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Multi-Level Predictors of Obesity and Diet in Multi-Ethnic Populations

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MULTI-LEVEL PREDICTORS OF OBESITY AND DIET IN MULTI-ETHNIC POPULATIONS

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The obesity epidemic in the United States is a major public health issue. Poor socio-economic conditions such as poverty or living under financial stress may adversely influence health outcomes such as obesity, and often disproportionately impact ethnic minority populations. Further, individuals living in poverty are often exposed to environments that promote unhealthy diet and obesity. Such obesogenic environments are characterized by increased exposure to foods high in sodium and low in potassium. In turn, growing evidence is linking high sodium and low potassium consumption independently to obesity. Yet these associations have not been adequately explored, especially among ethnic minority populations.

The current dissertation seeks to explore multilevel determinants of diet and obesity in multi-ethnic cohorts of women and men. Specifically, this dissertation seeks to determine 1) whether individual-level SES, as measured by exposure to poverty, is associated with trajectories of BMI over 20 years, using data from the Coronary Artery Risk Development In Young Adults Study of white and black adults; 2) whether neighborhood-level socio-economic environment is associated with individual-level measures of obesity and diet quality (urinary sodium, potassium, and sodium to potassium ratio), above and beyond
individual-level SES and other covariates, using data from the Heart Follow-Up Study, a population-based cohort of NYC adult residents; and 3) whether diet quality (sodium, potassium, and sodium to potassium ratio) is associated with obesity, independent of energy intake, using data from the Hispanic Community Health Study/Study of Latinos and the Study of Latinos: Nutrition and Physical Activity Assessment Study.

From fully-adjusted linear mixed effects regression models, sustained poverty was found to be associated with faster BMI growth in White men and women, slower BMI growth in Black men, and no association in Black women. Using multi-level regression models, low vs. high neighborhood socio-economic status was found to be associated with higher BMI and lower urinary potassium excretion among women but not men, above and beyond individual-level SES. Finally, from fully-adjusted linear regression analyses, higher sodium was found to be associated with higher BMI, waist circumference and body fat among Hispanics/Latinos, independent of energy. Lower potassium and higher sodium to potassium ratio were also associated with worse measures of obesity; however, such associations varied by duration of residence in the US. Taken together, the results highlight the multi-level and multi-factorial nature of the relationships among socio-economic status, dietary nutrients, and obesity among diverse populations.
DEDICATION

This dissertation research is dedicated to my mother, Ruth Elfassy, who taught me to be strong, independent, and kind. From a very early age she believed deeply in the power of three important factors: education, nutrition, and fitness. She always stressed that these three factors were critical to success and reinforced each other. Today, this idea guides my own work. I thank my mother for her endless love and inspiration that she continuously provides.
I would like to thank my entire dissertation committee for their time, guidance, and continuous support. Throughout this process, each committee member has played a special role and helped me both academically and professionally. I would especially like to thank my dissertation chair, Dr. Adina Zeki Al Hazzouri. She has been instrumental to my success and has always pushed me to be my best. I thank her for her wonderful mentorship, devotion, and good will. I am proud not only to call her a respected, dedicated mentor, but also a friend.
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Chapter 1: Introduction

I. Overview

Obesity is a major public health issue and one of the leading contributors to cardiovascular disease morbidity and mortality.\textsuperscript{1,2} In the US alone, 35% of the population is obese;\textsuperscript{3} this figure is even more striking among ethnic minority populations and those living in poverty, especially in women.\textsuperscript{4} Poverty has a pervasive impact on health.\textsuperscript{5} Often, negative health consequences of poverty, such as obesity, can take years, if not decades to develop. Further, poverty can be somewhat transient overtime.\textsuperscript{6} Thus, consideration of long-term exposure to poverty in relation to long-term changes in obesity is necessary to fully elucidate the nature of this relationship.

Predictors of obesity are multi-factorial.\textsuperscript{5} In fact, characteristics of the neighborhood in which we live may define the distribution of obesity and its risk factors at the population-level.\textsuperscript{7} For example, poor neighborhood socioeconomic status, high neighborhood poverty or unemployment rates have been associated with obesity.\textsuperscript{8-11} Obesogenic neighborhoods are characterized by poor socio-economic and retail environments which in turn create barriers to healthy behaviors and lifestyles.\textsuperscript{12} These neighborhoods often have relatively high numbers of fast-food restaurants and convenience stores which tend to have food high in nutrients associated with obesity, such as sodium,\textsuperscript{13} when compared with neighborhoods of higher socio-economic status\textsuperscript{14}. Furthermore, such neighborhoods tend to be associated with poor diet quality and limited access to
fresh fruits and vegetables, further contributing to obesity. While the relationship between the neighborhood environment and obesity is somewhat consistent across studies, the relationship between the neighborhood environment and sodium consumption is less established. Most previous research has utilized self-reported dietary sodium information, and only few investigations utilized 24-hour urine which is the gold standard sodium measurement. Likewise, when capturing diet quality, neighborhood and health studies tend to rely on subjective measures such as self-reported fruit and vegetable consumption, instead of objective measures shown to correlate well with diet quality such as urinary potassium excretion or Na-K ratio.

Ethnic minority populations, such as US Hispanics/Latinos, are more likely to experience economic hardship and to reside in high poverty and obesogenic neighborhoods where exposure to sodium tends to be high and that to fresh produce tends to be low. This is particularly salient because beyond its impact on blood pressure, high sodium consumption has been shown to be associated with obesity independent of energy intake. Yet, these relationships are relatively under-explored, especially among US Hispanics. Among US Hispanics, such relationships are particularly pertinent given that the few data available suggests that Hispanics have higher dietary sodium intake, lower dietary potassium intake, and higher rates of obesity compared with non-Hispanic whites. Further, Hispanics/Latinos have a unique acculturation experience during which their dietary habits and quality tend to worsen with greater duration of residence in the US. Thus, understanding how dietary
factors, such as sodium and potassium, are associated with obesity outcomes among Hispanics/Latinos, the fastest-growing US minority population, is of great medical and public health interest.

This dissertation seeks to improve our understanding of how individual-level and neighborhood-level predictors influence dietary intake (sodium and potassium) and obesity in multi-ethnic populations. To do so, this research involves analyses of three population-based cohorts, including the ongoing prospective CARDIA (Coronary Artery Risk Development in Young Adults) study of 5,114 young to middle-aged men and women (52% black and 48% white), the HFUS (Community Health Survey Health Follow-up Study), a cross-sectional representative sample of 1,645 racially and ethnically diverse NYC residents, and the ongoing HCHS/SOL (Hispanic Community Health Study/Study of Latinos Hispanic) study, an ongoing prospective study of 16,415 self-identified Hispanics of diverse ancestry. Each of these studies brings a unique contribution to this body of research by providing measures of sodium and potassium (24-hour urine and self-reported), measures of obesity, and multi-level predictors among non-Hispanic whites, non-Hispanic blacks and Hispanics.

II. Conceptual Framework

The Conceptual Framework (Figure 1.1) depicts the objectives of this dissertation in terms of exploring multilevel predictors of diet and obesity. In particular, we explored how individual-level SES (poverty) and individual-level diet (recall and urine-collected) influence measures of obesity, and how
neighborhood-level SES influences both individual-level diet and measures of obesity. All analyses were conducted in large and multi-ethnic epidemiologic cohorts, thus providing a framework for exploring those relationships in the context of race/ethnicity and acculturation (when applicable).

**Figure 1.1: Dissertation conceptual framework**

III. Public Health Aspects of Diet and Obesity

In the United States, two out of every three adults is either overweight or obese. The great burden posed by the obesity epidemic warrants the attention it receives, as it is a major risk factor and contributes substantially to cardiovascular disease, the leading cause of death. Both direct and indirect
economic costs of obesity are grave and are estimated to exceed 215 billion annually.⁴₀

**Figure 1.2**: Prevalence of self-reported obesity among US adults by state and territory, BRFSS, 2015

Source: Behavioral Risk Factor Surveillance System⁴¹

Obesity results directly from an energy imbalance—namely when energy intake exceeds energy expenditure.⁴² This typically occurs when energy is over-consumed and/or physical activity is insufficient.⁴² It is no surprise then, that the current obesity epidemic in the US has been at least partly attributed to the US food supply which has become increasingly processed.⁴³,⁴⁴ In particular, modern
day processed diets tend to be high in refined sugars, vegetable oils, dairy, and lacking fruits and vegetables.\textsuperscript{44}

In addition to being energy-dense and thus obesogenic,\textsuperscript{44,45} diets comprised of processed foods have unfavorable micronutrient contents.\textsuperscript{44} For example, sodium which is not commonly occurring in natural foods such as fruits and vegetables is often added to processed foods in great quantities by food manufacturers. In fact, it is estimated that 80\% of sodium consumed is derived from processed/pre-packaged or restaurant foods,\textsuperscript{46} and over 90\% of US adults consume sodium in excess of United States Department of Agriculture recommendations.\textsuperscript{47}

\textbf{Figure 1.3:} Estimated usual intake of sodium (in mg/day) among US adults by sex

\begin{center}
\includegraphics[width=0.5\textwidth]{sodium_intake.png}
\end{center}

Source: National Health and Nutrition Examination Survey, Cogswell et al 2012\textsuperscript{47}

Likewise, given the lack of fruits and vegetables in the modern diet,\textsuperscript{44} potassium is consumed much lower than the 4700 mg/day USDA
recommendation. In fact, less than 2% of US adults consume adequate amounts of potassium.\(^{47}\) Taken together, researchers note that sodium intake has increased by 400% while potassium intake has decreased by 400\%.\(^{48,49}\)

As highlighted above, the dietary changes that have occurred in modern history have adversely altered several dietary indicators which include factors such as sodium to potassium (Na-K) ratio along with other notable characteristics such as glycemic load, fatty acid composition, macronutrient and micronutrient composition, and fiber content.\(^{44}\) As a result of this diet shift, chronic illnesses have emerged,\(^{50}\) with obesity as a major driver. While the US population as a whole has been exposed to this altered food environment and obesity has increased dramatically in all groups,\(^{51}\) ethnic minority populations and populations living in poverty tend to be disproportionately impacted by obesity. For example the prevalence of obesity in Hispanics and non-Hispanic Blacks is significantly higher than in non-Hispanic Whites.\(^{3}\) Likewise, the prevalence of obesity, particularly among women living in poverty, is substantially higher compared with those not living in poverty 42.0% vs. 29.0%.\(^{4}\) In fact, ethnic minority populations and individuals living in poverty often have poor access to health care and often live in environments that foster unhealthy behaviors\(^{52}\) and thus obesity.\(^{12}\)

IV. Socio-Economic Status and Obesity

Low socio-economic status has pervasive effects on health. Its association with premature morbidity and increased mortality has been well-established;\(^{53}\)
and is known to differ by sex and race/ethnicity.\textsuperscript{54} For example, as eluded to earlier, individuals with lower income are more likely to be obese than their wealthier counterparts.\textsuperscript{55} While this association is widely accepted,\textsuperscript{56} income is often assessed at a single time point, even though it is dynamic and can thus vary markedly across the lifespan. Further, changes in BMI can occur at differential rates throughout life.\textsuperscript{57} Life course epidemiological studies of socioeconomic status reveal that exposure to low socio-economic status during certain periods in life may differentially influence risk for subsequent disease.\textsuperscript{58-62} Specifically, there are independent dose-response effects of both early life and adult exposure to low socio-economic status on adult obesity.\textsuperscript{63} Consequently, a single economic classification is inappropriate for determining causality;\textsuperscript{64,65} rather, consideration of cumulative long term exposures to low income on obesity is critical.\textsuperscript{60,66} However, few longitudinal studies include multiple income assessments;\textsuperscript{67-70} in those that do, trends in BMI is seldom the main outcome.\textsuperscript{70}

In a recent study in an older Japanese cohort, high income was associated with lower BMI but was not associated with a lower BMI growth rate compared with individuals of lower income.\textsuperscript{70} Results from the Coronary Artery Risk Development In Young Adults (CARDIA) study demonstrate independent associations of socio-economic status with waist to hip ratio.\textsuperscript{71} Further, data from the Health and Retirement study reveal that age at baseline and race are both predictive of differential BMI growth rates over time.\textsuperscript{57} Given these data, investigations of the impact of income in relation to BMI growth rate in a young, racially diverse cohort are warranted, and will help us better understand how
changes in income cumulatively influence health outcomes. Yet, to our knowledge, no prior studies have examined the longitudinal relationship between chronic exposure to poverty/income and trajectories of obesity.

V. Socio-Economic Status and Diet

Given the well documented link between poverty or low socio-economic status and obesity, particularly among women, there has been much research dedicated to mechanisms underlying such associations. Food insecurity, or the ability to obtain both an adequate quantity of food as well as inability to obtain desired food items, has been implicated as a potential mechanism of action linking low socio-economic status to higher rates of obesity. In short, poverty and food insecurity are known to be associated with low food expenditures, poor diet quality and low consumption of fruits and vegetables—all factors associated with higher rates of obesity. For example, individuals of low socio-economic status often cite cost as a barrier to healthy eating, and thus turn to cheaper foods which tend to be less nutritious, more calorically dense, and thus obesogenic. In fact, there is a documented inverse relationship between energy density and nutrient density. In other words, per calorie costs of foods that tend to be processed and full of refined sugars and fats, are lower than that of nutrient dense foods such as fruits and vegetables. Likewise, diets high in potassium and low in Na-K ratio have been shown to be more expensive than calorically equivalent diets low in potassium and high in Na-K ratio.
The neighborhood environment may also play an important role in defining the distribution of obesity and diet quality at the population level. There is a wealth of data supporting a relationship between the neighborhood context and health. Important characteristics of the neighborhood that may influence obesity and diet quality, include the socioeconomic and food/retail environments, which are closely linked. For example, unfavorable neighborhood socio-economic parameters such as high poverty have been associated with obesity in a number of studies. Neighborhoods with high poverty rates are often labeled obesogenic; such neighborhoods have higher densities of fast-food restaurants and convenience stores than neighborhoods with lower poverty rates. Further, in low income neighborhoods, the availability of fresh and quality produce is often limited, leading to the coined term “food desert” in much of the literature. Supermarkets which provide access to nutritious options are often greatly outnumbered by convenience stores and fast food restaurants which typically represent nutritionally devoid food options. Foods in convenience stores and fast food restaurants tend to be high in nutrients associated with obesity such as fat, sugar, and sodium. Consequently, research has suggested an association between the neighborhood environment with obesity and diet quality. The neighborhood environment has also been suggested to influence sodium consumption, which in turn may be an important contributor to the obesity
epidemic (sodium to obesity relationship is discussed below). As sodium is ubiquitous in our food supply – 80% of the sodium we consume is derived from packaged or restaurant foods – studies have shown associations between the neighborhood environment and individual level sodium intake. Additionally, neighborhoods with high fast-food density, liquor stores, and convenience stores tend to be more prevalent in areas with a high proportion of minorities. This is particularly problematic as ethnic/minority groups such as Blacks and Hispanics are not only disproportionately affected by the obesity epidemic, but are known to consume more sodium compared with non-Hispanic Whites. However studies exploring the associations of the neighborhood environment with individual-level sodium consumption are mixed and typically utilize self-reported data to measure sodium consumption rather than the gold standard 24-hour urine collection. Likewise, most neighborhood studies include subjective measures of diet quality such as healthy eating indices or self-reported fruit and vegetable intake, rather than objective biomarkers such as 24-hour urinary potassium. To our knowledge, few studies have included objectively measured biomarkers of diet such as sodium and potassium as derived via the gold standard 24-hour urine collection.

VII. Sodium, Potassium, Na-K Ratio and Obesity

As discussed, in the US sodium is consumed in excess and is associated with elevated blood pressure. Thus, sodium reduction has been recommended both on an individual and population-based level. But beyond the blood pressure altering effects, emerging evidence suggest that
sodium may also contribute to obesity.\textsuperscript{28-34,108-112} It has been suggested\textsuperscript{113} that associations between high sodium diets and obesity are likely explained by the “Salted Food Addiction Hypothesis,” which proposes that foods high in salt act in the brain like an opiate agonist\textsuperscript{114} and subsequently lead to an increase in consumption of unhealthy foods. However, research, including findings from longitudinal studies, have shown that high sodium consumption may be associated with obesity even after controlling for energy intake,\textsuperscript{28-34} suggesting that there may be a sodium-related mechanism in play beyond sodium induced cravings contributing to obesity.\textsuperscript{28} Further research is needed to help inform current sodium reduction efforts in the US\textsuperscript{107} and help elucidate potential obesity-related benefits of sodium reduction, especially in low income, minority groups.

Likewise, as previously discussed, less than 2\% of the US adults consume adequate amounts of potassium.\textsuperscript{47} Additionally, given the ubiquity of sodium in the US food supply, coupled with the scarcity of potassium, Na-K ratio has increased overtime and is less than ideal.\textsuperscript{44} Despite this, both potassium and Na-K have not been explored in relation to obesity in great detail. Limited studies suggest that potassium is inversely associated with obesity.\textsuperscript{35} Likewise, higher Na-K ratio, has also been shown to be associated with greater rates of obesity.\textsuperscript{110,115}

The relationships among sodium, potassium, Na-K and obesity are particularly salient for ethnic minority populations such as US Hispanics not only due to their higher obesity rates\textsuperscript{3,37,100} but also due to their higher dietary sodium and lower dietary potassium intakes compared with non-Hispanic whites.\textsuperscript{36}
Further, in the US, Hispanics have a unique acculturation experience during which their dietary habits and quality tend to worsen with greater duration of residence in the US. Thus exploration of these relationships among this fast-growing ethnic minority population is urgently needed.

VIII. Dissertation Objectives

Using data from three population-based cohorts, including the ongoing prospective CARDIA (Coronary Artery Risk Development in Young Adults) study of 5,114 young to middle-aged men and women (52% black and 48% white), the HFUS (Community Health Survey Health Follow-up Study), a cross-sectional representative sample of 1,645 racially diverse NYC residents, and the ongoing prospective HCHS/SOL (Hispanic Community Health Study/Study of Latinos Hispanic) study of 16,415 self-identified Hispanics of diverse ancestry, this dissertation explored the following specific aims and hypotheses. Each aim will then be discussed as a separate chapter.

Specific aim 1. Using data from the CARDIA study (N=5,114), determine the longitudinal association between sustained poverty and BMI growth rate over twenty years (1990-2010), and determine whether the associations varied by sex or race.

H1-1: BMI will increase among all participants throughout the twenty-year study period, with a faster increase with greater levels of sustained poverty, after adjustment for other factors.
H1-2: The effect of sustained poverty on BMI growth over twenty years will be stronger (i.e. a faster growth rate) among women compared with men and among blacks compared with whites, after adjustment for other factors.

Specific aim 2. Using data from the HFUS study (N=1,645), determine whether the neighborhood socio-economic environment is associated with individual level obesity (BMI and waist circumference) and measures of diet (sodium, potassium, and Na-K ratio) among diverse NYC adult residents, and determine whether these associations differ by sex.

H2-1: Low neighborhood socio-economic status (i.e. more disadvantaged) will be associated with higher BMI and waist circumference, and with higher sodium, lower potassium, and higher Na-K ratio, above and beyond individual level factors.

H2-2: The association of neighborhood socio-economic status with individual-level obesity and diet quality will be stronger in women vs. men.

Specific aim 3. Using data from the HCHS/SOL study (N=16,415), determine whether dietary factors (sodium, potassium, and Na-K ratio) are associated with measures of obesity (BMI, waist circumference, body fat, and percent body fat) among diverse Hispanics, and whether these associations differ by nativity/years in the US.
H3-1: High sodium, low potassium, and high Na-K ratio will be associated with higher BMI, higher waist circumference, more body fat, and a higher percent body fat, after adjusting for other factors including energy intake.

H3-2: The association between dietary factors (sodium, potassium, and Na-K ratio) and measures of obesity will be stronger among individuals with longer years in the US.

IX. Summary

The obesity epidemic in the United States is a major public health issue. Poor socio-economic conditions such as poverty or living under financial stress may negatively influence health outcomes such as obesity, and often disproportionately impact minority populations. Further, individuals living in poverty are often exposed to environments that promote unhealthy behaviors and obesity. Such obesogenic environments are characterized by increased exposure to foods with adverse micro nutrient content such as foods high in sodium but low in potassium. In turn, growing evidence suggests that high sodium and low potassium consumption are independently linked to obesity and can therefore potentially perpetuate obesity. Further exploration of such pathways is warranted, especially among ethnic minority populations.

The current proposal seeks to explore the relationships between poverty, the environment, sodium and potassium intakes, and obesity. To do that, three epidemiologic cohorts will be used in this dissertation. The Coronary Artery Risk Development in Young Adults Study, a prospective study encompassing a time-
frame of over 20 years, will be used to determine the relationship between sustained poverty and average annual changes in BMI over time in black and white adults using generalized linear mixed models. The Heart Follow-Up Study, a population based cohort representative of adult residents of NYC, will be used to determine whether there is an association between neighborhood socio-economic factors and individual level measures of obesity and diet; a hierarchical linear modeling approach will be employed. Finally, data from the Hispanic Community Health Study/Study of Latinos, a population based cohort of self-identified Hispanics, will be used to determine whether dietary factors (sodium and potassium intakes) are associated with obesity, independent of energy intake using linear regression analysis.

The current research is relevant as it addresses one of the most pressing public health challenges faced by the US: the obesity epidemic. This dissertation takes a comprehensive approach at quantifying contributors to obesity from multiple dimensions. This research explores not only how socio-economic status impacts obesity at the individual but also at the neighborhood level. It also explores the neighborhood as a contributor to diet quality which in turn may further perpetuate obesity. Further, the current research has a focus on diverse and underrepresented populations that are disproportionately impacted by obesity. Taken together, this dissertation research can further our understanding of the mechanisms associated with obesity in minority populations.
Chapter 2: Methods

I. Overview

This chapter provides a description of the analytical methods used to address each scientific aim of the current dissertation. Details about study design, sample selection, study participants, measurements, and statistical approaches are discussed. While chapters 3 to 5, specific to each scientific aim (working paper), also provide details of the methodology used, this section is meant provide more in depth analytical information.

II. Study Design

Data for this study are derived from four population based studies: the Coronary Artery Risk Development in Young Adults (CARDIA) study which is used to address Aim 1; the Heart Follow-Up Study (HFUS) which is used to address Aim 2; the Hispanic Community Health Study/Study of Latinos (HCHS/SOL) and the ancillary Study of Latinos Nutrition and Physical Activity Assessment Study (SOLNAS) both of which are used to address Aim 3. Detailed descriptions of each study are provided in the Data Sources section as outlined below.

The dissertation’s conceptual framework represented by Figure 1.1 of Chapter 1 provides a broad overview of the research questions being addressed, specifically scientific aims 1 to 3. Aim 1 addresses the association between individual-level poverty and BMI. Aim 2 addresses the association between
neighborhood-level socio-economic status and both diet quality and obesity, above and beyond individual level factors. Finally, Aim 3 addresses the association between dietary nutrients (sodium, potassium, and Na-K ratio) and measures of obesity. The overall conceptual framework (Figure 1.1) is not meant to depict causal relationships as in a Directed Acyclic Graph. Figures 2.7, 2.8, and 2.9 below provide detailed conceptual framework for each specific aim separately.

III. Data Sources

i. The Coronary Artery Risk Development in Young Adults (CARDIA)

The CARDIA study is an on-going prospective cohort study of 5,114 community dwelling participants that was initiated to examine life-style and other factors that lead to the development of cardiovascular disease in young adults. Beginning in 1984, participants who were aged 18 to 30 years old at the time were recruited from four urban areas: Birmingham, Alabama; Chicago, Illinois; Minneapolis, Minnesota, and Oakland, California. Participants were examined carefully per standardized protocols and definitions at baseline in 1985-86 and then re-examined two, five, seven, 10, 15, 20, and 25 years post-baseline, encompassing a time from 1985 through 2010. Recruitment was balanced within center by sex, age, education, and included 52% blacks and 48% whites. Standardized protocols were used to gather demographic, social, and clinical data for each follow-up visit and across sites. Thorough study details have been
documented elsewhere. For specific aim 1, data from study years 1990 through 2010 were used; as income data were not collected prior to 1990.

ii. The Heart Follow-Up Study (HFUS)

HFUS is a cross-sectional, population based study that was conducted in 2010 to estimate population-level sodium intake using gold-standard 24-hour urine collection from a representative sample of NYC adults (N=1756). Study participants in the HFUS were recruited from the parent Community Health Survey (CHS) study, which is an annual telephone survey conducted by the NYC Health Department and modeled after the Behavioral Risk Factor Surveillance System which includes 8,000 to 10,000 adult New Yorkers. To obtain a representative sample of non-institutionalized adult New Yorkers, the CHS uses a dual frame sample design consisting of random-digit-dial landline telephone exchanges and a second frame of cellular telephone exchanges that cover NYC. The CHS also incorporates a disproportionate stratified random sample design to allow for analysis at the city, borough and neighborhood levels. To account for the clustered sampling and over-sampling of certain populations, the CHS includes sampling weights and survey design variables to provide representative and unbiased estimates of the NYC population.

Upon completion of the CHS interview, participants were screened for HFUS eligibility based on three questions: 1) whether female participants were pregnant, 2) whether female participants were currently breastfeeding or lactating, and 3) whether participants were on current or had received kidney
dialysis with the past year. A response of “yes” to any of these questions disqualified an individual from participating in the HFUS. HFUS participants were offered $100 in incentive for participating. Figure 2.1 and Figure 2.2 provide an overview of the study protocol and details about the recruitment process.

**Figure 2.1.** HFUS protocol flow chart.

Source: Heart Follow-Up Study Methodology report118
Figure 2.2: HFUS participation flow chart.

Source: Adapted from the Heart Follow-Up Study methodology report118

iii. The Hispanic Community Health Study/Study of Latinos (HCHS/SOL)

The Hispanic Community Health Survey/Study of Latinos (HCHS/SOL) is an on-going population based prospective cohort study of US Hispanics. It was designed to examine risk and protective factors for chronic disease in various Hispanic sub-groups.100 The dataset includes information from 16,415 Hispanic individuals who self-identify as Central American, Cuban, Dominican, Mexican, Puerto Rican, or South American.119 A stratified random two-stage area probability design was used to select participants from households in four US study sites: Bronx, New York; Chicago, Illinois; Miami, Florida; and San Diego,
California. Study details have been described elsewhere, but in brief between 2008 and 2011 selected study participants underwent thorough clinical examinations during which fasting blood samples were collected and a questionnaire was used to assess medical history. Twenty four hour dietary recall was used to obtain dietary information at baseline and a second recall six weeks later. Surveys were made available in English and Spanish. Protocols were standardized across study sites. The HCHS/SOL includes sampling weights and survey design variables to account for its complex survey design.

iv. Study of Latinos Nutrition and Physical Activity Assessment Study (SOLNAS)

The HCHS/SOL SOLNAS ancillary study was designed to validate subjective self-reported measures of physical activity and nutrients with more objective measurements and to re-calibrate self-reported measures, including sodium, potassium, and energy intake. In short, 485 HCHS/SOL participants were recruited into the SOLNAS study. Enrollment targets were set at each site per age, BMI, and Hispanic heritage to mirror the larger HCHS/SOL parent study. Any participants who were pregnant, breast feeding, had lost or gained 15 pounds in the past 4 weeks, taking medications for diabetes, or had extended travel plans throughout the course of the study were deemed ineligible for SOLNAS participation. Of 1,360 HCHS/SOL participants who were invited to participate and screened for eligibility, 485 (35.7% of the total) signed an informed consent form and participated in the study, see Figure 2.3.
Among those who participated in SOLNAS, anthropometric measurements were taken, and biomarkers were measured from 24-hour urine collections (described in further detail below). The SOLNAS study protocol consisted of two in clinic visits as well as in home activities. Details of the measurements which took place at various visits are displayed in Figure 2.4.
IV. The Study Sample

Study sample for specific aim 1 (Chapter 3): to be included in this study, participants had to have at least one income and at least one BMI measurement between 1990 (study baseline) and 2010. The final analytical sample included 4,730 of the original 5,114 CARDIA participants.

Study sample for specific aim 2 (Chapter 4): to be included in the HFUS analysis, participants had to have a zip code (to define the neighborhood) and have at least one outcome of interest (BMI, waist circumference, sodium, etc.).
potassium, or Na-K ratio). Of the original 1775 individuals who provided urine samples, a total of 116 were excluded due to an incomplete or biologically implausible urine sample, defined using the following criteria: total urine volume < 500 mL, creatinine (measure described in detail below) < 6.05 mmol for men or < 3.78 mmol for women, or a participant reporting missing a collection. An additional 11 individuals were excluded due to lack of zip-code information, resulting in a final analytic sample of 1645, see Figure 2.5 below.
Study sample for specific aim 3 (Chapter 5): to be included in the HCHS/SOL analysis, participants had to have at least one exposure of interest (24-hour dietary recall value for sodium or potassium) and at least one outcome of interest (BMI or waist circumference). Of the original 16,415 individuals who participated in the HCHS/SOL, a total of 225 were excluded due to missing data on sodium, potassium, or energy. An additional 15 were excluded due to missing body mass index or waist circumference data, and 19 individuals were excluded
due to lack of both dietary and obesity data. The final analytic sample for this analysis was 16,156, see Figure 2.6 below.

**Figure 2.6: HCHS/SOL and SOLNAS analytic sample flow chart.**

For the SOLNAS analysis (also Specific Aim 3 / Chapter 5), participants had to have at least one exposure of interest (24-hour urine/DLW value for sodium, potassium, or energy) and at least one outcome of interest (BMI, body fat, or percent body fat). Of the original 485 individuals who participated in the SOLNAS, a total of 7 were excluded because they did not collect urine, and an additional 31 samples were excluded due to incomplete urine collections. The final analytic sample for this analysis was 447, see Figure 2.6 above.
V. Study Variables

This section describes how each variable used in the analysis was measured and/or defined. Variables are presented according to their respective data source.

i. CARDIA Variables

a. Sustained poverty (predictor of interest):

Income data were collected in 1990, 1992, 1995, 2000, 2005, and 2010. At these examinations, pre-tax household income for the past 12 months from all sources was self-reported and recorded in income categories. The income category midpoint was chosen as the participant’s income for that year (see Table 3.1).

Using income category midpoint and family size at each examination period, Census Bureau Federal Poverty Level (FPL) thresholds were used to identify whether participants’ income was less than 200 percent of the FPL for that year. Having an income <200% of the FPL was defined as being in poverty for that year/study visit. The income cutoffs for 200% of the FPL for a four-person household were $26,718 in 1990, $28,670 in 1992, $31,138 in 1995, $35,206 in 2000, $39,942 in 2005, and $44,630 in 2010. At each visit, sustained poverty was then defined as the proportion of visits that a participant was living in poverty between 1990 (our study baseline) and that visit. Sustained poverty, i.e. proportion of visits in poverty, was updated at successive visits and thus treated
as a time-varying exposure variable. At any study visit, sustained poverty ranged from 0 (never in poverty) to 1 (in poverty at all previous visits including current).

b. BMI (outcome of interest)

At each examination between 1990 and 2010, participants’ height and weight were measured while wearing light clothes and no shoes. BMI was calculated as weight/height\(^2\) (kg/meters\(^2\)). If a woman reported being pregnant, her BMI was set to missing.

c. Other covariates

Age at the time of study baseline examination in 1990 was treated as a continuous variable and updated at each subsequent examination. Sex was collected at the first examination and coded as male or female. All participants of the CARDIA study were classified as either Black or White. Education was assessed at each examination and was based on the question, “What is the highest grade (or year) of regular school you have completed?” Response options ranged from 1 (elementary school) through 20 (graduate school). Years of education in 1990 was treated as a continuous variable. Participants were also asked about their parents’ education with the following question: What is the highest grade (or year) of regular school completed by your father/or man [mother/or woman] responsible for you as a child?” Highest education completed by either parent was selected. Smoking status was assessed at every examination and classified as never, former, or current. Smoking status was time updated at each study visit.
Physical activity was assessed at every examination. It was measured using the interview-administered CARDIA Physical Activity History Questionnaire. The questionnaire assessed the total amount of moderate and vigorous physical activity performed throughout the year spent in 13 categories of physical activity. Each activity is assigned an intensity score and duration. Based on frequency, intensity, and duration, “total exercise units” was calculated. Physical activity based on total exercise units was treated as a continuous variable and time updated at each study visit.

Symptoms of depression were assessed using the 20-item Center for Epidemiologic Studies Depression Scale (CES-D; range 0 to 60) at examinations in 1990, 1995, 2005, and 2010. Previously published statistical techniques were followed to calculate a time-weighted average of depressive symptoms over the study period to be used in the models given that depression was not assessed at each time point. Time weighted average depression was treated as a continuous variable.

ii. HFUS Variables

a. Measures of obesity (outcomes of interest)

During in-home visits, participants were weighed without shoes and weight was rounded to the pound. Height was also recorded without shoes and rounded to the hundredth inch. BMI was calculated as weight/height² (kg/meters²). Waist circumference was measured with tape at the top of the lateral border of the right ilium and rounded to the nearest hundredth inch.
b. Measures of diet (outcomes of interest)

HFUS participants provided 24-hour urine samples which were sent to the collaborating laboratory at the Mount Sinai Hospital and Medical School and analyzed for sodium and potassium. Sodium and potassium were measured using the ion-selective electrode potentiometric method on the Roche DPP Modular analyzer. All laboratory values were normalized to a 24-hour collection period (mg/day) and treated as continuous variables. Na-K ratio was defined as the ratio between sodium (mg/day) and potassium (mg/day). Creatinine, used to assess urine completeness, was measured using the Jaffe kinetic colorimetric method also on the Roche DPP Modular analyzer on the same analyzer. All laboratory values were normalized to a 24-hour collection period (mg/day).

c. Other covariates

During an interview, participants were asked to report the category which best described their current age with response options: “65 or older,” “45 – 64,” “30 – 44,” “25 – 29,” or “18 – 24.” Responses were further categorized into the following age groups: 65 or older, 45-64, 25-44, or 18-24. Participants were also asked to report their sex as either male or female. To assess ethnicity, participants were first asked whether they were Hispanic or Latino. Those who responded yes were coded as “Hispanic.” Next participants were asked which race category best described themselves with responses: “White,” “Black or
African American,” “Asian,” “Native Hawaiian or Other Pacific Islander,” “American Indian or Alaska Native,” or “Other.” Responses were then categorized into the following mutually exclusive race/ethnic groups: non-Hispanic White, non-Hispanic Black, Hispanic, non-Hispanic Asian, or non-Hispanic Other. Participants were asked, “What is the highest grade or year of school you completed?” Response options were: “Never attended school or only attended kindergarten,” “Grades 1 through 8 (elementary),” “Grades 9 through 11 (some high school),” “Grade 12 or GED (High school graduate),” “College 1 year to 3 years (some college or technical school),” or “College 4 years or more (college graduate).” Education was then categorized into the following mutually exclusive groups: less than high school, high school graduate or equivalent, some college, or college graduate or more. Participants also reported family size as the number of individuals per household and then reported whether their household income from all sources fell within categories based on income as a percentage of the FPL. Participants reported whether their incomes were < 100% of the FPL, 100 – 199% FPL, 200 – 299% FPL, 300 – 399% FPL, 400 – 499% the FPL, 500 – 599% the FPL, or 600% or more of the FPL. For reference, the FPL in 2010 for a household of four people was $22,050.\textsuperscript{128} Participants were asked whether a doctor had ever told them they had diabetes, those who reported “yes” were coded as having diabetes. Additionally, two seated blood pressure measurements five minutes apart were taken by trained medical technicians and averaged.\textsuperscript{127} Participants were also asked to self-report whether they were on anti-hypertension medication. Hypertension was
subsequently defined as having a systolic blood pressure ≥140 mmHg, a diastolic blood pressure ≥ 90, or self-reported use of antihypertension medications. Regarding employment, participants were asked to choose from the following options which best described their current situation: employed for wages or salary, self-employed, a homemaker, a student, retired, unable to work, unemployed for 1 year or more, or unemployed for less than 1 year. Responses were categorized into three mutually exclusive groups: employed (representing those employed for wages or salary, or self-employed), not currently in the work force (representing homemakers, students, retirees, or those unable to work) and unemployed.

Finally, physical activity was measured using a series of physical activity questions used to calculate total minutes of moderate and vigorous physical activity. It was treated as a categorical variable with participants who reported an average of 150 moderate or 75 vigorous minutes of physical activity per week considered to have met 2008 physical activity guidelines.

d. **Neighborhood level variables (predictor of interest)**

The neighborhood, defined by zip code, is linked to each participant. The measures described in the following sub-section refer to neighborhood-level variables.

Neighborhood education was created from aggregating individual level education. It represents the proportion of individuals in a neighborhood with less than a high school education (range 0 to 100%). Neighborhood poverty was
created from aggregating individual level poverty status. It represents the proportion of households in each neighborhood with income below 100% of the federal poverty threshold (range 0 to 100%). Neighborhood unemployment was created from aggregating individual level employment status. It represents the proportion of individuals in the neighborhood who are unemployed (range 0 to 100%).

Neighborhood-level perceived safety was created from aggregating individual level perceived neighborhood safety. Participants were asked, “How safe from crime do you consider your neighborhood to be.” Response options included: “extremely safe,” “quite safe,” “slightly safe,” or “not safe at all”. Responses were dichotomized so that perceiving a neighborhood as unsafe was characterized by the following responses: reporting “slightly safe,” or “not safe at all.” Thus, neighborhood-level perceived safety represents the proportion of individuals in a neighborhood reporting their neighborhood is unsafe (range 0 to 100%).

e. Neighborhood socio-economic status composite score

We used a factor analysis (described in further detail below) to create a neighborhood socio-economic factor score from four indicators of neighborhood socio-economic status (neighborhood education, neighborhood poverty, neighborhood unemployment, and neighborhood level perceived safety, described above). The neighborhood socio-economic factor score was then
categorized into tertiles to further characterize a neighborhood of being of low SES, middle SES, or high SES.

iii. HCHS SOL Variables

a. Dietary factors (predictors of interest)

Two 24-hour dietary recalls were collected from the full sample of HCHS/SOL participants; the first recall was collected during the in-person clinic interview at baseline, and the second recall was collected via phone within three months of the first recall. Depending on language preference, interviews were conducted in English and in Spanish. A foods-amount booklet was given to all participants to quantify portion sizes. Using the Nutrition Data System for Research (NDS-R) software which uses the multiple-pass method and developed by the HCHS/SOL coordinating center at the University of Minnesota. The NDS-R software includes over 18,000 foods, 8,000 brand-name products, including Hispanic foods. Values for dietary sodium (mg/day), potassium (mg/day), and energy (kcal/day) were derived from the mean of the two 24-hour dietary recalls. The following measures were further derived: dietary Na-K ratio, sodium density as sodium intake (mg) per 1000 kcal, and potassium density as potassium intake (mg) per 1000 kcal.

b. Measures of obesity (outcomes of interest)

Body mass index (BMI) in kg/m² was derived from measured weight and height wearing light clothing, and treated as a continuous variable. Waist
circumference in centimeters was measured using tape at standardized reference points, and treated as a continuous variable.

c. Other covariates

Age was reported as a continuous variable by each study participant. Participants reported their sex which was classified as male or female. Participants were asked to select a category that best described their Hispanic/Latino heritage, with responses including: Dominican or Dominican descent, Central American or Central American descent, Cuban or Cuban descent, Mexican or Mexican descent, Puerto-Rican or Puerto Rican descent, South American or South American descent, more than one heritage, or other. For the current study, “more than one heritage” and “other” were combined. To assess education, participants were asked, “What was the highest grade/level of education achieved?” Response options were: elementary/primary school (includes grade 1-5), Middle school/junior high school (includes grades 6-8), High school/preparatory school, Trade school/vocational school, University/college. Education was further categorized responses to reflect the following mutually exclusive groups: less than a high school education, a high school degree or equivalent, some college, college graduate or more. Participants were asked to report their annual household income (including all members of the household) in income ranges: <$10,000, $10,001 - $15,000, $15,001 - $20,000, $20,001 - $25,000 $25,001 - $29,999, $30,000 - $40,000, $40,001 - $50,000, $50,001 - $60,000, $60,001 - $75,000, $75,001 - $100,000, or more than $100,000. Categories were collapsed into the following mutually exclusive groups: <
Finally, participants were asked whether they preferred English or Spanish and language preference was coded as such. Participants reported their nativity (place of birth) and were classified as US born or foreign born. Participants born in Puerto Rico were considered foreign born. Participants who were identified as foreign-born further reported the duration (in years) that they had lived in the US. Nativity/years in the US was classified as: foreign born, < 10 years in the US; foreign born, 10+ years in the US; or US born.134

Smoking was categorized as former, current, or never smokers. Alcohol use was assessed using a series of questions which asked whether the participant currently drank and if so, how many drinks did the participant have on a typical week. A heavy drinker was defined as drinking more than 7 drinks per week for women and more than 14 drinks per week for men. Physical activity was self-reported using the modified version of the World Health Organization Global Physical Activity Questionnaire.135 It includes questions related to duration, and frequency of both moderate and vigorous physical activity. Using data from these questions, total metabolic equivalent task units was calculated and treated as a continuous variable.

The 2010 Alternative Healthy Eating Index (AHEI, range from 0 to 110), described elsewhere,136 was used to assess overall diet quality using the 24-hour dietary recall, with higher scores indicating a more healthy diet. Scoring is based on 11 components of diet, 6 of which are considered ideal in greater quantities (vegetables, fruits, whole grains, nuts and legumes, and long chain omega three
fatty acids), with one component ideal in moderation (alcohol), and with five components considered unfavorable (fruit drinks and sugar-sweetened beverages, red and processed meats, trans fats, and sodium).

Three seated BP measurements were taken by a trained medical technician using an automatic sphygmomanometer (OMRON HEM-907 L), and hypertension was defined as having average measured systolic BP ≥ 140 mmHg or diastolic BP ≥ 90 mmHg, or documented use of anti-hypertension medication.\textsuperscript{137} Diabetes status/impaired glucose classification was defined based on the American Diabetes Association criteria\textsuperscript{138} as fasting plasma glucose ≥126 mg/dL, a 2 hour post load glucose level ≥200 mg/dL, A1C level ≥6.5%, or documented use of hypoglycemic agents.\textsuperscript{139} From blood tests, chronic kidney disease was defined as having an estimated glomerular filtration rate <60 ml/min/1.73m\textsuperscript{2}.\textsuperscript{140} Depression score was assessed using the Center for Epidemiologic Studies Depression Scale-10 (CESD range 0 to 30)\textsuperscript{141} and treated as a continuous variable.

iv. SOLNAS Variables

The SOLNAS study is a sub-study of the parent HCHS/SOL and is therefore linked to the full HCHS/SOL sample. As such, variables listed in this section below represent unique contributions of the SOLNAS sample. Unless otherwise noted below, variables and definitions used in any analyses pertaining to SOLNAS are identical to those described in the HCHS/SOL section above.
a. Urinary sodium and potassium (predictors of interest)

SOLNAS participants collected urine for a period of 24 hours in between SOLNAS study visits 1 and 2 (see Figure 2.4). Urinary sodium (mg/day) and potassium (mg/day) was determined using the ion-selective electrode method (Roche Diagnostics, Indianapolis, IN) at the central HCHS/SOL laboratory at the University of Minnesota. During the collection periods, participants kept detailed records of the number of voids that they either missed or spilled. A total of 30 individuals with a urine sample less than 500 mL, missing biomarkers, or reporting two or more missed urine collections were excluded, resulting in a total of 447 participants with a complete urine sample (see Figure 2.9). To determine whether complete urine samples were indeed collected, para-amino benzoic acid testing was further conducted in a 10% random sample; none of the random samples were deemed incomplete. Urinary Na-K ratio was calculated as the ratio of urinary sodium (mg/day) to urinary potassium (mg/day) and treated as a continuous variable.

b. Energy intake

To assess energy, doubly labeled water (DLW) and urinary nitrogen recovery biomarkers were used over a two week period to estimate total energy expenditure which provides an accurate estimate of energy intake. Energy intake was normalized to reflect kilocalories per day and treated as a continuous variable. Using energy intake, urinary Sodium and potassium density were estimated. Sodium density was defined as urinary sodium (mg) per 1000 kcal
Potassium density was defined as urinary potassium (mg) per 1000 kcal (also assessed using DLW). Both were treated as continuous variables.

c. BMI, Body fat and percent body fat (outcomes of interest)

Body mass index (BMI) in kg/m² was derived from measured weight and height wearing light clothing,¹¹⁹ and treated as a continuous variable. Body fat and percent body fat were also assessed using DLW techniques.¹²¹ Body fat was measured in kg while percent body fat was measured as the percent of the body composition made of fat. Both were treated as continuous variables.

VI. Statistical Analysis Methods

This section provides details regarding general statistical analysis methods and techniques utilized in this dissertation. Details of the specific analyses conducted are organized by each specific aim/paper in the analytic approaches sub-section below.

i. Regression Modeling

Each outcome of interest in the current research is a continuous variable and thus linear regression modeling will be used in each instance. The current research will utilize standard linear regression approaches (Aim 3) and a multi-level modeling approach (Aims 1 and 2). Below, relevant variations of linear regression are highlighted with their respective equations.
a. Simple linear regression model (Aim 3)

**Equation 2.1**: Simple linear regression equation.

\[ Y = \alpha + \beta X + \varepsilon \]

Where \( Y \) is the outcome; \( \alpha \) is the \( Y \) intercept (or estimated outcome when the level of the predictor \( X \) is set to 0); \( \beta \) is the projected change in the outcome per one unit change in the predictor \( (X) \); \( \varepsilon \) is the residual term.

b. Multi-level linear regression model (Aims 1 and 2)

**Equation 2.2**: Multi-level regression equation (with random intercepts).

\[ Y_{ij} = \gamma_{00} + \gamma_{01}Z_j + \gamma_{10}X_{ij} + \varepsilon_{ij} + u_{0j} \]

Where: \( Y_{ij} \) is sodium level for \( i \)th individual in \( j \)th neighborhood (this is in the case of subjects within neighborhoods, in the case of repeated measures within a subject we would have \( i \) measures and \( j \) individuals); \( \gamma_{00} \) is mean sodium level across neighborhoods for average \( X \); \( \gamma_{01} \) is the change in intercept (mean sodium) per unit change in neighborhood variable \( Z_j \); \( \gamma_{10} \) is average change in sodium per change in the individual predictor \( (X) \); \( X_{ij} \) is individual level income (or another \( X \)) for \( i \)th individual in \( j \)th neighborhood; \( \varepsilon_{ij} \) is individual residual term; and \( u_{0j} \) is unique neighborhood from the average sodium level intercept.

ii. Complex Survey Design Effects

The HFUS, HCHS/SOL, and SOLNAS data sources are considered to have complex survey designs. In other words, survey sampling occurs by strata
and thus data are clustered or correlated. Additionally, certain populations may be over-sampled to obtain reliable estimates for traditionally underrepresented groups. To account for the correlation among participants of a given strata and to adjust estimates to reflect the population of interest, complex surveys include design variables and weights. Where applicable analyses in this dissertation accounted for survey clustering and oversampling by utilizing survey design variables. Both SUDAAN and MPLUS software were used to properly account for such design factors.

iii. Factor Analysis

Factor analysis is a statistical approach used to describe variance shared among observed variables. It can be used to combine multiple dimensions of a similar construct. Observed variables must be correlated (or share some variance), yet they must be distinct variables. Linear combinations of the observed variable plus error are used to model a single observed latent variable (or factor). This method was used in Aim 3 (further details in analytical approach specific to Aim 3).

iv. Statistical Packages

Several statistical packages were utilized in this research. For data management which encompassed: data manipulation, cleaning, and recoding, SAS Version 9.3 (SAS Institute, Cary, NC) was used. SAS was also used for all analyses of aim 1. For aims 2 and 3 SUDAAN (Research Triangle Institute, Research Triangle Park, NC) was used for all descriptive analyses. SUDAAN
and MPLUS Version 7 (Muthen & Muthen, Los Angeles, CA) were used for regression modeling of aims 2 and 3, as both packages can apply appropriate design weights.

v. Missing Data

Depending on the analysis type, missing data were approached in various ways. For Aim 1 (analytic approach discussed further in the next section), the SAS procedure \textit{proc mixed} was used. This procedure utilizes restricted maximum likelihood estimation which assumes data are missing at random and utilizes all the data that are present to compute the maximum likelihood estimate of a parameter. MPLUS approaches missing data with a similar technique as it utilizes full information maximum likelihood with pairwise deletion. This approach also assumes that data are missing at random. Finally, the default missing data approach in SUDAAN is listwise deletion. This approach excludes the entire observation if a single variable required for the analysis is missing. As less than 5\% of all data were missing on all variables used in analyses conducted with SUDAAN, it is unlikely that this missing data approach would result in substantial bias—especially if data are missing at random.

VII. Analytic Approach to the Specific Aims

Analytical techniques employed were structured by aim with further details provided in the corresponding chapters.
Analytical Approach for Aim 1:

Aim 1: Using data from the CARDIA study (N=5,114), determine the longitudinal association between sustained poverty and BMI growth rate over twenty years (1990-2010), and determine whether the associations varied by sex or race.

The data structure for this analysis included repeated outcome (BMI) and predictor (poverty) measures within each participant, over a 20-year period. The study period was from 1990 till 2010 including baseline and six follow-up visits. Linear mixed effects growth models with random intercepts were used to estimate the associations between a 10% increase in sustained poverty and BMI growth rate over the 20-year period. By using a random intercept, initial BMI could vary between individuals. Participants’ BMI was treated as a time-dependent outcome, and thus the model estimates BMI as a function of time. Time was operationalized as calendar years of the study (totaling 20 years) and the regression coefficient for year was interpreted as BMI rate of change per year. To determine the association between sustained poverty and BMI growth, a sustained poverty by time interaction term was included in all models. Quadratic terms for time (year²), which measured whether BMI growth leveled off over time, and a sustained poverty by quadratic time interaction was tested and retained in the models if significant. A four-way interaction between sustained poverty, time, sex, and race was tested in a model which included all lower level interactions, to determine whether the association between sustained poverty and BMI growth varied by race and sex. Significant interactions resulted in stratified models.
Figure 2.7: Model for the relationship tested in Specific Aim 1 between sustained poverty and BMI.

Analytical Approach for Aim 2:

Aim 2: Using data from the HFUS study (N=1,645), determine whether the neighborhood socio-economic environment is associated with individual level obesity (BMI and waist circumference) and measures of diet (sodium, potassium, and Na-K ratio) among diverse NYC adult residents, and determine whether these associations differ by sex.

The data structure of this analysis included 2 levels: 1645 individuals in level 1 who are nested within 128 neighborhoods in level 2. Multi-level linear regression models were used to determine whether neighborhood SES score (as tertiles) was associated with measures of obesity (BMI, waist circumference) and dietary measures (sodium, potassium, and NA-K ratio). The beta coefficient for each neighborhood SES tertile was interpreted as the neighborhood level effect
on the outcome. We tested for effect modification by sex in crude models; significant interactions resulted in stratified models. Data were analyzed with appropriate survey design weights.

**Figure 2.8:** Model for the relationships tested in Specific Aim 2 between neighborhood-level socio-economic status and individual-level obesity (BMI and waist circumference) and diet (sodium, potassium, and Na-K ratio).

**Analytical Approach for Aim 3:**

**Aim 3:** Using data from the HCHS/SOL study (N=16,415), determine whether dietary factors (sodium, potassium, and Na-K ratio) are associated with measures of obesity (BMI, waist circumference, body fat, and percent body fat) among diverse Hispanics, and whether these associations differ by nativity/years in the US.

Linear regression models were used to estimate the association between dietary factors (dietary sodium, sodium density, potassium, potassium density, and Na-K ratio) and measures of obesity (BMI and waist circumference) in the full HCHS/SOL sample. Models were tested for effect modification by
nativity/years in the US. Significant interaction terms resulted in stratified models. Data were analyzed with appropriate survey design weights.

Next, using data from the SOLNAS ancillary study, linear regression models were used to determine the associations between objectively measured dietary factors (urinary sodium, sodium density, potassium, potassium density, and Na-K ratio) and measures of obesity (BMI, body fat, and body fat percent). Data were analyzed with appropriate survey design weights.

**Figure 2.9:** Model for the relationships tested in Specific Aim 3 between diet (sodium, potassium, and Na-K) and obesity (BMI, waist circumference, body fat, and percent body fat).

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**VIII. Human Subjects Protection**

All analyses pertaining to this dissertation utilized de-identified data. The CARDIA study was approved by Internal Review Board (IRB) of each of the four CARDIA study sites. Additionally, the University IRB of the University of Miami reviewed the current study protocol and found it exempt from IRB approval (study number 20150405). The HFUS Study was approved by the IRB of the NYC
health department and the current study protocol was ruled exempt from IRB approval by the University of Miami IRB (study number 20160648). Finally, the HCHS/SOL and SOLNAS studies have both been approved by IRBs at the four study centers (including the University of Miami) as well as at the coordinating center at the University of North Carolina at Chapel Hill. Participants of all four studies provided informed consent.
Chapter 3: Specific Aim/Paper # 1 – Sustained Poverty and BMI

I. Background

Obesity is a major public health issue and one of the leading contributors to cardiovascular disease morbidity, mortality, and increased healthcare costs.\textsuperscript{1,2,40} About 38\% of the US adult population is currently obese,\textsuperscript{51} with obesity disproportionately affecting minorities and populations with fewer economic resources or living in poverty.\textsuperscript{54} Exposure to low income has been associated with being overweight or obese,\textsuperscript{54,63,143,144} and this association has been shown to differ by sex and race.\textsuperscript{54,63,143} For example, in women,\textsuperscript{145} particularly white women, low income is consistently associated with higher rates of obesity.\textsuperscript{54} This pattern is less consistent in black women\textsuperscript{143} and white men.\textsuperscript{54} On the other hand, in Black men low income has been shown to have an inverse relationship with obesity.\textsuperscript{54}

Though such associations are well-described cross-sectionally,\textsuperscript{54,145-153} the longitudinal association between low income or poverty and change in BMI is less established, especially by sex and race.\textsuperscript{154} A longitudinal design, with repeated measures of BMI over a prolonged period of time, is critical for making inference on the growth rate of the BMI trajectory. Further, given that income is dynamic,\textsuperscript{6,155} especially in young adults, having repeated measures of income is warranted for capturing fluctuations in income over time or sustained exposure to low income. Finally, prior studies have also suggested that the association between income and BMI may in part be due to downward social drift.\textsuperscript{144} –
meaning that being overweight or obese results in a loss of earned income\textsuperscript{156} – particularly for women.\textsuperscript{144,157} Consequently, utilizing a large ongoing cohort of black and white men and women adults of the Coronary Artery Risk Development in Young Adults (CARDIA) study, the goals of this study are: 1) to examine the cross-sectional association between income and BMI as in previous studies; 2) to examine the longitudinal association between sustained exposure to low income over 20 years and changes in BMI; and 3) to rule out downward drift/ reverse causation as a sole explanation of the findings.

II. Methods
i. Sample

CARDIA is an ongoing multicenter longitudinal cohort study which enrolled 5,114 participants aged 18 to 30 years old in 1985-86 from 4 field centers: the University of Alabama at Birmingham (Birmingham, AL), the University of Minnesota (Minneapolis, MN), Northwestern University (Chicago, IL), and Kaiser Permanente (Oakland, CA). Recruitment was balanced within center by sex, age, and education. Individuals were asked to participate at baseline and were re-examined in 1987, 1990, 1992, 1995, 2000, 2005, and 2010. Standardized protocols were used to gather demographic, social, and clinical data for each follow-up visit and across sites. Details of the study have been described elsewhere.\textsuperscript{116} Appropriate informed consent was obtained from each study participant. The study was approved by the institutional review boards from each field center and the coordinating center.
ii. Variables

a. Sustained poverty (exposure of interest)

Income data were collected in 1990, 1992, 1995, 2000, 2005, and 2010. At these examinations, pre-tax household income for the past 12 months from all sources was self-reported and recorded in income categories. The income category midpoint was chosen as the participant’s income for that year (Table 3.1).

Table 3.1: Description of income range and category midpoint.*

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<tr>
<th>Income Range</th>
<th>Category Midpoint</th>
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<tr>
<td></td>
<td>1990 - 1995</td>
</tr>
<tr>
<td>&lt;$5,000</td>
<td>$2,500</td>
</tr>
<tr>
<td>$5,000 through $11,999</td>
<td>$8,500</td>
</tr>
<tr>
<td>$12,000 through $15,999</td>
<td>$14,000</td>
</tr>
<tr>
<td>$16,000 through $24,999</td>
<td>$20,500</td>
</tr>
<tr>
<td>$25,000 through $34,999</td>
<td>$30,000</td>
</tr>
<tr>
<td>$35,000 through $49,999</td>
<td>$42,500</td>
</tr>
<tr>
<td>$50,000 through $74,999</td>
<td>$62,500</td>
</tr>
<tr>
<td>$75,000 and greater</td>
<td>$75,000</td>
</tr>
<tr>
<td>$75,000 through $99,999</td>
<td>n/a</td>
</tr>
<tr>
<td>$100,000 and greater</td>
<td>n/a</td>
</tr>
</tbody>
</table>

*In 2000 changes in the income groups were made to accommodate higher incomes. Income categories for incomes under $75,000 were constant for all study years.

Using income category midpoint and family size at each examination period, Census Bureau Federal Poverty Level (FPL) thresholds were used to identify whether participants’ income was less than 200 percent of the FPL for that year. Having an income <200% of the FPL was defined as being in poverty for that year/ study visit. The income cutoffs for 200% of the FPL for a four-person household were $26,718 in 1990, $28,670 in 1992, $31,138 in 1995,
$35,206 in 2000, $39,942 in 2005, and $44,630 in 2010. At each visit, sustained poverty was then defined as the proportion of visits that a participant was living in poverty between 1990 (our study baseline) and that visit. Sustained poverty, i.e. proportion of visits in poverty, was updated at successive visits and thus treated as a time-varying exposure variable. At any study visit, sustained poverty ranged from 0 (never in poverty) to 1 (in poverty at all previous visits).

b. BMI (outcome of interest)

At each examination between 1990 and 2010, participants' height and weight were measured while wearing light clothes and no shoes. BMI was calculated as weight/height² (kg/meters²). If a woman reported being pregnant, her BMI was set to missing.

c. Other covariates

CARDIA participants reported their sex, race, marital status, years of education completed, and years of education their parents completed. Highest level of parental education from either parent was used. Smoking status (defined as never, current, and former) and physical activity were ascertained by interview at each study examination. Total amount of exercise in units was calculated using reports of the amount of time per week spent in 13 categories of physical activity over the past year. Symptoms of depression were assessed using the 20-item Center for Epidemiologic Studies Depression Scale (CES-D; range 0 to 60) at examinations in 1990, 1995, 2005, and 2010. Previously published statistical techniques were followed to calculate a time-weighted average of
depressive symptoms over the study period to be used in the models given that depression was not assessed at each time point.

iii. Analytic Sample Size

To be included in this study, participants had to have at least one income and at least one BMI measurement between 1990 (our study baseline) and 2010. The final analytical sample included 4,730 of the original 5,114 CARDIA participants. Those included vs. excluded did not significantly differ with respect to age, sex, BMI or education but did differ by race (p<0.05): 5% of Whites vs. 10% of Blacks were excluded in the final analytical sample.

iv. Statistical Analyses

Differences in baseline characteristics of the study population were assessed overall and by exposure to poverty (comparing those never vs. ever in poverty over 20 years). Differences in means and proportions between covariates were tested using ANOVA and chi-square tests respectively. The distribution of sustained poverty between 1990 and 2010 was illustrated across sex and race groups. To examine the cross-sectional association between poverty and BMI at baseline (year 1990), t-tests were used to determine whether mean BMI differed between individuals in poverty vs. not in poverty.

To examine the longitudinal association, linear mixed effects growth models with random intercepts were used to estimate the associations between a 10% increase in sustained poverty and BMI growth rate over the 20-year period. By using a random intercept, initial BMI could vary between individuals. The data structure included year 1990 (baseline) and six follow-up time points through
2010. Participants’ BMI was treated as a time-dependent outcome, and thus the model estimates BMI as a function of time. Time was operationalized as calendar years of the study (from 1990 to 2010, totaling 20 years) and the regression coefficient for year was interpreted as BMI rate of change per year. To determine the association between sustained poverty (our predictor) and BMI growth (our outcome), a sustained poverty by time interaction term was included in all models. Quadratic terms for time (year²), which measured whether BMI growth leveled off over time, and a sustained poverty by quadratic time interaction were tested and retained in the models if significant. A four-way interaction between sustained poverty, time, sex, and race was tested in a model which included all lower level interactions, to determine whether the relationship between sustained poverty and BMI growth varied by race and sex. The interaction was significant (p-value=0.025) and thus all subsequent models were stratified by sex and race. Final models were adjusted for baseline age, education, parental education, time dependent marital status, smoking and physical activity, and time-weighted average depressive symptoms. We explored including hypertension as an adjustment covariate even though we hypothesized hypertension to be a consequence of increased BMI (our outcome)—ultimately hypertension was not retained as results with and without it were identical. Using the fully-adjusted model estimates, we illustrated the 20-year trajectories of BMI across different levels of sustained poverty (never in poverty or 0, in poverty 50% of visits, and always in poverty).
To address the possibility of reverse causation, i.e. that obesity results in loss of income and consequently poverty, we repeated the multivariable analysis in a sample restricted to those not obese at baseline. To do that, we excluded 827 people who in 1990 had a BMI $\geq 30$ kg/m$^2$. The rationale was that participants who were not obese at baseline (i.e. those retained in the restricted sample) were less likely to experience social drift, and thus any observed positive association between poverty and BMI in the restricted sample would be less likely due to reverse causation. Reverse causation would imply that any positive association observed in the full sample would become null in the restricted sample. All analyses were performed with R and SAS version 9.3. Significance testing was 2-sided at an alpha of 0.05 and 0.10 for interactions.

III. Results

Mean age at baseline in 1990 was 30.0 years old, 54.9% were women and 50.4% were Black (Table 3.2). Those ever in poverty between years 1990 and 2010 were more likely to be women, Black, have lower mean years of education, and lower mean parental education compared with those never in poverty. Compared with individuals never in poverty, those ever in poverty were less physically active and had higher number of depressive symptoms at baseline.
Table 3.2: Baseline characteristics of the study population, overall and by poverty.*

<table>
<thead>
<tr>
<th></th>
<th>Overall (N=4730)</th>
<th>Never In Poverty between 1990 - 2010 (n=2,446)</th>
<th>In Poverty At Least Once Between 1990 - 2010 (n=2,284)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years (std)</td>
<td>30.0 (3.6)</td>
<td>30.56 (3.3)</td>
<td>29.3 (3.8)</td>
</tr>
<tr>
<td>Female, N (%)</td>
<td>2596 (54.9)</td>
<td>1286 (52.6)</td>
<td>1310 (57.4)</td>
</tr>
<tr>
<td>Black, N (%)</td>
<td>2383 (50.4)</td>
<td>891 (36.4)</td>
<td>1492 (65.3)</td>
</tr>
<tr>
<td>Education, years (std)</td>
<td>14.4 (2.4)</td>
<td>15.3 (2.3)</td>
<td>13.4 (2.1)</td>
</tr>
<tr>
<td>Parental education, year (std)</td>
<td>13.8 (3.1)</td>
<td>14.4 (3.1)</td>
<td>13.2 (3.0)</td>
</tr>
<tr>
<td>Married, N (%)</td>
<td>1743 (36.9)</td>
<td>1135 (46.4)</td>
<td>608 (26.6)</td>
</tr>
<tr>
<td>1990 Income, dollars (std)</td>
<td>$34,666</td>
<td>$47,081</td>
<td>$21,246</td>
</tr>
<tr>
<td>Smoking, N (%)</td>
<td>$29,772</td>
<td>$40,486</td>
<td>$18,321</td>
</tr>
<tr>
<td>Never</td>
<td>2480 (52.4)</td>
<td>1415 (57.9)</td>
<td>1065 (46.6)</td>
</tr>
<tr>
<td>Current</td>
<td>609 (12.9)</td>
<td>374 (15.3)</td>
<td>235 (10.3)</td>
</tr>
<tr>
<td>Former</td>
<td>1240 (26.2)</td>
<td>449 (18.4)</td>
<td>791 (34.6)</td>
</tr>
<tr>
<td>Physical Activity, exercise units (std)</td>
<td>379.7 (292.5)</td>
<td>404.9 (291.9)</td>
<td>352.6 (290.9)</td>
</tr>
<tr>
<td>Depressive Symptoms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CES-D score (std)</td>
<td>11.2 (8.1)</td>
<td>9.5 (7.1)</td>
<td>13.1 (8.7)</td>
</tr>
<tr>
<td>CESD Score ≥ 16, N (%)</td>
<td>1042 (22.0)</td>
<td>381 (15.6)</td>
<td>661 (28.9)</td>
</tr>
</tbody>
</table>

*All means/proportions of characteristics differed significantly (p<0.01) across poverty groups using Chi-square or T-tests.

The distribution of sustained poverty (i.e. proportion of visits in poverty) between years 1990 and 2010 is displayed in Figure 3.1, by sex and race. Blacks (men and women) were more likely to always be in poverty (i.e. sustained poverty of 1) and less likely to have never been in poverty (i.e. sustained poverty of 0) compared with Whites.
Figure 3.1: Distribution of sustained poverty (1990 – 2010) across sex and race groups.

This density function (Figure 3.1) represents the probability of having a specific value of sustained poverty which is determined by both the height and width of each data point. Thus, height can exceed 1 with a narrow width. Sustained poverty values of “0.0” indicate never in poverty over the 20-year study period (i.e. between 1990 and 2010) and “1.0” indicates always in poverty.

At baseline in 1990, being in poverty vs. not was not cross-sectionally associated with BMI in White men (25.7 vs. 25.6, p=0.675), but was associated with lower BMI in Black men (25.9 vs. 26.8, p=0.006) and with higher BMI in White women (25.4 vs. 24.1, p=0.008), Table 3.3. There was no cross-sectional association in Black women (28.5 vs. 27.9, p=0.193).
Table 3.3: Mean BMI by poverty status in 1990 by race and sex.

<table>
<thead>
<tr>
<th></th>
<th>1990 Poverty Status</th>
<th></th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In Poverty</td>
<td>Not in Poverty</td>
<td></td>
</tr>
<tr>
<td>White Men</td>
<td>25.7</td>
<td>25.6</td>
<td>0.6750</td>
</tr>
<tr>
<td>Black Men</td>
<td>25.9</td>
<td>26.8</td>
<td>0.0063</td>
</tr>
<tr>
<td>White Women</td>
<td>25.4</td>
<td>24.1</td>
<td>0.0079</td>
</tr>
<tr>
<td>Black Women</td>
<td>28.5</td>
<td>27.9</td>
<td>0.1929</td>
</tr>
</tbody>
</table>

In White men, results from fully-adjusted linear mixed effects model showed that BMI increased each year; at baseline this rate was 0.24 units per year (95% CI: 0.21, 0.28, p<0.01). The quadratic term was significant but negative, indicating a leveling off of BMI growth (-0.004, p<0.01), (Table 3.4, Model 3). A 10% increase in sustained poverty was not associated with BMI (-0.019, p=0.47) but was associated with faster BMI growth (0.004, p=0.06). Estimates from the sample restricted to those not obese at baseline were less precise but comparable to those from the full sample.
Table 3.4: Multivariable associations between 10% increase in time-dependent sustained poverty and BMI between 1990 and 2010, among white men.

<table>
<thead>
<tr>
<th></th>
<th>All White Men (n=1105)</th>
<th>White Men with BMI &lt; 30 at baseline (n=976)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beta LCL UCL P</td>
<td>Beta LCL UCL P</td>
</tr>
<tr>
<td>Model 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>25.53 25.25 25.82 &lt;.001</td>
<td>24.52 24.29 24.75 &lt;.001</td>
</tr>
<tr>
<td>Poverty</td>
<td>0.006 -0.042 0.054 0.810</td>
<td>-0.029 -0.075 0.016 0.210</td>
</tr>
<tr>
<td>Year</td>
<td>0.26 0.23 0.29 &lt;.001</td>
<td>0.26 0.23 0.30 &lt;.001</td>
</tr>
<tr>
<td>Year*Poverty</td>
<td>0.004 0.000 0.008 0.046</td>
<td>0.004 0.000 0.008 0.054</td>
</tr>
<tr>
<td>Year^2</td>
<td>-0.005 -0.007 -0.003 &lt;.001</td>
<td>-0.005 -0.007 -0.003 &lt;.001</td>
</tr>
<tr>
<td>Model 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>26.39 23.5 29.29 &lt;.001</td>
<td>23.72 21.5 25.93 &lt;.001</td>
</tr>
<tr>
<td>Poverty</td>
<td>-0.012 -0.064 0.039 0.650</td>
<td>-0.032 -0.081 0.017 0.200</td>
</tr>
<tr>
<td>Year</td>
<td>0.25 0.22 0.29 &lt;.001</td>
<td>0.25 0.21 0.29 &lt;.001</td>
</tr>
<tr>
<td>Year*Poverty</td>
<td>0.004 0.000 0.009 0.034</td>
<td>0.005 0.001 0.009 0.024</td>
</tr>
<tr>
<td>Year^2</td>
<td>-0.005 -0.006 -0.003 &lt;.001</td>
<td>-0.004 -0.006 -0.003 &lt;.001</td>
</tr>
<tr>
<td>Model 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>26.91 23.94 29.89 &lt;.001</td>
<td>24.39 22.1 26.68 &lt;.001</td>
</tr>
<tr>
<td>Poverty</td>
<td>-0.019 -0.071 0.033 0.480</td>
<td>-0.031 -0.081 0.019 0.220</td>
</tr>
<tr>
<td>Year</td>
<td>0.24 0.21 0.28 &lt;.001</td>
<td>0.24 0.21 0.28 &lt;.001</td>
</tr>
<tr>
<td>Year*Poverty</td>
<td>0.004 0.000 0.008 0.056</td>
<td>0.003 -0.001 0.008 0.100</td>
</tr>
<tr>
<td>Year^2</td>
<td>-0.004 -0.006 -0.003 &lt;.001</td>
<td>-0.004 -0.006 -0.002 &lt;.001</td>
</tr>
</tbody>
</table>

Model 1 is crude; Model 2 is adjusted for age, education, time dependent marital status, and highest level of parental education; model 3 is additionally adjusted for time dependent smoking and physical activity, and time weight average depression.

Significance was determined at p<0.05 for main effects and p<0.10 for interactions.

In Black men, results from fully-adjusted model showed that BMI increased each year; at baseline this rate was 0.32 units per year (95% CI: 0.28, 0.36, p<0.01), Table 3.5. The quadratic term was negative, indicating a leveling off of BMI growth (-0.005, p<0.01). A 10% increase in sustained poverty was negatively associated with BMI (-0.049, p=0.04) and with slower BMI growth (-
0.008, p<0.01). Estimates from the sample restricted to those not obese at baseline were comparable to those from the full sample.

**Table 3.5**: Multivariable associations between 10% increase in time-dependent sustained poverty and BMI between 1990 and 2010, among black men.

<table>
<thead>
<tr>
<th></th>
<th>All Black Men (n=1029)</th>
<th>Black Men with BMI &lt; 30 at baseline (n=849)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beta</td>
<td>LCL</td>
</tr>
<tr>
<td><strong>Model 1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>26.64</td>
<td>26.25</td>
</tr>
<tr>
<td>Poverty</td>
<td>-0.061</td>
<td>-0.102</td>
</tr>
<tr>
<td>Year</td>
<td>0.32</td>
<td>0.28</td>
</tr>
<tr>
<td>Year*Poverty</td>
<td>-0.009</td>
<td>-0.011</td>
</tr>
<tr>
<td>Year^2</td>
<td>-0.005</td>
<td>-0.006</td>
</tr>
<tr>
<td><strong>Model 2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>24.16</td>
<td>19.98</td>
</tr>
<tr>
<td>Poverty</td>
<td>-0.055</td>
<td>-0.100</td>
</tr>
<tr>
<td>Year</td>
<td>0.32</td>
<td>0.28</td>
</tr>
<tr>
<td>Year*Poverty</td>
<td>-0.008</td>
<td>-0.011</td>
</tr>
<tr>
<td>Year^2</td>
<td>-0.005</td>
<td>-0.007</td>
</tr>
<tr>
<td><strong>Model 3</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>24.74</td>
<td>20.06</td>
</tr>
<tr>
<td>Poverty</td>
<td>-0.049</td>
<td>-0.095</td>
</tr>
<tr>
<td>Year</td>
<td>0.32</td>
<td>0.28</td>
</tr>
<tr>
<td>Year*Poverty</td>
<td>-0.008</td>
<td>-0.011</td>
</tr>
<tr>
<td>Year^2</td>
<td>-0.005</td>
<td>-0.007</td>
</tr>
</tbody>
</table>

Model 1 is crude; Model 2 is adjusted for age, education, time dependent marital status, and highest level of parental education; model 3 is additionally adjusted for time dependent smoking and physical activity, and time weight average depression.

Significance was determined at p<0.05 for main effects and p<0.10 for interactions.

In White women (Table 3.6, Model 3), results from fully-adjusted model showed that BMI increased each year; at baseline this rate was 0.25 units per year (95% CI: 0.21, 0.29, p<0.01). The quadratic term was negative, indicating a leveling off of BMI growth (-0.003, p<0.01). A 10% increase in sustained poverty
was associated with higher BMI (0.072, p<0.01), faster BMI growth (0.013, p=0.03), and earlier leveling off of BMI growth (-0.003, p=0.05). In the analysis restricted to those not obese at baseline, sustained poverty remained associated with faster BMI growth.

**Table 3.6:** Multivariable associations between 10% increase in time-dependent sustained poverty and BMI between 1990 and 2010, among white women.

<table>
<thead>
<tr>
<th>Model 1</th>
<th>All White Women (n=1242)</th>
<th>White Women with BMI &lt; 30 at baseline (n=1107)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>24.17 23.81 24.53 &lt;.001</td>
<td>22.84 22.56 23.12 &lt;.001</td>
</tr>
<tr>
<td>Poverty</td>
<td>0.079 0.029 0.130 0.002</td>
<td>0.044 -0.002 0.090 0.063</td>
</tr>
<tr>
<td>Year</td>
<td>0.27 0.23 0.31 &lt;.001</td>
<td>0.27 0.24 0.30 &lt;.001</td>
</tr>
<tr>
<td>Year*Poverty</td>
<td>0.016 0.005 0.028 0.005</td>
<td>0.007 0.003 0.010 &lt;.001</td>
</tr>
<tr>
<td>Year²</td>
<td>-0.004 -0.006 -0.002 &lt;.001</td>
<td>-0.004 -0.006 -0.002 &lt;.001</td>
</tr>
<tr>
<td>Year²*Poverty</td>
<td>-0.001 -0.001 0.000 0.023</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model 2</th>
<th>All White Women (n=1242)</th>
<th>White Women with BMI &lt; 30 at baseline (n=1107)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>31.25 27.54 34.96 &lt;.001</td>
<td>27.14 24.33 29.95 &lt;.001</td>
</tr>
<tr>
<td>Poverty</td>
<td>0.083 0.031 0.136 0.002</td>
<td>0.036 -0.012 0.085 0.100</td>
</tr>
<tr>
<td>Year</td>
<td>0.26 0.22 0.30 &lt;.001</td>
<td>0.25 0.22 0.28 &lt;.001</td>
</tr>
<tr>
<td>Year*Poverty</td>
<td>0.014 0.002 0.026 0.019</td>
<td>0.006 0.002 0.010 0.001</td>
</tr>
<tr>
<td>Year²</td>
<td>-0.003 -0.005 -0.002 0.003</td>
<td>-0.003 -0.005 -0.002 &lt;.001</td>
</tr>
<tr>
<td>Year²*Poverty</td>
<td>-0.001 -0.001 0.000 0.058</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model 3</th>
<th>All White Women (n=1242)</th>
<th>White Women with BMI &lt; 30 at baseline (n=1107)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>29.63 25.80 33.46 &lt;.001</td>
<td>26.72 23.8 29.64 &lt;.001</td>
</tr>
<tr>
<td>Poverty</td>
<td>0.072 0.019 0.124 0.008</td>
<td>0.033 -0.016 0.081 0.190</td>
</tr>
<tr>
<td>Year</td>
<td>0.25 0.21 0.29 &lt;.001</td>
<td>0.24 0.21 0.28 &lt;.001</td>
</tr>
<tr>
<td>Year*Poverty</td>
<td>0.013 0.001 0.025 0.029</td>
<td>0.005 0.001 0.009 0.008</td>
</tr>
<tr>
<td>Year²</td>
<td>-0.003 -0.005 -0.001 0.002</td>
<td>-0.003 -0.004 -0.001 &lt;.001</td>
</tr>
<tr>
<td>Year²*Poverty</td>
<td>-0.001 -0.001 0.000 0.054</td>
<td></td>
</tr>
</tbody>
</table>

Model 1 is crude; Model 2 is adjusted for age, education, time dependent marital status, and highest level of parental education; model 3 is additionally adjusted for time dependent smoking and physical activity, and time weight average depression.

Significance was determined at p<0.05 for main effects and p<0.10 for interactions.
In Black women, results from fully-adjusted model showed that BMI increased each year; at baseline this rate was 0.39 units per year (95% CI: 0.34, 0.43, p<0.01), Table 3.7. The quadratic term was negative, indicating a leveling off of BMI growth (-0.006, p<0.01). A 10% increase in sustained poverty was not associated with BMI (0.010, p=0.7) or with BMI growth (-0.002, p=0.14).

Estimates from the sample restricted to those not obese at baseline were comparable to those from the full sample.

**Table 3.7**: Multivariable associations between 10% increase in time-dependent sustained poverty and BMI between 1990 and 2010, among black women.

<table>
<thead>
<tr>
<th></th>
<th>All Black Women (n=1354)</th>
<th>Black Women with BMI &lt; 30 at baseline (n=971)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beta</td>
<td>LCL</td>
</tr>
<tr>
<td>Model 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>28.21</td>
<td>27.73</td>
</tr>
<tr>
<td>Poverty</td>
<td>-0.009</td>
<td>-0.054</td>
</tr>
<tr>
<td>Year</td>
<td>0.42</td>
<td>0.38</td>
</tr>
<tr>
<td>Year*Poverty</td>
<td>-0.002</td>
<td>-0.005</td>
</tr>
<tr>
<td>Year²</td>
<td>-0.008</td>
<td>-0.010</td>
</tr>
<tr>
<td>Model 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>26.77</td>
<td>21.69</td>
</tr>
<tr>
<td>Poverty</td>
<td>0.009</td>
<td>-0.040</td>
</tr>
<tr>
<td>Year</td>
<td>0.40</td>
<td>0.36</td>
</tr>
<tr>
<td>Year*Poverty</td>
<td>-0.001</td>
<td>-0.004</td>
</tr>
<tr>
<td>Year²</td>
<td>-0.007</td>
<td>-0.009</td>
</tr>
<tr>
<td>Model 3</td>
<td></td>
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</tr>
<tr>
<td>Intercept</td>
<td>25.80</td>
<td>20.41</td>
</tr>
<tr>
<td>Poverty</td>
<td>0.010</td>
<td>-0.040</td>
</tr>
<tr>
<td>Year</td>
<td>0.39</td>
<td>0.34</td>
</tr>
<tr>
<td>Year*Poverty</td>
<td>-0.002</td>
<td>-0.005</td>
</tr>
<tr>
<td>Year²</td>
<td>-0.006</td>
<td>-0.008</td>
</tr>
</tbody>
</table>

Model 1 is crude; Model 2 is adjusted for age, education, time dependent marital status, and highest level of parental education; model 3 is additionally adjusted for time dependent smoking and physical activity, and time weight average depression.

Significance was determined at p<0.05 for main effects and p<0.10 for interactions.
Figure 3.2 displays BMI trajectories between years 1990 and 2010 at various levels of sustained poverty (never in poverty, in poverty at 50% of visits, and always in poverty). Trajectories are based on the fully-adjusted models 3 of Tables 3.4, 3.5, 3.6, and 3.7.

**Figure 3.2:** Predicted trajectories of BMI between 1990 and 2010 by levels of sustained poverty, in the full sample and the restricted sample (BMI<30 kg/m²).
IV. Discussion

Over a 20-year period BMI increased in a curvilinear fashion in all sex-race groups. Our cross-sectional findings suggest that being in poverty at baseline in 1990 was associated with lower BMI in Black men and higher BMI in white women. Our longitudinal findings showed that the effect of sustained poverty on BMI growth also differed by sex and race. Increases in sustained poverty were associated with faster BMI growth among white men and women, and slower BMI growth among black men. There was no longitudinal association in black women. We found little evidence of reverse causation, as our main findings were mostly comparable in the sample restricted to those not obese at baseline. Taken together, our findings suggest that sustained poverty was a strong predictor of changes in BMI over the recent two decades in young to middle-aged adults, and that whites may be particularly vulnerable to the potential obesogenic effects of chronic poverty.

Like other studies, in white men, we found that poverty was not associated with BMI cross-sectionally. Results from repeated National Health and Nutrition Examination Surveys (NHANES) 1971-2002 showed inverse associations between income and BMI among white men, but not at every examination period. However, in the current study sustained poverty was longitudinally associated with changes in BMI. These seemingly contradictory findings highlight the importance of the longitudinal timeframe of the current analysis as well as the usage of multiple income assessments to characterize sustained exposure to poverty. In black men, the cross-sectional and longitudinal
associations were consistent and in line with prior research showing a protective effect of poverty on BMI. More specifically, that black men at higher vs. lower income distributions experience larger gains in BMI. It has been hypothesized that men in poverty are more likely to engage in occupations that are physically demanding and energy consuming, which could help explain this finding. Further, food insecurity has been shown to be more common in poor blacks vs. poor whites, offering a potential mechanistic explanation of the inverse association in black but not white men.

Women, on the other hand, have been shown to be more susceptible to the obesogenic effects of poverty than men. In a repeated cross-sectional study of Finnish adults aged 25-64 years, high income was associated with lower BMI among women. Similarly, data from NHANES showed strong inverse associations between income and BMI in white women at all examination periods. Consistent with prior literature, our findings, which used repeated income and BMI measurements, showed a BMI gradient by sustained poverty which grew more apparent over time. It is suggested that in white women, poverty and obesity may be mutually reinforcing due to the stigma that often accompanies being overweight or obese. In fact, white women experience income penalties for just being mildly overweight, and overweight/obese white women report more weight-based discrimination than overweight/obese black women or men. However, we found little evidence of reverse causation among white women, as our main findings were unchanged in analyses restricted to those not obese at baseline. In black women, the
association between income and other indicators of SES and obesity has been less consistent than in white women.\textsuperscript{54,158,165} Findings from NHANES have showed that among black women, lower income was associated with slower BMI growth.\textsuperscript{158} Yet, findings from other studies,\textsuperscript{143,165} such as the Study of Women’s Health Across the Nation showed no associations in black women. Our results mirror the later findings and show no longitudinal associations. Given the initially high BMI at baseline in black women, future studies may consider exploring the association even earlier in the life course.

Pathways underlying the relationship between poverty and health include low income being associated with unhealthy behaviors,\textsuperscript{166-168} limited access to resources,\textsuperscript{169} inadequate living environments such as limited access to recreational facilities,\textsuperscript{167} limited access to high quality foods,\textsuperscript{12,83,101,170} and greater exposure to stress-inducing mechanisms.\textsuperscript{171-174} However, such pathways cannot explain the inverse association found in black men. Furthermore, while BMI often increases with age, the steep and substantial BMI growth experienced by all sex and race groups over the 20-year period is most likely a reflection of the obesity epidemic. Yet, despite the large BMI increases, a quadratic trend was also observed in all groups indicating a slowdown in the obesity growth rate, a finding that has been matched by some studies.\textsuperscript{175,176} Whether this slowdown reflects a natural ceiling effect to the BMI trajectory or is a consequence of active obesity reduction initiatives,\textsuperscript{177} is unknown. However, recent findings from NHANES show that the prevalence of obesity has continuously increased in
women without a slowdown, warranting further investigation of BMI and obesity trends over time.

i. Limitations

This study has some limitations that are worth noting. Despite our cohort being relatively young (mean age of 30 at baseline), BMI differences by baseline poverty status were already established, and mean BMI was already high, especially among black women. Thus, the full extent of BMI growth could not be fully captured. Further, income was recorded as a range rather than actual income; though this would likely result in a non-differential bias if any.

ii. Strengths

Despite such limitations, this study has several strengths. The prospective design of our study allowed us to more accurately characterize the longitudinal relationship between income and BMI, and thus builds upon previous literature that is primarily cross-sectional. Additionally, our findings rely on repeated measurements of income and BMI over 20 years going from young adulthood into midlife. The bi-racial nature of the cohort allowed us to examine the associations across racial/ethnic and sex groups. Finally, our results were robust to analyses aimed at ruling out reverse causation/social drift as a sole explanation.

iii. Conclusions

In conclusion, between 1990 and 2010, increased sustained poverty was associated with faster BMI growth in white men and women, and with slower BMI growth in black men. These results could not be explained by reverse causation,
i.e. higher BMI resulting in low income. The current findings provide evidence supporting a link between sustained poverty and changes in BMI, especially in whites.
Chapter 4: Specific Aim/Paper # 2 – Neighborhood SES, Diet, and Obesity

I. Background

Obesity is a major public health crisis in the United States (US). Currently, two in three US adults are either overweight or obese. Obesity results directly from an energy imbalance—namely an overconsumption of energy coupled with insufficient levels of physical activity. Thus, quality of diet, often related to energy intake, is an important contributor to obesity such that poor dietary quality is associated with higher rates of obesity. For example, potassium intake, an indicator of fruit and vegetable consumption and healthy diet quality, is inversely associated with obesity. Likewise, sodium, as well as Na-K ratio, both indicators of diets high in processed foods, are associated with poor diet quality and higher rates of obesity.

Contributors to diet quality and obesity are multifactorial. Low socio-economic status (SES) has been associated with obesity, particularly among women, and with poor diet quality. Mechanisms underlying this relationship include poverty being associated with greater exposure to stress-inducing mechanisms and unhealthy behaviors. For example, for individuals of low SES, cost is often a barrier to healthy diet eating, and thus they often consume less nutritious, more calorie-dense and obesogenic food. Above and beyond these individual-level mechanisms, there is growing research to suggest that the neighborhood social environment may further contribute to poor diet quality and obesity through pathways related to...
inadequate access to healthy foods, recreational spaces, and neighborhood safety. For example, findings from the landmark Moving To Opportunity study showed that moving to a higher income neighborhood was associated with a lower prevalence of obesity\textsuperscript{184} and improved physical health outcomes in youth girls but not boys.\textsuperscript{185} Despite such findings and clear individual-level differences in the SES-obesity association by sex,\textsuperscript{54,144} the relationship between neighborhood SES and measures of obesity or diet quality are seldom explored by sex and results are mixed.\textsuperscript{123,186-188} Additionally, most neighborhood studies include subjective measures of diet quality such as healthy eating indices or self-reported fruit and vegetable intake,\textsuperscript{16,17,82,97,98,101} which can be prone to measurement error. To our knowledge, only two previous studies have included objectively measured biomarkers of diet such as sodium and potassium assessed via 24-hour urine collection.\textsuperscript{22,23}

Using data from the Heart Follow-Up Study (HFUS), a population based study of New York City (NYC) adult residents, we examined the cross-sectional association between neighborhood SES and measures of obesity, namely body mass index (BMI) and waist circumference (WC), and dietary biomarkers of sodium, potassium, and Na-K ratio assessed using the gold standard 24-hour urine collection. We also investigated whether these associations varied across sex.
II. METHODS

i. Sample

The New York City Community Health Survey (CHS) Heart Follow-Up Study (HFUS) is a cross-sectional study conducted in 2010 to assess population-based sodium intake from a representative sample of 1,775 NYC adults ages 18 years or older. Details of the study have been previously published and can be found in the comprehensive methodology report.\textsuperscript{118} Study participants in the HFUS were recruited from the CHS parent study, which is an annual telephone survey conducted by the NYC Health Department that includes 8,000 to 10,000 adult New Yorkers.\textsuperscript{117} To obtain a representative sample of non-institutionalized adult New Yorkers, the CHS uses a dual frame sample design consisting of random-digit-dial landline telephone exchanges and a second frame of cellular telephone exchanges that cover NYC. The CHS also incorporates a disproportionate stratified random sample design. In brief, study participants in the HFUS answered survey questions and collected urine for a 24-hour period. During a home visit, a trained medical technician took anthropometric measurements, aliquoted the urine, and sent it directly to the research laboratory. The complete clinical protocol has been described elsewhere.\textsuperscript{127} All study participants provided informed consent. This study was approved by the IRB at both the University of Miami and the NYC health department.

ii. Variables
a. Measures of obesity.

During in-home visits, participants were weighed without shoes and weight was rounded to the pound. Height was also recorded without shoes and rounded to the hundredth inch. BMI was calculated as measured weight in kg divided by measured height in meters-squared. WC was measured as waist girth at the top of the lateral border of the right ilium and rounded to the nearest hundredth inch.127

b. Urinary sodium and potassium

HFUS participants provided 24-hour urine samples which were sent to the collaborating laboratory at the Mount Sinai Hospital and Medical School and analyzed for sodium, potassium, and creatinine. Sodium and potassium were measured using the ion-selective electrode potentiometric method on the Roche DPP Modular analyzer. Creatinine, used to assess urine completeness, was measured using the Jaffe kinetic colorimetric method on the same analyzer. All laboratory values were normalized to a 24-hour collection period (mg/day). Sodium, potassium, and creatinine measures from 24-hour urine collection were linked to participants’ survey responses. Na-K ratio was defined as the ratio between sodium (mg/day) and potassium (mg/day).

c. Other Covariates

Through survey questionnaires, participants reported their age in age groups (18-24, 25-44, 45-64, or 65+), sex, and race/ethnicity (white non-hispanic, black non-hispanic, hispanic, asian, or other). Participants reported family size as the number of individuals per household, and reported whether their
household income from all sources fell within categories based on income as a percentage of the FPL. For reference, the FPL in 2010 for a household of four people was $22,050.128 Participants reported whether their incomes were < 100% of the FPL, 100 – 199% FPL, 200 – 299% FPL, 300 – 399% FPL, 400 – 499% the FPL, 500 – 599% the FPL, or 600% or more of the FPL. Participants also reported their educational attainment defined as: < high school (HS), HS graduate, some college, or college graduate or more. Employment status was recorded and defined as employed, unemployed, or not in the labor force. Participants were also asked whether a doctor had ever told them they had diabetes, those who reported “yes” were coded as having diabetes. Additionally, two seated blood pressure measurements five minutes apart were taken by trained medical technicians and averaged.127 Participants were also asked to self-report whether they were on anti-hypertension medication. Hypertension was subsequently defined as having a systolic blood pressure ≥140 mmHg, a diastolic blood pressure ≥ 90, or self-reported use of antihypertension medications. Participants also answered a series of questions about their physical activity which were used to calculate their total minutes of moderate and vigorous physical activity.129 Participants who reported an average of 150 moderate or 75 vigorous minutes of physical activity per week were considered to have met 2008 physical activity guidelines.130
d. Neighborhood SES

Neighborhoods were defined per zip codes which were linked to each HFUS participant. We used factor analysis to create a neighborhood SES factor
score using zip code level variables. The principle factor method was utilized to estimate factor scores with a loading threshold of 0.3 set to indicate whether a variable should be retained. The final selected variables included: percentage of households in the neighborhood with income 100% below the Federal poverty line, percentage of individuals in the neighborhood who are unemployed, percentage of individuals in the neighborhood with less than a HS education, and percentage of individuals in a neighborhood who report living in an unsafe neighborhood. Perceiving a neighborhood as unsafe (“slightly safe” or “not safe at all”) was reported in response to the question of “How safe from crime do you consider your neighborhood to be” with responses including “extremely safe,” “quite safe,” “slightly safe,” or “not safe at all”. We then created tertiles from the neighborhood SES score to further characterize neighborhoods as having low SES, middle SES, or high SES.

iii. Statistical Analyses

Of the original 1775 individuals who provided urine samples, a total of 116 were excluded due to an incomplete or biologically implausible urine sample, defined using the following criteria: total urine volume < 500 mL, creatinine < 6.05 mmol for men or < 3.78 mmol for women, or a participant reporting missing a collection. An additional 11 individuals were excluded due to lack of geographic residence (zip code) information, resulting in a final analytic sample of 1645.

The data structure of this analysis includes 2 levels: 1645 individuals in level 1 who are nested within 128 neighborhoods in level 2. We first assessed
individual-level socio-demographic characteristics of the sample overall and by sex. We then assessed neighborhood-level characteristics overall and across tertiles of neighborhood SES score. Next we estimated mean obesity (BMI and WC) and mean dietary characteristics (sodium, potassium, and Na-K ratio) across tertiles of neighborhood SES score, for women and men separately. We used t-tests to determine whether differences were significant across tertiles using high SES neighborhood as the reference category. All means and proportions were age standardized to the US 2010 population.

To determine whether a multi-level model was appropriate (i.e. whether overall variation in each outcome of interest is explained by the neighborhood SES score), we calculated intraclass correlations. Intraclass correlations were 4.4%, 3.6%, 0.17%, 6.6%, and 8.0% respectively for BMI, WC, sodium, potassium, and Na-K ratio, indicating sufficient neighborhood level clustering for all outcomes but sodium. We then fit multi-level linear regression models to determine whether neighborhood SES score (as tertiles) was associated with BMI, WC, sodium, potassium, and NA-K ratio. We tested for effect modification by sex in crude models; neighborhood SES by sex interactions were significant for outcomes of potassium (p<0.05) and WC (p<0.05), all models were then stratified by sex. We adjusted for individual level age, race/ethnicity, education, poverty, employment status, diabetes, hypertension, physical activity (for BMI and WC models), and BMI (for sodium, potassium, and Na-K models). Data were analyzed with survey weights and design variables using SUDAAN (version
10.0; Research Triangle Institute, Research Triangle Park, North Carolina) and MPLUS (Version 7; Muthen and Muthen 1998-2012).

III. Results

Approximately 13.3% of the NYC adult population was age 18-24, 44% were age 25-44, 28% were 45-64, and 15% were 65 or older (Table 4.1). A total of 39% of the population was non-hispanic white, 23% was non-hispanic black, 24% was hispanic, and 10% was asian. Approximately 21% had less than a HS education, 48% were under 200% of the FPL, and 10% were unemployed. Compared with men, women were more likely to have less than a HS education and be in poverty, and less likely to be employed.
**Table 4.1**: Individual-level socio-demographic characteristics of the study sample, overall and by sex.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Overall (N=1645)</th>
<th>Men (n=689)</th>
<th>Women (n=956)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% (SE)</td>
<td>% (SE)</td>
<td>% (SE)</td>
</tr>
<tr>
<td>Age group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18-24</td>
<td>13.3 (1.6)</td>
<td>14.0 (2.4)</td>
<td>12.6 (2.3)</td>
</tr>
<tr>
<td>25-44</td>
<td>43.5 (2.0)</td>
<td>45.4 (3.1)</td>
<td>41.8 (2.7)</td>
</tr>
<tr>
<td>45-64</td>
<td>27.9 (1.6)</td>
<td>27.7 (2.4)</td>
<td>28.0 (2.2)</td>
</tr>
<tr>
<td>65+</td>
<td>15.4 (1.2)</td>
<td>12.9 (1.6)</td>
<td>17.5 (1.8)</td>
</tr>
<tr>
<td>Race/Ethnicity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>39.0 (1.7)</td>
<td>45.8 (2.6)</td>
<td><strong>33.5 (2.3)</strong></td>
</tr>
<tr>
<td>Black</td>
<td>23.4 (1.5)</td>
<td>21.9 (2.2)</td>
<td>24.4 (2.2)</td>
</tr>
<tr>
<td>Hispanic</td>
<td>23.6 (1.6)</td>
<td>16.9 (2.0)</td>
<td><strong>29.3 (2.4)</strong></td>
</tr>
<tr>
<td>Asian</td>
<td>10.3 (1.4)</td>
<td>11.4 (2.3)</td>
<td>9.4 (1.6)</td>
</tr>
<tr>
<td>Other</td>
<td>3.7 (1.4)</td>
<td>4.0 (1.3)</td>
<td>3.5 (1.1)</td>
</tr>
<tr>
<td>Less than HS Education</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; HS</td>
<td>21.3 (1.7)</td>
<td>17.6 (2.4)</td>
<td><strong>24.5 (2.5)</strong></td>
</tr>
<tr>
<td>HS</td>
<td>27.0 (1.8)</td>
<td>27.6 (2.7)</td>
<td>26.7 (2.4)</td>
</tr>
<tr>
<td>Some college</td>
<td>22.0 (1.5)</td>
<td>23.4 (2.4)</td>
<td>20.7 (2.0)</td>
</tr>
<tr>
<td>College grad</td>
<td>29.6 (1.5)</td>
<td>31.3 (2.4)</td>
<td>28.1 (2.0)</td>
</tr>
<tr>
<td>Poverty</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 200% FPL</td>
<td>48.1 (1.9)</td>
<td>41.9 (2.9)</td>
<td><strong>53.0 (2.6)</strong></td>
</tr>
<tr>
<td>≥200% FPL</td>
<td>45.9 (1.8)</td>
<td>54.0 (2.7)</td>
<td><strong>39.2 (2.4)</strong></td>
</tr>
<tr>
<td>Don’t know/Refused</td>
<td>6.0 (1.1)</td>
<td>4.1 (1.2)</td>
<td>7.7 (1.9)</td>
</tr>
<tr>
<td>Employment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Employed</td>
<td>56.7 (1.8)</td>
<td>62.6 (2.3)</td>
<td><strong>51.2 (2.6)</strong></td>
</tr>
<tr>
<td>Unemployed</td>
<td>10.4 (1.2)</td>
<td>10.8 (1.60)</td>
<td>10.1 (1.6)</td>
</tr>
<tr>
<td>Not in labor force</td>
<td>32.9 (1.6)</td>
<td>26.6 (1.9)</td>
<td><strong>38.7 (2.4)</strong></td>
</tr>
</tbody>
</table>

Estimates are age standardized to the US 2000 population
Boldface indicates proportion differs significantly in women compared with men.

Table 4.2 shows the distribution of neighborhood-level characteristics across tertiles of the neighborhood SES score. The proportion of households with income <100% of the FPL (i.e. defined in poverty) was 38% in the lowest neighborhood SES tertile compared with 6% in the highest neighborhood SES tertile. The proportion of individuals reporting living in an unsafe neighborhood
was 56% in the lowest neighborhood SES tertile and 10% in the highest neighborhood SES tertile. Likewise, the proportion of individuals who are unemployed or with less than a HS education was highest (12% and 27% respectively) in the lowest neighborhood SES tertile and was lowest in the highest neighborhood SES tertile (6% and 7% respectively).

**Table 4.2:** Neighborhood-level characteristics of the study sample, overall and across tertiles of the neighborhood socioeconomic status score.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Overall</th>
<th>Neighborhood SES Score Tertile</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of households with income &lt; 100% of the FPL</td>
<td>21%</td>
<td>38% 18% 6%</td>
</tr>
<tr>
<td>% of individuals reporting their neighborhood is unsafe</td>
<td>31%</td>
<td>56% 27% 10%</td>
</tr>
<tr>
<td>% of individuals who are unemployed</td>
<td>90%</td>
<td>12% 10% 6%</td>
</tr>
<tr>
<td>% of individuals with less than a HS education</td>
<td>14%</td>
<td>27% 13% 7%</td>
</tr>
</tbody>
</table>

Mean 24-hour urinary sodium excretion was 3240 mg/day and did not differ significantly by neighborhood tertile in men or women (Table 4.3). Among men, living in a low vs. high SES neighborhoods was associated with significantly lower urinary potassium excretion (2131 vs. 2404 mg, p<0.01), and higher Na-K ratio (1.92 vs. 1.61, P=0.01). Among women, residing in a low vs. high SES neighborhood was associated with higher BMI (29.3 vs. 26.1 kg/m², p<0.01), higher WC (36.4 vs. 32.9 inches, p<0.01), and lower urinary potassium excretion (1911 vs. 2238, p<0.01). Additionally, women residing in middle vs. high SES neighborhoods also had significantly higher BMI (28.3 vs. 26.1 kg/m², p<0.01),
higher WC (35.8 vs. 32.9 inches, p<0.01), and lower urinary potassium excretion (1890 vs. 2238, p<0.01).

**Table 4.3**: Mean obesity and dietary characteristics of the study sample across tertiles of neighborhood SES score, stratified by sex.

<table>
<thead>
<tr>
<th></th>
<th>MEN</th>
<th></th>
<th>WOMEN</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Neighborhood SES Score Tertile</td>
<td></td>
<td>Neighborhood SES Score Tertile</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low N=216</td>
<td>Middle n=258</td>
<td>High n=215</td>
<td>Low N=422</td>
</tr>
<tr>
<td><strong>Mean (SE)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI (kg/m2)</td>
<td>28.6 (0.5)</td>
<td>28.6 (0.8)</td>
<td>27.3 (0.6)</td>
<td>29.3 (0.5)</td>
</tr>
<tr>
<td>Waist Circum. (inch)</td>
<td>37.6 (0.5)</td>
<td>37.6 (0.7)</td>
<td>36.9 (0.5)</td>
<td>36.4 (0.4)</td>
</tr>
<tr>
<td>Sodium (mg/day)</td>
<td>2699 (159)</td>
<td>3734 (134)</td>
<td>3377 (159)</td>
<td>2961 (106)</td>
</tr>
<tr>
<td>Potassium (mg/day)</td>
<td>2131 (87)</td>
<td>2667 (135)</td>
<td>2404 (92)</td>
<td>1911 (63)</td>
</tr>
<tr>
<td>Na-K Ratio</td>
<td>1.92 (0.08)</td>
<td>1.63 (0.08)</td>
<td>1.61 (0.10)</td>
<td>1.73 (0.07)</td>
</tr>
</tbody>
</table>

Estimates are age standardized to the US 2010 population. Bold face indicates estimate is significantly different from the reference group (high SES).

In multilevel linear regression models, neighborhood SES was not associated with individual-level BMI, Table 4.4. Among women, in crude models, living in a low vs. high SES neighborhood was significantly associated with 3.60 kg/m² higher BMI (95% CI: 2.00, 5.19). Likewise, living in a middle vs. high neighborhood SES was significantly associated with 2.21 kg/m² higher BMI (95% CI: 1.00, 3.43). Adjusting for individual-level socio-demographic factors (models 2 and 3) slightly attenuated the associations but remained significant. These associations remained significant in fully-adjusted models. Specifically, living in a low vs. high SES neighborhood was associated with 1.93 inches higher BMI.
(95% CI: 0.47, 3.38). Living in a middle vs. high neighborhood SES was significantly associated with 1.58 kg/m² higher BMI (95% CI: 0.41, 2.74).

**Table 4.4:** Associations of tertiles of neighborhood SES score with individual-level BMI by sex.

<table>
<thead>
<tr>
<th>Model</th>
<th>BMI (kg/m²)</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beta (95% CI)</td>
<td>Beta (95% CI)</td>
<td></td>
</tr>
<tr>
<td>Model 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Neighborhood SES</td>
<td>1.17 (-0.39, 2.74)</td>
<td>3.60 (2.00, 5.19)</td>
<td></td>
</tr>
<tr>
<td>Middle Neighborhood SES</td>
<td>1.12 (-1.69, 3.93)</td>
<td>2.21 (1.00, 3.43)</td>
<td></td>
</tr>
<tr>
<td>High Neighborhood SES</td>
<td>Ref</td>
<td>Ref</td>
<td></td>
</tr>
<tr>
<td>Model 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Neighborhood SES</td>
<td>0.92 (-0.63, 2.47)</td>
<td>2.37 (0.84, 3.89)</td>
<td></td>
</tr>
<tr>
<td>Middle Neighborhood SES</td>
<td>1.00 (-1.47, 3.47)</td>
<td>1.79 (0.49, 3.10)</td>
<td></td>
</tr>
<tr>
<td>High Neighborhood SES</td>
<td>Ref</td>
<td>Ref</td>
<td></td>
</tr>
<tr>
<td>Model 3</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Low Neighborhood SES</td>
<td>0.62 (-1.11, 2.35)</td>
<td>2.25 (0.70, 3.80)</td>
<td></td>
</tr>
<tr>
<td>Middle Neighborhood SES</td>
<td>0.85 (-1.56, 3.25)</td>
<td>1.65 (0.36, 2.94)</td>
<td></td>
</tr>
<tr>
<td>High Neighborhood SES</td>
<td>Ref</td>
<td>Ref</td>
<td></td>
</tr>
<tr>
<td>Model 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Neighborhood SES</td>
<td>0.28 (-1.33, 1.89)</td>
<td>1.93 (0.47, 3.38)</td>
<td></td>
</tr>
<tr>
<td>Middle Neighborhood SES</td>
<td>0.76 (-1.62, 3.14)</td>
<td>1.58 (0.41, 2.74)</td>
<td></td>
</tr>
<tr>
<td>High Neighborhood SES</td>
<td>Ref</td>
<td>Ref</td>
<td></td>
</tr>
</tbody>
</table>

Model 1 is unadjusted; Model 2 is adjusted for individual-level age, and race/ethnicity; Model 3 is additionally adjusted for individual-level education, poverty, and employment status; Model 4 is additionally adjusted for individual-level diabetes, hypertension, and physical activity.

In multilevel linear regression models, neighborhood SES was not associated with individual-level WC among men, Table 4.5. Among women, in crude models, living in a low vs. high SES neighborhood was significantly associated with 2.94 inches larger WC (95% CI: 0.80, 5.09). Likewise, living in a middle vs. high neighborhood SES was significantly associated with 2.00 inches larger WC (95% CI: 0.46, 3.58). Adjusting for individual-level socio-demographic
factors (models 2 and 3) slightly attenuated the associations but remained significant. In fully-adjusted models, living in a low vs. high SES neighborhood was no longer associated with WC (1.82; 95% CI: -0.12, 3.76). Living in a middle vs. high neighborhood SES was significantly associated with 1.52 inches larger WC (0.50, 2.98).

**Table 4.5:** Associations of tertiles of neighborhood SES score with individual-level waist circumference by sex

<table>
<thead>
<tr>
<th>Model 1</th>
<th>Waist Circumference (inches)</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beta (95% CI)</td>
<td></td>
<td>Beta (95% CI)</td>
</tr>
<tr>
<td>Low Neighborhood SES</td>
<td>0.19 (-1.42, 1.81)</td>
<td>2.94 (0.80, 5.09)</td>
<td></td>
</tr>
<tr>
<td>Middle Neighborhood SES</td>
<td>0.18 (-1.77, 2.13)</td>
<td>2.00 (0.46, 3.58)</td>
<td></td>
</tr>
<tr>
<td>High Neighborhood SES</td>
<td>Ref</td>
<td>Ref</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Model 2</th>
<th>Waist Circumference (inches)</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beta (95% CI)</td>
<td></td>
<td>Beta (95% CI)</td>
</tr>
<tr>
<td>Low Neighborhood SES</td>
<td>0.55 (-1.24, 2.33)</td>
<td>2.21 (0.19, 4.24)</td>
<td></td>
</tr>
<tr>
<td>Middle Neighborhood SES</td>
<td>0.35 (-1.52, 2.23)</td>
<td>1.83 (0.27, 3.39)</td>
<td></td>
</tr>
<tr>
<td>High Neighborhood SES</td>
<td>Ref</td>
<td>Ref</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Model 3</th>
<th>Waist Circumference (inches)</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beta (95% CI)</td>
<td></td>
<td>Beta (95% CI)</td>
</tr>
<tr>
<td>Low Neighborhood SES</td>
<td>0.18 (-1.74, 2.09)</td>
<td>2.07 (0.01, 4.14)</td>
<td></td>
</tr>
<tr>
<td>Middle Neighborhood SES</td>
<td>0.29 (-1.57, 2.14)</td>
<td>1.69 (0.05, 3.33)</td>
<td></td>
</tr>
<tr>
<td>High Neighborhood SES</td>
<td>Ref</td>
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</table>

<table>
<thead>
<tr>
<th>Model 4</th>
<th>Waist Circumference (inches)</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beta (95% CI)</td>
<td></td>
<td>Beta (95% CI)</td>
</tr>
<tr>
<td>Low Neighborhood SES</td>
<td>-0.13 (-1.95, 1.69)</td>
<td>1.82 (-0.12, 3.76)</td>
<td></td>
</tr>
<tr>
<td>Middle Neighborhood SES</td>
<td>0.17 (-1.69, 1.72)</td>
<td>1.52 (0.50, 2.98)</td>
<td></td>
</tr>
<tr>
<td>High Neighborhood SES</td>
<td>Ref</td>
<td>Ref</td>
<td></td>
</tr>
</tbody>
</table>

Model 1 is unadjusted; Model 2 is adjusted for individual-level age, and race/ethnicity; Model 3 is additionally adjusted for individual-level education, poverty, and employment status; Model 4 is additionally adjusted for individual-level diabetes, hypertension, and physical activity.

In multilevel models, neighborhood SES was only associated with sodium among women in fully adjusted models. Middle vs. high neighborhood SES was associated with a 268 mg/day lower sodium (95% CI: -516, -20), Table 4.6.
Table 4.6: Associations of tertiles of neighborhood SES with individual-level urinary sodium excretion, by sex.

<table>
<thead>
<tr>
<th>Model</th>
<th>Sodium (mg/day)</th>
<th>Men Beta (95% CI)</th>
<th>Women Beta (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Model 1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Neighborhood SES</td>
<td>12 (-426, 451)</td>
<td>42 (-217, 301)</td>
<td></td>
</tr>
<tr>
<td>Middle Neighborhood SES</td>
<td>64 (-410, 538)</td>
<td>-61 (-318, 195)</td>
<td></td>
</tr>
<tr>
<td>High Neighborhood SES</td>
<td>Ref</td>
<td>Ref</td>
<td></td>
</tr>
<tr>
<td><strong>Model 2</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Neighborhood SES</td>
<td>-2 (-512, 508)</td>
<td>-116 (-362, 129)</td>
<td></td>
</tr>
<tr>
<td>Middle Neighborhood SES</td>
<td>77 (-335, 489)</td>
<td>-156 (-416, 103)</td>
<td></td>
</tr>
<tr>
<td>High Neighborhood SES</td>
<td>Ref</td>
<td>Ref</td>
<td></td>
</tr>
<tr>
<td><strong>Model 3</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Neighborhood SES</td>
<td>-21 (-591, 550)</td>
<td>-130 (-404, 144)</td>
<td></td>
</tr>
<tr>
<td>Middle Neighborhood SES</td>
<td>80 (-325, 486)</td>
<td>-183 (-452, 87)</td>
<td></td>
</tr>
<tr>
<td>High Neighborhood SES</td>
<td>Ref</td>
<td>Ref</td>
<td></td>
</tr>
<tr>
<td><strong>Model 4</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Neighborhood SES</td>
<td>63 (-477, 603)</td>
<td>-226 (-502, 50)</td>
<td></td>
</tr>
<tr>
<td>Middle Neighborhood SES</td>
<td>142 (-200, 484)</td>
<td><strong>-268 (-516, -20)</strong></td>
<td></td>
</tr>
<tr>
<td>High Neighborhood SES</td>
<td>Ref</td>
<td>Ref</td>
<td></td>
</tr>
</tbody>
</table>

Model 1 is crude; Model 2 is adjusted for individual-level age, and race/ethnicity; Model 3 is additionally adjusted for individual-level education, poverty, and employment status; Model 4 is additionally adjusted for individual-level diabetes, hypertension, and BMI.

Among men, living in a low vs. high SES neighborhood was significantly associated with 403 mg/day less potassium (95% CI: -628, -178); this association became non-significant with further adjustments, Table 4.7. Among women, in an unadjusted model, living in a low or middle SES neighborhood vs. high SES neighborhood was significantly associated with 426 mg/day less potassium (95% CI: -614, -238) and 425 mg/day less potassium (95% CI: -604, -245), respectively. These associations were attenuated but remained significant after adjusting for individual-level covariates. In fully-adjusted models, living in a low or
middle SES neighborhood vs. high SES neighborhood was significantly associated with 258 mg/day less potassium (95% CI: -418, -99) and 350 mg/day less potassium (95% CI: -516, -185), respectively.

Table 4.7: Associations of tertiles of neighborhood SES with individual-level urinary potassium excretion, by sex.

<table>
<thead>
<tr>
<th></th>
<th>Potassium (mg/day)</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Men</td>
<td>Women</td>
</tr>
<tr>
<td></td>
<td>Beta (95% CI)</td>
<td>Beta (95% CI)</td>
</tr>
<tr>
<td>Model 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Neighborhood SES</td>
<td>-403 (-628, -178)</td>
<td>-426 (-614, -238)</td>
</tr>
<tr>
<td>Middle Neighborhood SES</td>
<td>-14 (-235, 208)</td>
<td>-425 (-604, -245)</td>
</tr>
<tr>
<td>High Neighborhood SES</td>
<td>Ref</td>
<td>Ref</td>
</tr>
<tr>
<td>Model 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Neighborhood SES</td>
<td>-98 (-323, 127)</td>
<td>-266 (-446, -86)</td>
</tr>
<tr>
<td>Middle Neighborhood SES</td>
<td>235 (-101, 571)</td>
<td>-331 (-509, -152)</td>
</tr>
<tr>
<td>High Neighborhood SES</td>
<td>Ref</td>
<td>Ref</td>
</tr>
<tr>
<td>Model 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Neighborhood SES</td>
<td>31 (-195, 257)</td>
<td>-244 (-415, -73)</td>
</tr>
<tr>
<td>Middle Neighborhood SES</td>
<td>319 (-13, 651)</td>
<td>-328 (-507, -148)</td>
</tr>
<tr>
<td>High Neighborhood SES</td>
<td>Ref</td>
<td>Ref</td>
</tr>
<tr>
<td>Model 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Neighborhood SES</td>
<td>39 (-183, 261)</td>
<td>-258 (-418, -99)</td>
</tr>
<tr>
<td>Middle Neighborhood SES</td>
<td>318 (21, 616)</td>
<td>-350 (-516, -185)</td>
</tr>
<tr>
<td>High Neighborhood SES</td>
<td>Ref</td>
<td>Ref</td>
</tr>
</tbody>
</table>

Model 1 is crude; Model 2 is adjusted for individual-level age, and race/ethnicity; Model 3 is additionally adjusted for individual-level education, poverty, and employment status; Model 4 is additionally adjusted for individual-level diabetes, hypertension, and BMI.

Finally, living in a low vs. high SES neighborhood was associated with 0.40-unit higher Na-K ratio for men (95% CI: 0.13, 0.66) and 0.36-unit higher Na-K ratio for women (95% CI: 0.16, 0.56), only in the unadjusted models, Table 4.8. The associations became non-significant with further adjustments.
Table 4.8: Associations of tertiles of neighborhood SES with individual-level urinary sodium to potassium ratio by sex.

<table>
<thead>
<tr>
<th>Model 1</th>
<th>Men Na-K Ratio Beta (95% CI)</th>
<th>Women Na-K Ratio Beta (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Neighborhood SES</td>
<td>0.40 (0.13, 0.66)</td>
<td>0.36 (0.16, 0.56)</td>
</tr>
<tr>
<td>Middle Neighborhood SES</td>
<td>0.13 (-0.10, 0.36)</td>
<td>0.27 (0.05, 0.49)</td>
</tr>
<tr>
<td>High Neighborhood SES</td>
<td>Ref</td>
<td>ref</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model 2</th>
<th>Men Na-K Ratio Beta (95% CI)</th>
<th>Women Na-K Ratio Beta (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Neighborhood SES</td>
<td>0.11 (-0.13, 0.34)</td>
<td>0.09 (-0.08, 0.27)</td>
</tr>
<tr>
<td>Middle Neighborhood SES</td>
<td>-0.08 (-0.33, 0.17)</td>
<td>0.13 (-0.04, 0.30)</td>
</tr>
<tr>
<td>High Neighborhood SES</td>
<td>Ref</td>
<td>ref</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model 3</th>
<th>Men Na-K Ratio Beta (95% CI)</th>
<th>Women Na-K Ratio Beta (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Neighborhood SES</td>
<td>0.05 (-0.19, 0.29)</td>
<td>0.04 (-0.13, 0.21)</td>
</tr>
<tr>
<td>Middle Neighborhood SES</td>
<td>-0.11 (-0.34, 0.12)</td>
<td>0.10 (-0.07, 0.26)</td>
</tr>
<tr>
<td>High Neighborhood SES</td>
<td>Ref</td>
<td>ref</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model 4</th>
<th>Men Na-K Ratio Beta (95% CI)</th>
<th>Women Na-K Ratio Beta (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Neighborhood SES</td>
<td>0.03 (-0.21, 0.27)</td>
<td>-0.02 (-0.19, 0.16)</td>
</tr>
<tr>
<td>Middle Neighborhood SES</td>
<td>-0.14 (-0.37, 0.09)</td>
<td>0.06 (-0.12, 0.24)</td>
</tr>
<tr>
<td>High Neighborhood SES</td>
<td>Ref</td>
<td>ref</td>
</tr>
</tbody>
</table>

Model 1 is crude; Model 2 is adjusted for individual-level age, and race/ethnicity; Model 3 is additionally adjusted for individual-level education, poverty, and employment status; Model 4 is additionally adjusted for individual-level diabetes, hypertension, and BMI.

IV. Discussion

Findings from this study suggest strong associations between low neighborhood SES and higher BMI and WC, and lower urinary potassium excretion among women but not men. Among women, residing in a low vs. high SES neighborhood was associated with a 1.93 kg/m² higher BMI and a 258 mg/day lower urinary potassium excretion, above and beyond individual-level
characteristics. Results suggest that women may be particularly vulnerable to obesogenic and other negative effects of residing in a low SES neighborhood.

Several studies point to an association between neighborhood SES and measures of obesity.\textsuperscript{11,88,181-183} For example, findings from the Dallas Heart Study, a multiethnic cohort, found that moving from a higher to a lower SES neighborhood was associated with weight gain.\textsuperscript{182} Likewise, among women of the Black Women’s Health Study, lower neighborhood SES was associated with ten year weight gain.\textsuperscript{189} In our multiethnic cohort of NYC adult residents, we too found that living in a low SES neighborhood was associated with measures of obesity such as higher BMI—however, the association was only present in women. Prior work has shown individual-level SES to be more strongly associated with obesity in women than in men.\textsuperscript{54,144} However, in the neighborhood literature, the association between neighborhood SES and measures of obesity is seldom explored by sex, and results are mixed.\textsuperscript{123,186-188} Among participants of the 1986 American’s Changing Lives Study, neighborhood poverty was associated with higher BMI among women but not men.\textsuperscript{123} Contrary to our findings, results from the Multi-Ethnic Study of Atherosclerosis found no association between the social environment and BMI among women.\textsuperscript{188} Further studies exploring associations between the neighborhood environment and obesity with a focus on sex differences are warranted to help clarify these conflicting findings.

On the other hand, low neighborhood SES was not associated with urinary sodium excretion in men or women. Given the low sodium intraclass
correlations, indicative of no neighborhood level sodium clustering, this was expected. Further, findings from another study conducted in the same HFUS cohort, also showed that neighborhood poverty alone was not associated with individual sodium intake. Results from a Japanese cohort of young women similarly showed no association between neighborhood SES and 24-hour urinary sodium excretion. We hypothesize that these results point to ubiquity of sodium in the US food supply—which is regardless of neighborhood characteristics, and thus, we are all equally exposed. Similarly, on an individual level, 24-hour urinary sodium excretion has not been shown to differ by poverty status in either men or women.

Though neighborhood SES was not associated with sodium, we did find strong associations with 24-hour urinary potassium excretion—an objective indicator of fruit and vegetable consumption and healthy diet. Prior studies have also linked neighborhood characteristics to individual diet quality. In Japan, neighborhood availability of supermarkets is associated with higher urinary potassium excretion. Other studies which have focused on the neighborhood SES environment, often correlated with the neighborhood retail environment, have echoed these results. Findings from the National Health Nutrition and Examination survey show that higher neighborhood SES was associated with increased fruit and vegetable intake. Likewise, in a study conducted in another NYC sample, residing in a neighborhood of low vs. high SES was associated with reporting lower fruit and vegetable intake.
Previous studies have signaled gender differences in the associations between individual-level SES and fruit and vegetable consumption.\textsuperscript{25,193} However, to our knowledge prior neighborhood studies in the US have not explored these relationships by sex in detail or utilized 24-hour potassium excretion as a measure of diet quality. A systematic review of European studies did find that lower neighborhood SES was associated with lower fruit and vegetable consumption, with no sex differences detected.\textsuperscript{191} But, in our study, we found neighborhood SES to be a strong indicator of objectively measured potassium among women but not men. While our findings directly contradict prior results from the same HFUS cohort showing no neighborhood poverty-potassium association,\textsuperscript{22} our methods differed in a number ways. We included more neighborhood level units (i.e. 128 vs 42 neighborhoods), our neighborhood SES construct was comprised of multiple dimensions of SES, rather than just poverty, and we directly tested for and found a significant interaction by sex. Had we used overall and not sex-stratified models we would not have detected an association. Finally, Na-K ratio also differed by neighborhood SES. In unadjusted models, residing in a neighborhood of low vs. high SES was associated with a 0.40 and 0.36-unit higher Na-K ratio in men and women respectively. Though limited studies exist, our finding mirrors a study of Japanese women which showed that low vs. high neighborhood SES was associated with higher Na-K ratio, adjusting for only minimal individual level characteristics such as living status and region of residence.\textsuperscript{190} However, in our
study, associations of neighborhood poverty with Na-K were no longer significant once we adjusted for covariates.

i. Limitations

The current study has few limitations that are worth noting. First, while our study was population based and representative of non-institutionalized NYC adults, our results may not necessarily be extrapolated to other geographical locations given the uniqueness of NYC neighborhoods. We also relied on zip codes to define neighborhoods, though lower level groups such as census blocks exist but could not be accessed. Additionally, 24-hour urine measures reflect sodium and potassium intake during the previous day and may not necessarily be indicative of habitual sodium and potassium consumption. Further, given the multi-level nature of the analysis we were not adequately powered to test for interaction by race/ethnicity. Finally, the HFUS was cross-sectional, thus any observed associations may reflect self-selection of certain individuals into certain neighborhoods rather than the effect of a neighborhood on an individual.194

ii. Strengths

Despite such limitations, the study possesses noteworthy strengths. Our measure of neighborhood SES was rich as it utilized a variety of SES domains. Most notably, our outcomes were objectively measured and therefore subject to less measurement error. This is particularly true of our dietary indicators, the HFUS study is the only population-based representative study in the US to use the gold-standard of 24-hour urine to measure sodium and potassium intake.

iii. Conclusions
In our study, representative of NYC adults, residing in a low vs. high SES neighborhood was associated with measures of obesity and lower urinary potassium excretion among women but not men. This research contributes to the growing body of evidence showing that the neighborhood environment is associated with health. We highlight that the association of SES with obesity and potassium—an objective dietary biomarker—is moderated by sex. Future research related to neighborhood level effects should focus on exploring such sex differences.
I. Background

Two of every three adults in the United States (US) is either overweight or obese.\(^{39}\) Obesity, or excess body fat, results from an energy imbalance—namely an overconsumption of energy coupled with insufficient levels of physical activity.\(^{42}\) It is no surprise then, that the current obesity epidemic in the US has been at least partly attributed to the increasingly processed diet and its composition,\(^{43,44}\) which is not only energy-dense\(^{44,45}\) but also rich in sodium and low in potassium.\(^{44}\) More than 90% of US adults consume sodium in excess of the United States Department of Agriculture recommendations.\(^{47}\) While high amounts of dietary sodium are concerning primarily due to the well-established blood pressure raising effect of sodium,\(^{106}\) there is emerging evidence to suggest that sodium may also be associated with obesity.\(^{28-34,108-112}\) On the other hand, potassium, a nutrient found commonly in fruits and vegetables and an indicator of diet healthfulness,\(^{26}\) is lacking in most diets.\(^{44}\) Currently, less than 2% of the US adults consume adequate amounts of potassium.\(^{47}\) Further, given the ubiquity of sodium in the US diet,\(^{46}\) coupled with lack of potassium, Na-K ratio has increased overtime and is less than ideal.\(^{44}\) Yet, the relationships of potassium and Na-K ratio with obesity have not been explored in great detail. Findings from limited studies suggest that lower potassium and higher Na-K ratio are associated with greater rates of obesity.\(^{35,110,115}\)

In minority populations, such as US Hispanics/Latinos, the relationships among sodium, potassium, Na-K ratio, and obesity are particularly pertinent and
yet they remain underexplored. Hispanics/Latinos have higher dietary sodium intake, lower dietary potassium intake,\textsuperscript{36} and higher rates of obesity\textsuperscript{37} compared with non-Hispanic whites. Further, Hispanic/Latinos have a unique acculturation experience during which their dietary habits and quality tend to worsen with greater duration of residence in the US.\textsuperscript{38} Thus, understanding how dietary composition such as sodium and potassium are associated with obesity outcomes among Hispanics/Latinos, the fastest-growing US minority population, is of great medical and public health interest.

Establishing a direct association between dietary nutrients, sodium in particular, and obesity independent of energy intake is particularly important yet challenging given the strong correlation between nutrients such as sodium and energy intake. Thus, adequately accounting for energy is critical. Yet, most prior studies have adjusted for energy intake derived from dietary recall or food frequency questionnaire,\textsuperscript{28,30-33,109} both of which are prone to measurement error.\textsuperscript{195} Fewer studies have explored sodium density (estimated as sodium divided by energy intake) in relation to obesity,\textsuperscript{29,111} and to our knowledge, no prior study in the US has used doubly labeled water (DLW) method\textsuperscript{196} to objectively measure and quantify energy intake.

Using data from the Hispanic Community Health Study/Study of Latinos (HCHS/SOL), an ongoing population-based study of 16,415 US Hispanics/Latinos, we will examine the following: 1) the association of dietary sodium, sodium density, potassium, potassium density, and Na-K ratio with measures of obesity, and 2) whether these associations vary by duration of US
residence. We will also use data from the ancillary Study of Latinos Nutrition & Physical Activity Assessment Study (SOLNAS) to determine the associations of gold standard 24-hour urine collected sodium, potassium, Na-K ratio with measures of obesity after controlling for DLW derived energy.

II. Methods:

i. Sample

The HCHS/SOL is a population based study of 16,415 community dwelling self-identified Hispanics/Latinos of varying heritage. In brief, participants aged 18-74 were recruited in areas surrounding 4 field sites: Bronx, NY; Chicago, IL, Miami-Dade, FL; and San Diego, CA. A two-stage area probability sample of households was selected; stratification and over-sampling at each stage was utilized to obtain a diverse and representative sample of Hispanics/Latinos. Once selected, participants underwent a comprehensive examination between 2008-2011. Participants were asked to bring in their current medications for review, to undergo a clinical examination, have fasting blood samples collected, answer a questionnaire pertaining to their medical histories and health behaviors, including a 24-hour diet recall. After excluding 259 individuals without at least one exposure and outcome of interest, our final analytic HCHS/SOL sample was 16,156 (see Figure 2.6). All participants provided informed consent and the study was approved by each study site Institutional Review Board. Detailed study methods have been described elsewhere. In 2010, a sub-set of HCHS/SOL participants (n=485) enrolled in the SOLNAS ancillary study whose primary aim was to assess measurement error
of nutrients derived from dietary recall, including sodium, potassium, and energy intake. Twenty-four-hour urine samples were collected. All participants provided informed consent.

ii. Variables

a. Indicators of Diet (sodium and potassium)

   *24-hour dietary recall sodium, potassium and energy measures:* Two 24-hour dietary recalls were collected from the full sample of HCHS/SOL participants; the first recall was collected during the in-person clinic interview at baseline, and the second recall was collected via phone three months later. Depending on language preference, interviews were conducted in English and in Spanish. A foods-amount booklet was given to all participants to quantify portion sizes. Using the Nutrition Data System for Research (NDS-R) software which uses the multiple-pass method and developed by the HCHS/SOL coordinating center at the University of Minnesota, values for dietary sodium (mg/day), potassium (mg/day), and energy (kcal/day) were derived. The following measures were further derived: dietary Na-K ratio, sodium density as sodium intake (mg) per 1000 kcal, and potassium density as potassium intake (mg) per 1000 kcal. The NDS-R software includes over 18,000 foods, 8,000 brand-name products, including Hispanic foods. The two dietary recalls were averaged; 99% of the sample provided at least one dietary recall. Sodium, potassium, and energy intake were derived from the mean of two 24-hour dietary recalls.

   *24-hour urinary sodium, potassium, and energy measures:* A total of 477 of the 485 (98%) SOLNAS participants collected urine for a period of 24 hours
Urinary sodium (mg/day) and potassium (mg/day) was determined using the ion-selective electrode method (Roche Diagnostics, Indianapolis, IN) at the central HCHS/SOL laboratory at the University of Minnesota. A total of 30 individuals with a urine sample less than 500 mL, missing biomarkers, or reporting two or more missed urine collections were excluded, resulting in a total of 447 participants with a complete urine sample. To determine whether complete urine samples were indeed collected, para-amino benzoic acid testing was further conducted in a 10% random sample; none of the random samples were deemed incomplete. Using a DLW recovery biomarker, total energy expenditure was assessed over a 2-week period and used as a more accurate measure of energy intake. The following measures were further derived: Na-K ratio, sodium density as sodium intake (mg) per 1000 kcal, and potassium density as potassium intake (mg) per 1000 kcal.

b. Measures of Obesity

Body mass index (BMI) in kg/m² was derived from measured weight and height wearing light clothing. Waist circumference (WC) in centimeters was measured using standardized reference points. Additionally, in the SOLNAS subsample, DLW methods, described elsewhere, were used to measure body fat in kg and percent body fat.

c. Other Covariates

All study participants reported their language preference (Spanish or English), age, sex, and educational attainment (< high school, high school degree, or more than high school). Individuals also reported their incomes which
were grouped into categories: < $20,000, $20,000 - $50,000, ≥ $50,000, or missing income. Participants were asked to select a category that best described their Hispanic/Latino heritage, with responses including, Dominican, Central American, Cuban, Mexican, Puerto-Rican, South American, more than one group, or other. Additionally, participants reported their nativity (place of birth) and were classified as US born or foreign born. Participants born in Puerto Rico were considered foreign born. Participants who were identified as foreign-born further reported the duration (in years) that they had lived in the US. Nativity/years in the US was classified as: foreign born, < 10 years in the US; foreign born, 10+ years in the US; or US born.134

Participants reported their smoking status (never, current, or former) and alcohol consumption (‘heavy drinkers’ were defined as having more than 7 drinks/week for women and more than 14 drinks/week for men). Physical activity was self-reported using the modified version of the World Health Organization Global Physical Activity Questionnaire.135 Described elsewhere,136 the 2010 alternative healthy eating index (AHEI, range from 0 to 110) was used to assess overall diet, with higher scores indicating a more healthful diet. Three seated BP measurements were taken using an automatic sphygmomanometer (OMRON HEM-907 L), and hypertension was defined as having average measured systolic BP ≥ 140 mmHg or diastolic BP ≥ 90 mmHg, or documented use of anti-hypertension medication.137 Diabetes status/impaired glucose classification was defined based on the American Diabetes Association criteria138 as fasting plasma glucose ≥126 mg/dL, a 2 hour postload glucose level ≥200 mg/dL, A1C level
≥6.5%, or documented use of hypoglycemic agents. Chronic kidney disease (CKD) was defined as having an estimated glomerular filtration rate <60 ml/min/1.73m². Depression score was assessed using the Center for Epidemiologic Studies Depression Scale-10 (CESD range 0 to 30).

iii. Statistical Analyses

Demographic and clinical characteristics of the HCHS/SOL sample were assessed overall and by nativity/years in the US. Mean dietary sodium, sodium density, potassium, potassium density, and Na-K ratio was assessed by nativity/years in the US. T-tests were used to determine whether means differed by nativity/years in the US, with US born as the referent category. Estimates were age adjusted to the US 2010 standard population.

Next using linear regression models, we first examined whether nativity/years in the US modified the associations between each dietary exposure and measures of obesity using multiplicative interaction terms. We found that nativity/years in the US modified the associations of dietary potassium, potassium density, and Na-K ratio with BMI and WC (p values of interactions < 0.05), but not sodium or sodium density, thus resulting in stratified models for potassium, potassium density, and Na-K ratio. Model 1 was adjusted for age, sex, Hispanic/Latino heritage, education, income, language preference, and study site; and model 3 was additionally adjusted for smoking, hypertension, diabetes, chronic kidney disease, alcohol use, depression, physical activity, and energy intake (except in density models).
We repeated similar linear regression models, in the SOLNAS sub-sample, to estimate the associations between urinary sodium, sodium density, potassium, potassium density, and Na-K ratio with measures of obesity. Due to sample size limitations in SOLNAS we did not test for effect modification by nativity/years in US. All associations were estimated for increments of: 500 mg/day for sodium and potassium, 250 per 1000 kcal for sodium and potassium density, and 0.50 for Na-K ratio. Analyses were conducted in SUDAAN (Version 11.0.1, Research Triangle Institute, NC).

III. Results

The mean age was 41 years old, and approximately 53% were women (Table 5.1). Hispanic/Latino heritage differed with 10% Dominican, 7% Central American, 21% Cuban, 37% Mexican, 16% Puerto Rican, and 5% South American. In total, 34% had less than a high school education, 43% had an income < 20,000 per year, 76% preferred Spanish to English, 21% smoked, 25% had hypertension, and about 17% had diabetes. Mean daily energy intake was 1893 kcal and mean AHEI diet score was 47.8. Compared with those born in the US, those foreign born were less likely to be of Mexican or Puerto Rican heritage, and to have CKD and were more likely to have lower levels of educational attainment, lower incomes, prefer Spanish, and have higher AHEI scores.
Table 5.1: Demographic and clinical characteristics of the HCHS/SOL overall and by nativity/years in the US.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Overall</th>
<th>By Nativity/Years in the US</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N=16,156</td>
<td>Foreign Born, &lt; 10 years in the US</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Foreign Born, 10+ years in the US</td>
</tr>
<tr>
<td></td>
<td></td>
<td>US Born</td>
</tr>
<tr>
<td></td>
<td>% (SE)</td>
<td>% (SE)</td>
</tr>
<tr>
<td>Age, mean (SE)</td>
<td>41.1 (0.2)</td>
<td>38.6 (0.4)</td>
</tr>
<tr>
<td>Female</td>
<td>52.6 (0.5)</td>
<td>54.8 (1.0)</td>
</tr>
<tr>
<td>Heritage group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominican</td>
<td>9.8 (0.7)</td>
<td>8.3 (0.9)</td>
</tr>
<tr>
<td>Central American</td>
<td>7.3 (0.5)</td>
<td>8.8 (0.9)</td>
</tr>
<tr>
<td>Cuban</td>
<td>21.1 (1.7)</td>
<td>40.0 (2.9)</td>
</tr>
<tr>
<td>Mexican</td>
<td>36.5 (1.6)</td>
<td>30.1 (2.3)</td>
</tr>
<tr>
<td>Puerto Rican</td>
<td>16.4 (0.8)</td>
<td>3.6 (0.6)</td>
</tr>
<tr>
<td>South American</td>
<td>5.1 (0.3)</td>
<td>7.2 (0.7)</td>
</tr>
<tr>
<td>More than one/other</td>
<td>3.9 (0.3)</td>
<td>2.0 (0.3)</td>
</tr>
<tr>
<td>&lt; HS Education</td>
<td>33.5 (0.7)</td>
<td>28.7 (1.1)</td>
</tr>
<tr>
<td>&lt; $20,000 Income</td>
<td>42.5 (0.9)</td>
<td>47.8 (1.4)</td>
</tr>
<tr>
<td>Spanish language Preference</td>
<td>76.4 (0.9)</td>
<td>98.2 (0.3)</td>
</tr>
<tr>
<td>Current smoker</td>
<td>20.9 (0.6)</td>
<td>18.6 (1.0)</td>
</tr>
<tr>
<td>Heavy drinker</td>
<td>5.8 (0.3)</td>
<td>4.4 (0.4)</td>
</tr>
<tr>
<td>Physical activity (total METS), mean (SE)</td>
<td>685.1 (13.4)</td>
<td>657.7 (24.6)</td>
</tr>
<tr>
<td>Energy, Kcal, mean (SE)</td>
<td>1892.4 (10.3)</td>
<td>1951.4 (18.7)</td>
</tr>
<tr>
<td>Healthy Eating Index, mean (SE)</td>
<td>47.8 (0.2)</td>
<td>47.2 (0.3)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>25.1 (0.5)</td>
<td>24.9 (0.9)</td>
</tr>
<tr>
<td>Diabetes</td>
<td>16.7 (0.4)</td>
<td>13.1 (0.8)</td>
</tr>
<tr>
<td>CKD</td>
<td>5.0 (0.3)</td>
<td>4.6 (0.5)</td>
</tr>
<tr>
<td>CESD score, mean (SE)</td>
<td>7.1 (0.1)</td>
<td>6.6 (0.1)</td>
</tr>
</tbody>
</table>

All estimates are age adjusted to the US 2010 Standard population
Bold face indicates estimate is significantly different compared with US born as the referent group

Mean dietary sodium differed by nativity/years in the US and ranged from 3071 mg/day among those foreign born with 10+ years in the US, to 3376 mg/day among the foreign born with < 10 years in the US, Figure 5.1. Mean
dietary potassium and Na-K ratio—both indicators of diet quality—were least favorable among those born in the US: compared with those born in the US, those foreign born with < 10 years had higher dietary potassium (2512 vs. 2294, p<0.01), higher dietary potassium density (1333 vs. 1198 per 1000 kcal, p<0.01), and had lower mean dietary Na-K ratio (1.41 vs. 1.50, p<0.01).

**Figure 5.1:** Age-adjusted mean dietary sodium, sodium density, potassium, potassium density and sodium to potassium ratio by nativity/years in the US.

All estimates are age adjusted to the US 2010 standard population.
*Mean is significantly different compared with US Born (referent group).

In sociodemographic adjusted linear regression models (Table 5.2), 500 mg higher dietary sodium was not associated with BMI (0.00 kg/m², 95% CI: -0.05, 0.05) or WC (0.11 cm, 95% CI: -0.01, 0.24). However, in fully-adjusted
models—including an adjustment for energy intake, 500 mg higher dietary sodium was associated with a 0.07 kg/m² (95% CI: 0.00, 0.15, p<0.05) higher BMI and a 0.18 cm (95% CI: 0.00, 0.36, p<0.05) higher WC. Likewise, in fully adjusted models, a 250 mg per 1000 kcal higher dietary sodium density was associated with a 0.07 kg/m² (95% CI: 0.01, 0.14) higher BMI and a 0.17 cm (95% CI: 0.01, 0.34) higher WC.

Table 5.2: Associations of dietary sodium and sodium density with body mass index and waist circumference the HCHS/SOL.

<table>
<thead>
<tr>
<th></th>
<th>Body Mass Index</th>
<th>Waist Circumference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beta Estimate (95% CI)</td>
<td>Beta Estimate (95% CI)</td>
</tr>
<tr>
<td>Sodium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model 1</td>
<td>0.00 (-0.05, 0.05)</td>
<td>0.11 (-0.01, 0.24)</td>
</tr>
<tr>
<td>Model 2</td>
<td>0.07 (0.00, 0.15)</td>
<td>0.18 (0.00, 0.36)</td>
</tr>
<tr>
<td>Sodium Density</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model 1</td>
<td>0.12 (0.05, 0.18)</td>
<td>0.31 (0.13, 0.49)</td>
</tr>
<tr>
<td>Model 2</td>
<td>0.07 (0.01, 0.14)</td>
<td>0.17 (0.01, 0.34)</td>
</tr>
</tbody>
</table>

Model 1 is adjusted for age, sex, ancestry, education, income, language preference, nativity, and study site; Model 2 is additionally adjusted for smoking, hypertension, diabetes, chronic kidney disease, alcohol use, depression, physical activity, and energy intake (except for in sodium density models).

Increments of 500 mg/day of sodium and 250 mg per 1000 kcal units for sodium density were modeled.

Figure 5.2 displays the fully-adjusted associations between dietary potassium, potassium density, Na-K ratio and BMI across categories of nativity/years in the US. For dietary potassium, a 500 mg increment was not associated with BMI in the foreign born with <10 years in the US (0.15 kg/m², 95% CI: -0.01, 0.31), but was associated with lower BMI in the foreign born with 10+ years in the US (-0.13 kg/m², -0.25, 0.00, p<0.05) and in the US born (-0.62
kg/m², 95% CI: -0.92, -0.31). **For dietary potassium density**, 250 mg per 1000 kcal increment was associated with higher BMI in the foreign born with <10 years in the US (0.18 kg/m², 95% CI: 0.03, 0.34), was not associated with BMI in the foreign born with 10+ years in the US (0.01 kg/m², 95% CI: -0.10, 0.13), but was significantly associated with lower BMI among the US born (-0.55 kg/m², 95% CI: -0.82, -0.28). **For dietary Na-K ratio**, a 0.50-unit increment was not associated with BMI in the foreign born with <10 years in the US (-0.12 kg/m², 95% CI: -0.31, 0.06), but was associated with higher BMI in the foreign born with 10+ years in the US (0.22 kg/m², 0.07, 0.37) and in the US born (0.39 kg/m², 95% CI: 0.08, 0.70). Patterns for WC (Figure 5.3) largely mirrored those of BMI.

**Figure 5.2**: Fully-adjusted* associations of dietary potassium, potassium density, and sodium to potassium ratio with body mass index stratified by nativity/years in the US.

*All models are adjusted for age, sex, ancestry, education, income, language preference, center number, smoking, hypertension, diabetes, chronic kidney disease, alcohol use, depression, physical activity, and calories (except for in density models); boldface indicates a significant estimate (p<0.05)
**Figure 5.3:** Fully-adjusted* associations of dietary potassium, potassium density, and sodium to potassium ratio with body mass index stratified by nativity/years in the US.

![Graph showing associations of dietary potassium, potassium density, and Na-K ratio with body mass index](image)

*All models are adjusted for age, sex, ancestry, education, income, language preference, center number, smoking, hypertension, diabetes, chronic kidney disease, alcohol use, depression, physical activity, and calories (except for in density models); boldface indicates a significant estimate (p<0.05)

Dietary potassium was significantly and positively associated with AHEI score after adjusting for age and energy intake (data not shown). This association was moderated by nativity/years in the US (p<0.05), such that it was weakest among those foreign born with < 10 years.

Among SOLNAS participants, in fully-adjusted linear regression models (Table 5.3), a 500 mg higher urinary sodium excretion was associated with a 0.27 kg/m² higher BMI (95% CI: 0.09, 0.43), a 0.53 kg higher body fat (95% CI: 0.16, 0.91), and a 0.34 higher percent body fat (95% CI: 0.12, 0.57). A 250 mg per 1000 kcal increment of urinary sodium density was associated with a 0.40 (95% CI: 0.12, 0.67) higher percent body fat. Urinary potassium and potassium...
density were not associated with BMI, body fat, or percent body fat. A 0.50-unit higher urinary Na-K ratio was associated with a 0.38 kg/m² higher BMI (95% CI: 0.05, 0.71), a 0.82 kg higher body fat (95% CI: 0.17, 1.48), and a 0.59 higher percent body fat (95% CI: 0.21, 0.97).

Table 5.3: Fully-adjusted associations of 24-hr urinary sodium, potassium, and sodium to potassium ratio with body mass index, body fat, and percent body fat in the SOLNAS sample.

<table>
<thead>
<tr>
<th></th>
<th>Body Mass Index Beta (95% CI)</th>
<th>Body Fat (kg) Beta (95% CI)</th>
<th>Percent Body Fat Beta (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium</td>
<td>0.27 (0.09 0.43)</td>
<td>0.53 (0.16 0.91)</td>
<td>0.34 (0.12 0.57)</td>
</tr>
<tr>
<td>Sodium density</td>
<td>0.13 (-0.11 0.37)</td>
<td>0.43 (-0.04 0.89)</td>
<td>0.40 (0.12 0.67)</td>
</tr>
<tr>
<td>Potassium</td>
<td>0.20 (-0.16 0.56)</td>
<td>0.42 (-0.35 1.19)</td>
<td>0.26 (-0.20 0.71)</td>
</tr>
<tr>
<td>Potassium density</td>
<td>-0.39 (-0.85 0.06)</td>
<td>-0.51 (-1.38 0.36)</td>
<td>0.10 (-0.40 0.60)</td>
</tr>
<tr>
<td>Na-K ratio</td>
<td>0.38 (0.05 0.71)</td>
<td>0.82 (0.17 1.48)</td>
<td>0.59 (0.21 0.97)</td>
</tr>
</tbody>
</table>

Models are adjusted for age, sex, ancestry, education, income, language preference, nativity/years in the US, study site, smoking, hypertension, alcohol use, depression, physical activity, and energy (except in models of density measures).

Increments of 500 mg/day of sodium and potassium, 250 mg per 1000 kcal unit for sodium density and potassium density, and 0.50 unit increments of sodium to potassium ratio were modeled.

Individuals with diabetes or CKD did not partake in urine collection and therefore diabetes and CKD are not adjusted for as covariates.

IV. Discussion

In the current study of over 16,000 diverse US Hispanics/Latinos, sodium was consistently associated with measures of obesity—indepenent of energy intake. Each 500-mg increment of daily dietary sodium was associated with a 0.07 kg/m² higher BMI and 0.18 cm higher WC. Similar results were observed with dietary sodium density. The associations of dietary potassium, potassium
density, and Na-K ratio with BMI and WC varied by nativity/years in the US, such that the associations were stronger with more years spent in the US. For example, while higher dietary potassium was not associated with WC among the foreign-born with <10 years in the US, higher dietary potassium was associated with 0.36 cm lower WC among foreign-born with 10+ years, and 1.42 cm lower WC among the US born. The associations with measures of obesity were much stronger when using urinary sodium and Na-K ratio, independent of DLW derived energy expenditure, suggesting a direct relationship.

Sodium is ubiquitous in the US food supply, and therefore highly correlated with energy intake. High sodium diets are also known to increase fluid intake, such as the consumption of sugary drinks which in turn contribute to weight gain. It has also been suggested that association between sodium and obesity is partially explained by the “Salted Food Addiction Hypothesis,” which proposes that foods high in sodium act in the brain like an opiate agonist and subsequently lead to an increase in consumption of unhealthy foods. Thus, the sodium—obesity relationship has largely been attributed to indirect downstream processes related to increased energy intake. However, emerging evidence suggests a direct relationship between sodium and obesity exists independent of energy intake. For example, in a population based UK sample that assessed sodium using 24-hour urine, a 400 mg per day higher sodium was independently associated with a 26% greater odds of being obese even after controlling for sugary drinks and energy intake using DLW. In agreement with such findings, our study, which was the first of its kind in the US
to use objective measures of both sodium and energy, found a strong and direct association between sodium and measures of obesity, independent of energy intake. While the biological rationale for this association has not been fully explored, experimental studies in rodents show that high sodium diets induce higher adiposity compared with rats with identical but low sodium diets.\textsuperscript{204} Consistent with this animal model, we found that a 500 mg/day higher urinary sodium excretion was significantly associated with 0.53 kg more body fat.

In our study, potassium, a nutrient positively associated with healthfulness of diet and fruit and vegetable consumption,\textsuperscript{25,26} was associated with BMI and WC, though this relationship varied by nativity/years in the US. For example, higher dietary potassium was not associated with BMI or WC among those foreign-born with <10 years in the US, but was significantly associated with lower BMI and lower WC among those foreign-born with 10+ years and among those US born. In the context of the acculturation process, we hypothesized that the current findings may be the consequence of worsening of dietary habits as subjects become more acculturated (as with greater time in the US).\textsuperscript{205,206} Therefore, among less acculturated subjects, potassium may not necessarily reflect diet quality and healthfulness to the extent that it does in a diet of a more acculturated subject. This would explain the lack of associations between dietary potassium and measures of obesity among the foreign-born with < 10 years in the US. In our study, overall dietary summary scores were indeed higher (i.e. healthier) among Hispanics/Latinos that were foreign-born vs. US born. Furthermore, consistent with our hypothesis, adjusted for age and energy, dietary
potassium was a weaker predictor of dietary summary score among the foreign born with <10 years in the US than among the foreign born with 10+ years in the US or the US born. In the SOLNAS sample, neither urinary potassium nor potassium density were associated with obesity, though we were underpowered to test for moderation by nativity/years in the US.

Similar to potassium, the associations between Na-K ratio—another indicator of diet quality—and measures of obesity also varied by nativity/years in the US, such that the associations were only significant in those with longer years in the US (foreign-born with 10+ years and the US born). To our knowledge this moderation has not been previously documented and may again reflect Na-K ratio, similar to potassium, as being a better indicator of healthfulness of diet in more acculturated US Hispanics/Latinos. However, unlike with dietary potassium, we did not find Na-K to be a weaker predictor of dietary score among foreign born in the current study. Results from the SOLNAS sample showed a very strong positive association among urinary Na-K with BMI, body fat, and percent body fat. For example, we found a 0.5 unit increase in Na-K to be associated with 0.82 kg more body fat. Consistent with our findings, spot urine—a more easily available approach to measuring Na-K ratio—has also shown to be independently associated with percent total body fat measured using DXA in a multi-ethnic US cohort.\textsuperscript{110}

i. Limitations

The current study possesses a number of important limitations. First, given the cross-sectional design we could not establish temporality. Further, our
main measure of sodium and potassium was derived via 24-hour dietary recall, which is subject to measurement error.\textsuperscript{207} However, we also reported associations using sodium and potassium density which are less error prone\textsuperscript{197} and results were similar to those of sodium and potassium. Further, we were able to repeat our analyses using objective biomarkers from 24-hour urine in the SOLNAS sub-sample, and found consistent and sometimes stronger associations. However, even the gold-standard 24-hour urine possesses its own limitations,\textsuperscript{195} as it only reflects sodium intake on one day and is not necessarily reflective of habitual sodium intake. Finally, though we used nativity/years in the US as a proxy measure for acculturation, we acknowledge that this measure may not accurately reflect the dynamic acculturation process.

ii. Strengths

Despite such limitations, our study has several notable strengths. To our knowledge, this was the first study conducted in a population based sample of diverse US Hispanics/Latinos—an understudied minority population. The sample was large and comprised of mostly immigrants. Thus, we were adequately powered to test for interactions by length of time in the US—an alternative indicator for acculturation. Finally, we also had multiple markers of obesity, including BMI, waist circumference, body fat, and percent body fat. Using multiple nutrient markers—including gold standard 24-hour urine collection, and multiple indicators of obesity our results were consistent and robust.
iii. Conclusions

In the current population based study of US Hispanics/Latinos, higher sodium was associated with higher BMI, WC, and body fat. Potassium and Na-K ratio were stronger predictors of BMI and WC as duration of US residence increased. Although the mechanisms underlying such relationships have not been adequately explored, our findings along with other studies suggest that sodium may be directly related to measures of obesity, above and beyond energy intake. Future studies investigating the longitudinal relationship between sodium, potassium, Na-K ratio, with changes in measures of obesity are warranted.
Chapter 6: Discussion and Conclusions

I. Overview

This dissertation research examined individual-level and neighborhood-level determinants of diet and obesity measured in multi-racial/ethnic populations, using cross-sectional as well as longitudinal study designs. In particular, the association between sustained poverty, a measure of individual-level socioeconomic status, and BMI growth rate was examined over twenty years using repeated measures of income and BMI among young Black and White adults. Second, the cross-sectional associations of neighborhood-level socioeconomic status with individual-level measures of obesity (BMI and waist circumference) and diet (urinary sodium, potassium, and Na-K ratio) were examined in a representative and diverse sample of NYC adult residents. Finally, the independent associations between dietary markers (sodium, potassium, and Na-K ratio) and measures of obesity (BMI, waist circumference, and body fat) were examined in a diverse cohort of US Hispanics.

Overall, the findings suggest that between 1990 and 2010, cumulative socioeconomic disadvantage, as measured by sustained poverty at the individual-level, was associated with faster BMI growth in white men and women, and with slower BMI growth in black men who are members of the CARDIA study. This could not be explained by reverse causation, i.e. higher BMI resulting in low income. The current findings provide evidence supporting a link between sustained poverty and changes in BMI, especially among whites.
The findings further suggest that, above and beyond individual-level SES, Neighborhood-level SES was also associated with obesity (BMI and Waist circumference) and with at least one dietary biomarker—potassium, among NYC adult women. Residing in a low vs. high SES neighborhood was associated with higher BMI and waist circumference and lower urinary potassium excretion among women but not men. This research contributes to the growing body of evidence showing that the neighborhood environment is associated with health. In particular, this research highlights important sex differences that should be explored in future neighborhood-level research.

Dietary factors were also found to be associated with measures of obesity among US Hispanics, independent of energy intake. As expected, higher dietary sodium was associated with higher BMI and waist circumference. These findings were corroborated using objectively measured urinary markers showing that higher urinary sodium intake was associated with higher BMI, body fat, and percent body fat. Lower potassium and higher Na-K ratio were both associated with higher BMI and waist circumference; with stronger associations among US Hispanics who have lived in the US longer (as an alternative marker to greater level of acculturation). Although the mechanisms underlying such relationships have not been adequately explored, these current findings along with those from other studies suggest that sodium may be directly related to measures of obesity, above and beyond energy intake. Future research should focus on investigating whether sodium, potassium, Na-K ratio, are associated with changes in measures of obesity over time.
Taken together, these findings suggest that both individual-level SES and neighborhood-level SES contribute to obesity, even trajectories of obesity over time, with some indication to influencing dietary biomarkers as well. Dietary biomarkers may further contribute to obesity.

II. Poverty and Obesity – Specific Aim 1

This aim sought to determine whether sustained poverty over a 20-year period was associated with a faster BMI rate of change among young adults, and whether this rate of change differed by sex and race. This analysis used longitudinal data collected from 1990 until 2010, and used linear mixed effects growth models to assess change in BMI over time.

**H1-1:** BMI will increase among all participants throughout the twenty-year study period, with a faster increase with greater levels of sustained poverty, after adjustment for other factors.

**H1-2:** The effect of sustained poverty on BMI growth over twenty years will be stronger (i.e. a faster growth rate) among women compared with men and among blacks compared with whites, after adjustment for other factors.

Results indicated that, between 1990 and 2010, BMI increased dramatically for the entire sample. There was a significant quadratic trend, signaling that BMI growth has leveled off in more recent years. Though the hypothesis was that sustained poverty would be associated with a faster growth rate among all groups, this was not the case. Findings showed that sustained poverty was associated with faster BMI growth among White men and women,
with slower BMI growth among Black men; and with no association among Black women.

Given that BMI may adversely impact earning potential due to weight-based discrimination in the workplace, an attempt was made to rule out reverse causation as a sole explanation of the findings. After excluding individuals who were obese at baseline in 1990, results were largely unchanged. These findings suggest that even among those with a relatively lower BMI, sustained poverty was indeed associated with faster BMI growth among Whites and slower BMI growth among Black men, with no association among Black women.

As highlighted, the longitudinal association between sustained poverty and BMI growth rate differed by both sex and race, (p-value for the four-way interaction is 0.02). Given such differences, each sex/race group was considered separately. Results of the analysis were not consistent with the original hypotheses stating that the association between sustained poverty and BMI growth would be stronger among women and Blacks. For example, among Whites, sustained poverty was associated with a steeper BMI growth rate in both men and women. Direct comparisons between the BMI rates of change in these two groups could not be made due to different models parameters. Specifically, among white women there was a significant interaction between sustained poverty and quadratic time. In other words, with more time spent in poverty, BMI increased at a faster rate, but also leveled off sooner. Among White men, BMI also increased at a faster rate with more time spent in poverty, but there was not
a significant leveling off. Among Blacks, sex differences were detected with a stronger association in men—opposite to what was hypothesized. In fact, among Black women, sustained poverty was not associated with rate of BMI change. Among Black men, being in poverty was protective; i.e. more time spent in poverty was associated with a slower BMI growth rate. Taken together, results suggest that Whites might be particularly vulnerable to the obesogenic effects of poverty.

In the literature, the association between poverty and obesity has been inconsistent among White men. Findings from the current research showed no cross-sectional association between sustained poverty and higher BMI, though there was a longitudinal association between sustained poverty and faster BMI growth rate. The observed discrepancy between cross-sectional and longitudinal findings among White men underscores the utility and importance of longitudinal data and multiple assessments of BMI which may be necessary to detect associations of interest. Among Black men, findings were in accordance with the literature showing that those at higher vs. lower income distributions experience larger gains in BMI. This counterintuitive association has been at least partially attributed to occupation—i.e. that men in poverty are more likely to engage in occupations that are physically demanding and thus expend more energy.

Much of the literature suggests that poverty or socioeconomic disadvantage is associated with greater obesity, especially among white women. Among white women, poverty and BMI may be mutually
reinforcing.\textsuperscript{144,162,163} In other words, high BMI might result in weight-based discrimination and thus lower income which may then perpetuate obesity.\textsuperscript{144} This may help explain the clear BMI by poverty gradient which could be detected throughout the twenty year study period. Among Black women, the association between income and other indicators of SES and obesity has been less consistent.\textsuperscript{54,158,165} For example, data from the National Health and Nutrition Examination Survey show that among Black women lower income is associated with slower BMI growth.\textsuperscript{158} Yet, findings from the Study of Women’s Health Across the Nation\textsuperscript{143,165} showed no association between education and BMI growth among black women. This dissertation’s findings are consistent with the latter study showing no associations found between sustained poverty and BMI among Black women.

In conclusion, BMI increased substantially between 1990 and 2010 with a significant leveling off of the BMI growth in recent years. Increased sustained poverty was associated with faster BMI growth among White men and women, slower BMI growth among Black men, and with no association among Black women. Results could not be explained by reverse causation alone. Taken together these findings suggest that sustained exposure to poverty is associated with changes in BMI, especially among whites.

III. Neighborhood and Diet/Obesity – Specific Aim 2

This aim sought to determine whether neighborhood socio-economic status is associated with individual level obesity (BMI and waist circumference)
and measures of diet (sodium, potassium, and Na-K ratio), above and beyond individual-level SES among NYC adult residents using data from the HFUS study (N=1,645); and to determine whether these associations differ by sex. Multi-level linear regression analyses were used to explore these associations overall and by sex.

**H2-1:** *Low neighborhood socio-economic status (i.e. more disadvantaged) will be associated with higher BMI and waist circumference, and with higher sodium, lower potassium, and higher Na-K ratio, above and beyond individual level factors.*

**H2-2:** *The association of neighborhood socio-economic status with individual-level obesity and diet quality will be stronger in women vs. men.*

Results from the HFUS study showed that neighborhood SES was associated with measures of obesity, and these associations were only found significant among women. More specifically, lower neighborhood SES was associated with higher BMI and higher WC among women, above and beyond individual-level SES. A handful of studies have examined how the neighborhood may differentially influence obesity among women and men. The current findings are consistent with some of these studies. For example, findings from the American’s Changing Lives Study\cite{123} found that neighborhood socio-economic disadvantage was independently associated with higher BMI among Black and White women but not among Black or White men. Results from the Behavioral Risk Factor Surveillance Survey showed that state inequality was associated with
higher individual level BMI among women but not men.\textsuperscript{186} Finally, the landmark Moving To Opportunity Study (MTO) showed that moving to a higher income neighborhood was associated with a lower prevalence of obesity\textsuperscript{184} and improved physical health outcomes in youth girls but not boys.\textsuperscript{185} While findings from the MTO experiment are somewhat consistent with this study’s current findings, they did not randomize any specific neighborhood-level factor and thus could not investigate which aspect of the neighborhood may have been the mechanism in play. However, the current results were inconsistent with findings from the Multi-Ethnic Study of Atherosclerosis showing no association between the social environment and BMI among women.\textsuperscript{188} Thus, while the associations of individual SES with measures of obesity and how they vary by sex have been well-examined in the literature,\textsuperscript{54,144} more work is needed to better understand how neighborhood-level SES may influence measures of obesity by sex.

In the HFUS cohort, mean sodium intake did not differ by tertiles of neighborhood SES—this was reflected by the near zero intraclass correlation coefficient. Thus, it was no surprise that multi-level models showed no association between neighborhood SES and urinary sodium excretion. Such findings likely point to the sheer ubiquity of sodium throughout the US food supply\textsuperscript{99}—irrespective of geographic area. These results have been duplicated by other studies showing that neighborhood poverty or socioeconomic status is not associated with urinary sodium excretion.\textsuperscript{22} Likewise, results from a cohort of young women in Japan also showed no association between neighborhood SES and urinary sodium excretion.\textsuperscript{190}
Despite the lack of an association between neighborhood SES and sodium, neighborhood SES was associated with potassium intake—an objective indicator of fruit and vegetable consumption and healthy diet. More specifically, low neighborhood SES was associated with lower potassium intake among women. This finding is consistent with prior studies showing that both women and individuals of higher SES consume more potassium, fruits and vegetables, and have better quality diets compared with their counterparts. Neighborhood level studies, though limited, generally show similar findings. For example, in Japan, neighborhood availability of supermarkets was found to be associated with higher urinary potassium excretion. Other studies which have focused on the neighborhood SES environment, often correlated with the neighborhood retail environment, have mirrored such results. Findings from National Health Nutrition and Examination survey showed that higher neighborhood SES was associated with increased fruit and vegetable intake. Yet, studies exploring such associations by gender in US populations are sparse and certainly warrant more attention given the current results.

Neighborhood SES was only associated with Na-K ratio in unadjusted models. In these analyses, living in a low vs. high neighborhood SES was associated with 0.40-unit higher Na-K ratio among men and 0.36-unit higher Na-K ratio among women. These associations were attenuated and became non-significant when adjusted for individual-level factors. These findings mirror a study of Japanese women showing low vs. high neighborhood SES to be
associated with higher Na-K ratio after adjusting for minimal individual level
ccharacteristics.\textsuperscript{190}

Taken together, results suggest that residing in a neighborhood of low vs.
high SES is associated with higher BMI, higher waist circumference, and lower
potassium intake among women. This research highlights that neighborhood
parameters may influence diet and obesity and that such associations may be
particularly pertinent among women. Future studies to explore and replicate
such sex differences are warranted.

IV. Diet and Obesity – Specific Aim 3

This aim sought to determine whether dietary markers (sodium,
potassium, and Na-K ratio) are associated with measures of obesity (BMI, waist
circumference, body fat, and percent body fat) among diverse Hispanics using
data from the HCHS/SOL study (N=16,415), and to determine whether
associations differed by nativity/years in the US. Linear regression analyses
were used to explore these associations overall and by nativity/years in the US.

\textbf{H3-1: High sodium, low potassium, and high Na-K ratio will be associated with
higher BMI, higher waist circumference, more body fat, and a higher percent
body fat, after adjusting for other factors including energy intake.}

\textbf{H3-2: The association between dietary factors (sodium, potassium, and Na-K
ratio) and measures of obesity will be stronger among individuals with longer
years in the US.}
Results indicated that sodium was associated with measures of obesity, independent of energy intake. More specifically, every 500-mg increment of daily dietary sodium was associated with a 0.07 kg/m² higher BMI and 0.18 cm higher WC. Similarly, 250 mg more sodium per every 1,000 calories (also known as sodium density) was associated with a 0.07 kg/m² higher BMI and 0.17 cm higher waist circumference.

Though the biological mechanisms for this association have not been fully explored in humans, experimental animal models exist. Studies in rodents show that high sodium diets may induce adiposity, offering a potential mechanism of action.\textsuperscript{204} Consistent with this potential mechanism, results from the SOLNAS sub-sample showed that every 500-mg increment of daily urinary sodium was associated with a 0.27 kg/m² higher BMI, 0.53 kg more body fat, and 0.34 higher percent body fat, after adjusting for urine-derived energy intake and other important covariates. These findings were similar to results from the United Kingdom showing a strong association between urinary sodium with obesity after adjusting for objectively measured energy intake.\textsuperscript{34}

The associations of dietary potassium, potassium density, and Na-K ratio with BMI and waist circumference varied by nativity/years in the US; such that the associations were stronger with more years spent in the US. For example, while a 500 mg/day higher dietary potassium was not associated with WC among the foreign-born with <10 years in the US in fully adjusted models, it was associated with 0.36 cm lower WC among foreign-born with 10+ years, and 1.42 cm lower WC among the US born. Similar results were found for potassium
density. Likewise, while a 0.50 higher Na-K ratio (i.e. worse) was not associated with BMI among the foreign-born with <10 years in the US, it was associated with 0.22 kg/m² higher BMI among those who are foreign-born with 10+ years in the US, and with 0.39 kg/m² higher BMI among those US born. These findings (specific to potassium and Na-K ratio) which show stronger associations with longer duration of time in the US are hypothesized to be a consequence of worsening of dietary habits as subjects become more acculturated (as with greater time in the US). Among more acculturated subjects (i.e. like those born in the US) potassium and Na-K ratio may be better indicators of diet quality. Consistent with this hypothesis, potassium was more strongly associated with overall diet summary score among those with greater time in the US. Finally, while the association between urinary potassium and measures of obesity within the SOLNAS subsample were not significant, higher urinary Na-K ratio was associated with higher BMI, body fat, and percent body fat. Due to sample size issues, these associations were not investigated by duration of years in the US.

Taken together the results suggest that high sodium is independently associated with measures of obesity. Further, low potassium and high Na-K ratio are associated with measures of obesity and these associations were stronger with greater time spent in the US. Further studies exploring potential longitudinal associations are needed.
V. Limitations and Strengths

i Limitations

There are several limitations to this dissertation research worth noting. First, with regards to specific aim 1, exact income data was not available. To cope with this issue, the midpoint income within the range was selected. Any measurement error that was potentially introduced was likely to be non-differential. Further, despite the CARDIA cohort being relatively young (mean age of 30 at baseline), BMI differences by baseline poverty status were already established, and mean BMI was already high, especially among black women. Thus, the full extent of BMI growth could not be fully captured.

While data analyzed for aim 1 were longitudinal and encompassed a twenty-year timeframe and included repeated measures, analyses for aims 2 and 3 were cross sectional. As such, temporality of the associations could not be established. For example, when assessing the effects of neighborhood poverty on individual-level outcomes, the observed associations may reflect self-selection of individuals into neighborhoods rather than the effect of a neighborhood on an individual's outcome.

Additionally, while aims 2 and 3 incorporated gold-standard measures of specific dietary nutrients—namely 24-hour urine collections to assess sodium, potassium, and Na-K ratio, it is important to highlight that 24-hour urine measures reflect sodium and potassium intake during the previous day. These measures may not necessarily be indicative of habitual sodium and potassium
consumption. This may be particularly pertinent for aim 3 as measures of obesity (i.e. BMI and waist circumference) are unlikely to change from day to day while nutrient intake is quite variable. Despite this, any bias that may have arisen was also likely to be non-differential resulting in more conservative estimates. Also, related specifically to aim 3, the current study was limited in its ability to measure acculturation. As a proxy for acculturation, nativity/years in the US was measured. Though this measure has served as an acculturation proxy in other studies, it is important to acknowledge that this measure may not accurately reflect the dynamic acculturation process.

Finally, as a general limitation, BMI was used as an outcome in all aims explored in the study. BMI as an indicator of obesity possesses its own limitations. It does not necessarily reflect excess body weight. For example, individuals with a high proportion of muscle mass may be categorized as overweight or even obese despite having relatively little body fat. To account for this issue, the current study utilized a number of obesity measures besides BMI which included: waist circumference, body fat, and percent body fat.

ii. Strengths

Despite the aforementioned limitations, the current dissertation has multiple strengths. First, this study details the dramatic rise in obesity among a racially diverse group of US young adults during the obesity epidemic. Specific aim 1 utilizes data which encompasses a timeframe of 20 years and leverages repeated measures of both income and BMI. Further, results of this particular
analysis were adequately powered to detect and highlight important differences by race and sex. Overall, results from specific aim 1 build upon previous studies which are primarily cross-sectional in nature and thus greatly contribute to the literature and the understanding of how long-term exposure to poverty influences trajectories or changes in BMI.

Another strength of the current dissertation pertains to the measures employed. Each data source utilized in this study included indicators of obesity (BMI, waist circumference, body fat, percent body fat) which were objectively measured in accordance with standardized protocols. Further, rather than focusing on one specific outcome (such as BMI), analyses were performed on a variety of obesity indicators. Results were also consistent and robust across the different indicators of obesity—reinforcing the strength of the associations of interest. The measures of diet utilized by this dissertation research were also notable. Dietary measures are notoriously rife with measurement error. Yet in each analysis which examined sodium or potassium, an objective measure was also available. Results tended to be stronger with objectively measured nutrients/biomarkers. For example, a 500 mg/day higher sodium intake was associated with a 0.07 kg/m² higher BMI using 24-hour dietary sodium versus 0.27 kg/m² higher BMI when using 24-hour urinary sodium. Such a substantial difference in association strength underscores the importance of having objective measures, whenever possible.

Also noteworthy, this dissertation research used a broad approach to highlight the association between SES and components of health. There is
growing recognition that contextual neighborhood-level factors can affect health, above and beyond individual-level characteristics. In aim 2, we focused on the effect of the neighborhood’s socioeconomic status on measures of obesity and diet, above and beyond individual level SES. Thus, by focusing on both the individual and neighborhood context, a comprehensive characterization of the associations of interest was determined.

Finally, a major strength of the current research is the diversity in study populations. Ethnic minority populations are traditionally underrepresented in health research. In the current research, ethnic/minority populations were represented in all three cohorts used. Furthermore, the current research aims specifically addressed associations of interest across race/ethnicity and sex.

VI. Implications

The overall findings of the current research suggest that lower SES both at the individual and neighborhood level is associated with worse measures of obesity (cross-sectionally and longitudinally), and with notable sex and race differences. Further, low neighborhood SES is shown to be associated with poor diet quality, specifically low potassium and high Na-K ratio among women but not men. Finally, dietary factors, such as sodium and potassium, are shown to be associated with measures of obesity, independent of energy intake. Taken together these findings have major clinical and policy implications.

The SES-health gradient has long been described. As such, policies aimed at ameliorating the impact of poor SES on various health outcomes occur
nationally through programs such as Medicaid\textsuperscript{213} as well through local initiatives. For example, in an effort to combat obesity and increase access and consumption of fruits and vegetables among the poor, farmer’s markets and other fruit and vegetable vendors are incentivized to provide services in traditionally underserved areas.\textsuperscript{214}

Additionally, in recent years, national efforts have been made to dramatically alter the food supply and thus passively change dietary behaviors. The National Salt Reduction Initiative\textsuperscript{215} is one such program, which aims to reduce the amount of sodium in processed and pre-packaged foods. Based on a similar and successfully implemented initiative in the United Kingdom which reduced population wide sodium intake by 15\%,\textsuperscript{216} the aim of this program is to lower blood pressure by reducing sodium and thus reduce cardiovascular disease. In fact, it is projected that on a population basis, a 1200 mg/day reduction in sodium would result in 32,000 to 66,000 less stroke events per year by way of the blood pressure lowering effect.\textsuperscript{217}

In addition to reducing blood pressure and in turn cardiovascular disease, population-wide sodium reduction may have other potential unintended and beneficial outcomes. In this dissertation research, sodium was significantly associated with measures of obesity, independent of energy intake. In fact, the findings showing strong associations between higher urinary sodium and higher body fat suggest that sodium reduction may indeed have obesity-related benefits. Though speculative given the lack of evidence from longitudinal data, population-
based sodium reduction may be explored as a potential obesity-related intervention.

VII. Future Directions

Sustained poverty was associated with changes in BMI among White men and women along with Black men. Results showed no associations in Black women. Similarly other studies have shown inconsistent or null associations among Black women. Given that Black women suffer from very high rates of obesity, and that baseline BMI among Black women tended to be higher than any other group, examination of early contributors to obesity may be warranted for this population.

The effects of SES, both at an individual level (in aim 1) and at the neighborhood level (aim 2), were found to vary across sex. For example, while neighborhood SES was not associated with individual-level potassium intake, when examined by sex, there was a clear association among women that would have otherwise been missed. Overall, despite the well-documented SES-sex interaction with regards to obesity, studies of neighborhood level SES effects on obesity as well as diet often fail to consider sex as a potential modifier. Future studies may benefit from exploring whether those associations differ across sex.

Finally, though a longitudinal analysis was conducted in Aim 1 examining sustained poverty and trajectories of BMI, the remaining analyses were all cross-sectional in nature. Thus, any causal interpretations of findings were limited. As such, longitudinal analyses are needed to substantiate any cross-sectional
findings. In particular, future studies should focus on whether sodium reduction or reduced sodium diets are associated with less weight gain over time.
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