

DIETARY CARBOHYDRATE, PHYSICAL ACTIVITY, ADIPOSITY AND RISK FOR
METABOLIC SYNDROME IN COLLEGE-AGED FEMALES

by

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(Under the Direction of Ellen M. Evans)

ABSTRACT

This study explored the associations between carbohydrate, fiber, and whole grain intakes, and metabolic syndrome (MetS) associated outcomes controlling for physical activity (PA) and adiposity (%Fat). Females (n = 336; 18.7 ±1.2 years) were assessed for dietary intake using 3 day dietary records. PA was assessed using accelerometry. %Fat was determined via dual-energy x-ray absorptiometry. Biomarkers were determined from fasting blood samples. Women were normal BMI (24.4 kg/m² ± 4.7) with %FAT of 35.2 ± 7.0% averaging 10,228 ± 3740 steps/day. Few women met the 2010 Dietary Guideline recommendations for whole grain (6.6%) and fiber intake (16.9%) and 4.2% were defined as having MetS with low presence of individual risk factors (all < 26%). Although carbohydrate outcomes were associated with C-reactive protein, insulin, and the homeostatic model (r range = 0.13- 0.25, all p<0.05), no independent relations existed after controlling for oral contraceptive use, race, PA and %Fat (all p>0.05).

INDEX WORDS: Metabolic syndrome, College females, Carbohydrate, Whole grain, Fiber, Physical activity, Triglycerides, C-reactive protein, Glucose, Insulin

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CHAPTER 1

INTRODUCTION

1.1 Significance

Metabolic syndrome (MetS), defined by a collection of inter-related clinical criteria, has become one of the major public-health challenges facing the world today [1, 2]. Individuals with MetS are at increased risk for both type 2 diabetes mellitus (T2DM) and cardiovascular disease (CVD), with CVD being the leading cause of death for adults in the United States and one of the top five causes of death in young adults ages 15-24 [3-5]. Moreover, it is estimated that approximately 12.6 million women aged 20 years or older have diabetes in the U.S., diagnosed or undiagnosed [5]. Among young women in particular, recent estimates indicate that the prevalence of MetS is 17%, with 54% of college-age (18-21 years) women exhibiting at least one risk factor [3, 6]. Given these high rates of MetS risk factors, the current young adult population is at greater risk of T2DM and CVD than previous generations. Importantly, although the transition from adolescence to young adulthood is linked with increased obesity risk [4], MetS can also occur despite a healthy weight status [3]. Therefore, early identification of MetS risk is critical to embracing lifestyles targeted at preventing T2DM and CVD [7].

Numerous indicators aid in helping to identify young individuals at increased risk for MetS including abdominal obesity, elevated serum triglyceride (TAG) levels, reduced high density lipoprotein (HDL), elevated blood pressure, and elevated fasting glucose (GLU). Other indices such as the Homeostatic Model Assessment for insulin (INS) resistance (HOMA; $GLU * INS / 405 \text{ mg/dL}$) [8], and markers of inflammation such as CRP have also been associated

with the development of MetS [9]. Approximately 31% of the adult U.S. population exhibit elevated serum TAG, with younger age groups (20-49) exhibiting marked increases over the past 20 years [10]. Although obesity is multi-factorial, the increase in obesity prevalence since the 1980s has been linked with an increase in dietary carbohydrate (CARB) intake [11-13]. Relatedly, dietary fiber and whole grain intake are two aspects of CARB quality that have recently received considerable attention as they relate to MetS risk [12]. An inverse relationship between whole grain intake and BMI has been reported among combined gender cohorts [11, 13, 14]. In addition, dietary fiber may help reduce the risk of obesity, T2DM, and CVD [11, 15-17]. Lifestyle factors including PA and exercise (EX) are also likely important determinants of MetS risk in young adults [7, 18, 19]. Although MetS is an active area of research interest, the relationships among dietary CARB quantity and quality, PA, adiposity, and risk for MetS have not been comprehensively examined in young women. Morrell et al. examined MetS prevalence among college men and women and found that 9.9% and 3.0%, respectively, had MetS. Saturated fat, fiber, magnesium, and PA were significantly related to MetS; however, PA was measured subjectively and fat mass was not measured [6].

1.2 Specific Aims

Specific Aim 1: To determine if dietary CARB quantity and quality is related to serum TAG and fasting GLU levels, independent of PA and adiposity. It is anticipated that independent of PA and adiposity, young women with a) a higher intake of CARB, as expressed by percentage of daily energy intake, will have higher levels of serum TAGs and fasting GLU, and b) a higher intake of dietary fiber and whole grain will have lower levels of TAG and GLU.

Specific Aim 2: To determine if dietary CARB quantity and quality is related to insulin (INS) and CRP, independent of PA and adiposity. Similar to above, it is anticipated that

independent of PA and adiposity, young women with a) a higher intake of CARB will have higher levels of INS and CRP, and b) a higher intake of dietary fiber and whole grain will have lower levels of INS and CRP

1.3 Public Health and Scientific Significance

Estimates suggest that approximately 17% of young women in the United States have MetS [9]. It is well established that habitual PA and EX training can reduce risk factors for MetS including TAG, GLU, INS, and CRP factors. Moreover, a large body of literature suggests that diets high in fiber and whole grain may be inversely associated with MetS risk factors. Alternatively, diets higher in low nutrient density CARB have been shown to be positively associated with risk for MetS. From a public health perspective, it is beneficial to identify the potential relationships among dietary patterns, PA, adiposity, and MetS risk factors among females ages 18-24. This information could influence future recommendations and guidelines aimed at preventing chronic metabolic disease later in life.

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CHAPTER 2

LITERATURE REVIEW

2.1 Metabolic Syndrome: Definition and Prevalence

Metabolic syndrome (MetS) has become a major public-health challenge facing the world today. MetS is a condition characterized by a clustering of cardio-metabolic risk factors that include abdominal obesity, elevated triglyceride (TAG) levels, low high-density lipoprotein (HDL) levels, elevated blood pressure, and elevated fasting blood glucose (GLU). Although not conventional risk factors, serum insulin (INS), related to INS resistance, and C-reactive protein (CRP), related to chronic systemic inflammation, are also contemporary biomarkers of interest associated with MetS [1]. The root causes of MetS are overweight/obesity, physical inactivity, and genetic factors [2]. The significance of MetS lies in its ability to help identify individuals at high risk of chronic diseases including type 2 diabetes mellitus (T2DM) and cardiovascular disease (CVD), with the latter disease being an increasingly common health concern and the leading cause of death for adults in the United States [3].

Although debated among scientists and clinicians, the National Cholesterol Education Program's Adult Treatment Panel III [2] criteria for diagnosis of MetS is well established and endorsed by many organizations including the American Heart Association and the American Diabetes Association [4]. The Adult Treatment Panel III defines MetS as being present if an individual has or is taking medication for ≥ 3 of the following: 1) abdominal obesity (waist circumference >102 cm in men and >88 cm in women), 2) serum TAG ≥ 150 mg/dL, 3) HDL levels ≤ 40 mg/dL in men and ≤ 50 mg/dL in women, 4) blood pressure $\geq 130/85$ mm Hg, and 5)

impaired fasting blood GLU \geq 110 mg/dL [5]. This definition also states that the primary clinical outcome of MetS is CVD [6].

One of the most common risk factors for MetS is elevated waist circumference. Among the total U.S. population, waist circumference increased from 45.4% to 56.1% from 1999 to 2010. In addition, hyperglycemia incidence has risen from 12.9% in 1999 to 19.9% in 2010 [7]. National Health and Nutrition Examination Survey (NHANES) data collected from 1999 and 2010 determined that the prevalence of MetS in asymptomatic adults (18-70 years) without T2DM or CVD was 20.5% [3]. In the female population, it has been estimated that approximately 12.6 million women aged 20 years or older have diagnosed or undiagnosed diabetes in the U.S., which is a disease that often develops after MetS criteria have been met [8]. Recent estimates indicate that the prevalence of MetS among women in the United States is 17%, with 54% of college-age (18-21 years) women exhibiting at least one MetS risk factor [3, 9]. In adolescent through young-adult cohorts (18-24), MetS is an increasingly frequent risk factor for CVD [3, 10]. Given these alarming statistics and increasing rates of MetS risk, the current young adult female population is at greater risk of T2DM and CVD than previous generations. Primordial prevention is of utmost importance to prevent development of MetS and chronic diseases, especially CVD, in the future [11].

2.2 Physical Activity/Exercise and Risk for Metabolic Syndrome

Lifestyle factors are important determinants of MetS [5]. It has been well established that habitual physical activity (PA) and exercise (EX) training reduces risks for MetS, T2DM and CVD and is of primary importance for weight management. The Physical Activity Guidelines for Americans recommend that adults (ages 18-64) obtain at least 150 minutes a week of moderate-intensity, or 75 minutes a week of vigorous-intensity aerobic physical activity in order to obtain

substantial health benefits and reduce chronic disease risk [12]. It is also well established that EX training improves TAG [7]. Reviews indicate that EX, in the absence of weight loss, has been shown to significantly improve TAG levels between 2-5% in adult women ≥ 18 years of age [13], as well as reduce TAG levels in overweight/obese children and adolescents [14].

Higher levels of PA are also correlated with INS sensitivity in adolescents [15]. Similarly, EX training has been shown to improve fasting INS and INS resistance, particularly in overweight and obese children and adolescents, even in the absence of significant weight loss or change in body composition [16].

A contemporary factor for CVD risk is chronic systemic inflammation. In a pattern that resembles TAG and INS levels, CRP levels are higher among sedentary adults when compared to their more physically active peers [17]. There is evidence for an association between higher PA and lower levels of inflammatory cytokines [18]. An extensive literature exists utilizing both cross-sectional and longitudinal exercise training studies documenting an “anti-inflammatory” effect of exercise. For example, in a sample of over 13,000 individuals >20 years of age in NHANESIII, the odds ratio for elevated CRP were 0.98 (95% CI 0.78-1.23), 0.85 (0.70-1.02), and 0.53 (0.40-0.71) for participants who engaged in light, moderate, and vigorous PA, respectively, compared with those who did not engage in any leisure-time PA [19]. Moreover, recent research shows aerobic EX training in healthy adults can result in decreased CRP levels [16, 20]. Despite the existing evidence regarding the beneficial effects of PA/EX on inflammation, there is limited data examining this link among young women.

Although the importance of EX and PA is well established for the prevention of MetS and the related biomarkers INS and TAG, the prevalence of physical inactivity is high for the college female cohort. As a reminder, current physical activity recommendations for adults (18-

64 years) call for an accumulation of 150 minutes of moderate-intensity aerobic activity or 75 minutes of vigorous-intensity aerobic activity every week as well as muscle-strengthening activities that work all major muscle groups on 2 or more days of the week [21]. Data suggests that approximately 55% of young adult women (age 18-30) in the U.S. do not meet the PA recommendations and fail to obtain enough PA/EX to result in beneficial effects for the prevention of MetS and CVD [22]. National data consistently reports that males engage in leisure time PA at higher rates than females. For example, in a cohort of 871 undergraduate students who completed the Godin Leisure-Time Exercise Questionnaire, males engaged in more minutes per session of vigorous and moderate intensity PA than females [23]. It is critical to obtain more data regarding PA/EX habits among young adult women. Lifelong habits are formed during this stage of life and early identification and possible prevention of metabolic risk factors are crucial to reduce the prevalence of MetS, T2DM, and CVD later in life.

2.3 Dietary Carbohydrate Intake and Risk for Metabolic Syndrome

Dietary CARBs are a critical component to the human diet and are essential for a variety of functions involving numerous systems, especially the central nervous system and skeletal muscle. The relationships between dietary CARB intake and MetS risk are not as well characterized as other factors such as PA/EX, and the potential interactive effects of CARB quality and quantity and PA/EX on risk for MetS have not been investigated. Very high CARB diets can exacerbate the dyslipidemia of MetS [4]. Data suggests that among sedentary college-age women TAG, a primary MetS risk factor, increases over time (2 years) [24], and increased dietary CARB consumption is related to TAG [25]. Increasing CARB intake may adversely affect blood lipid and lipoprotein concentrations as well as GLU metabolism, as has been observed among middle-age men and women (mean age 54) [26]. These adverse changes

associated with dietary CARB intake lead to greater risk of MetS and CVD, particularly in women [27]. It is unclear whether the total CARB quantity (e.g. gm/day,) the relative contribution to energy intake (gm/kcal/day) and/or the quality of CARB (e.g. refined grain, whole grain, fiber, etc.) are the key factors involved in the relation between dietary CARB intake and MetS risk

Low CARB diets have been increasing in popularity recently, especially as a treatment for MetS, T2DM and CVD. For example, a systematic review of 17 randomized clinical trials examining dietary habits and cardiovascular risk factors among adults (≥ 18 years of age) reported a low-CARB diet to be associated with significant decreases in body weight, BMI, abdominal circumference, blood pressure, TAG, fasting plasma glucose, plasma insulin, and CRP (26). However, it has yet to be determined if the beneficial effects reported in these studies were due to lower CARB intake or lower overall calorie intake as some of the trials utilized weight loss diets. Recent updated guidelines including the Dietary Guidelines for Americans 2010 suggest no additional benefits to alterations in macronutrient content of the diet beyond what is conferred by increased adherence to the dietary regimen in a weight loss diet. Studies have shown that when the macronutrient distribution of diets are varied with the energy density kept constant, the effects of fat, CARB, and protein on satiety as well as weight loss are similar [28]. Notably, there is conflicting evidence on the intake of total dietary CARB and GLU and INS sensitivity. Slight but significant decreases in fasting plasma GLU (-1.05 mg/dL 95% CI -1.67/-0.44) have been reported among adults (18 and older) following a low-CARB diet [26].

2.4 Whole Grain Intake and Risk for Metabolic Syndrome

Dietary CARB sources that are considered whole grain contain all of the essential parts and naturally-occurring nutrients of the entire grain, and are a source of nutrients including

magnesium, iron, B vitamins and dietary fiber. Aside from rice, whole grains are low in fat, and have approximately 10-15% protein per gram. Whole grains can be consumed as either whole foods (e.g. oats, barley, brown rice) or ingredients of foods (e.g. wheat flour, corn, etc.) and they are rich in bioactive compounds that possess anti-inflammatory properties and can slow the rate of GLU appearance in the blood [29]. Current recommendations from the Dietary Guidelines for Americans 2010 advise that at least half of total grain intake should be whole grain [30]. Less than 5% of Americans meet the recommendations for whole grain intake [30]. Women ages 18-30 are recommended to consume approximately 1800-2400 calories/day based on their activity level, with 3-4 ounce equivalents of whole grain [25].

Numerous investigational studies have examined the relationship among whole grain consumption and various health outcomes of interest. Increased consumption of whole grain foods decreases the development of coronary heart disease and T2DM and improves INS sensitivity and chronic systemic inflammation as assessed by CRP in adults [31, 32]. Among combined gender cohorts, inverse relationships have been determined between whole grain intake and BMI [33-35]. In the Physician's Health Study whole grain breakfast cereal intake was associated with lower BMI [36]. In addition, studies show beneficial effects of a high consumption of dietary fiber or whole grain foods on INS sensitivity [37]. Fasting INS concentrations are lower among individuals reporting higher dietary fiber [38] or whole grain intake [39] after adjustment for other lifestyle factors. Among adolescent boys and girls, as well as adults, greater INS sensitivity was observed across increasing tertiles of whole grain consumption [32]. The positive effects of whole grain intake on risk for MetS [35], T2DM [26], CVD, and all-cause mortality is evident across the majority of the lifespan, notably in middle-age and older women [40]. Mckeown et al. [26] found that fasting INS concentrations, BMI, waist-

to-hip ratio, and total cholesterol were inversely associated with whole grain intake. Whole grain intake is also inversely associated with the homeostatic model assessment for insulin resistance (HOMA) and a lower prevalence of MetS among older men and women (26-82 years) [39], as well as reduced risk of T2DM [34]. However, for the ample data supporting the positive influence of whole grain on risk for MetS and T2DM, there is less evidence to specifically support this relationship among the young adult female population [41] and limited literature on the dietary patterns in college-aged women in general. Butler et al., [42] reported an overall decrease in energy consumption among young females transitioning from high school to college; however, these results did not specifically examine whole grain intake nor did they relate CARB intake to risk for chronic disease.

Regarding mechanisms of action, components in whole grain that may potentially be protective against chronic metabolic disease include compounds that affect the gut environment, including dietary fiber, resistant starch, and oligosaccharides. Oligosaccharides are CARBs with a low (2-20) degree of polymerization. Studies have shown that oligosaccharides are able to alter human fecal flora and have similar effects as dietary fiber on the gut, improving microflora [43]. Whole grain foods also contain large amounts of antioxidants including phenolic acid, lignans, and phytoestrogens as well as vitamin E and selenium. Some of these compounds may potentially suppress oxidant damage to the intestinal epithelium and reduce inflammation. Additionally, foods high in whole grain may modulate the glycemic response leading to improved glucose tolerance and reduced insulin resistance [43].

2.5 Dietary Fiber and Risk for Metabolic Syndrome

Dietary fiber consists of non-digestible CARBs and lignin that are intrinsic and intact in plants [30]. Fibers have many roles such as increasing laxation, delaying gastric emptying, and

reducing blood cholesterol concentrations. It is important to consume adequate amounts of fiber in order to promote healthy lipid profile and glucose tolerance, as well as healthy digestion. The Adequate Intake (AI) for total fiber is 38 g and 25 g per day for young men and women, respectively, and was set based on the amount of fiber observed to protect against coronary artery disease (28). AI is the recommended average daily intake level based on experimentally determined approximations and is used when a recommended dietary allowance cannot be made. The average fiber intake among American adults is 16 grams/day [44]. Dietary fiber is known to have a variety of health benefits including reduced risk for obesity, T2DM, and CVD with strong influences on TAG and INS [38, 45, 46]. The inverse association between CARB intake and BMI may be partially due to fiber consumption. In the Framingham offspring study, a significant inverse association between fiber intake and the MetS was shown [39], perhaps operating through its role in weight management.

Evidence exists supporting the role of dietary fiber and weight management [47, 48]. An example regarding young adults is a study of 2,900 black and white participants 18 to 30 years of age that determined there was a linear relationship from lowest to highest quintile of dietary fiber intake with body weight. Dietary fiber had an independent association to body weight even after adjustment for dietary CARB, protein, and fat intake. Additionally, when examining 10-year weight gain, participants who consumed the most fiber gained less weight compared with individuals who consumed the least amount of fiber, regardless of fat intake [38].

Many mechanisms have been suggested for how dietary fiber aids in weight management. Both satiety (the feeling of fullness that persists after eating), and satiation (the satisfaction of appetite that occurs during the eating occasion and causes one to stop eating), affect energy intake, and both may be influenced by fiber intake [49]. A fiber-rich meal is

typically processed more slowly and nutrient absorption occurs over a longer period of time [50]. A diet that provides adequate fiber typically is larger in volume than a low-fiber diet. This larger mass of food takes longer to ingest and its presence in the stomach may bring a feeling of satiety sooner. Additionally, fiber affects gastrointestinal physiology and functions including the delaying gastric emptying. This may cause an extended feeling of fullness and may delay absorption of glucose and other nutrients [49]. Dietary fiber may also influence fat oxidation and fat storage [49].

2.6 Dietary Carbohydrate, Whole Grain, Fiber, and Systemic Inflammation

CRP is a well-known marker of systemic inflammation and has been extensively studied with regard to many varied diseases [52]. CRP is produced in the liver and regulated by inflammatory cytokines, mainly IL-6 and TNF-alpha [31]. Obesity in adults is strongly associated with CRP and indicates a chronic state of low-grade inflammation [53]. Epidemiological and cross-sectional studies have demonstrated a correlation between inflammatory markers and factors of MetS such as hyperinsulinemia, hypertriglyceridemia, low HDL cholesterol, and hypertension [31]. In healthy adolescents (ages 10-16), CRP is significantly associated with INS resistance [54]. Cross-sectional studies have shown inflammatory markers are also associated with lifestyle factors including diet, adiposity, and PA [55] and have suggested that lifestyle modification may reduce the risk of inflammation and CVD [56].

Dietary factors, specifically CARB, whole grain, and fiber, have also been linked to chronic systemic inflammation. The pro-inflammatory process may be mediated by consumption of dietary fiber. The link between dietary fiber and CRP has been observed in several studies, including an analysis using cross-sectional data among men and women ≥ 20 years old from the

NHANES 1999-2000 [57], a longitudinal cohort of 524 healthy adults ages 50-79 [58] and a clinical trial involving normal and obese individuals 18 to 49 years [59]. Of note, many of these studies have used food-frequency questionnaires to assess dietary intake [36, 57, 58], which has been shown to be less accurate than both 24-hour recalls and food records [60]. Lower CRP concentrations have also been associated with higher whole grain consumption [33, 61] and low-CARB diets [62]. Despite being one of the earliest predictors of disease to appear, CRP and other markers of inflammation are rarely studied in younger cohorts, although research interest is increasing. It is important to identify variables that explain the development of MetS risk factors in college-age (18-24 yo) populations, as this is a critical time for establishing lifestyle behaviors. While studies have investigated MetS prevalence in this age group, it is rare that objectively measured PA and body composition measures are taken into account.

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CHAPTER 3

DIETARY CARBOHYDRATE, PHYSICAL ACTIVITY, ADIPOSITY, AND RISK FOR METABOLIC SYNDROME IN COLLEGE-AGED FEMALES¹

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Abstract

This study explored the associations between carbohydrate intake, fiber, whole grain, and metabolic syndrome (MetS) associated outcomes controlling for physical activity (PA) and adiposity (%Fat) in young women. Females (n = 336; 18.7 ± 1.2 years) were assessed for dietary intake using 3 day dietary records. PA was assessed using accelerometry. %Fat was determined via dual-energy x-ray absorptiometry. Biomarkers were determined from fasting blood samples. Women were normal BMI (24.4 kg/m² ± 4.7) with %FAT of 35.2 ± 7.0% averaging 10,228 ± 3740 steps/day. Few women met the 2010 Dietary Guideline recommendations for whole grain (6.6%) and fiber intake (16.9%) and only 4.2% were defined as having MetS with low presence of individual risk factors (all < 26%). Although carbohydrate outcomes were associated with CRP, INS and HOMA (r range = 0.12- 0.25, all p<0.05), no independent relations existed after controlling for oral contraceptive use, race, PA and %Fat (all p>0.05).

3.1 Introduction

Metabolic syndrome (MetS) is a condition characterized by a clustering of interrelated cardiovascular and metabolic risk factors that has become a major public health challenge [1, 2]. Importantly, MetS is often a precursor to chronic diseases including both type 2 diabetes mellitus (T2DM) and cardiovascular disease (CVD) [2]. Additionally, the occurrence of MetS is strongly associated with increased morbidity and all-cause mortality [1]. The most frequently used and widely accepted definition of MetS was developed by the National Cholesterol Education Programs Adult Treatment Panel III [3]. This organization defines MetS as being present if an individual possesses or is taking medication for ≥ 3 of the following: 1) abdominal obesity (waist circumference >102 cm in men and >88 cm in women), 2) elevated serum triglycerides (TAG) ≥ 150 mg/dL, 3) high-density lipoprotein (HDL) levels ≤ 40 mg/dL in men and ≤ 50 mg/dL in women, 4) elevated blood pressure (BP) $\geq 130/85$ mm Hg, and 5) impaired fasting blood glucose (GLU) ≥ 110 mg/dL [4]. Although not conventional risk factors, insulin resistance and chronic system inflammation, measured via serum insulin (INS) and C-reactive protein (CRP), respectively, are also considered contemporary biomarkers associated with MetS, T2DM, and CVD [5].

National Health and Nutrition Examination Survey (NHANES) data collected from 2009 and 2010 determined that the prevalence of MetS among asymptomatic adults ≥ 20 years old was 22.9% [6]. Recent estimates indicate that the U.S. prevalence of MetS among young women (18-29 years) is 17%, with 54% of college-age women (18-24 years) exhibiting at least one MetS risk factor [7, 8]. Although the prevalence of MetS increases with both age and Body Mass Index (BMI), the individual risk factors can appear at any stage of life, independent of weight status. In young adult cohorts (18-24 years), MetS is an increasingly frequent risk factor for the

development of CVD later in life [8, 9]. Approximately 31% of the adult U.S. population exhibits elevated serum TAG, with younger age groups (20-49 years) exhibiting marked increases over the past 20 years [10]. First year college students also experience weight gain faster than an average adult with both lack of physical activity (PA) and poor diet quality contributing to an increase in MetS risk factors [11].

The development of MetS is often thought to be a consequence of overweight/obesity; however, other factors are associated with MetS including PA and exercise (EX), independent of weight status [12]. It is well established that greater amounts of PA decrease risk for MetS, T2DM, and CVD and are linked with decreased development of MetS risk factors [6]. Reviews indicate that various types of PA, including aerobic EX, have been shown to significantly improve TAG levels by 12% in adolescents (5-19 years) [13], as well as improve both fasting INS and INS resistance [14]. Additionally, CRP levels are higher among sedentary adults compared to their more physically active peers [15], and increases in aerobic EX have been associated with reduced CRP levels [16].

There is increasing evidence that reducing sedentary behaviors such as prolonged sitting and increasing leisure-time PA are beneficial for weight control independent of the amount of exercise [17]. Increases in non-sedentary time have been associated with decreases in BMI [18]. Unfortunately, data from the Physical Activity Guidelines Advisory Committee Report suggests that approximately 55% of young adult women (18-30 years) do not gain enough PA/EX to confer beneficial effects for the prevention of MetS and CVD [18, 19].

An additional factor that may theoretically influence risk for MetS is dietary carbohydrate (CARB) intake [20]. Although obesity is multifactorial, the increase in obesity prevalence since the 1980s has been linked with an increase in dietary CARB intake [21]. Diets containing excess

CARB beyond an individual's energy requirements can exacerbate dyslipidemia [21], as well as negatively affect GLU metabolism [22]. Additionally, literature suggests that excess CARB consumption is related to an increase in TAGs [23]. Dietary fiber and whole grain intake are two aspects of CARB quality that have recently received considerable attention as they relate to MetS risk [24]. An inverse relationship between whole grain intake and BMI has been reported among combined gender adult cohorts [21, 25, 26]. In addition, dietary fiber may help reduce the risk of obesity, CVD, and T2DM [21, 27-29]. Whole grain foods modulate the glycemic response which can lead to improved glucose tolerance and reduced insulin resistance. Additionally, foods high in dietary fiber aid in weight management by increasing satiety and aiding healthy digestion [28]. It is unclear whether the total CARB quantity (e.g. grams/day), the relative contribution to energy intake (grams/kcal/day), and/or the quality of CARB (e.g. refined grain, whole grain, fiber, etc.) are the key factors involved in the relationship between dietary CARB intake and MetS risk.

The potential interactive effects of CARB intake and quality, PA, and adiposity on TAG, INS, GLU and CRP are also of great interest. It is possible that the adverse effects of higher quantity/poorer quality CARB intake could be mitigated by increased levels of PA. Alternatively, poor CARB dietary habits and low PA could interact to augment MetS risk. The relationship between dietary CARB intake and MetS risk is not well characterized. There is a paucity of data examining CARB intake, PA, and body composition and their independent effects on biomarkers of MetS risk in college-age females [7]. Literature exists examining the prevalence of MetS in college-age cohorts; however, these reports do not account for objectively measured PA and rarely examine body composition. Additionally, dietary examination is often

completed using food frequency surveys rather than more accurate methods such as multiple pass 24-hour recalls [7,8,11].

In this context, the aims of the present study were to determine if the quantity and quality of dietary CARB intake is related to conventional MetS risk factors of serum TAG and fasting GLU levels, as well as the associated MetS risk factors of INS and CRP, independent of PA and adiposity. It was hypothesized that independent of PA and adiposity, young women with a) a higher intake of CARB will have higher serum TAG, fasting GLU, INS, and CRP, and b) a higher intake of dietary fiber and whole grain will have lower levels of serum TAG, GLU, INS, and CRP.

3.2 Materials and Methods

The present study is a cross-sectional secondary analysis using data from two larger projects. The first study (n = 275) used a cross-sectional design to explore PA, dietary behaviors, body composition, and risk for MetS in first-year college students. The second study (n=61) used a parallel-arm randomized design and explored differential effects of sprint-interval training versus steady-state cycling on risk for MetS in overweight sedentary college-aged females. The present study used only the baseline data from this second study.

Participants

Regarding the first study, college-aged women were recruited via email and print advertising. Participants were required to be full-time students between the ages of 18 and 20 years. Varsity athletes, current smokers, and women who were pregnant, planning to become pregnant, or who had given birth within the past 12 months were excluded. For the second randomized parallel-arm design study, centrally overweight/obese women were recruited. Enrollment was limited to inactive (<30 minutes of moderate-vigorous PA <2 days/week) female

students ages 18-24 years. Additionally, women using progestin-only contraceptives or other non-oral hormonal contraceptive methods (i.e. hormonal patch, intrauterine device, vaginal ring, subdermal implant, or hormonal injection) were excluded. The study protocols and informed consent documents were approved by the university institutional review board.

Participants completed two visits to the measurement laboratory, and visits were completed within a 7-10 day period to allow for PA monitoring as well as diet intake recording in the interim. Participants also completed basic demographic and health history questionnaires for assessment of age, current and past medical conditions, and current medication use.

Blood Sampling and Markers of MetS

Participants completed a fasting blood draw, with blood being drawn by a certified phlebotomist. The standard lipid profile (total cholesterol, HDL-C, LDL-C, and TAG) as well as fasting GLU levels were measured from blood samples using spectroscopy. Plasma INS levels were measured using immunoassay, and high-sensitivity CRP was analyzed using laser nephelometry. All blood analyses were conducted through the University Health Center, and all biochemical analyses were performed using a nationally certified lab (Quest Diagnostics). The homeostatic model assessment (HOMA) was used as an indicator of both INS resistance and beta cell function ($INS * GLU / 405$) [30]. Blood pressure was measured in a seated position with an automated cuff after resting for five minutes.

Dietary Analysis

Participants were asked to complete self-reported 3 day food diaries either by hand or utilizing the National Cancer Institute's Automated Self-Administered 24-hour Recall system (ASA24; version 11), to determine total energy intake and macronutrient consumption. The format and design of ASA24 mimics an interview-administered 24-hour recall, and is comprised

of both a respondent website and a researcher website. All participants were asked to record all foods and beverages consumed on 2 weekdays and 1 weekend day. Those using ASA24 (n=61), were prompted by the software to provide details and clarification of food and beverage.

Participants involved in the cross-sectional study recorded paper food diaries (n=275) and were interviewed by a nutrition professional at visit 2 after completing their food diaries. They were prompted to provide more food and beverage detail when necessary to ensure all information was clear and complete. All hand written records were subsequently entered into the Nutrition Data System for Research (NDSR) (University of Minnesota, 2010, 2013) by a research nutritionist and analyzed.

ASA24 is based on the United States Department of Agriculture's Automated Multiple Pass Method [31, 32]. This method is the dietary interview component of the NHANES, and it has been validated to accurately report energy intake in normal-weight subjects [32]. Preliminary analyses of diet recall data from ASA24 are consistent with results from NHANES. Additionally, the developers of ASA24 conducted multiple pilot tests to ensure comprehension and user friendliness of the program. NDSR and ASA24 software utilize the United States Department of Agriculture (USDA) Nutrient Data Laboratory and the USDA Food and Nutrient Database for Dietary Studies to obtain nutrient content of foods. Each program assesses food group consumption information along with daily macronutrient totals. Daily energy intake, macronutrient composition, and food group totals were averaged among the three days to create one composite score which was used in the statistical analysis. Data was included in analyses only if participants completed ≥ 2 days of dietary recall utilizing either of the dietary intake assessment methods.

Physical Activity

Participants were given a New Lifestyles 1000 (New Lifestyles, Inc., Lees Summit, MO) accelerometer upon their initial visit to the laboratory. Participants were instructed to wear the pedometers on their non-dominant hip during all waking hours, except when swimming or bathing. Participants recorded the time spent wearing the monitor and the steps taken each day on a written log, which were verified by a staff member using the memory feature of the NL-1000. Ten hours of wear time were required for a valid day, and at least four valid days were required for the participant to be included in the analysis. Step counts were calculated using the average step count from valid wear days.

Anthropometric Measures and Body Composition

Barefoot standing height was measured using a stadiometer (Seca, Model 242; Chino, California) to the nearest 0.1 cm. Body weight was measured using a calibrated digital scale with subjects wearing light clothing and no shoes (Tanita WB-110A Class III, TANITA Corporation, Japan) to the nearest 0.1 kg. Body mass index was calculated as weight (kg) divided by height (m) squared (kg/m^2). Waist circumference was assessed at the narrowest circumference above the iliac crest and below the rib cage using standard clinical methodology. Whole body soft tissue composition including relative fat mass was measured via dual energy x-ray absorptiometry (DXA) (Lunar iDXA, v 11.30.062, GE Healthcare, Madison, WI). Scans were analyzed by two technicians for quality assurance.

Statistical Analysis

This study utilized data collected from two completed studies among college-age females, thus no a priori power calculations were conducted. Statistical analysis was performed using SPSS software, version 22 for Windows (IBM Corp: Armonk, NY). The data were

inspected for normality and outliers. As raw values for CRP, INS, HOMA, and TAG were not normally distributed, log transformations were performed which normalized the distributions. Analyses were performed with transformed variables but raw data scores are shown in tables to enhance interpretation. Descriptive statistics are presented in the form of $M \pm SD$. Although oral contraceptive use and race were not variables of interest, evidence indicates that these two factors influence risk for MetS [33, 34]; therefore, they were controlled for in the analyses. Pearson correlations were performed to examine associations between steps/day, dietary measures (dietary fiber, whole grain, %CARB) and blood markers (CRP, INS, HOMA, TAG, GLU). Partial correlations were conducted to determine if relationships among these variables of interest remained significant after controlling for OC use and race. Multiple hierarchical linear regression analyses were performed to determine the independent associations of dietary CARB outcomes, PA and adiposity, and MetS outcomes as well as the interactive effects of PA and adiposity on outcomes of interest. For each dependent variable, regression analyses were conducted in the following order, with sequential addition of a new variable or variables with each step: step 1, dietary variable (%CARB, dietary fiber, or whole grain), oral contraceptive use and race; step 2, physical activity (steps/day); step 3, adiposity (%Fat); step 4, interaction term for PA and adiposity.

3.3 Results

This study included female undergraduate students ($n=336$; 18.7 ± 1.2 years) at a major university in the Southeast United States. Reasons for exclusion included: fewer than 2 complete days of dietary recall and incomplete blood analysis. Subject characteristics are presented in Table 1. The sample was 66.8% white ($n=205$), 11.4% black ($n=35$), 16.2% hispanic ($n=19$), and 15.6% other ($n=48$). On average, the sample was categorized as normal BMI ($24.4 \text{ kg/m}^2 \pm 4.7$)

with %Fat of 35.2 ± 7.0 . The mean steps/day for the sample exceeded the public health recommendation to achieve 10,000 steps/day ($10,228 \pm 3,740$ steps/day) [35].

Descriptive statistics for dietary intake outcomes of interest are presented in Table 2. Figure 1 shows participants in the sample who met CARB recommendations according to the Dietary Guidelines for Americans 2010 (DGA-2010). The majority of the sample (74.7%) fell within the recommended range of CARB intake. In contrast, on average both dietary fiber and whole grain intakes were lower than the DGA-2010 for women ages 18-24 with only 16.9% (n=56) and 6.6% (n=22) meeting the recommendations, respectively (see Figure 2).

Participants exhibited, on average, normal or optimal clinical values for all MetS markers (Table 2). Of note, 1 participant displayed a CRP value of 52 mg/L however was kept in the data set due to having complete data. The range of CRP values without this participant was 1-27 mg/L. In the sample, only 4.2% (n=14) met the diagnostic threshold of MetS per the definition of the National Cholesterol Education Programs Adult Treatment Panel III [3]. Figure 3 depicts participants who exhibited diagnostic levels of MetS risk factors of interest and three non-classical MetS risk factors: HOMA, CRP, and INS. Elevated INS, elevated CRP, and low HDL-C, were the most common risk factors with 26.4% (n=81), 19.9% (n=61), and 22.5% (n=69), presenting risk factors, respectively. Approximately 41.1% (n=138) of the sample displayed ≥ 1 MetS risk factor.

Relationships among variables of interest are shown in Table 4. As expected, %Fat was weakly positively related to all MetS related factors with the strongest associations being with CRP, INS and HOMA (r range; 0.25 to 0.54, all $p < 0.01$). PA was also negatively significantly related to CRP, INS, HOMA, TAG and GLU (r range; -0.15 to -0.34, all $p < 0.01$). In contrast to our hypothesis, CARB intake was significantly negatively associated with CRP, INS and HOMA

(r range; -0.12 to -0.21, all $p < 0.05$), although the associations were weak; CARB intake was not associated with TAG or GLU. Similarly, dietary fiber and whole grains were significantly and negatively related to CRP, INS and HOMA but not TAG or GLU with the strongest relation being with INS and HOMA (both $r = -0.25$ and -0.21 , respectively, $p < 0.01$). When the relationships among CARB intake (% energy), dietary fiber, and CRP, INS, and HOMA were examined controlling for OC use and race, the associations were similar, and remained significant (data not shown). Graphical representation of the relationships among variables of interest is included in Appendix A.

As expected, OC, race, PA and %FAT were significantly and independently related to the majority of MetS related outcomes of interest. However, CARB quantity or quality did not independently contribute to any MetS factors. As the whole grain analysis and results paralleled that for fiber, the data is not shown.

A significant portion of variance in CRP levels was explained by OC use, %CARB, and fiber (all $p < 0.01$) as observed in Step 1 of the regression analysis (Table 5). The addition of PA and adiposity had a significant impact on CRP and removed the influence of dietary variables of interest. In the full model, OC use, PA and %Fat remained the only significant predictors of CRP explaining 43% of the variation in CRP. No significant relationship was noted for the interaction of PA and %Fat when included in the model.

A significant portion of variance in fasting INS was explained by %CARB, dietary fiber, OC use, and race (all $p < 0.05$) as observed in Step 1 of the analysis (Table 6). The addition of PA and adiposity had a significant impact on INS. In the full model, inclusive of OC, race, PA, %Fat, and dietary measures, the only significant predictors of INS were OC use, PA, and adiposity (all $p < 0.05$) explaining 33% of the variance in INS. When the interaction term was

included in the model, a significant relationship was observed indicating that the effect of adiposity on INS is different based on different values of PA.

The only significant predictor of fasting GLU in Step 3 of the regression model was adiposity ($p < 0.01$). The quantity and quality of dietary CARB were not significant predictors of GLU (Table 7). When the interaction term was added, %Fat remained the only significant predictor of GLU explaining 4% of the variance in GLU ($p < 0.01$).

A significant portion of variance in HOMA levels was explained by %CARB and dietary fiber, OC use, and race as observed in Step 1 of the analysis. The addition of PA and adiposity significantly impacted HOMA and removed any dietary influence explaining 33% of the variance in HOMA (all $p < 0.01$). There was a significant relationship among the interaction term of PA and %Fat, and HOMA (Table 8).

A significant portion of variance in TAG was explained by OC use (Table 9). In Step 3 of the regression, inclusive of OC, race, PA, %Fat, and dietary measures, the only significant predictors of TAG was OC use and adiposity ($p < 0.01$).

3.4 Discussion

The potential influences of CARB quantity and quality on MetS risk factors, particularly when accounting for PA and adiposity, has not been well characterized in the college female population. Understanding the link between dietary intake and MetS risk factors is critical to preventing the development of MetS in younger cohorts and improving health outcomes over the lifespan. The aim of this study was to determine if quantity and/or quality of dietary CARB intake is related to MetS risk factors of serum TAG and fasting GLU, as well as the associated MetS risk factors of INS and CRP, independent of PA and adiposity. Although weak relationships were observed between CARB and MetS factors (Table 4), when accounting for PA

and %Fat as well as OC use and race, CARB quantity and/or quality did not independently influence MetS risk.

Unfortunately, little attention has been paid to MetS risk in this young female adult population and few studies have examined dietary intake and prevalence of risk for MetS, especially while controlling for PA and adiposity [36]. Our data parallels other reports suggesting that HDL and elevated CRP (.3.0 mg/L) are the two most prevalent associated MetS risk factors in the college population, particularly among females [38]. Moreover, our results that 41.1% of our cohort had at least 1 risk factor for MetS align with previous reports that found a 54% incidence of MetS risk factors in the college population [6]. A study involving 12-19 year old males and females examined diet intake and PA via questionnaires, and found that lower intake of fruit and lower PA levels were both associated with a higher incidence of MetS [37]. Similar to our findings, Morrell et al., (2012) reported a significant association between low fiber and increased risk for MetS; however, authors did not account for PA and %Fat. Indeed, little research has attempted to determine the effects of CARB on risk for MetS independent from PA and %Fat [7].

Besides contributing to the literature examining prevalence of MetS in the young female population, our data reveals important information regarding dietary habits during this stage of life. On average in this cohort, dietary fiber and whole grain intake were below the recommendations for young females. This agrees with findings from other reports utilizing similar dietary reporting strategies that college students do not meet recommendations for dietary fiber intake or whole grain consumption [7, 39]. Bailey et al. examined dietary behavior in a cohort of over 300 college-age women using dietary questionnaires and found that there was low adherence to the DGA-2010 on consumption of whole grains, vegetables, and refined grains

[40]. The current findings from our study highlight the need to tailor dietary interventions specifically for college-age individuals to prevent chronic disease late in life.

The lack of relationship among dietary CARB intake and MetS risk factors may be, in part, attributable to several factors. First, of all independent and dependent variables considered in this study, measurement errors in the dietary outcomes are of most concern. Self-report is considered to be one of the more accurate ways of measuring dietary intake [41]; however, it is known that reported intakes tend to be underestimates of true energy intake [42, 43]. Participants may not have accurately reported all foods and drinks consumed in both the ASA24 online recall program and the paper food log. In addition to dietary measurement, because the intakes of dietary fiber and whole grain were so low in this cohort, there was a restricted range of independent variables. This aligns with the second potential contribution to lack of associations with CARB and MetS risk which is the low prevalence of MetS risk factors in this cohort, thus restricting the range of the dependent variables. Third, it is important to note the high level of PA in this cohort, largely due to active transportation, with on average achievement of the recommended 10,000 steps per day. Fourth, the most robust independent variable of interest was adiposity. Indeed, %Fat was an influential independent outcome for most of the MetS related outcomes. Importantly this cohort had on average a higher than expected adiposity but also a greater range (35.2 ± 7.0 ; 20-59%), which exceeds the average in %Fat reported in similar populations [38]. This range of scores, unlike CARB outcomes, likely strengthened the associations with MetS. Moreover, our results highlight that adiposity is an important target for prevention of MetS in this population. However, it is important to note that a portion of the sample (n=61) was recruited with central adiposity as an inclusion criteria.

Finally, although not an outcome of primary interest in this study, the influence of OC use on risk for MetS is notable. Moreover, determining the independent contributions of CARB intake, PA, and %Fat on risk for MetS in OC users versus non users will require sophisticated data analytic techniques requiring larger sample sizes due to the complicated inter-relationships among the independent outcomes of interest. For example, higher fiber intake was associated with lower INS, lower %Fat and higher PA but only %Fat was independently related to INS. It may be that fiber is a moderating variable but not an independent predictor variable. These relations potentially may differ with OC users due to influence on either the independent or dependent variables. Physical activity and dietary behaviors in young females using OCs and the impact on risk for MetS remains an important but relatively unstudied area potentially of clinical importance given the rising rates of obesity in the young female population.

This study has added to our understanding of the prevalence and development of MetS risk factors in the young female population, as well as dietary habits and characteristics, and physical activity behaviors. However, the present study is not without limitations. Owing to the cross-sectional nature of our investigation, causality cannot be inferred. Because our sample included young women from a single university with similar educational status, it is not appropriate to apply the results to other populations. It is possible that because participants knew they were involved in an investigation examining dietary and PA habits, they may have altered their behaviors to appear healthier (i.e. social desirability effect). Finally, although subjects received instruction and education related to portion sizes and data collection, dietary information was based on self-report and dependent upon subject participation. Despite these limitations, the inclusion of objective PA measurement and body composition analysis are

strengths of the study and contribute important descriptive data to the literature on this population.

In conclusion, the findings from the present study suggest that 1) the intake of dietary fiber and whole grain are low in the young female population and 2) MetS risk factors are not common among young females despite the population exhibiting relatively high levels of %Fat. Although weakly associated with MetS, the amount of dietary CARB and the quality of dietary CARB does not appear to significantly directly and independently influence risk factors for MetS after controlling for OC use, race, PA, and %Fat. More work is needed to elucidate specific dietary and PA habits that could potentially contribute to %Fat in younger age-groups, and subsequently the potential development of MetS later in life. Knowledge gained from longitudinal studies examining this topic to uncover chronic implications of poor dietary habits in young populations has the potential to influence future dietary and PA recommendations and interventions. Additionally, future analysis examining the impact of OC use and %Fat on MetS risk factors in this population is of interest. Lastly, it may be informative to examine the relationship between simple sugars or refined CARB intake and MetS risk factors, which was unfortunately beyond the scope of the present study.

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CHAPTER 4

CONCLUSION

The associations of dietary intake, specifically CARB quantity and quality, with MetS risk factors were assessed in 336 college-age females. Dietary intake was measured via 3 day food records and computer analysis software. Biomarkers for metabolic disease risk were determined from fasting blood samples analyzed using standard clinical measures. Adiposity was determined via dual-energy x-ray absorptiometry, and PA was assessed objectively via accelerometry. On average, the sample assessed was categorized as normal BMI ($24.4 \text{ kg/m}^2 \pm 4.7$) with %Fat of 35.2 ± 7.0 averaging $10,228 \pm 3,740$ steps/day. The majority of the cohort consumed dietary CARB within the recommended percentage of daily caloric intake; however, on average, both dietary fiber and whole grain intakes were lower than the DGA-2010. Few participants exhibited clinically significant levels of MetS risk factors, with only 4.2% ($n=14$) of the sample being defined as having MetS. Bivariate correlations revealed significant positive relationships between %Fat and all MetS related factors. Additionally, PA was negatively significantly related to CRP, INS, HOMA, and TAG. CARB intake was significantly negatively associated with CRP, INS, and HOMA. Dietary fiber and whole grain showed weak but significant inverse relationships to CRP, INS, and HOMA.

Multiple linear regression was used to examine independent predictors of CRP, INS, GLU, HOMA, and TAG. The majority of MetS related outcomes of interest were significantly and independently related to OC, race, PA, and %Fat. Dietary fiber and whole grain did not significantly independently contribute to any MetS risk factors.

Results of this study suggest that 1) the intake of dietary fiber and whole grain are low in the young female population and 2) MetS risk factors are not common among young females despite the population exhibiting relatively high levels of %Fat. Moreover, the amount and quality of dietary CARB do not appear to significantly directly and independently influence risk factors for MetS after accounting for PA and %Fat.

From a public health perspective, it is beneficial to identify relationships between dietary patterns, PA, adiposity, and MetS risk factors. Further research utilizing longitudinal study design is warranted to gather more accurate information regarding chronic implications of poor dietary habits in young populations. Additionally, this data could potentially influence dietary and PA recommendations and interventions to prevent chronic metabolic diseases later in life.

Table 1. Descriptive statistics for participants (n = 336)

Variables	Mean \pm SD	Range
Age (yrs)	18.7 \pm 1.2	18-24
BMI (kg/m ²)	24.4 \pm 4.7	17.3-42.9
Adiposity (%Fat)	35.2 \pm 7.0	20-59
Steps/day	10,228 \pm 3,740	1,717-24,815

BMI=body mass index; Adiposity measured via dual-energy x-ray absorptiometry. Steps/day measured via NL-1000 accelerometer. All values expressed as means \pm SD.

Table 2 Descriptive dietary characteristics

Variables	Mean \pm SD	Range	Recommended
Energy intake (kilocalories)	2013 \pm 581	664.2 - 3659.5	1800-2400
Carbohydrate (g)	252.7 \pm 76.4	60.3-503.1	\geq 130g/day
Energy Intake from Carbohydrate (%)	50.7 \pm 8.2	23-75	45-65
Protein (g)	78.3 \pm 25.8	20.4-173.3	\geq 46g/day
Energy Intake from Protein (%)	15.7 \pm 3.5	7-26	10-35
Fat (g)	78.0 \pm 29.4	23.4-193.1	28g/day
Energy Intake from Fat (%)	34.3 \pm 6.4	16-52	20-35
Fiber (g)	17.7 \pm 8.6	2.8-67.1	25g/day
Whole grain (oz. equivalents)	1.5 \pm 1.3	0-8.7	3-4 oz. equivalents

DRI=dietary reference intake. Recommended values chosen based on dietary reference intakes and the Dietary Guidelines for Americans 2010 for women ages 18-24. All values expressed as means \pm SD.

Table 3 Metabolic syndrome risk factors

Variables	Mean \pm SD or Median (25 th , 75 th)	Range
Triglycerides (mg/dL)	75 (58, 102)	30-398
Glucose (mg/dL)	85.0 \pm 6.4	54-113
Systolic blood pressure (mmHg)	116.1 \pm 14.1	79-166
Diastolic blood pressure (mmHg)	71.3 \pm 10.7	45-114
High-density lipoprotein (mmol/L)	60.3 \pm 14.6	28-109
Waist Circumference (cm)	75.0 \pm 10.5	56.5-121.6
Non-classical risk factors		
C-reactive protein (mg/L)	0.8 (0.3, 2.4)	0.00-52
Fasting insulin (uIU/mL)	3.0 (1.0, 6.1)	1-57
Homeostatic model (mg/dL)	0.64 (0.21, 1.33)	0.1-12.6

Top portion describes MetS risk factors as defined by ATPIII. All values expressed as means \pm SD for normally distributed variables and median (25th, 75th) for skewed variables.

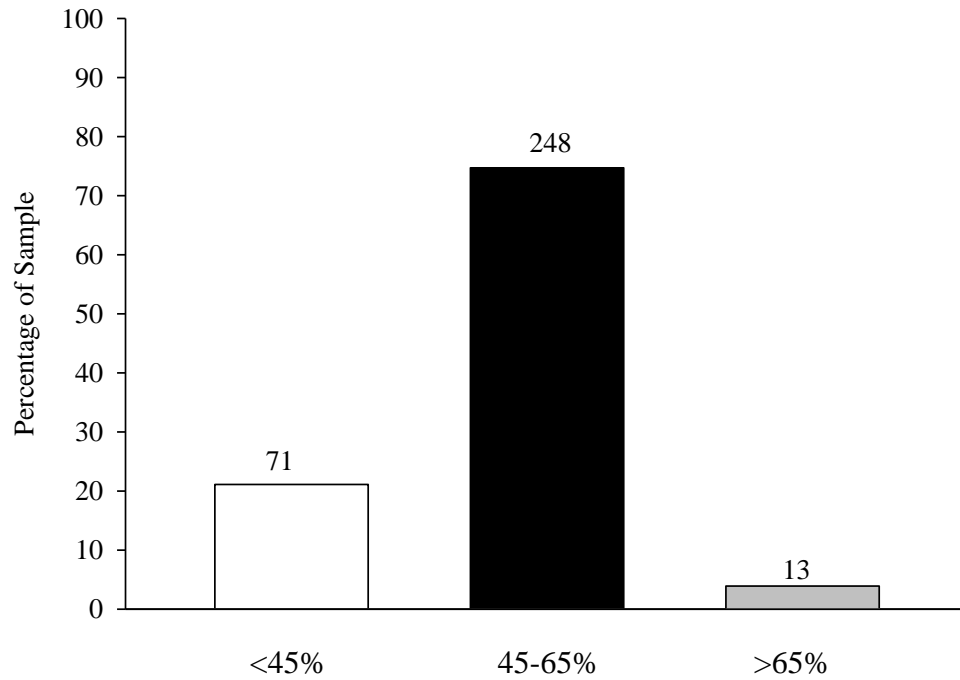


Figure 1. Percentage of participants who, on average, fell below (<45%), within (45-65%), or above (>65%) the recommendations based on the daily recommended intake of carbohydrates. Numbers above bars indicate sample size within cohort.

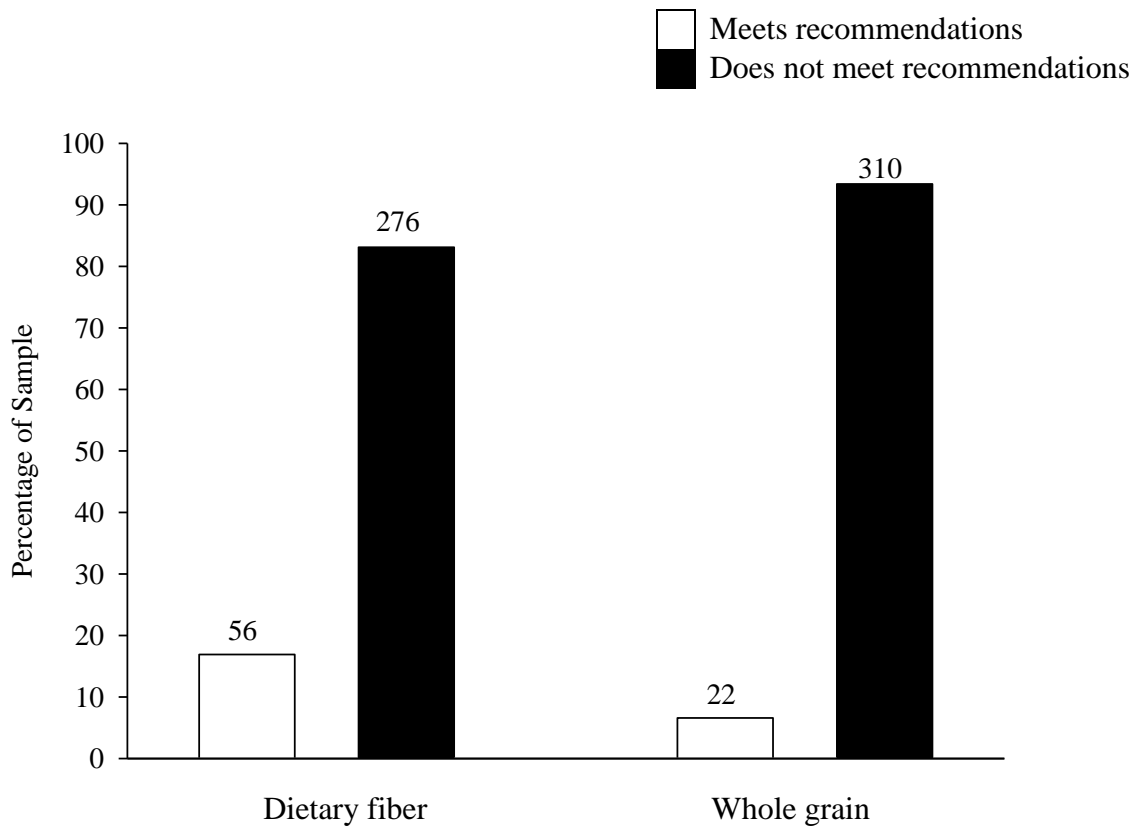


Figure 2. Percentage of participants who, on average, met dietary fiber ($\geq 25\text{g/day}$) and whole grain (≥ 3 ounce equivalents) recommendations based on the 2010 Dietary Guidelines for Americans. Numbers above bars indicate sample size within cohort.

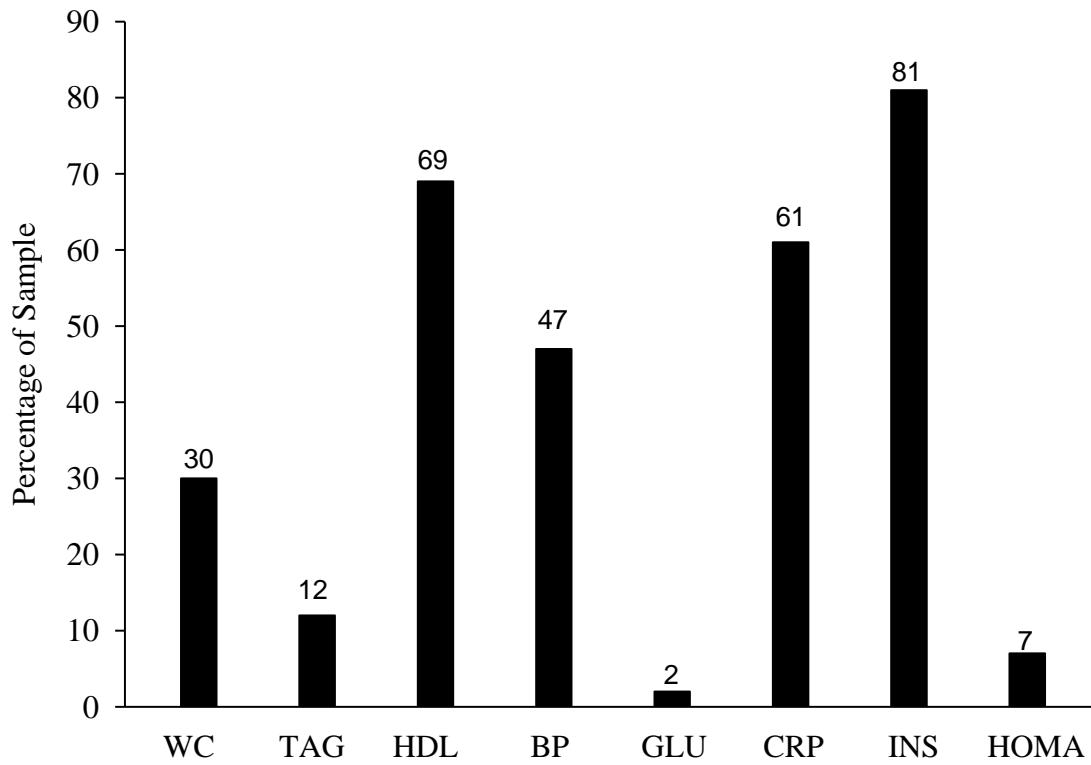


Figure 3. Percentage of participants who exhibited normal and at risk levels of classical metabolic syndrome risk factors and non-classical metabolic markers. WC=waist circumference; TAG=triglycerides; HDL=high density lipoprotein; BP=blood pressure; GLU=glucose, CRP=C-reactive protein; INS=insulin; HOMA=homeostatic model. Numbers above bars indicate sample size within cohort.

Table 4 Bivariate correlations

	1	2	3	4	5	6	7	8	9	10	11
1.CRP	1	0.33**	0.33**	0.36**	0.13*	-0.02	-0.12*	-0.18**	-0.15**	-0.33**	0.46**
2.INS		1	0.99**	0.20**	0.35**	0.01	-0.21**	-0.25**	-0.18**	-0.34**	0.54**
3.HOMA			1	0.21**	0.42**	0.01	-0.21**	-0.25**	-0.18**	-0.34**	0.54**
4.TAG				1	0.10	-0.14**	0.05	-0.09	-0.07	-0.20**	0.22**
5.GLU					1	-0.04	0.01	-0.10	-0.08	-0.15**	0.25**
6.Energy intake						1	-0.20**	0.39**	0.14*	0.06	-0.17**
7.CARB (%)							1	0.34**	0.29**	0.18**	-0.21**
8.Fiber (g/day)								1	0.48**	0.25**	-0.36**
9.WG (oz. eqvlt/day)									1	0.08	-0.21**
10.Steps/day										1	-0.43**
11.Adiposity (%Fat)											1

CRP=C-reactive protein; INS=insulin; HOMA=homeostatic model; TAG=triglycerides; GLU=glucose; CARB=carbohydrate; WG=whole grain. Log=Log₁₀ transformation. * p < 0.05; ** p < 0.01.

Table 5 Linear regression analysis C-reactive protein

	Carbohydrate		Fiber	
	R ²	β	R ²	β
Step 1	0.224[†]		0.227[†]	
CARB/Fiber(g)		-0.150[†]		-0.159[†]
OC Use		0.439[†]		0.427[†]
Race		-0.052		-0.042
Step 2	0.293[†]		0.291[†]	
CARB/Fiber(g)		-0.106[*]		-0.099[*]
OC Use		0.398[†]		0.392[†]
Race		-0.075		-0.065
Steps/day		-0.269[†]		-0.263[†]
Step 3	0.431[†]		0.428[†]	
CARB/Fiber(g)		-0.053		0.014
OC Use		0.414[†]		0.417[†]
Race		-0.087		-0.074
Steps/day		-0.096[*]		-0.103[*]
Adiposity		0.418[†]		0.430[†]
Step 4	0.437[†]		0.434[†]	
CARB/Fiber(g)		-0.053		0.003
OC Use		0.410[†]		0.411[†]
Race		-0.086		-0.074
Steps/day		0.274		0.275
Adiposity		0.594[†]		0.601[†]
Interaction		0.344		-0.341

CARB%=dietary carbohydrate as %total energy; OC use=oral contraceptive use; Race coded as white or other; Adiposity= relative fat mass (%). Interaction= steps/day*adiposity.

β=standardized regression coefficients; [†]*p*<0.01; ^{*}*p*<0.05

Table 6 Linear regression analysis insulin

	Carbohydrate		Fiber	
	R ²	β	R ²	β
Step 1	0.066[†]		0.081[†]	
CARB/Fiber(g)		-0.187[†]		-0.224[†]
OC Use		0.123[*]		0.105
Race		0.130[*]		0.139[*]
Step 2	0.150[†]		0.155[†]	
CARB/Fiber(g)		-0.139[†]		-0.158[†]
OC Use		0.078		0.068
Race		0.104		0.113[*]
Steps/day		-0.297[†]		-0.283[†]
Step 3	0.325[†]		0.320[†]	
CARB/Fiber(g)		-0.078		-0.034
OC Use		0.096[*]		0.095
Race		0.090		0.102[*]
Steps/day		-0.103[*]		-0.107[*]
Adiposity		0.471[†]		0.472[†]
Step 4	0.337[†]		0.333[†]	
CARB/Fiber(g)		-0.079		-0.051
OC Use		0.090		0.086
Race		0.091		0.102[*]
Steps/day		0.401		0.425
Adiposity		0.710[†]		0.720[†]
Interaction		-0.467[*]		-0.492[*]

CARB%=dietary carbohydrate as %total energy; OC use=oral contraceptive use; Race coded as white or other; Adiposity= relative fat mass (%) Interaction= steps/day*adiposity. β=standardized regression coefficients; [†] $p<0.01$; ^{*} $p<0.05$

Table 7 Linear regression analysis glucose

	Carbohydrate		Fiber	
	R ²	β	R ²	β
Step 1	0.003		0.014	
CARB/Fiber(g)		-0.007		-0.104
OC Use		-0.048		-0.059
Race		0.930		-0.002
Step 2	0.029		0.033	
CARB/Fiber(g)		0.020		-0.071
OC Use		-0.073		-0.079
Race		-0.002		-0.016
Steps/day		-0.166		-0.146*
Step 3	0.072[†]		0.070[†]	
CARB/Fiber(g)		0.050		-0.012
OC Use		-0.064		-0.066
Race		-0.008		-0.020
Steps/day		-0.069		-0.063
Adiposity		0.234[†]		0.233[†]
Step 4a	0.082		0.080[†]	
CARB/Fiber(g)		0.049		-0.027
OC Use		-0.070		-0.073
Race		-0.007		-0.020
Steps/day		0.384		0.409
Adiposity		0.449[†]		0.442[†]
Interaction		-0.420		-0.437

CARB%=dietary carbohydrate as %total energy; OC use=oral contraceptive use; Race coded as white or other; Adiposity= relative fat mass (%) Interaction= steps/day*adiposity. β=standardized regression coefficients; [†]*p*<0.01; **p*<0.05

Table 8 Linear regression analysis homeostatic model insulin resistance

	Carbohydrate		Fiber	
	R ²	β	R ²	β
Step 1	0.062[†]		0.080[†]	
CARB/Fiber(g)		-0.182[†]		-0.225[†]
OC Use		0.116[*]		0.098
Race		0.127[*]		0.134[*]
Step 2	0.148[†]		0.155[†]	
CARB/Fiber(g)		-0.134[*]		-0.159[†]
OC Use		0.071		0.060
Race		0.10		0.109[*]
Steps/day		-0.301[†]		-0.286[†]
Step 3	0.326[†]		0.322[†]	
CARB/Fiber(g)		-0.072		-0.034
OC Use		0.089		0.088
Race		0.086		0.097[*]
Steps/day		-0.105[*]		-0.108[*]
Adiposity		0.474[†]		0.474[†]
Step 4a	0.338[†]		0.335[†]	
CARB/Fiber(g)		-0.073		-0.051
OC Use		0.082		0.079
Race		0.088		0.097[*]
Steps/day		0.415		0.441
Adiposity		0.721[†]		0.730[†]
Interaction		-0.483[*]		-0.508[*]

CARB%=dietary carbohydrate as %total energy; OC use=oral contraceptive use; Race coded as white or other; Adiposity= relative fat mass (%) Interaction= steps/day*adiposity. β=standardized regression coefficients; [†]*p*<0.01; ^{*}*p*<0.05

Table 9 Linear regression analysis triglycerides

	Carbohydrate		Fiber	
	R ²	β	R ²	β
Step 1	0.147[†]		0.152 [†]	
CARB/Fiber(g)		0.024		-0.078
OC Use		0.359[†]		0.349[†]
Race		-0.056		-0.075
Step 2	0.176[†]		0.175[†]	
CARB/Fiber(g)		0.052		-0.042*
OC Use		0.332[†]		0.328[†]
Race		-0.072		-0.089
Steps/day		-0.176[†]		-0.158[†]
Step 3	0.210[†]		0.205[†]	
CARB/Fiber(g)		0.079		0.011
OC Use		0.340[†]		0.339[†]
Race		-0.078		-0.093
Steps/day		-0.089		-0.083
Adiposity		0.208[†]		0.200[†]
Step 4	0.216[†]		0.210[†]	
CARB/Fiber(g)		0.079		-0.001
OC Use		0.335[†]		0.334[†]
Race		-0.076		-0.093
Steps/day		0.264		0.275
Adiposity		0.376[†]		0.366[†]
Interaction		-0.328		-0.331

CARB%=dietary carbohydrate as %total energy; OC use=oral contraceptive use; Race coded as white or other; Adiposity= relative fat mass (%) Interaction= steps/day*adiposity. β=standardized regression coefficients; [†]*p*<0.01; **p*<0.05

CHAPTER 5
APPENDICES

APPENDIX A

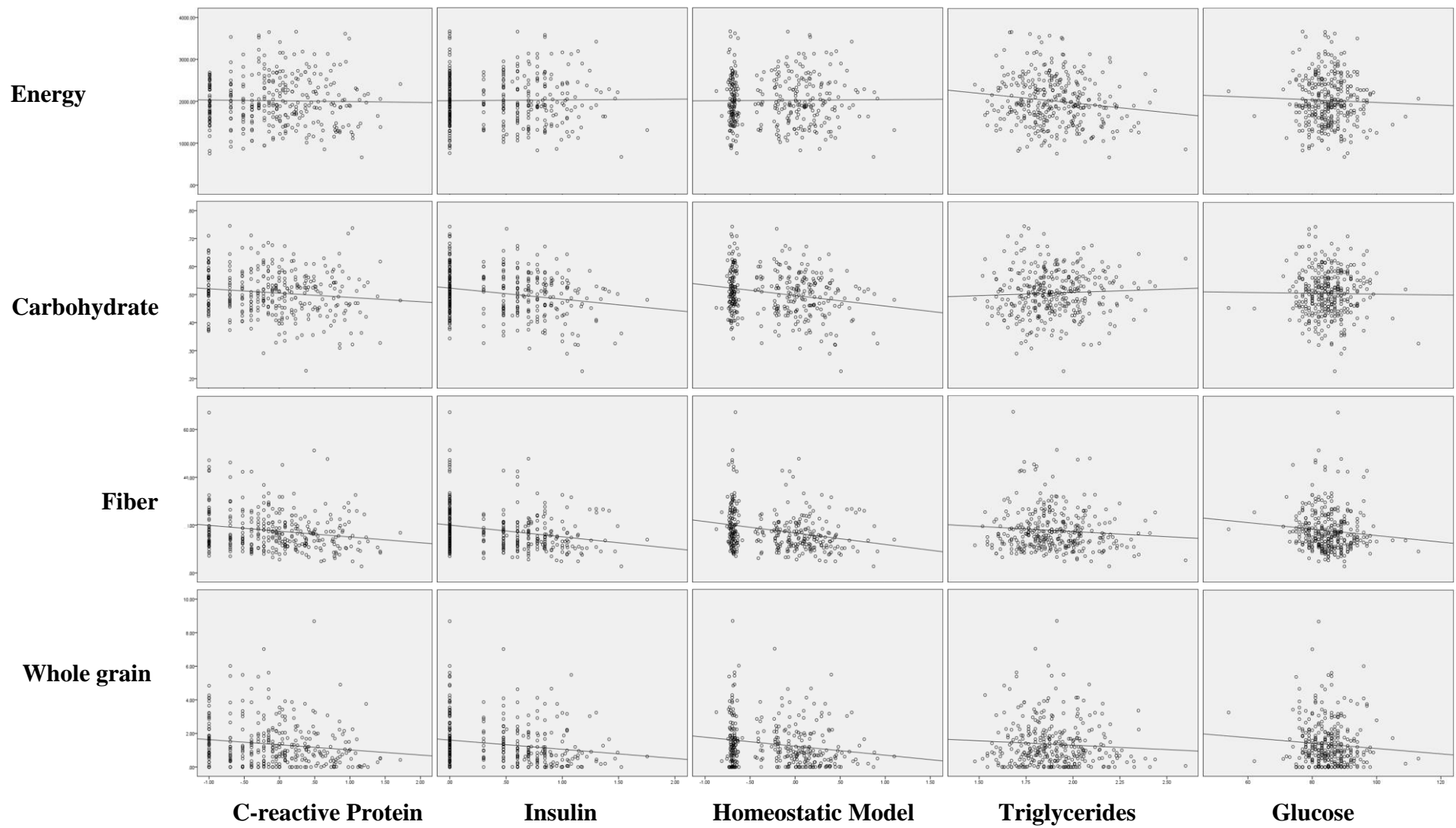


Figure 1. Distribution of metabolic syndrome variables of interest and dietary variables of interest. Whole grain measured in ounce equivalents. Fiber measured in grams/day. Carbohydrate intake expressed as % total energy intake. Energy intake expressed as average kilocalories/day,