folate, iron, calcium and potassium (Ledikwe et al., 2006). Future research may wish to examine if there is greater probability of weight loss maintenance associated with more narrow ranges of fat intake as a percentage of total calories.

4.3 Group Differences in Micronutrient Intake

In the analysis of micronutrient intake from diet and supplements, WLM met recommendations for the majority of micronutrients and were significantly more likely than Controls to meet the EAR for copper, magnesium, potassium, vitamin A, thiamin, riboflavin, vitamin B6, vitamin C, folate, and vitamin E compared to Controls. Similarly, research comparing NWCR members and adults in NHANES III, successful WLM in the NWCR had significantly higher intakes of calcium, vitamin A, and vitamin C compared to adult women in NHANES III data (Shick et al., 1998). Other research has found that a significantly greater proportion of adults with normal weight compared obesity met the EAR for vitamin A, C, D, E, calcium and magnesium (Agarwal et al., 2015). In the present study, WLM compared to Controls were significantly more likely to meet the EAR for the five out of six of the same micronutrients: vitamin A, C, E, and magnesium, but not vitamin D. The group differences in micronutrient adequacy likely reflect diet quality differences. As noted earlier, WLM had higher HEI scores relative to Control. Current research indicates diets high in ultra-processed foods are associated with reduced dietary intake calcium, magnesium, phosphorus, potassium, zinc, vitamin A, C, D, and E, (Martínez Steele et al., 2017). The WLM compared to Controls were more likely to meet the EAR for thiamin, riboflavin, folate, and potassium, which are found in less processed foods such as whole grains, legumes, fruits and vegetables. This study examined successful WLM who had significantly lower current body weight than the control group, however, 45.4% of WLM had BMIs classified as overweight and 19.4% in classified as obese. The WLM group had significantly higher odds for meeting the EAR for vitamins and minerals despite nearly two thirds having BMIs classified as overweight or obese. Thus, improved micronutrient intake was observed despite the likely retention of significant fat mass. Future research may seek to quantify the extent to which WLM have improved health outcomes due to improved diet quality, lower weight, or a synergistic effect.

Considering micronutrients that do not tend to be deficient in the diets of US adults, Agarwal et al., (2015) found that at least 80% of adults in the NHANES met the EAR for thiamin, riboflavin, niacin, B6, B12, copper, iron, selenium, phosphorus and zinc. This is consistent with the present study for the WLM, however among Controls, only 78% of participants met the EAR for thiamin. This difference is likely due to diet quality as the main sources of thiamin in the diet are typically from whole grains, meat, and fish while low in refined grains.

Micronutrients that were not met by at least 85% of WLM were calcium (54% met EAR), potassium (10.1% met AI), magnesium (81.4%), vitamins D (54%) and E (61.2%). This was not surprising since these micronutrients are frequently found to be deficient in the US diet. Despite not meeting the EAR for these micronutrients, WLM achieved a higher proportion meeting the EAR compared to US adults (NHANES 2001-2008) where 40-60% did not meet EAR for vitamin C, calcium, and magnesium, and 90% didn't meet the EAR for vitamin D and E (Agarwal et al., 2015). For potassium, only 3% of NHANES adults had intake above the AI, which was consistent with the Controls (2.9% met or exceed AI), while 10.1% of WLM met or exceed the AI for potassium.

4.4 Demographic Correlates of Micronutrient Sufficiency

Independent of group we examined odds of meeting the EARs for micronutrients from diet plus supplements. Among the covariates, older adults had higher odds of meeting the EAR for iron, vitamin C, and vitamin D with lower odds of meeting the EAR for calcium. A higher likelihood of meeting the EAR for iron is likely due to a lower EAR threshold for women over the age of 50 compared to younger women who have a high prevalence of iron deficiency anemia (Vaccaro & Huffman, 2013). Conversely, the EAR for calcium is higher for women over 50 which likely reduced the odds of meeting the EAR with older age. In a recent study of NHANES 2011-2014, intake of folate, zinc, vitamin A, D and B12 were found to increase with age, however this is not consistent with the findings in this present study (Cowan et al., 2019). Men had higher odds for meeting the EAR for potassium, thiamin, niacin, vitamin B6, and vitamin B12 but lower odds of meeting the EAR for magnesium and folate.   These results are consistent with an analysis of gender differences in micronutrient intakes, where women were found to be less likely to be deficient in zinc compared to men, but more likely to be deficient in folate, vitamin B12, vitamin C, D, E, calcium, selenium, copper and iron (Vaccaro & Huffman, 2013). The higher observed odds for meeting the EAR these nutrients by men is likely the result of a higher consumption of total of calories per day due to higher daily caloric requirements compared to women. Being employed was associated with significantly lower odds of meeting the EAR for selenium, vitamins A, B6, D, and E. Employment in our sample may be associated with less time to shop and prepare meals and higher consumption of ultra-processed foods with lower nutrient quality.   Having lower income was related to significantly lower odds of meeting the EAR for phosphorus, selenium, vitamin A, and niacin.   This is consistent with research using NHANES data from 2001-2004 which found higher income adults are much more likely to meet national dietary guidelines for healthy eating compared to lower income adults

(Kirkpatrick, Dodd, Reedy, & Krebs-Smith, 2012). This is likely because ultra-processed foods tend to be more inexpensive than minimally processed foods in high income countries (Monteiro et al., 2018). Higher lifetime maximum weight in kg was associated with increased odds for meeting EAR for magnesium, potassium, zinc, niacin, and vitamin A. These increased odds are likely due to men having a higher probability for having a higher lifetime maximum weight and having a higher overall total daily calorie consumption.

4.5 Supplement Intake

It has been hypothesized that the increased prevalence of micronutrient deficiencies in adults with obesity may further exacerbate the risk for developing chronic diseases (Astrup & Bügel, 2018). In the present study we analyzed micronutrient intake from both food and supplement intake. NHANES 2011-2012 data estimates that more than one half of US adults (52%) report taking at least one dietary supplement in the past 30 days and 45% taking more than one product (Gahche et al., 2018). In the present study the WLM had greater supplement intake (76.6%), but the difference with Controls (68.6%) was not statistically significant. A higher proportion of WLM and Controls reported taking at least one supplement compared to NHANES, however the DHQ-II asks about intake over the year rather than the past month. We did not examine if any participants reported taking supplements greater than the UL.

Depending on gender and life stage, combined with typical eating patterns in the Western diet, the majority of adults are not likely to meet all of the recommended micronutrient requirements from diet alone. A considerable number of studies have looked at the efficacy of multivitamin and mineral supplements for the prevention of chronic disease. A significant association was found for women who used multivitamin and minerals for at least three years and reduced risk of death from CVD however, in the fully adjusted models no significant association was found between the use of multivitamins and CVD mortality (Bailey et al., 2015). Recommending multivitamin and mineral supplements remains controversial given the inconsistency of the results and even possible harm (Blumberg et al., 2018). The *Dietary Guidelines for Americans 2015-2020* recommend getting the majority of micronutrients from food sources. (https://health.gov/dietaryguidelines/2015/guidelines/) Overall, the proportion of WLM and Controls who met the EAR increased as a result of including supplements, but recommending specific supplements is beyond the scope of this research and should be considered on an individual basis based on age, gender and average intake from diet. Future research should examine the implications of inadequate dietary micronutrient intake among adults with obesity who are already at greater risk for cardiovascular, cancer, and metabolic disease and consider what policy implications should be addressed to improve adequacy in the US population.

While adults with obesity tend to have higher caloric intake, there is also an association between obesity and a higher prevalence of low serum micronutrient levels (Kimmons et al., 2006). Causality has not been determined and it is unclear if this relationship is due to insufficient intake or if there are metabolic affects related to excess adiposity and inflammation that result in reduced serum levels of vitamins and minerals (García et al., 2009). Vitamin and mineral deficiency can lead to significant disease risk. Vitamin D and calcium are vital in bone health and deficiency is associated with osteomalacia and hyperparathyroidism (Kaidar-Person et al., 2008a). Fat soluble vitamins A and E are antioxidants that play a protective role in reducing oxidative damage. Deficiency in antioxidants such as vitamins A, C, and E have been associated with increased oxidation of LDL which increases the risk of atherosclerosis, and also impairment in glucose metabolism and insulin resistance (Kimmons et al., 2006). Vitamin B1 (thiamin) is required for oxidative ATP synthesis therefore deficiency is associated with negative metabolic effects especially on major organs which have high metabolic needs therefore severe thiamin deficiency can impact both the cardiovascular system and nervous system (Kerns & Gutierrez, 2017). Dietary intake of adequate B-vitamins are important in cognitive function and associated with decreased risk for dementia and depression (McNulty, Ward, Hoey, Hughes, & Pentieva, 2019). Folate is important in methylation of proteins and DNA synthesis and inadequate levels have been associated with increased risk of CVD and incidence of breast and colon cancer (Kaidar-Person et al., 2008a). Dietary deficiency of magnesium is associated with increased risk of CVD, incidence of diabetes, and lower bone density (Kimmons et al., 2006). Iron is essential for electron transfer reactions and the binding and delivery of oxygen to tissues. The most common mineral deficiency is iron deficiency and is associated with anemia and impaired thermoregulation, immune function, and mental function (Beard, 2001). Higher potassium intake has been found to be associated with lower CVD incidence and ischemic heart disease mortality (Yang et al., 2011). Selenium is an important mineral in antioxidant reactions and reducing the generation of oxidative stress and inflammation (Goldhaber, 2003). Selenium deficiency has been associated with CVD and cancer (Kaidar-Person et al., 2008b). Zinc is involved in over 300 enzymes as a constituent or regulatory component and important in the insulin signaling pathway, lipolysis regulation and among individuals with T2D who had zinc deficiency, providing zinc supplementation improved glucose outcomes through a reduction in fasting blood glucose or improved HbA1c levels (Ruz et al., 2019). Overall, adequate intake of vitamins and minerals are essential for health and reduction in the risk for disease, but research is still ongoing for the metabolic implications of micronutrient deficiency among individuals with obesity. The cross-sectional design of this study makes it impossible to conclude whether the higher probability of meeting the EAR for micronutrients is a consequence of WLM, or if meeting the EAR for micronutrients has metabolic effects that benefit and prolong WLM. Currently, there is little known about the micronutrient intake of successful WLM and future research should examine the possible long-term benefits of improved micronutrient intake.

Strengths of this cross-sectional study include in depth evaluation of dietary quality and micronutrient adequacy using the DHQ-II which is a validated FFQ. Dietary analysis was conducted for over 1,200 long-term WLM and the comparison group of more than 100 Controls. One limitation is that dietary and micronutrient intake was based solely on self-report in the DHQ-II. FFQs require both memory and cognitive reasoning to estimate frequency of intake and underreporting has been found for total calories and protein for both men and women and overall greater underreporting among individuals with higher BMI (Kipnis et al., 2003; Subar et al., 2003). In future research, measuring blood levels of micronutrients would provide clinical evidence of micronutrient sufficiency in the diet, rather than relying on self-report in the DHQ-II. In addition, iodine and molybdenum intake are not captured on the DHQ-II, so they were not considered in the analysis for meeting the EAR for these micronutrients. The DHQ-II is comprehensive in capturing the dietary intake over a year and typically takes an hour to complete.

Among the WLM, only 17.7% completed the DHQ-II, while 14.1% of the Controls completed the questionnaire which may imply the two groups are less comparable. In addition, there were significant demographic differences among the adults who chose to complete the DHQ-II including age, currently in WW, current weight, weight loss since WW start, weight loss from maximum weight, current BMI, race, and employment. There were also significant differences in the demographic characteristics of the WLM and the Controls with the WLMs tending to be older, higher percent female, more likely to be currently in WW, lower maximum lifetime weight, lower current weight, and having lost more weight from their maximum weight. These findings may not generalize to other populations. Also, given the large number of statistical analyses being completed on a single data set, there is a greater risk having a Type 1 error and stating that there is a relationship between two variables when that is not the case. Finally, a long-term intervention study is needed to follow up on these results to examine a causal relationship between higher diet quality and improved weight loss maintenance.

The WW program through its *PointsPlus®* system, emphasizes higher quality more nutritious foods, however we did not measure the dietary intake of the WLM while they were losing weight. Future research may wish to examine the extent to which usual dietary intake varies during the weight loss phase compared to weight loss maintenance. It is uncertain if the current diet of WLM captured by the DHQ-II questionnaire is the same dietary pattern that participants used to lose weight on the WW program.

In conclusion, WW participants who were successful long-term WLM consumed a healthier and more micronutrient rich diet than adults who are weight stable and obese. Obesity and micronutrient deficiency are both significant and interrelated risk factors for the development of disease. The WLM would therefore be expected to benefit not only from weight loss, but also from higher diet quality and improved micronutrient adequacy to substantially reduce the risk of chronic disease. Future research should consider examining the relationship between higher diet quality and improved micronutrient intake among WLM and additional reductions in the risk of morbidity and mortality from chronic diseases.

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