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Early Life Nutrition, Adult Diet, and Cardio-metabolic Disease Risk in Rural Guatemala

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Abstract

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By Nicole Dionne Ford

Latin America is facing an increasing burden of obesity and cardio-metabolic disease (CMD). The nutrition transition, a shift from whole foods-based traditional diets to diets high in fat, sugar, and processed foods, is thought to contribute to CMD risk. Despite increases in obesity and CMD, there is a persistent burden of childhood undernutrition. People exposed to early life undernutrition might have growth patterns that confer distinct risk for CMD, yet little is known about the long term consequences of early life undernutrition in obesogenic environments.

The first aim of this research was to explore body mass index (BMI) trajectories from infancy through mid-adulthood, early life nutrition, and CMD risk using data from the Institute of Nutrition of Central America and Panama (INCAP) Nutrition Supplementation Trial Longitudinal Cohort. We identified two BMI latent classes in women (low and high) and three in men (low, medium, and high) that separated in infancy and tracked through adulthood, suggesting that early life factors are important in establishing BMI trajectories. Exposure to a nutrition supplement (*Atole*) from conception to age 2y (i.e. the first 1,000 days) was not associated with BMI latent class trajectory membership. In men only, higher BMI latent class was negatively associated with metabolic syndrome and dysglycemia. BMI trajectory was not associated with most CMD risk factors after controlling for current BMI.

The second aim was to explore adult diet, 12y change in dietary patterns, and CMD risk. While adult diets remained largely reliant on corn tortillas, there was evidence of dietary diversification from 2002-2016 by decreased intake of traditional foods and a mixture of consumption trends for Western foods. In addition to a traditional pattern, our adult dietary pattern analyses suggested the emergence of two Western patterns (meat-based and starch-based) – one of which was associated with increased prevalence of low high density lipoprotein cholesterol (HDL-c) in men. The traditional diet had a differential association with some CMD risk factors by sex.

Our findings highlight the importance of establishing and maintaining healthy BMI throughout the lifecourse, including appropriate growth in early life and preventing excessive weight gain in adulthood. To help mitigate nutrition-related CMD risk, future research should explore approaches to encourage adoption of healthier foods while minimizing the addition of energy-dense, nutrient-poor foods.

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Chapter 1 – Introduction

Non-communicable diseases (NCD) represent a growing proportion of disease burden in low- and middle-income countries (LMIC) (1). While NCDs are often thought of as diseases of development, in Latin America these diseases now account for 77% of deaths in the region (2), and the total burden of these diseases is expected to double in the next 40 years in countries like Mexico (3). Risk factors for cardio-metabolic diseases (CMD) like type 2 diabetes mellitus and metabolic syndrome are especially prevalent in the region; the Latin American Consortium Studies in Obesity (LASO) found high prevalence of low HDL cholesterol (53%), abdominal obesity (36%), hypertriglyceridemia (27%), and hypertension (20%) (4). CMD's toll on the health system and society is high because these diseases affect people during productive working years, reducing economic contributions to both households and society. In Guatemala, 40% of NCD deaths are among people younger than 60 years old (5).

The shift from a predominantly infectious disease burden to a pattern where chronic disease predominates is a direct result of demographic, social, and economic changes influencing dietary and physical activity patterns, among other factors (6). In particular, high-fat, high-sugar, processed foods begin to replace traditional diets (characterized by whole foods like grains and legumes) in a shift known as the nutrition transition (7). Globally, 64% of cardiovascular disease-related deaths were attributable to dietary risk factors associated with modern diets typified by nutrition transition including high intakes of unhealthy food groups like processed

meats and sugar-sweetened beverages and low intakes of healthful food groups like fruits, vegetables, and whole grains (8). Because diet is a major modifiable determinant of CMD risk (9), understanding diet and how diets are changing and identifying which dietary patterns increase risk is important for informing CMD prevention and mitigation strategies. The nutrition transition has been well-documented in Mexico, Brazil, and Chile (10–12); however, little is known about dietary change in less economically developed countries in Latin America, like Guatemala.

Despite the rise in obesity prevalence and obesity-related NCDs in Latin America, childhood undernutrition remains a serious problem in countries like Guatemala. As of 2015, 47% of children under-five were stunted (height-for-age Z [HAZ] scores < -2 SD), indicating widespread and chronic nutritional inadequacy (13). Early life undernutrition is thought to increase risk of CMD (14). Birth size has been associated with adiposity, obesity, type 2 diabetes, lipid profile, and blood pressure in later childhood, adolescence, and/or adulthood (15–19). The "Developmental Origins of Health and Disease Hypothesis" posits that structural and functional adaptations in response to early life undernutrition – possibly to preserve brain and vital organ development – combined with an obesogenic environment later in life predisposes an individual to develop CMD (20). While the hypothesis was developed based on disease patterns observed in Europe (21), the hypothesis has since been supported by evidence from animal studies (22) and from cohorts with high prevalence of fetal and childhood underweight (23–26).

Despite evidence supporting a connection between early life undernutrition and adult CMD, there is little data from LMIC populations about the long term consequences of chronic early life undernutrition in obesogenic environments (27). If people exposed to low nutrient environments in early life – especially those later exposed to hyper-caloric environments consistent with developing economies – have growth patterns which confer distinct risk for CMD, life course growth analysis can help understand differential risk. Because the burden of under-five stunting is substantially higher in Guatemala relative to other countries in Latin America (**Table 1.1**), the potential impact of growth faltering on future CMD prevalence could be considerable.

Finally, nutrition supplementation programs targeting childhood undernutrition in LMICs may be inadvertently increasing risk for adult obesity and subsequently, obesity-related NCDs (28,29). Interventions to promote rapid growth following growth deficits has been shown to increase risk of overweight later in childhood in high-income populations (30,31). In Chile, a nutrition supplementation program for pre-school children was associated with a 50% increase in the number of overweight children and a threefold increase in the number of obese children during the first year of the program (32,33). Despite this potential conflict between promoting optimal growth and risk of overweight, there is a dearth of data to assess the long term effects of child nutrition interventions on body mass index (BMI) gain in LMICs. Understanding how nutrition supplementation to manage stunting and other early life factors are associated with life course BMI gain is imperative for

maternal and child nutrition strategies in LMICs – especially in countries where food assistance policies are common (33).

The overall aim of this research is to explore changes in BMI and diet over the life course and their association with CMD risk in the context of nutrition transition in Guatemala. We use rich longitudinal data from the INCAP Nutrition Supplementation Trial Longitudinal Cohort whose members were born in rural Guatemala from 1962-1977, participated in a longitudinal study of nutrition supplementation, have been followed for more than 40 years, and have serial measures of variables beginning at birth or early childhood.

The specific aims of this proposal are:

Specific Aim 1 – Life course BMI trajectories and cardio-metabolic disease risk

- To describe BMI trajectories from birth/early childhood through mid-adulthood and assess early life factors associated with these trajectories, including childhood household socioeconomic status and nutrition supplementation during the first 1,000 days (conception to age 2y); and
- To investigate an association between BMI trajectories from birth/early childhood to mid-adulthood with markers of CMD risk including body composition, blood glucose and lipids, blood pressure, and metabolic syndrome.

Chapter 4: We estimated the association of an energy- and protein-containing nutrition supplement (*Atole*) during the first 1,000 days and of early-childhood household SES on the timing and rate of BMI gain from infancy through mid-adulthood using latent class growth analysis (LCGA).

Chapter 5: We examine the role of life course BMI trajectories from birth or early childhood through mid-adulthood on CMD risk in a rural sub-sample of the INCAP Nutrition Supplementation Trial Longitudinal Cohort.

Specific Aim 2 – Diet, the nutrition transition, and cardio-metabolic disease risk

- To describe changes in diet over time and the extent to which changes are consistent with nutrition transition; and
- To characterize dietary patterns and to examine the association between dietary pattern and CMD risk.

Chapter 6: We use data from a rural sub-sample of the INCAP Nutrition Supplementation Trial Longitudinal Cohort to (a) describe food group intake as a percentage of total caloric intake in 2002-04 and in 2015-16; (b) characterize dietary patterns at both time points using principal components analysis (PCA); (c) examine the association between dietary patterns and sociodemographic

characteristics; and (d) explore 12 year change in food group intake, dietary factors, and PCA-derived dietary patterns.

Chapter 7: Using 2002-04 cross-sectional data from the INCAP Nutrition Supplementation Trial Longitudinal Cohort, we characterize dietary patterns using principal components analysis (PCA) and examine the association between dietary patterns and CMD risk in a population of Guatemalan young adults.

Table 1.1. Prevalence of stunting (height-for-age Z score <-2 SD) among children under 5 years in 19 Latin American countries

Country	Under-5 Stunting, %
Guatemala	46.5
Ecuador	25.2
Nicaragua	23.0
Honduras	22.7
Panama	19.1
Bolivia	18.1
Peru	14.6
El Salvador	14.0
Mexico	13.6
Venezuela	13.4
Colombia	12.7
Paraguay	10.9
Uruguay	10.7
Argentina	8.2
Brazil	7.1
Dominican Republic	7.1
Cuba	7.0
Costa Rica	5.6
Chile	1.8

Source**:** UNICEF/WHO/World Bank Joint Child Malnutrition Estimates, September 2016 edition (34).

Chapter 2 - Background

There are two distinct sections to this background. Part I is a comprehensive review of the distinctive features of overweight/obesity, its causes and related prevention and management efforts, data gaps, and recommendations for future research in LMICs. While there are similar trends in obesity, obesity-related NCDs, and nutrition transition across many developing countries, the specific context in Guatemala is important for understanding our research. Thus, Part II of the background highlights sub-sections of Part I and expands upon them in the context of Guatemala. Specifically, Part II reviews the burden of obesity-related NCD, the double burden of under- and over-nutrition, and the nutrition transition in Guatemala.

Part I: Obesity in Low- and Middle-Income Countries: Burden, Drivers, and Emerging Challenges

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Abbreviations used: AHA, American Heart Association; BMI, body mass index; BPA, Bisphenol A; DALY, disability-adjusted life year; DDT, dichlorodiphenyltrichloroethane; GDP, gross domestic product; HIC, high income country (World Bank classification); low- and middle-income country (World Bank classification); NCD, non-communicable disease; PCB, polychlorinated biphenyl; POP, persistent organic pollutant; SES, socioeconomic status; WHO, World Health Organization.

Abstract

We reviewed the distinctive features of excess weight, its causes, and related prevention and management efforts, data gaps, and recommendations for future research in low- and middle-income countries (LMICs). Obesity is rising in every region of the world and no country has been successful at undoing the epidemic once it has begun. In LMICs, overweight is higher in women compared with men, in urban compared with rural settings, and in older compared with younger individuals; however, the urban-rural overweight differential is shrinking in many countries. Overweight occurs alongside persistent burdens of underweight in LMICs, especially in young women. Changes in the global diet and physical activity are among the hypothesized leading contributors to obesity. Emerging risk factors include environmental contaminants, chronic psychosocial stress, neuroendocrine dysregulation, and genetic/epigenetic mechanisms. There is little data on effective strategies to prevent the onset of obesity in LMICs or elsewhere. This is a key priority for future research and has important possibilities to contribute to reverse innovation that may inform interventions in high income countries as well.

Introduction

By 2013, two billion individuals worldwide were overweight or obese, and 62% of the world's obese population resided in developing countries (35). Obesity in turn is implicated in the epidemiologic transition from predominantly communicable disease and nutritional deficiency to non-communicable diseases (NCDs) such as cardiovascular conditions, diabetes, and cancer in the population (36–40). Currently ranked as the 6th leading cause of disability-adjusted life years (DALYs) globally (41), obesity-related DALYs have been steadily rising in low and middle income countries (LMICs) since 1990 (**Figure 2.1**). In the next 40 years, obesity-related NCDs are expected to double or more than double in LMICs like Mexico (3). Here, we review the distinctive features of the burden of overweight/obesity in LMICs, including its causes, related prevention and management efforts, data gaps, and recommendations for future research. Although overweight and obesity levels are rising among all age groups in LMICs (42), we focus on adolescent and adult populations because those are the most affected by obesity today.

Distribution and Epidemiology of Obesity in LMICs

The global rise of BMI and current prevalence of overweight and obesity

In the past three decades, global overweight (BMI ≥ 25 kg/m^2) increased from 28.8% to 36.9% in men and 29.8% to 38.0% in women (35), while age-standardized obesity (BMI ≥30 kg/m^2) increased from 3.2% to 10.8% in men and from 6.4% to 14.9% in women (43). Overweight/obesity is increasing even in

countries with historically high levels of undernutrition such as Bangladesh, Nepal, and India where overweight among women of reproductive age increased from 2.7 to 8.9% in Bangladesh, from 1.6 to 10.1% in Nepal, and from 10.6 to 14.8% in India from 1996-2006 (44). Currently, a lower proportion of the LMIC population is obese relative to high income country (HIC) populations (35). The prevalence of overweight and obesity in LMICs ranged from a low of 3.2% in Timor-Leste to a high of 83.5% in Tonga among adult men (>20y) and from a low of 4.7% in the Democratic Republic of Korea to a high of 88.3% in Tonga among adult women (35). In Tonga, Samoa, and Kiribati, the three heaviest LMICs, more than 75% of men and women were overweight or obese (35). The number of obese and overweight individuals, however, are important for healthcare resource planning. More than half of the world's 671 million obese people live in ten countries, eight of which are LMICs—Brazil, China, Egypt, India, Indonesia, Mexico, Pakistan, and Russia (35). China and India account for 15% of the world's obese individuals despite relatively low obesity prevalence (35).

A regional shift in obesity has occurred over time. In 1980, women in Central and Eastern Europe and southern Africa had the highest mean BMI (25.8-26.6 kg/m^2) in LMICs. By 2008, women in North Africa, the Middle East, and southern Africa had the highest mean BMI (≥28.0 kg/m^2 for all) (45). Currently, the Pacific Islands, Latin America and the Caribbean, and the Middle East have the highest burden of overweight and obesity. Over 20% of women are obese in 14 countries in Latin America (35), and over 30% of women in several countries in the Middle East, and North and southern Africa are obese (43). Overweight and obesity in adolescent

girls (15-19y) follows the same regional patterning as is seen in adult women (35). Among adolescent girls in Latin America and the Caribbean – the most overweight and obese adolescents – obesity prevalence is projected to increase by 5% in the next decade (46).

Features of the obesity burden in LMICs

Trends in obesity over time

Some researchers have suggested that obesity may be increasing more rapidly in LMICs than in HICs (47), following marked change in dietary structure in as little as a decade in some LMICs; similar dietary changes occurred over the course of the first half of the 20th century in the U.S. and Europe (48). However, with the exception of Honduras and Egypt for women, the Global Burden of Disease study reported the largest increases in the rate of obesity from 1980-2013 were in HICs such as the U.S., Australia, the U.K., and Saudi Arabia (35). Further, increases in obesity during the 33 year study period were not smaller among countries that already had high prevalence of obesity (35). Overall, there is a lack of reliable, national-level time-trend data in many countries to assess the rate of change in obesity in many LMICs.

The World Health Organization (WHO) introduced a voluntary target to stop the rise on obesity by 2025 (49). According to NCD Risk Factor Collaboration (NCD RisC), there is virtually zero probability of achieving this target at the global level (43). To date, no country has reversed its rise in obesity (50), and current trends suggest that global adult obesity prevalence will reach 18% in men and 21% in

women by 2025 (43). Evidence from some HICs suggests a plateauing of obesity since the mid-2000s (35,45,51). Of countries with Demographic and Health Survey data, Benin shows a slight decrease in rural areas and a stabilization in urban areas, and data from Mexico show a slowing in the annual increase in prevalence of overweight among women of reproductive age (52). Furthermore, periods of stabilization of obesity have historically been followed by later periods of increase, suggesting that current leveling-off trends, where they exist, may be short-lived. For instance, urban areas of Rwanda, Zambia, and Brazil saw large increases in annual change in overweight among women of reproductive age after previously having stable or decreasing overweight (52). Adolescents in LMICs are also experiencing a rise in obesity; a 2009 study from seven LMICs—Bahrain, China, Democratic Republic of the Congo, Egypt, Mexico, Nigeria, and Vietnam—reported increasing prevalence of overweight among adolescents across all countries (53). Some researchers suggest that without interventions obesity will continue to increase, albeit at a slower rate than seen in previous decades. It remains unclear whether all LMICs are on a trajectory to reach obesity levels as high as some Pacific Island nations where more than 50% of men and 75% of women are obese (35).

Dual burden of under- and over-nutrition

The rise of overweight and obesity have occurred alongside large burdens of underweight in many LMICs (54–56). Although the prevalence of overweight exceeded underweight among adult women in most LMICs by 2000, levels of

underweight are much higher than what is observed in HICs (57). Only rural areas in East Asia, the Pacific, South Asia, and Sub-Saharan Africa have higher levels of underweight than overweight (13), and in select areas of rural East Asia, South Asia, and the Pacific overweight prevalence is approaching underweight prevalence (52). Among adolescent girls, 18% of LMICs have simultaneous increases in underweight and overweight in urban areas (46). To our knowledge, no country has experienced a meaningful reduction in underweight without experiencing higher overweight and obesity.

Income gradients in obesity

The role of socioeconomic status (SES) in the rise of obesity in developing countries is debated. Although overweight has traditionally been considered a disease of affluence in LMICs (58), it is no longer confined to the wealthy (59). There is increasing evidence that the burden of obesity shifts to lower SES groups as countries develop (60). Monteiro *et al.* found that when GDP per capita per annum <$2,500, poverty is inversely associated with overweight; above this threshold, the burden of overweight shifts from the wealthy to the poor (61). In addition to influencing prevalence of overweight, SES might influence rate of increase in overweight and/or the type of obesity. A study of women of reproductive age in 37 LMICs found larger increases in overweight prevalence over time among low income women relative to high income women (62).

Furthermore, country-level income inequality also influences obesity. Wilkinson *et al.* found that high income inequality was associated with higher levels

of obesity – independent of national wealth (63), whereas Jones-Smith *et al.* found that income inequality modifies the association between economic development and the SES gradient for obesity (64). Among LMICs in the highest GDP tertile and lower country-level income inequality (including Armenia, Egypt, Indonesia, Kazakhstan, and Turkey), there was a faster increase in overweight in women among lower SES groups relative to higher SES groups. Among LMICs in the highest GDP tertile and higher country-level income inequality (including Colombia, Guatemala, and Namibia), the opposite was true: there was slower growth in overweight prevalence among the lower SES groups relative to the higher SES groups.

The specific drivers of the disproportionate increase in overweight among lower income groups in LMICs are unclear. People with lower income may be increasingly exposed to classical risk factors for obesity, such as high-calorie diets and low energy expenditures associated with the shift away from subsistence agriculture to industrial and service-oriented economies. Conversely, people with low income may have different responses to the same environment; for example, socioeconomically disadvantaged groups may exhibit different coping strategies during food crises relative to those with greater income (64) – possibly explaining the finding that economic shocks are associated with decreased likelihood of obesity among women in low income countries but associated with an increased likelihood of obesity in middle income countries (65).

Gender differences in obesity

Women in LMICs bear a disproportionate burden of obesity (66–68). In 119 of 130 LMICs examined in a review, women had higher overweight/obesity prevalence relative to men; the difference in prevalence percentage points ranged from 0.2 in Vietnam to 28.7 in Domenica (35). Nine of 11 countries where men had higher prevalence of overweight/obesity than women were in Africa (35). Given that overweight/obesity among girl children is lower or on par with boys in LMICs, it appears that the higher obesity among females emerges during adolescence or adulthood (35,69). Data from Tunisia show that compared with childhood, obesity prevalence in adolescence is higher among girls while it is lower in boys (70). A study of obesity among South African adolescents found that the obesity incidence among girls was highest in adolescence while obesity among boys did not increase (71).

In contrast, large gender differences in overweight/obesity are apparent only in some race/ethnic groups in HICs (72). Higher obesity among women compared with men in LMICs could be driven by several factors, including sex differences in physiological responses to early life nutrition, pregnancy-associated weight gain combined with higher parity (73), hormonal signaling related to energy expenditure (74), physical activity levels (75), alcohol consumption (76), depression (77), past and present economic circumstances (78), and sociocultural factors such as perception of ideal body size and beliefs surrounding acceptability of physical activity in some contexts (70,79). Because maternal obesity is a risk factor

for childhood obesity, the rising obesity prevalence among women of reproductive age could have important inter-generational effects in LMICs (80).

Urbanization and economic development

As of 2014, 33%, 39%, and 63% of people in low, lower-middle, and upper-middle income countries lived in urban areas, respectively (81). Obesity is generally higher in urban compared with rural settings across LMICs. However, as LMICs further urbanize and as the prevalence of overweight/obesity rises globally, the urban-rural obesity differential appears to be shrinking, largely due to increases in overweight among rural populations. While overweight prevalence is increasing in both rural and urban areas, the rate of increase is higher in many rural populations. In a study of women of reproductive age, Jaacks *et al.* found that overweight was increasing at a greater rate in rural areas relative to urban areas in nearly half of LMICs (52). A study of adolescent girls found a trend towards higher overweight over time in rural areas but not urban areas (46). With the exception of Sub-Saharan Africa, Popkin and Slining found greater annual increases in obesity in rural areas relative to urban areas in all regions of the world; however, the burden of overweight is similar in both rural and urban areas in LMICs except in South Asia and Sub-Saharan Africa (82).

The urban-rural obesity differential is hypothesized to occur due to changes in infrastructure, transportation, employment, income, food access, and physical activity that accelerate obesity in urbanized and economically developed areas (83). The urban food environment is characterized by high availability of calorically-

dense, cheap foods (84). Urbanization also facilitates reduced physical activity through changes in infrastructure, transportation, and occupational activities (85) (86). Additionally, higher obesity in urban areas may be due to higher individual- and community-level SES in urban centers (87). In more developed LMICs like India and Brazil, the prevalence of overweight/obesity is even increasing in urban slums despite persistent poverty (88,89). As countries continue to economically develop and urban centers expand, the distinction between urban and rural residence has become less pronounced. For example, elements of economic development that were historically concentrated in urban environments, such as packaged and ultra-processed foods, have spread to rural areas – aided by media and marketing (90). Thus, rural areas may not continue to enjoy an obesity advantage as they have in the past.

Regional/ethnic differences in defining obesity

International BMI thresholds for overweight and obesity are defined based on risks to cardiovascular health in European populations (91,92). However, the relationship between anthropometry and adiposity tends to differ by ethnic background. For example, young African American men are more likely to be classified as obese based on BMI despite lacking excess directly-measured adipose tissue (93). Conversely, adiposity in South Asians may be underestimated by BMI classifications of obesity (94,95). In addition, the association between BMI and health risks appear to vary by ethnic background, with evidence from multi-ethnic studies suggesting that several non-European groups experience the same levels of

glucose and lipids at roughly 6 kg/m^2 lower BMI than Europeans (96). Most studies assessing the need for alternative ethnic-specific cut-points focus on Asians and suggest that they are more likely to have diabetes and other cardiovascular disease outcomes than non-Asians at any given BMI (97–100). The WHO has recommended alternative lower cut-points for action for Asians, defining excess risk at BMI of 22.5 kg/m^2 upwards (101). Some authors have concluded that data in other non-Caucasian groups are too limited to make a conclusion about alternative cut-points (102).

General versus central obesity

BMI, a measure of general obesity, has long been recommended to assess adult overweight/obesity (92) and is the most commonly reported metric of obesity in the literature (103). However, measures of central adiposity (waist-based measures such as waist circumference, waist-height ratio, and waist-hip ratio), are also associated with excess risk of cardio-metabolic disease and may be superior to BMI in some populations. In the 52-country INTERHEART study, each standard deviation in waist-hip ratio was associated with a 37% higher adjusted odds of myocardial infarction while each standard deviation in BMI was associated with a 10% higher adjusted odds. However, one recent study found comparable effect sizes associated with waist circumference and BMI in models of prevalent hypertension in South Asians, South Africans, and South Americans, and higher (though statistically indistinguishable) effect sizes for waist circumference than BMI in relation to diabetes in South Africans and South Asians (104). Given that the

location of fat may be responsible for specific health effects (105), waist circumference could provide information complementary to BMI (106).

Drivers of Obesity in LMICs

Traditional drivers of obesity (diet and physical activity)

Conventionally, obesity has been thought a consequence of prolonged caloric intake in excess of energy requirements (107). However, emerging data challenge the notion that a simple sum of energy input through diet and energy output through physical activity explain obesity and instead suggest that factors contributing to dysregulation of neuroendocrine mechanisms may be involved in the complex process that leads to obesity (108). The following section outlines changes in global diets, the global food system, and physical activity as well as emerging risk factors of interest. Emerging risk factors are not unique to LMICs; however, they likely represent a different proportion of the risk burden relative to HICs and might help inform obesity prevention or management strategies in developing countries.

Nutrition transition

The nutrition transition refers to the shift from traditional diets comprised of whole foods including pulses and whole grains that are low in animal-source foods, salt, and refined oils, sugars, and flours (109) to an energy-dense and nutrient-poor diet comprised of refined carbohydrates, high fat intake, and processed foods (7,10,110). Relative to traditional diets, both total caloric intake and energy density

tend to be higher in contemporary diets due to increased consumption of processed foods and fats (111) facilitated by increased income, urbanization, and shifts in food availability and pricing (6). Relevant to excess caloric consumption, ultra-processed foods, typically high in fat, salt, and sugar, are designed to be highly palatable and can overcome homeostatic eating signals; for example, high salt content can override fat-mediated satiety cues and promote overconsumption (112).

Yet traditional diets are not necessarily healthy, and some aspects of dietary change associated with the nutrition transition are desirable. Staple food-based diets typically lack dietary diversity and have been associated with micronutrient deficiencies (113). Furthermore, diets high in carbohydrates and low in fat are associated with increased plasma triglycerides and decreased high-density lipoprotein cholesterol (HDL-c) – both of which are associated with cardio-metabolic disease (114,115). In a U.S. cohort of Puerto Rican adults, adherence to the traditional rice and beans dietary pattern was associated with higher risk of metabolic syndrome (OR: 1.7; 95% CI: 1.04, 2.70) and lower HDL-c (116). A positive effect of the nutrition transition includes improved dietary diversity through greater inclusion of fruits and vegetables, eggs, cheese, milk, meat, and fish in some settings; however, processed foods are often included along with the new fresh, whole foods (7), and are typically energy dense, nutrient poor, and low in fiber (109). Adherence to balanced diets high in whole grains, fruits and vegetables, and healthy fats, like the Mediterranean diet, have been associated with reduced obesity incidence (117) and NCDs including diabetes (118).

A shift away from traditional foods has led to a sweetening of the global diet. Added sugars are a dietary driver of obesity worldwide – especially when consumed in beverages such as soft drinks, sweetened coffee and tea, juices, and alcoholic beverages (55). In most LMICs, sugar-sweetened beverages (SSBs) sales are increasing (in daily calories per person) (119) and represent an important source of caloric intake in many parts of the developing world – the consequences of which have been well documented in Mexico (12,120). Liquid calories influence weight gain by contributing to excess caloric consumption because, relative to solid foods, liquids are less satiating (121,122). Consequently, people do not compensate for energy consumed from beverages, contributing to excess caloric intake (123). A meta-analysis of SSBs and health outcomes commissioned by the WHO found a positive association between SSBs intake, total caloric intake, and body weight (54).

Global trade and the food environment

Globalization and trade liberalization play a role in the nutrition transition in LMICs through their influence on the food system – particularly, the availability and price of food (124). Broadly, trade liberalization encourages greater imports of food, facilitates foreign direct investment in food production and processing, and stimulates growth of transnational food companies (124). Treaties like the Central American Free Trade Agreement (CAFTA), and the proposed Transatlantic Trade and Investment Partnership (TTIP) reduce or eliminate tariffs on animal feed and meat, processed foods, and ingredients for processed foods. Notably, trade liberalization has led to increased availability of edible oil; global availability of

plant oils tripled from 1961-90 (7). Increased importation and production of vegetable-source fats leads to increased availability and affordability (7). These changes in food availability and pricing in turn lead to new food consumption patterns such as snacking and consumption of processed or fast foods (125) and, subsequently, increased caloric intake. For example, snacking was associated with higher daily energy intake (+102 to 289 kcal/d per snack) among Mexican school children (126). More research is needed on the factors influencing food choice in LMICs to better target obesity prevention efforts.

Declining physical activity

Decreases in physical activity have been cited as a primary driver of rising obesity levels (127). A study of 122 countries representing 88.9% of the world's population found that 31.1% of adults age ≥15y are physically inactive (128). Further, physical activity is lower in LMICs relative to HICs (128). Shifts from manual labor to more sedentary jobs have resulted in significant loss of physical activity (84) and are an important dimension of low energy expenditure. Moreover, modern technology such as refrigeration and other appliances has decreased the energy expenditure needed for domestic activities (111). Mechanization of domestic work such as washing clothes and cleaning dishes was associated with a 111 kcal/day mean savings in energy expenditure relative to manually performing these tasks (129). Active transportation (i.e. commuter walking and cycling) has also decreased. While data on active transport in LMICs is scarce, only 64.1% of adults reported walking for at least 10 minutes consecutively on ≥5 days per week (128).

China has witnessed substantial increase in motorized transportation since 1990 with strong associations between vehicle ownership and obesity (130). There is little indication that people in LMICs are compensating for reductions in occupational physical activity and active transport with increased leisure time physical activity (128). In fact, leisure time may be more sedentary than in the past due to technologies such as TVs, and sedentary activities are often associated with obesogenic behaviors like snacking (111).

The diet versus physical activity debate

Diet and physical activity are two competing and complementary drivers of obesity. Findings from a systematic review of sedentary behavior and obesity risk were equivocal due to limited evidence from high quality studies (131). Swinburn *et al.* argue that excessively caloric diets due to changing food systems rather than declining physical activity is the predominant driver of obesity (47). Their arguments rest on two primary ecological observations. First, the rise of population-level BMI in the U.S. more closely corresponds to the time period of surplus caloric availability rather than the time period of energy expenditure decline. Second, temporal changes and regional variation in the built environment is not sufficient to account for global obesity patterns. Similarly, at the individual level, modifying caloric consumption rather than physical activity has been cited as an optimal strategy to achieve energy balance (132). High energy consumption would require substantial increases in energy expenditure (via vigorous intensity and/or long duration physical activity) to prevent weight gain (133). Small but persistent

positive energy balance of only 30 kJ per day could explain observed increases in overweight (134). For this reason, obesity reduction policy efforts, such as the soda tax implemented in Mexico, aim to address obesity through the caloric consumption side of the energy balance equation (135). Because many of the health risks associated with physical inactivity are independent of its influence on body weight (136), promoting active lifestyles would be beneficial for overall health regardless of its impact on obesity or weight loss.

Other emerging risk factors

Genetic and epigenetic influences

The heritability of BMI is estimated to be 40-70% (137), through means including the control of the physiologic response to caloric excess and regulation of appetite via hormones such as leptin (138). There is increasing interest in how interactions between the environment, behavior, and the genome can modify gene expression. The epigenome – or non-sequence-based DNA modifications – include alterations such as DNA methylation. Dalgaard and colleagues elucidated an epigenetic network, tested in mouse models, that triggers obesity in an ON/OFF manner; however, it is not yet known whether this bimodal system exists in humans (139). Human studies have shown that four distinct variably methylated regions, located in or near genes previously implicated in body weight regulation, covary with BMI (140).

Epigenetic mechanisms regulate several obesity-related pathways including food intake, energy expenditure, and adiposity (141). Diet influences epigenetic states both directly (e.g. vitamin A) and indirectly (e.g. methyl donors including folate). Studies from The Gambia have shown that maternal diet influences DNA methylation patterns (142). Environmental factors, such as exposure to persistent organic pollutants (POPs), can also perturb epigenetic mechanisms. Furthermore, the availability of certain nutrients can effect toxicant metabolism, suggesting an overlap between dietary and environmental exposures and the development of the epigenetic footprint (143). This point could be especially important for populations with high toxin exposure coupled with nutritional insufficiencies. Because epigenetic changes can be heritable during cell division, future generations can be affected by past nutrition or environmental exposures (144). Advances in understanding of genetic and epigenetic influences on obesity could inform future personalized medicine to prevent or treat obesity based on genotype and phenotype to the extent to which adverse changes are modifiable (145).

Early life undernutrition and later life obesity and cardio-metabolic disease

The vast majority of undernourished children reside in LMICs (146). With socioeconomic advancement and improved living conditions, these children are increasingly exposed to obesogenic environments outside of the womb. Adult obesity and cardio-metabolic disease in LMICs might be influenced by the mismatch between conditions in early and later life. The "Developmental Origins of Health and Disease Hypothesis" posits that structural and functional adaptations in response to

in utero undernutrition – possibly to preserve brain and vital organ development – combined with a plentiful environment outside of the womb predisposes an individual to develop cardio-metabolic disease (20). While the initial hypothesis was developed to address disease patterns observed in England and Wales (21), there has been much supporting evidence from animal studies (22) and from cohorts where low birth weight (a proxy for fetal undernutrition) and childhood underweight continue to be high (23–26). Birth size has been associated with adiposity, obesity, type 2 diabetes, lipid profile, and blood pressure (15–19). Taken together, early life undernutrition and a rapid shift in diet and physical activity could explain why people in LMICs are experiencing chronic disease, on average, 10-15 years younger than people in HICs (147).

Nutrition supplementation/food assistance programs

Nutrition supplementation programs targeting childhood undernutrition may be inadvertently increasing risk for adult obesity (28,29). Interventions to promote rapid growth following prenatal and/or infant growth deficits can increase the risk of overweight and adiposity in later childhood (30,31). A nutrition supplementation program for pre-school children in Chile was associated with a 50% increase in the number of overweight children and a threefold increase in the number of obese children during the first year of the program (32,33). Understanding how nutrition supplementation to manage stunting is associated with obesity is particularly important in LMICs where food assistance policies are common (33).

Gut microbiome and enteric infections

The gut microbiome is a collection of microbial organisms residing in the gut. Together with host genotype and lifestyle factors, the gut microbiome may play a role in the pathophysiology of obesity (148) through energy use and storage and by regulating expression of genes associated with fat production and deposition (149). For example, the "obese microbiome" has increased capacity to harvest energy from the diet and promote fat deposition relative to the "lean microbiome" (148).

Researchers speculate that interaction between dietary changes, such as a shift to a modern diet from a traditional diet, or differences in microbial ecology between individuals in LMICs vs HICs, and the gut microbiome affect predisposition to obesity (149). There is a 'core' microbiome, and deviation from this core is associated with obesity and poor child growth (150,151). Breastfeeding, food, and water security are critical factors in the maturation of healthy gut microbiota (152). Gut microbiome maturation primarily occurs by age 3y and is associated with increased microbe diversity; microbiota are vertically transmitted from mother to child via *in utero* colonization, vaginal delivery, and breastfeeding (152). Microbiota are also shaped by diet throughout life. Administration of a Western diet to non-obese mice altered the composition of the microbiota, and subsequently increased transfer of calories from the diet to the host, and affected the metabolism of the absorbed calories (150).

Environmental contaminants

Persistent organic pollutants (POPs) are man-made chemicals used as agriculture fertilizers and insecticides for mosquito control which were largely restricted in HICs beginning in the 1970-80s. Organochloride insecticides like dichlorodiphenyltrichloroethane (DDT), however, are still heavily used for malaria control in countries like India and throughout the African continent (153). These chemicals are resistant to natural environmental degradation, biomagnify in the food chain, and bioaccumulate in human tissues. POPs are thought to influence obesity risk by disrupting endocrine function by mimicking hormones, modulating gene transcription factors, altering endogenous hormone availability, or through epigenetic mechanisms (154).

Exposure to chemicals including polychlorinated biphenyl (PCBs), DDT, bisphenol A (BPA), and arsenic is positively associated with obesity (155), and there is concern that exposure during sensitive developmental periods such as *in utero* or in infancy through means including breastmilk consumption could have important implications for the epigenome and the regulation of endocrine function. The highest concentration of DDT in breastmilk was observed in Africa with slightly lower concentrations among mothers in Asia, Mexico, and Central America; high levels of PCBs were also reported in breastmilk in mothers from Asia (156). More long-term, longitudinal research is needed to elucidate the role of POPs on obesity pathophysiology – particularly how simultaneous exposures to various environmental contaminants might behave synergistically.

Chronic stress

Chronic stress associated with poverty, unemployment, crime, lack of safety, poor social networks, and other factors in LMICs could be contributing to rising obesity. In the short term, hormonal response to acute stressors (i.e. release of cortisol) helps to reestablish homeostasis; however, repeated hypothalamic-pituitary-adrenal axis activation due to chronic stress can overload the regulatory system (157). Elevated cortisol from a stress response is associated with increased appetite, visceral adiposity, and the propensity for weight gain (157). In addition to the hormonal changes, stress-related coping behaviors such as emotional eating are positively associated with obesity risk (158). While much of the evidence on chronic stress and obesity are from HICs, data from India showed that chronic stress (measured by an urban stress index) was associated with poor health behaviors including tobacco use (159).

Sleep deprivation

Sleep deprivation has been associated with poor food choices and an increased risk of obesity. Longitudinal studies have shown a positive association between short sleep duration and obesity risk. A meta-analysis of prospective studies found an increased risk of obesity for short sleep duration (≤5h) relative to normal sleep duration (7h) (pooled OR 1.45; 95% CI 1.25, 1.67) (160). To our knowledge, there is only one study of sleep duration and obesity risk from a LMIC (India) (161). The mechanisms through which short sleep duration increase obesity risk are not entirely understood; however, sleep deprivation is thought to increase

hunger and preference for high fat and sweet foods (162). An experimental study in adolescents found that while self-reported hunger was not increased, sleep restriction (<6.5h) was associated with an 11% increase in total energy intake relative to healthy sleep duration (10h) (163). Another study found that sleep loss in adults increases the hedonic reward for consuming sweet, salty, and fatty snack foods via increased levels of endocannabinoid (164). Finally, stress and sleep deprivation are thought to have a synergistic effect on obesity risk; increased cortisol secretion associated with the acute stress reaction is linked to impaired sleep (165).

Challenges

Obesity Prevention and Management Efforts

Obesity prevention

Intentional weight loss and subsequent weight management is challenging. Only one in six U.S. adults who were ever overweight or obese have long-term weight loss maintenance of at least 10% (166). Obesity prevention is seen as a more effective strategy than management for LMICs where 1) obesity is still emerging as a major health issue; and 2) management is particularly challenging because health systems developed to attend to infectious disease and maternal and child undernutrition must be entirely re-designed to contend with the dual burden of disease (167). Poverty and other factors affecting access to healthcare services further limit obesity management in LMICs. Children may be the most effective target group for prevention efforts because evidence suggests that propensity for

overweight and obesity begins as early as six months (168,169), and data from HICs show that overweight tracks from childhood into adulthood (170). Furthermore, diet-related behaviors such as food preference are established early in life (171), motivating obesity prevention programming targeting children. Examples of initiatives to promote healthy diet and weight in children include efforts by public educational institutions to purchase locally-produced healthy foods (172) and school-based nutrition education to improve food literacy (171). While focusing on obesity prevention in children will have little short-term impact on population prevalence of overweight/obesity, it would support long term goals of reduced burden of overweight over time. Approaches intended to promote obesity prevention in the entire population include subsidizing nutritious food (173) or, conversely, taxing unhealthy foods such as SSBs (174).

Management of obesity

Considering more conventional clinical approaches, the American Heart Association (AHA) provides summary recommendations for obesity that may be applicable to LMICs. To identify individuals who need to lose weight, the AHA recommends that both BMI and waist circumferences should be measured and patients be advised according to their classification based on current cut-points (175). AHA further notes that there is strong evidence to counsel overweight/obese patients with cardiovascular risk factors regarding the benefits of lifestyle changes, including improved diet. There is also strong evidence that bariatric surgery for obesity treatment is advised for individuals with BMI ≥40 or BMI ≥35 with

comorbid conditions that have not responded to other lifestyle changes, but this is applicable to a very narrow fraction of the obese population. Surgical options may also not be feasible in very low resource settings.

Although not restricted to obese individuals, the Exercise is Medicine Global Initiative is designed to support health care professionals in prescribing exercise to patients by training providers to assess patient physical activity levels, imparting behavioral counseling to increase activity using change models, and referring patients to resources available to facilitate physical activity (176). This Initiative already exists in LMICs and evaluation of its impact will provide important data on how to adapt and scale up this program to encourage healthy activity levels and weight status.

Data Gaps and Research Agenda

Data gaps and recommendations for research include:

1. Gap: Lack of sufficient surveillance systems to monitor national-level overweight and obesity in both genders and at all ages. Recommendation: Include population subgroups such as men, adolescents, and older adults in existing surveys of weight status and build routine surveillance of weight status into national health programs.

2. Gap: Lack of surveillance systems to monitor obesity-related health outcomes. Recommendation: Include routine data collection of diabetes, cardiovascular disease, and hypertension as well as other obesity-related conditions such as sleep apnea and osteoarthritis in population-based surveys.

3. Gap: Lack of validated cut-points to define overweight and obesity – especially in some ethnic groups, children, and adolescents – makes cross-country and cross-study comparisons difficult. Recommendation: Develop a consensus around internationally-accepted cut-points alongside ethnic- and age-specific cut-points; encourage reporting overweight and obesity by both internationally- and locally-accepted classifications. This will be facilitated by more data on BMI, waist, and related health outcomes in populations (i.e., addressing gaps 1 and 2).

4. Gap: Little obesity prevention research is catered to the needs of LMICs. Recommendation: Well-conducted intervention trials in LMICs to build the evidence base needed to support obesity prevention and treatment in these populations.

5. Gap: Policy-level data on designing food systems and a built environment that promotes healthy weight. Recommendation: Primordial prevention strategies targeting children to develop health habits early in life and avert the onset of obesity in later life. Additionally, more evaluation research on food policy, such as improved front-of-package food labeling, taxation on SSBs, or restricting marketing of unhealthy foods to children.

Conclusion

Obesity is rising in every region of the world, including across even the poorest of LMICs. The food environment is a primary driver of the rise in obesity worldwide over the past half-century. Other established and emerging contributing factors include a combination of diet, physical activity, built environment, genetics

and epigenetics, environmental pollutants, and stress. While each driver may have only a small effect on obesity risk, the accumulation of many small effects could explain the substantial increases in overweight/obesity seen in LMICs. Perhaps the most salient distinguishing feature of the obesity epidemic in LMICs is that it is unfolding against the backdrop of a large burden of maternal and child undernutrition and related disorders. The appearance of dual burdens of child undernutrition and adult over-nutrition, may exacerbate risk of obesity and associated cardio-metabolic disorders through hypothesized fetal programming pathways and is also taxing on underdeveloped health systems. In addition, common cardio-metabolic disorders such as hypertension and diabetes exist in large proportion in LMICs even in the absence of widespread obesity; rising obesity levels are therefore particularly worrisome. Yet, we have very little data on effective strategies to maintain weight as we age and to prevent the onset of obesity in LMICs. This is a key priority for future research and has important possibilities to contribute to reverse innovation that may inform interventions in HICs as well.

Summary Points

- Although age-standardized obesity is generally lower in low- and middle-income countries (LMICs) relative to high income countries, overweight has increased in all regions of the world.
- Rising overweight and obesity occurs alongside persistent burdens of underweight in LMICs, especially in young women.
- Overweight and obesity is higher in women compared with men, in urban compared with rural settings, and in older compared with younger individuals; however, the urban-rural divide is shrinking in many countries.
- The global diet has become sweeter, higher in fat, and saltier, while physical activity—especially related to occupation—has declined; these are among the hypothesized leading contributors to the rise of obesity.
- Emerging risk factors for obesity include environmental contaminants, chronic psychosocial stress, and sleep deprivation. The role of genetics, epigenetics, the gut microbiome, and neuroendocrine regulation are also being explored.
- Obesity prevention theoretically offers a more effective strategy than management for LMICs where 1) obesity is still emerging as a major health issue; and 2) management is challenging.
- Obesity prevention efforts targeting children has the best potential to avert obesity in adults of the future and should be rigorously evaluated.
- Surveillance systems to monitor weight status in both genders at all ages and obesity-related chronic diseases are needed in LMICs. Similarly, prevention

research and policy-level data to better understand how to design environments that promote healthy weight in LMICs should be a public health priority.

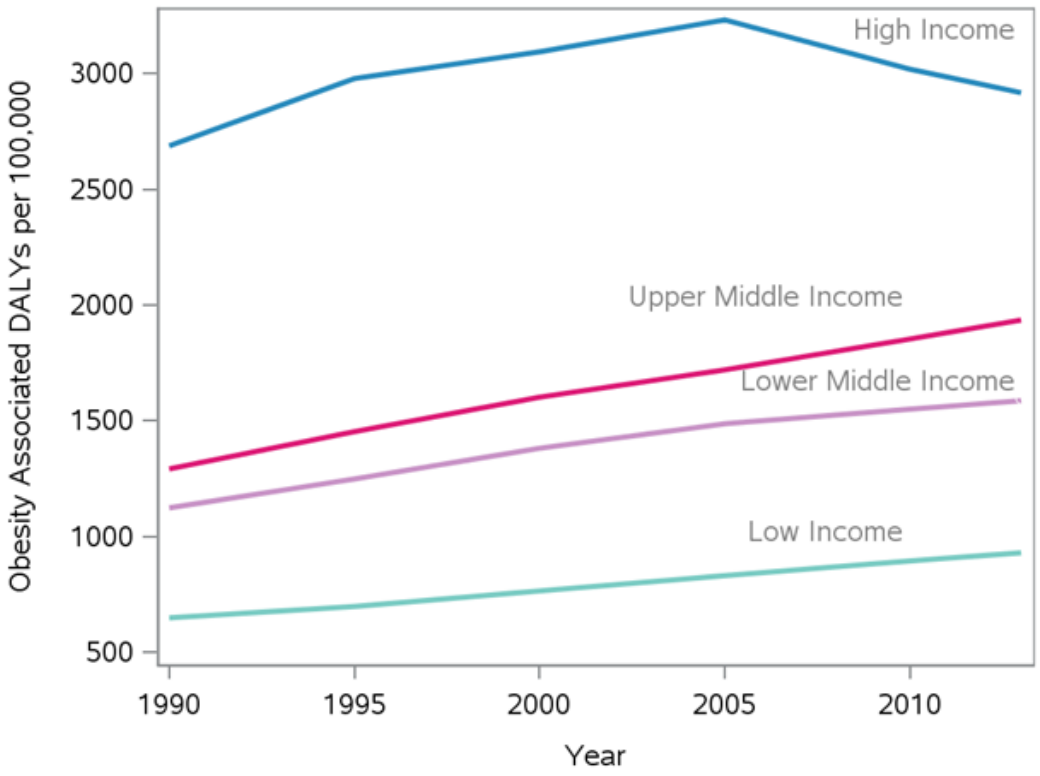

Figure 2.1. Total obesity associated Disability Adjusted Life Years (DALYs) per 100,000 population by World Bank income category, 1990-2010. Data Source: Global Burden of Disease Study (177).

Part II: Cardio-metabolic Disease, the Dual Burden, and Nutrition Transition in Guatemala

The previous section described the burden of overweight/obesity, drivers of weight gain (both established and emerging), and consequences of excess adiposity in LMICs. While there are similar trends in weight gain, chronic disease, and nutrition transition across many LMICs, the specific context in Guatemala is important for understanding the research in this dissertation. This section reviews the burden of obesity-related NCD, the double burden of under- and over-nutrition, and the nutrition transition in Guatemala.

Cardio-metabolic Disease in Guatemala

Obesity-related NCDs represent a growing proportion of the disease burden in Latin America (177). In the next 40 years, obesity-related NCDs are expected to double in the region (3). Guatemala has a high burden of these conditions; according to the Global Burden of Disease study, high fasting plasma glucose, high BMI, high blood pressure, and low glomerular filtration are among the top contributors to combined death and disability (8). Chronic diseases are also the main cause of mortality in Guatemala, and 40% of these deaths are among people < 60y old (5). Based on current trends, the number of deaths in the region attributable to cardiovascular conditions is estimated to increase by 60% from 2000-2020 relative to 5% in HIC (4,178,179).

Population aging is driving increases in NCDs. The demographic transition, which tracks with the epidemiologic and nutrition transitions, is characterized by a shift from high to low fertility coupled with a decrease in age-specific mortality rates and increased life expectancy (6). Both of these indicators have shifted over the last 60 years in Guatemala. The total fertility rate decreased from 6.5 children per woman in 1960 to 3.8 children per woman in 2012 while the under 5 mortality rate decreased from 92.7 deaths per 1,000 live births in 1987 to 35.7 deaths per 1,000 live births in 2009 (180). Life expectancy in Guatemala has also increased from 45.5 years in 1960 to 71.6 years in 2012 (180). Increasing longevity does not necessarily lead to improved health or quality of life; the WHO estimated that 23% of all illness and death is among people over 60y old and that the burden is largely due to NCDs including diabetes and cancer (181). While population aging in Guatemala contributes to the country's NCD burden, this dissertation research aims to explore social and behavioral changes associated with CMD risk.

The projected increases in the NCD burden is also driven by a rise in the prevalence of CMD risk factors over the last 20 years; obesity, hypertension and dyslipidemia (high triglycerides and low HDL-C) are the most widespread risk factors in Latin America (125,178,182). In Guatemala in 2014, 13% of men and 24% of women over age 18y were obese (183). Obesity prevalence was lower in Guatemala relative to Latin American average (18.6% vs. 22.3%)(177), however, even among those with a normal BMI, small increases in weight can affect cardiovascular disease risk (184). Evidence from multiple Latin American countries has shown that women are at especially high risk for overweight/obesity (66,73).

Following both Latin American and national trends, the INCAP cohort has also experienced increasing overweight/obesity. From 1997 to 2004, 42% of men and 56% of women gained more than five kilograms (185). Triglycerides, total cholesterol, glucose, and prevalence of the metabolic syndrome increased significantly in both genders during the same time period (185).

The Double Burden in Guatemala

Despite recent increases in obesity prevalence, Guatemala has a long history of persistent undernutrition. In 1966, the national prevalence of under-five stunting was 63.5% (186). In the INCAP cohort, 67% of participants were stunted (HAZ <-2 SD) by age 24 months (187). Guatemala has made great strides in reducing child undernutrition; national prevalence of underweight (weight-for-age Z [WAZ] scores < -2 SD) among children under 5y decreased from 28% in 1987 to 13% in 2015, and stunting prevalence decreased from 66% to 47% over the same time period (13). While caloric undernutrition is no longer a widespread problem in Guatemala, nearly half of all children under 5y were stunted in 2015, indicating persistent and pervasive nutritional inadequacy (13).

Beyond its role in reduced cognitive development and poor child health outcomes (188,189), early life undernutrition is thought to increase risk of adult CMD – particularly among people exposed to hyper-caloric environments later in life (14). The rise of overweight and obesity have occurred alongside persistent burdens of undernutrition in many LMICs (56). With rapid change, countries experience the “double-edged sword” of malnutrition wherein undernourished

children grow to become stunted, over-nourished adults at increased risk for NCDs (182,190). Guatemala has the highest prevalence of dual burden households in Latin America where 23% of households contain a stunted child and an overweight adult (191,192). Because nearly half of Guatemala's population is under 18y old, child nutrition plays a central role in the country's current and future disease burden (193).

The Nutrition Transition in Guatemala

The large increase in non-communicable diseases over the past 20 years is a direct result of demographic, social, and economic changes influencing dietary and physical activity patterns, and other factors (6). The nutrition transition is marked by changes in diet from staple foods to high-fat, high-sugar, processed foods (7). While trade liberalization and the expansion of transnational food corporations have changed the availability and pricing of ultra-processed foods in Guatemala, the extent to which Guatemalans have adopted Western diets is unclear. To date, little has been published about individual adult diets in Guatemala (194–197).

Globalization and the food environment in Guatemala

Globalization and trade liberalization have influenced the food environment in Guatemala. Broadly, trade liberalization encourages food imports, facilitates foreign direct investment in food production and processing, and stimulates growth of transnational food companies (124). The Central American-Dominican Republic Free Trade Agreement (CAFTA), ratified by Guatemala in July 2006, has been a

major driver of change in the food environment. The treaty eliminated tariffs on packaged and processed foods such as sweet pastries, corn chips, frozen pizzas, and chocolate products (124). Accordingly, food imports ($US mil) increased from 1,706 in 2002 to 3,944 in 2012 (180). By 2008, partially and highly processed foods each accounted for 20% of total caloric availability in Guatemala (198). The treaty also opened advertising markets to the United States. Marketing and advertising play important roles in the perception of processed foods in Guatemala – particularly those branded with licensed characters from movies or television (199,200).

Globalization has also played a role in the proliferation of supermarkets in Latin America, influencing the availability and price of foods. In Guatemala, the number of supermarkets doubled from the late 1990s to 2008 and represent an increasing share of the retail food market (198). Supermarket chains in Latin America have tended to concentrate on food items where they have a comparative advantage over markets, namely, highly processed and packaged foods. One study found that the share of processed and packaged foods in supermarkets was two to three times higher than the share of fresh foods (201). A 2008 study from Guatemala found that supermarket purchases increased the share of highly and partially processed foods at the expense of staple foods like corn (198). Increasingly, *tiendas* (small convenience stores) are providing access to ultra-processed foods (202). While globalization and trade liberalization are not the cause of the nutrition transition per se, they are likely a driver behind the rate of dietary change in Latin America (124).

Diet in Guatemala

Traditional diets are comprised primarily of whole foods including pulses and whole grains and are low in animal-source foods, salt, refined oils, refined sugars, and flours (109). In Guatemala, maize dominates the diet; corn tortillas and tamales are the primary cereal-based foods. As of 2008, corn and corn products accounted for 40% of total national caloric availability (198). Historically, black beans also provide a major energy source in the Guatemalan diet (202). A hallmark of the nutrition transition is a shift from a traditional diet to a Western diet that is energy dense and nutrient poor with high intake of refined carbohydrates and processed foods - accelerated by increased income, urbanization, and shifts in food availability and pricing (7,10,110). Despite documented alterations to the food environment as discussed in the sections above, the extent to which Guatemala has undergone extensive dietary change is unclear. Data from neighboring countries such as Mexico are not very informative because of significant heterogeneity in diet across countries (203).

There is some evidence of dietary change in Guatemala – namely, changes in dietary diversity and consumption of processed foods. From the 1950s - 2000s, one study reported an increase in food variety, decreased intake of nutrient-dense foods, and increased intake of processed foods among both *Ladino* (mixed European and indigenous descent) and Mayan Guatemalan populations (196). Some have argued that the hallmark of changing diets in the Guatemalan diet is the substitution of

wheat-based products for corn (84) – facilitated by bakeries and bread truck routes (83).

Several studies have highlighted rural/urban differences in diet as evidence of change. Because dietary changes consistent with nutrition transition typically appear first among urban populations, urban populations would be expected to have a more Western diet relative to the rural population in transitioning countries (6). Urban diets in Guatemala tend to have greater dietary diversity relative to rural diets (84). One study reported that 70% of the rural diet was comprised of only 10 foods and beverages relative to 40% of the urban diet (194). Other studies have also found differences in the types of foods consumed; urban populations in Guatemala tended to consume animal-based foods (204), soda, bread, milk (205), and "modern" processed foods, such as instant coffee and margarine, more frequently than rural populations (194).

Despite some differences in diversity and types of foods consumed, available data show that traditional foods constituted the majority of the Guatemalan diet in the early 2000s – even among urban populations (194,206). While the INCAP cohort reported consuming "transitional" foods such as hamburgers, hot dogs, ice cream, potato chips, and other snacks in 2003 (205), these foods comprised only 2% of the diet during this study wave (206).

Contributions of this dissertation

This research addresses several gaps in the literature. To our knowledge, we are the first study to explore BMI trajectories from birth/early childhood through mid-adulthood in a LMIC population using LCGA. In non-latent class type growth modeling, a single curve is used to describe average growth patterns – potentially obscuring heterogeneity in growth (207). In contrast, LCGA allows us to analyze the continuity of growth over the life course and to identify distinct growth patterns in cohort sub-groups not readily identifiable using other modeling techniques (208).

Beyond identifying distinct growth patterns from infancy/early childhood through mid-adulthood, this research also aims to explore both early life predictors of life course BMI trajectories and their downstream health consequences. Despite the potential conflict between nutrition supplementation to promote optimal growth and risk of childhood overweight, there is a paucity of data to assess the long term effects of child nutrition interventions on BMI gain in LMICs. Furthermore, the role of childhood SES in the development of obesity is not well understood.

Moreover, the association between the timing and tempo of BMI gain over the life course and chronic disease outcomes is not clear. Studies of life course BMI trajectories and CMD risk have focused on HIC populations (209–212); however, growth patterns in LMICs are likely distinct due to persistent childhood undernutrition. Studies from LMIC populations have explored the role of smaller segments of the life course, for example, adolescence, with CMD outcomes (211,213,214) - the limited focus likely owing to the relatively young age of most

LMIC birth cohorts (17,215–217). If people exposed to early life undernutrition – especially those later exposed to hyper-caloric environments consistent with developing economies - have growth patterns which confer distinct risk for CMD, life course growth analysis can help identify groups in need of targeted prevention. Yet there is little data from LMIC populations about the long term consequences of persistent early life undernutrition in obesogenic environments (27).

Our analyses assessing dietary change in the context of nutrition transition and those exploring dietary patterns and CMD outcomes also address current gaps in the literature. The nutrition transition has been well-documented in Mexico, Brazil, and Chile (10–12); however, little is known about dietary change in less economically developed Latin American countries. Few published studies explore adult diet in Guatemala (194–197,206), and, to our knowledge, no studies have examined individual dietary change over time.

Furthermore, there is little information about how Guatemalan dietary habits influence CMD risk. One study of diet scores and CMD risk found that neither score-based indices of diet quality nor single nutrients were consistently associated with CMD risk factors (206,218,219); however, individuals with identical diet scores can have diverse consumption patterns (220). Data-driven dietary pattern analysis goes beyond intake and adequacy of individual nutrients and attempts to characterize dietary behavior and link patterns of consumption of foods and beverages to health outcomes, including anthropometry, metabolic syndrome, and diabetes (221–223). Because diet is a major modifiable determinant of chronic disease risk (9),

understanding how dietary patterns are associated with CMD risk is important for informing public health strategies.

The overarching theme of this research is change in BMI and diet over the life course and its association with CMD risk in the context of nutrition transition. To address the gaps in the literature, we use data from the Institute of Nutrition of Central America and Panama (INCAP) Nutrition Supplementation Trial Longitudinal Study cohort whose members were born in rural Guatemala from 1962-1977 and participated in a longitudinal study of nutrition supplementation as children. More details on the cohort and its study waves are provided in Chapter 3. The research was designed based on a conceptual framework (**Figure 2.2**), showing the inter-connected relationships between early life exposures, BMI gain over the life course, adult exposures such as dietary pattern, and CMD risk. Chapters 4-8 address these relationships in detail.

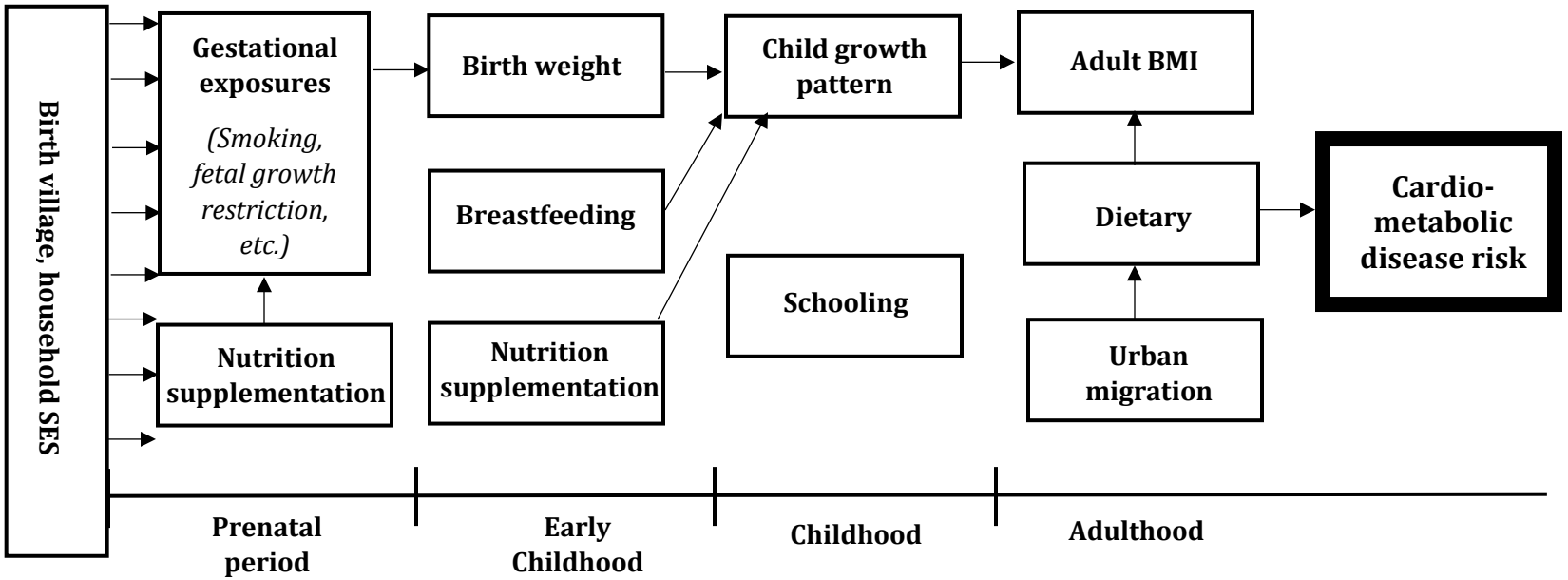

Figure 2.2. Conceptual framework

Chapter 1 and 2 References

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Chapter 3 – Overview of cohort and study waves

The INCAP Nutrition Supplementation Trial Longitudinal Cohort is notable for its contributions to understanding the role of early life undernutrition on health and cognitive development in developing countries. The original nutrition supplementation trial was designed to assess the influence of early life undernutrition on cognitive and physical development. The follow-up studies were implemented to assess longer-term effects of the original intervention. Study wave targets and coverage are presented in **Table 3.1.** This chapter provides a brief summary of the INCAP Longitudinal Study and the follow-up studies relevant to the research in this dissertation.

The INCAP Longitudinal Study, 1969-77

The main purpose of the INCAP longitudinal study was to assess the impact of intrauterine, early life, and pre-school malnutrition on child mental development–specifically protein malnutrition. The study took place from January 1, 1969 to February 28, 1977 in four villages in the El Progreso department in southeastern Guatemala. All women who were pregnant or lactating and all children under 7 years old (born January 1962 – February 1977) who were living in the study villages were included in the study design. Specifically, children who were 7y or younger at the start of the trial and those born during the trial were followed up through the study's end or age seven, whichever came first (N=2,392).

Two sets of matched villages were randomized to *Atole*, a dietary supplement made from INCAPARINA (a vegetable protein mixture developed by INCAP), dry skim milk, and sugar (6.4 g protein/100mL; 0.4 g fat/100mL; 90 kcal energy/100mL) or *Fresco*, a low-energy beverage with no protein or fat (33 kcal/100mL, all calories from sugar). Both supplements were fortified with micronutrients in equal quantities by volume. The supplement was available in a central location in each village twice daily. Children could be exposed prenatally through maternal supplement intake and/or postnatally through breastmilk or the child's own consumption through age seven years. Additionally, the study provided all with medical care free of charge in clinics adjacent to the supplementation feeding halls, including immunizations and deworming; however, no health or nutrition education were provided beyond encouragement to attend the nutrition supplementation centers and to receive recommended vaccinations. Details of the study design are available elsewhere (1).

The INCAP Follow-up Study, 1988-89

The main purpose of the INCAP follow-up study (1988-89) was to explore whether improved nutrition in early childhood led to enhanced human capital formation. Of the 2,392 children in the original trial, 9.4% (n=224) died before the follow-up study – largely in early childhood (1). Cohort members who lived in or near to the study villages or in Guatemala City at the time of data collection were eligible for the follow-up study. Participants were 11-27y old. Additional data were collected on participants who were not included in the original nutrition

supplementation trial including people living in nearby villages identified as potential study sites but which were not selected for the original trial; however, these subjects will not be included in this dissertation research because they do not have longitudinal data on the relevant variables. Details about the design of the INCAP follow-up study are published elsewhere (2).

Cardiovascular Disease Risk Follow-up Study, 1997-99

The main purpose of the cardiovascular disease risk follow-up study (1997-99) was to examine the impact of prenatal and early childhood malnutrition on adult cardiovascular disease risk factors. Data were collected on a sub-sample of the cohort who had at least 12 months of infant growth data available, who lived in or near to the study villages or in Guatemala City, and who were not pregnant or less than 6 months post-partum at the time of data collection. Because of the requirement for infant growth data, this sub-study was a younger subset of the cohort. Participants were 20-29y old. Details about the design of this follow-up study wave are available elsewhere (3).

The Human Capital Study, 2002-04

The main purpose of the 2002-04 Human Capital Study was to explore the impact of early childhood nutrition for adult human capital formation and economic productivity. During this study wave, the participants from the original nutrition supplementation trial were 26-41y old. All cohort members who were living in

Guatemala during this study wave were eligible to participate. Details about the design of this follow-up study wave are available elsewhere (4).

The Metabolic Study, 2015-17

The main purpose of the Metabolic Study was to test the hypothesis that improving early life nutrition can attenuate the development of cardiometabolic disease risk through impacts on the metabolomics and cardiometabolic profiles. Of the original 2,392 children in the original trial, 15.2% (n=364) had died by 2015 and 4.6% (n=111) were untraceable (**Figure 3.1**). Of the remaining 1,917 cohort members, 12.3% (n=236) were living outside Guatemala in 2015. The targeted population for the Metabolic Study were the 1,681 cohort members who were living in Guatemala. During this study wave, the participants were 37-54y old. It is important to note that at the time of writing, data collection in the Metabolic Study was ongoing. Thus, analyses in this dissertation using data from the Metabolic Study wave are limited to participants who were living in the original study villages (n=1,040).

Table 3.1. Study sample, coverage, and select variables in the original trial and relevant follow-up studies

Year(s)	Study Wave Name	Study Target	Target sample, N	Coverage*, N (%)	Anthro	Blood Glucose and Lipids	Diet	Clinical exam°	Health behaviors (ie. smoking, alcohol use, physical activity)	SES
1969-77	INCAP nutrition supplementation trial	Children <7y old in study villages at start of trial, and children born in study villages during trial	2,392	1,992 (83)† 1,449 (61)‡	X			X		X
1988-89	Follow-up study	All cohort members §	2,169	1,577 (73)	X			X	X	X
1997-99	CVD risk factor study	Cohort members born during the trial and who had ≥12 months of infant growth data§	608	473 (78)	X	X	X	X	X	X
2002-04	Human capital Study	All cohort members §	1,855	1,571 (85)	X	X	X	X	X	X
2015-16	Metabolic Study	All cohort members ¥	1,681 1,040	1,200* (70) 896 (86)€	X	X	X	X	X	X

*With at least partial information; †Anthropometry; ‡Supplement: attending the feeding center at least once every 3 months from birth to 24 months, every 6 months from 25-48 months, and every 12 months from 49 to 84 months; §Living in or near to study villages or in Guatemala City; ¥Living in Guatemala; *Expected; €Living in original study villages; °Clinical exam included blood pressure, personal and family medical history, medication use, and reproductive history.

Abbreviations: Anthro, anthropometry; SES, socioeconomic status.

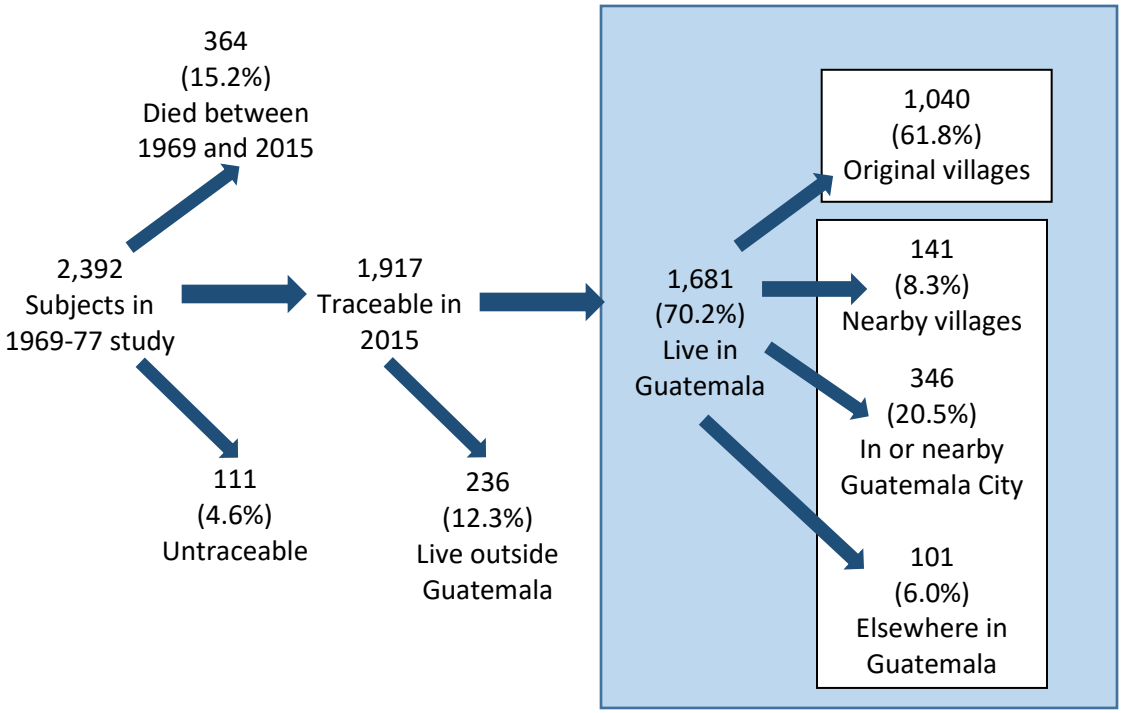

Figure 3.1. Tracking of the Metabolic Study 2015-16 sample. Of the original 2,392 individuals in the 1969-77 INCAP Nutrition Supplementation Trial, 15.2% (n=364) had died by 2015, and 4.6% (n=111) of the original cohort members were untraceable. Of the remaining 1,917, 1,681 (70.2%) lived in Guatemala in 2015.

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Chapter 4 - Life-Course Body Mass Index Trajectories Are Predicted by Childhood Socioeconomic Status but Not Exposure to Improved Nutrition during the First 1000 Days after Conception in Guatemalan Adults

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Abbreviations used: BMI, body mass index; DD, difference-in-difference; INCAP, Institute of Nutrition of Central America and Panama; LCGA, latent class growth analysis; LiNS, lipid-based nutrient supplement; low- and middle-income country; SES, socioeconomic status; WHO, World Health Organization.

Abstract

Background: Latin America has experienced increases in obesity. Little is known about the role of early life factors on body mass index (BMI) gain over the life-course.

Objective: The objective of this research was to examine the role of early life factors (specifically, nutrition supplementation during the first 1,000 days (conception-2 years) and childhood household socioeconomic status (SES)) on the pattern of BMI gain from birth or early childhood through mid-adulthood using latent class growth analysis.

Methods: Study participants (711 women, 742 men), born in four villages in Guatemala (1962-77), have been followed prospectively since participating in a randomized nutrition supplementation trial as children. Sex-specific BMI latent class trajectories were derived from 22 possible measures of height and weight from 1969-2004. To characterize early life determinants of BMI latent class membership, we used logistic regression modeling and estimated the difference-in-difference (DD) effect of nutrition supplementation during the first 1,000 days.

Results: We identified two BMI latent classes in women (low (57%) and high (43%)) and three classes in men (low (38%), medium (47%), and high (15%)). Nutrition supplementation during the first 1,000 days was not associated with BMI latent class membership (DD test – $P > 0.15$ for men and women) while higher SES was associated with increased odds of high BMI latent class membership in both

men (Odds Ratio (OR):1.98; 95% Confidence Interval (CI):1.09, 3.61) and women (OR:1.62; 95% CI:1.07, 2.45) for highest relative to lowest tertile.

Conclusion: In a cohort of Guatemalan men and women, nutrition supplementation provided during the first 1,000 days was not significantly associated with higher BMI trajectory. Higher childhood household SES was associated with increased odds of high BMI latent class membership relative to the poorest households – the pathways through which this operates still need to be explored.

Introduction

In the last two decades, Latin America has experienced decreases in underweight and increases in overweight (1–3). Age-standardized prevalence of adult overweight (20-70 years) in Central America increased from 45% in 1994 to 59% in 2000 (4). In high income countries, rapid weight gain during the first two years and high protein intake increase the risk of childhood overweight and adiposity (5–7). Conversely, the first 1,000 days after conception is a critical window to prevent stunting and to achieve optimal growth for health and cognitive development (8,9). Despite this potential conflict, there is a paucity of data to assess the long term effects of child nutrition interventions on body mass index (BMI) gain in low- and middle-income countries (LMICs).

Furthermore, the role of socioeconomic status (SES) in the development of obesity in developing countries is debated. Overweight in LMICs has traditionally been considered a disease of affluence; however, there is increasing evidence that the burden of obesity shifts to lower SES groups as countries undergo economic development (10,11). Existing studies of SES and obesity in LMICs have focused on adults (12,13); however, SES likely influences BMI gain early in the lifecourse.

Using experimental data from a longitudinal cohort study of Guatemalan men and women, we estimated the association of an energy- and protein-containing, nutrition supplement (*Atole*) during the first 1,000 days and of early-childhood household SES on the timing and rate of BMI gain from infancy through mid-adulthood using latent class growth analysis (LCGA). Understanding heterogeneity

in BMI gain over the lifecourse and its early life predictors could help inform nutrition programming in countries facing the dual burden of stunting and increasing obesity.

Methods

Study population

Study participants were born in four villages in southeastern Guatemala from 1962-77 and participated in the Institute of Nutrition of Central America and Panama (INCAP) Oriente Longitudinal Study (1969-77) and its follow-up studies (1989-2004) (14). The original trial was designed to assess the influence of early life undernutrition on cognitive and physical development. The follow-up studies were implemented to assess longer-term effects of the original intervention. In 1969-77, two sets of matched villages were randomized to *Atole*, a dietary supplement made from INCAPARINA (a vegetable protein mixture developed by INCAP), dry skim milk, and sugar (6.4 g protein/100mL; 0.4 g fat/100mL; 90 kcal energy/100mL) or *Fresco*, a low-energy beverage with no protein or fat (33 kcal/100mL, all calories from sugar). Both supplements were fortified with micronutrients in equal quantities by volume. The supplement was available in a central location in each village twice daily. Children could be exposed prenatally through maternal supplement intake and/or postnatally through breastmilk or the child's own consumption through age seven years. Children were followed up

through the study's end or age seven, whichever came first. Three follow-up waves (1988-9, 1997-99, and 2002-04) provide anthropometric measures in adulthood.

Because a minimum of three BMI values are needed for model stability in LCGA (15), individuals were excluded if they < 2 BMI values in childhood (0-84 months) and zero non-pregnant adult BMI values (10-42 years). Of the 2,392 individuals who participated in the original trial, 9% (205) were excluded for having no height and/or weight measurements, 20% (483) were excluded for having < 2 childhood BMI values, and 11% (251) were excluded for having zero non-pregnant adult BMI values (**Figure 4.1**). The final analyses included 1,443 (60%) participants (742 men and 711 women).

Data collection and variable specification

BMI. From 1969-77, child weight and length were measured by trained personnel using standard procedures (16). For subsequent study waves, trained field workers collected weight and height. Height was measured to the nearest 0.1cm and weight to the nearest 10g. All measurements were taken in duplicate; if the difference exceeded 500g for weight or 1cm for height, a third measurement was taken and the average of the closest measurements was used. BMI was calculated as weight (kg) divided by height squared (m^2).

Nutrition supplement and timing of exposure. Treatment assignment (*Atole* or *Fresco*) was based on birth village. Age of exposure was determined based on the child's date of birth and the trial start (March 1, 1969) and end (February 28, 1977)

dates. We assumed all participants were born at term. Participants born between November 28, 1969 and March 11, 1975 were considered exposed for the first 1,000 days, while children conceived prior to March 1, 1969 would not have been fully exposed during gestation, and children conceived after June 14, 1974 would not have been exposed through age 24 months (17).

Childhood household SES. Data on socioeconomic factors were collected by interview. SES was a cumulative score developed from principal components analyses of household characteristics and consumer durable goods measured in a 1967 survey of participant households (18). We categorized household SES score into tertiles.

Covariates. Maternal age in years and maternal years of schooling were ascertained by interview and specified as continuous variables in the models.

All data collection followed protocols that were approved by the institutional review boards of Emory University (Atlanta, GA) and INCAP (Guatemala City, Guatemala). All participants or their parents, as appropriate, gave written informed consent.

Statistical methods

LCGA can help identify distinct growth patterns in cohort sub-groups not readily identifiable using other modeling techniques. In non-latent class type growth modeling, a single curve is used to describe average growth patterns – potentially obscuring heterogeneity in growth (19). With LCGA, similar individuals are grouped

together based on their growth characteristics, and each latent class has its own growth curve (20).

We derived BMI latent class trajectories from up to 22 possible measures of height and weight: five from 1-12 months; three from 13-23 months; five from 24-50 months; three from 51-84 months; two from 10-20 years; and four from 21-42 years (**Supplemental Figure 9.1**). Among included participants, 5% had three measurements, 39% had 4-9 measurements, 34% had 10-14 measurements, and 23% had ≥ 15 measurements. Due to potential sex differences in the physiological responses to early life nutrition, we modeled sex-specific trajectories (21).

Variance and covariance estimates for growth factors were fixed to zero, so, within a given latent class, participants had the same slope and intercept (15). We developed models using all available data and robust maximum likelihood estimation. To minimize local solutions, we specified 200 random starting values. We assessed overall model fit using the Bayesian Information Criterion, the Bootstrap Likelihood Ratio Test, the Lo–Mendell–Rubin Likelihood Ratio Test, and took the interpretability of classes into account in determining the final model (15). To assess the quality of classification, we used entropy (a statistic ranging from 0-1 assessing accuracy of classification where a higher value indicates greater classification accuracy) and posterior probabilities (probability of assigning observations to groups given the data) (19,22). Age at onset of overweight was visually assessed by graphing the mean BMI for each class at the available ages and assessing the age at which mean BMI exceeded 25 kg/m^2.

To characterize early life determinants of BMI latent class membership, we used binomial and multinomial logistic regression for women and men, respectively. We estimated the difference-in-difference (DD) effect of *Atole* relative to *Fresco* during the first 1,000 days. Model 1 included a variable for supplement (coded 1 for *Atole* and 0 for *Fresco*), a variable for age of exposure (coded 1 for exposure during the first 1,000 days and 0 for exposure at other ages), and an interaction term representing the differential effect of exposure to *Atole* versus *Fresco* during the first 1,000 days, after subtracting the difference between participants exposed to *Atole* versus *Fresco* at other ages (ie. those coded 0 for "age of exposure") (17). Analyses focused on the estimate and significance of this interaction term. Model 2 included household SES tertile, maternal age, and maternal education. Model 3 included all variables from Models 1 and 2.

In sensitivity analyses, we estimated the DD effect of *Atole* during the first 1,000 days on obesity (BMI ≥30 kg/m^2) at the last age observed, controlling for birth year. We also derived latent class trajectories excluding BMI values taken during the first 1,000 days and re-ran all multivariate logistic analyses.

Analyses were conducted using MPlus v.7.3. Because 84% of participants had at least one sibling in the trial, standard errors were adjusted using the CLUSTER option to account for within-family correlation (23). Statistical significance was set *a priori* at $P < 0.05$. All p-values were two-sided.

Results

The study sample was 51% male (**Table 4.1**). Twenty-five percent of women and men were exposed to *Atole* during the first 1,000 days.

Based on model fit and quality of classification, we identified two BMI latent classes for women (**Supplemental Table 9.1**): low (*n* = 407, 57%) and high (*n* = 304 43%) (**Figure 4.2a**). For men, we identified three classes: low (*n* = 290, 389%), medium (*n* = 348, 47%), and high (*n* = 104 15%) (**Figure 4.2b**). The Lo–Mendell–Rubin Likelihood Ratio Test and Bootstrap Likelihood Ratio Test suggested that inclusion of an additional class did not improve model fit (**Supplemental Table 9.2**). The two-class model for women and the three-class model for men had the highest entropy (0.76 and 0.77, respectively) and highest posterior probabilities (~0.93 and ~0.91, respectively) of the candidate models, suggesting high class separation.

Median age at onset of overweight among women was 29 years and 23 years for the low and high BMI latent classes, respectively. Among men, median age at onset of overweight was 34 years for the low BMI latent class and 29 years for the medium and high classes. At 42 years, the mean difference in mean BMI between the low and high BMI latent classes was 5.2 kg/m^2 for women and 6.0 kg/m^2 for men.

The interaction term (estimating the DD effect of *Atole* relative to *Fresco* during the first 1,000 days on BMI latent class membership) was not significant in women (*P* = 0.16 for the high versus low BMI latent classes) (**Table 4.2**) or in men

(*P* = 0.29 and *P* = 0.43 for the middle and high BMI latent classes, respectively, vs. low BMI latent class) (**Table 4.3**). In sensitivity analyses, estimates were robust to restricting trajectories to BMI values after the first 1,000 days (DD *P* > 0.58 for men and women). Furthermore, *Atole* during the first 1,000 days was not significantly associated with obesity at the last age observed (DD *P* > 0.30 for men and women) in multivariate analyses.

High SES tertile was associated with increased odds of high BMI latent class membership in both women (OR:1.97; 95% CI:1.29, 3.00) and men (OR:1.98; 95% CI 1.09, 3.61) relative to the lowest tertile. Among women, middle SES tertile was also associated with increased odds of high BMI latent class membership (OR:1.63; 95% CI:1.06, 2.51) relative to the lowest tertile.

Discussion

With experimental data from a longitudinal cohort of Guatemalan men and women, we examined the role of early childhood factors on the timing and rate of BMI gain using LCGA. We identified two BMI latent classes in women and three in men. Early separation of the latent classes and lack of overlapping trajectories over the lifecourse suggest that pre-conceptional or early life factors are important in establishing BMI trajectories or reflect persistent circumstances and/or behaviors. Exposure to *Atole* during the first 1,000 days was not associated with BMI latent class membership, while higher childhood household SES tertile was associated with increased odds of high BMI latent class membership in both women and men.

Atole, a food-based protein-energy supplement, was associated with

improved child growth among those exposed before age three years (24). Nevertheless, we did not find evidence to suggest that exposure to Atole during the first 1,000 days was associated with BMI latent class membership. Studies in high income countries have shown an association between rapid growth before age two years and obesity risk (25–27); however, others found no increased risk when weight gain was appropriate for linear growth (28,29). A study of infant BMI trajectories in the Philippines found that accelerated infant BMI did not have long term consequences on young adult BMI (30). In the original trial, Atole exposure before age three years was associated positively with linear growth and weight, negatively with fat-folds, and had no association with weight-for-height (24,31). Other studies in these villages also suggest that to date the increases in length-for-age have not been accompanied by increases in overweight (32,33).

Excessive weight gain relative to linear growth could be the result of inappropriate or unbalanced nutrition. Atole had relatively higher protein and fat compared to Fresco and higher protein but lower fat compared to lipid-based nutrient supplements (LiNS) used to prevent undernutrition in some LMICs. Among children 15-36 months of age, mean energy contribution of *Atole* to the total diet was 150 kcal/day, 10g of protein and 0.6g of fat versus 25 kcal/day and 0g of protein or fat for *Fresco*, with minor substitution by the nutrition supplements to the home diet (31). The recommended dose of small-quantity LiNS in infants and young children is 110-120 kcal/day which provides 2.6g of protein and 9.6g of fat (34). To date, trials have not found conclusive evidence to support a positive effect of small-quantity LiNS on linear growth (35–37). Our findings suggest that nutrition

supplementation with sufficient protein provided during the first 1,000 days can improve linear growth but is not significantly associated with higher BMI trajectory in these analyses.

The lack of association between nutrition supplementation and higher BMI trajectory in this study could be due to the substantial burden of undernutrition during the original trial. At age two years, 86% of the study population was stunted (height-for-age Z (HAZ) scores < -2 SD), suggesting a strong need for nutritional support (24). Studies from Chile found that a complementary feeding program was associated with increases in child weight-for-length without increases in length-for-age in a population with a mean HAZ score close to zero (1,38); however, this national program targeted all children under six years, including those not at high risk for nutrition deficiencies. This is typical in Latin America were only 25% of food programs use anthropometry to target beneficiaries (39). Garmendia *et al.* found that only 5-6% of supplementary feeding program beneficiaries in the region were truly underweight (40). Ensuring that programs target high risk populations, address underlying nutrition deficiencies, and focus on healthy growth (appropriate weight gain and linear growth) could help prevent inadvertent increases in child obesity in LMICs.

In both men and women, high childhood household SES was associated with increased odds of high BMI latent class membership relative to the poorest SES tertile. Little is known about how childhood SES influences adult obesity risk in LMICs. For childhood overweight (BMI-for-age Z > 2 SD), prevalence does not differ

substantially by household SES in most LMICs. Among 78 LMICs with data, prevalence of child overweight was on average 1.31 times higher (95% CI:0.55, 3.60) in the richest quintile relative to the poorest (41). In the INCAP cohort, < 2% of participants were overweight in childhood (33). For adult overweight, high SES is positively associated with obesity in low income countries (10). However, the burden of obesity often shifts from the wealthy to the poor as countries move to middle income – an important distinction for countries with developing economies (42). To inform obesity prevention, more research is needed to understand the mechanisms through which SES increases risk. Childhood household SES likely functions as a proxy for a number of important factors influencing the early life environment such as access to healthcare (43).

Since the trial ended in 1977, the cohort has been exposed to the cumulative effects of changing food environment, urbanization, and other factors that could influence BMI (44,45). Better early growth and development leads to increased educational attainment and income (17), and these might be associated with lifestyle risk factors for weight gain such as sedentarism or ability to acquire energy-dense diets. The early separation of the BMI latent classes suggests that later life influences, such as parity in women (46), might contribute to adult BMI gain but do not contribute to establishment of BMI classes.

There was a high burden of overweight in this cohort which increases the risk for chronic disease. For all latent classes, mean BMI exceeded 25 kg/m2 by age 34 years, and the mean BMI in the high BMI latent classes exceeded 30 kg/m2 by 42

years. The Global Burden of Disease study found that BMI > 23 kg/m^2 increases risk of cardiovascular disease, diabetes, among other diseases (47).There is a strong need for chronic disease risk factor prevention and management in this population.

This study used experimental data from a randomized trial of a nutrition supplement and its follow-up studies. The cohort has >40 years of follow-up with serial measures of clinically-measured anthropometry. The cohort has experienced relatively low attrition, and prior studies have indicated that attrition has not biased estimates of early life exposures and adult outcomes (48). To our knowledge, this is the first study to explore BMI trajectories from early childhood through mid-adulthood in a LMIC population using LCGA. Most studies of BMI from birth to adulthood have focused on high-income country populations; however, growth patterns in LMICs are likely distinct due to high rates of childhood undernutrition (49,50). Studies from other LMIC cohorts have been limited by the relatively young age of the study participants (51,52). In a region where compensatory growth is promoted and an estimated 20% of the population receives food assistance from nutrition programs, understanding how nutrition supplementation is associated with BMI gain is important in Latin America's landscape of stunting and emergent obesity (1). Finally, in sensitivity analyses, *Atole* during the first 1,000 days was not associated with obesity at the oldest age observed, and all findings were robust to restricting trajectories to BMI values after the first 1,000 days.

There are several limitations to this study. The nutrition supplement was randomized by village, so village-level effects on BMI are not adequately addressed

by randomization but are captured within the difference-in-difference design. We did not analyze the quantity of the supplement actually consumed. If the effect of *Atole* during the first 1,000 days on BMI latent class was small, we might have had limited power to detect an association. Finally, while LCGA helps identify heterogeneity in BMI gain, classes are not "real" but instead are heuristic - reflecting a continuum of growth in the population (53). Care should be taken to avoid oversimplification of the groups; instead, they should be considered a tool to help visualize variability within a global distribution.

Conclusion

Early separation of the BMI latent classes suggests that early life factors are important in establishing BMI trajectory over the lifecourse or reflect persistent circumstances and/or behaviors; however, exposure to *Atole* during the first 1,000 days was not associated with higher BMI latent class. This finding suggests that supplemental feeding programs during this critical developmental window are unlikely to adversely affect BMI trajectories. Higher childhood household SES was associated with increased odds of high BMI latent class membership relative to the poorest households – the pathways through which this operates still need to be explored.

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Table 4.1. Selected characteristics of the study population, by sex, in the INCAP Nutrition Supplementation Trial Longitudinal Cohort

	Females (*n* = 711)			Males (*n* = 742)		
	Atole during full first 1,000 days (*n* =176)	Other[1] (*n* =535)		Atole during full first 1,000 days (*n* =183)	Other[1] (*n* =559)	
	%	%	*P* value[2]	%	%	*P* value[2]
Childhood household SES tertile			0.1			0.09
Poorest	28.8	37.1		29.5	37.9	
Middle	36.4	30.4		35.5	29.3	
Wealthiest	34.7	32.4		34.9	32.7	
Maternal age, years	27.3 (7.3)	27.1(7.0)	0.7	27.5 (7.2)	27.5 (7.1)	0.9
Maternal schooling, years	0.9 (1.4)	1.0 (1.4)	0.5	1.0 (1.3)	1.1 (1.4)	0.4
BMI latent class			<0.0001			<0.0001
Low	33.5	65.1		28.4	42.6	
Medium				48.6	46.4	
High	66.4	34.8		22.9	10.9	

All values are mean ± SD or percentages.[1] Other includes children exposed to Atole at ages other than the first 1,000 days and all children exposed to Fresco.[2] For categorical variables, the *P* values were calculated by chi-squared tests for equality of proportions across levels of BMI latent class. All *P* values are two-sided.
Abbreviations: BMI, body mass index; INCAP, Institute of Nutrition of Central America and Panama; SES, socioeconomic status.

Table 4.2. Multivariate binomial logistic regression predicting BMI latent class membership based on Atole exposure during the first 1,000 days and childhood household SES in females in the INCAP Nutrition Supplementation Trial Longitudinal Cohort

	Females (*n* = 711)		
	Model 1[1]	Model 2[2]	Model 3[3]
High vs. Low (Ref.) BMI Latent Class			
Supplement type (Atole vs. Fresco)	1.51 (0.98, 2.32)		1.40 (0.82, 2.29)
Exposure during full first 1,000 days (vs exposure at other ages)	2.28 (1.43, 3.61)		2.20 (1.38, 3.68)
Interaction (Exposure to Atole during full first 1,000 days)	1.58 (0.84, 2.96)		1.63 (0.81, 3.26)
Childhood household SES tertile			
Middle vs. poorest		1.76 (1.17, 2.65)	1.63 (1.06, 2.51)
Wealthiest vs. poorest		2.19 (1.48, 3.29)	1.97 (1.29, 3.00)

All values are ORs (95% CI). [1] Model 1 included a dummy variable for supplement assignment and birth village (Atole vs. Fresco), a dummy for age of exposure (conception to 2y vs. other), and a multiplicative term for the interaction between supplement type and age of exposure. [2] Model 2 included SES tertile, maternal age in years, and reported maternal years of schooling. [3] Model 3 included all components of Model 1 and Model 2. We controlled for clustering of participants within households. For all models, low BMI trajectory class is the reference. Abbreviations: CI, confidence interval; INCAP, Institute of Nutrition of Central America and Panama; OR, odds ratio; SES, socioeconomic status.

Table 4.3. Multivariate multinomial regression predicting BMI latent class membership based on Atole exposure during the first 1,000 days and childhood household SES in males in the INCAP Nutrition Supplementation Trial Longitudinal Cohort

	Males (*n* = 742)		
	Model 1[1]	Model 2[2]	Model 3[3]
Medium vs. Low (Ref.) BMI Latent Class			
Supplement type (Atole vs. Fresco)	1.63 (1.07, 2.48)		1.91 (1.21, 3.03)
Exposure during full first 1000 days (vs exposure at other ages)	1.48 (0.95, 2.31)		1.48 (0.92, 2.39)
Interaction (Exposure to Atole during full first 1,000 days)	0.86 (0.45, 1.62)		0.69 (0.35, 1.37)
Childhood household SES tertile			
Middle vs. poorest		1.43 (0.96, 2.13)	1.30 (0.86, 1.95)
Wealthiest vs. poorest		1.69 (1.13, 2.55)	1.62 (1.07, 2.45)
High vs. Low(Ref.) BMI Latent Class			
Supplement type (Atole vs. Fresco)	1.65 (0.84, 3.23)		1.87 (0.87, 4.00)
Exposure during full first 1,000 days (vs exposure at other ages)	1.42 (0.69, 2.92)		1.46 (0.66, 3.21)
Interaction (Exposure to Atole during full first 1,000 days)	1.76 (0.68, 4.54)		1.51 (0.53, 4.25)
Childhood household SES tertile			
Middle vs. poorest		1.27 (0.68, 2.39)	1.07 (0.56, 2.03)
Wealthiest vs. poorest		2.18 (1.21, 3.92)	1.98 (1.09, 3.61)

All values are ORs (95% CI).[1] Model 1 included a dummy variable for supplement assignment and birth village (Atole vs. Fresco), a dummy for age of exposure (conception to 2y vs. other), and a multiplicative term for the interaction between supplement type and age of exposure. [2] Model 2 included SES tertile, maternal age in years, and reported maternal years of schooling. [3] Model 3 included all components of Model 1 and Model 2. We controlled for clustering of participants within households. For all models, low BMI trajectory class is the reference. Abbreviations: CI, confidence interval; INCAP, Institute of Nutrition of Central America and Panama; OR, odds ratio; SES, socioeconomic status.

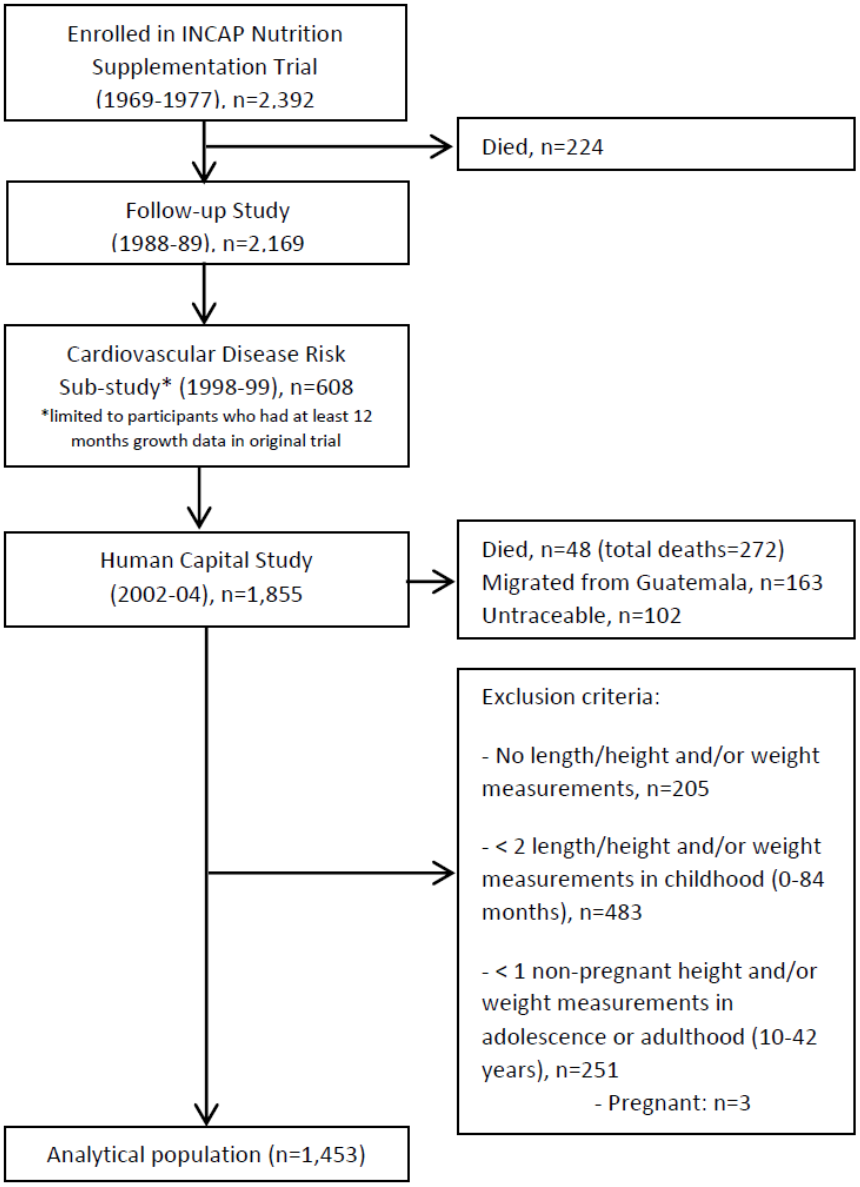

Figure 4.1. Participant retention across follow-up periods for the INCAP Nutrition Supplementation Trial Longitudinal Cohort.

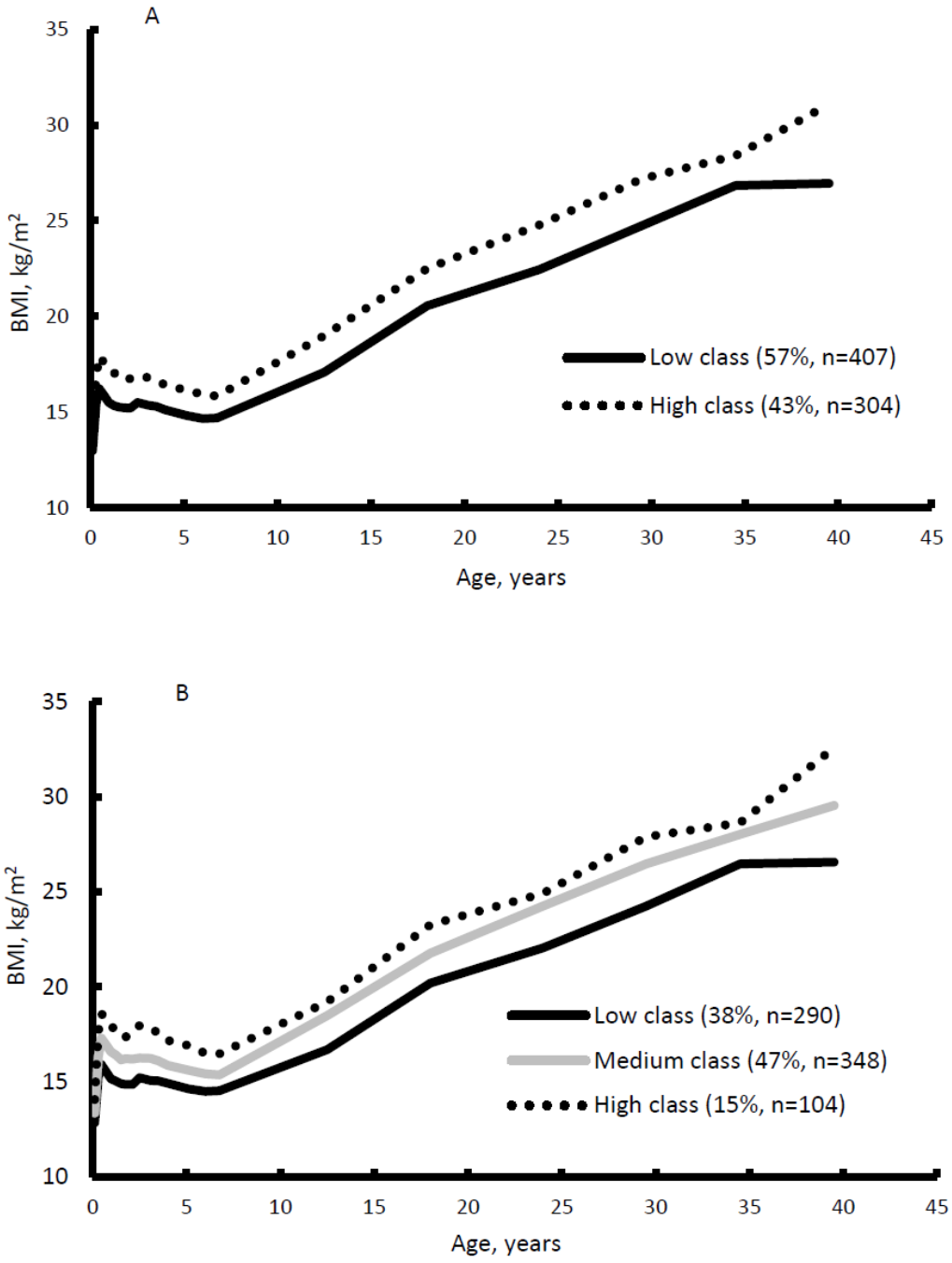

Figure 4.2. Mean body mass index (BMI) by latent class group in females (A) and males (B) in the INCAP Nutrition Supplementation Trial Longitudinal Cohort. Sex-specific BMI latent class trajectories were derived from 22 possible measures of height and weight from 1969-2004.

Chapter 5 - BMI trajectories and markers of CMD risk in rural Guatemalan adults

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The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

Abbreviations used: BMI, body mass index; CMD, cardio-metabolic disease; HAZ, height-for-age Z score; HDL-c, high density lipoprotein cholesterol; HIC, high income country; INCAP, Institute of Nutrition of Central America and Panama; IOM, Institute of Medicine; LCGA, latent class growth analysis; LMIC, low- and middle-income country; MetS, metabolic syndrome; NCD, non-communicable disease; NCEP ATP III, National Cholesterol Education Program Adult Treatment Panel III; NHLBI, National Heart Lung and Blood Institute; PAL, physical activity level; SES, socioeconomic status; WC, waist circumference; WHO, World Health Organization; WHtR, waist—height ratio; WHZ, weight-for-height Z score.

Abstract

Objective: Obesity-related non-communicable diseases represent a growing proportion of the disease burden in Latin America. Our study explored the role of life-course body mass index (BMI) trajectories on cardio-metabolic disease (CMD) risk in a cohort of rural Guatemalan adults.

Methods: Study participants were born in *El Progreso* department in Guatemala from 1962-77 and have been followed prospectively since participating in a nutrition supplementation trial as children. Sex-specific BMI latent class trajectories were derived from up to 22 BMI values from age 1 month to 42y measured between 1969 and 2004. CMD risk was assessed in 2015-16 (at age 37 – 53y) using anthropometry, blood glucose and lipids, and blood pressure. We used multinomial and ordinal logistic regression to assess the role of BMI trajectory class on CMD risk. The final analytic sample included 689 participants (408 women and 281 men).

Results: We identified two BMI latent classes for women: low (n = 238, 58%) and high (n = 170, 42%). We identified three classes for men: low (n = 113, 40%), medium (n = 133, 47%), and high (n = 35, 13%), and collapsed the medium and high classes (n = 168, 60%). Abdominal obesity by waist—height ratio (99% of women and 87% of men), low HDL-c (91% of women and 75% of men), and elevated triglycerides (78% of women and 72% of men), were the most prevalent CMD risk factors. BMI trajectory class was not associated with most CMD risk factors after controlling for current BMI; however, among men, relative to low BMI latent class, high/medium BMI latent class was negatively associated with metabolic syndrome

(PR 0.44, 95% CI 0.21, 0.94) and dysglycemia (PR 0.55, 95% CI 0.31, 0.99) in fully adjusted models.

Conclusion: For most CMD risk factors we analyzed, the role of early life growth on adult CMD appeared to be mediated by adult BMI – highlighting the need to establish and maintain healthy body weight over the life course.

Introduction

Obesity-related non-communicable diseases (NCD) represent a growing proportion of the disease burden in Latin America (1). In the next 40 years, obesity-related NCDs are expected to double in the region (2). Guatemala has a high burden of these conditions; according to the Global Burden of Disease study, high fasting plasma glucose, high body mass index (BMI), high blood pressure, and low glomerular filtration are among the top contributors to combined death and disability (3).

Despite the rise in obesity prevalence, childhood undernutrition remains a serious problem in Guatemala. As of 2015, 46.5% of children under-five were stunted (height-for-age Z [HAZ] scores < -2 SD) (4). Early life undernutrition is thought to increase risk of adult cardio-metabolic disease (CMD) – particularly among people exposed to hyper-caloric environments later in life (5). Yet there is little data from low- and middle-income country (LMIC) populations about the long term consequences of persistent early life undernutrition in obesogenic environments (6).

Understanding the role of childhood and adolescent body size on adult disease risk is challenging for several reasons. First, adult BMI is likely on the causal pathway from childhood BMI to adult CMD (7). Further, conventional mediation models do not work well with three or more repeated measures (8). Finally, growth models using a single curve to describe average growth can potentially obscure heterogeneity (9). In contrast, latent class growth analysis (LCGA) allows us to

analyze the continuity of growth over the life course, to identify distinct growth patterns in cohort sub-groups not readily identifiable using other modeling techniques, and to minimize collinearity of repeated measures (10).

Studies of life course BMI trajectories and CMD risk have focused on high income country (HIC) populations (11–14); however, growth patterns in LMICs are likely distinct due to persistent childhood undernutrition. Studies from LMIC populations have explored the role of smaller segments of the life course, for example, adolescence, with CMD outcomes (13,15,16) - the limited focus likely owing to the relatively young age of most LMIC birth cohorts (17–20). If people exposed to low nutrient environments in early life – especially those later exposed to hyper-caloric environments consistent with developing economies - have growth patterns which confer distinct risk for CMD, life course growth analysis can help identify differential risk.

The objective of this research was to examine the role of life course BMI trajectories from birth or early childhood through mid-adulthood on CMD risk in a prospective cohort of rural Guatemalan adults.

Methods

Study Population

Study participants were born in four villages in southeastern Guatemala from 1962-77 and participated in the Institute of Nutrition of Central America and Panama (INCAP) Oriente Longitudinal Study (1969-77) and its follow-up studies

(1989-2016) (21). The original trial was designed to assess the influence of early life undernutrition on cognitive and physical development. The follow-up studies were implemented to assess longer-term effects of the original intervention. The original trial provided the anthropometric measures in childhood and four follow-up waves (1988-89, 1997-99, 2002-04) provided measures in adolescence/adulthood for derivation of life course BMI trajectories. The 2015-16 follow-up study provided anthropometric, biochemical, clinical, and sociodemographic information. Full details of the original trial and its follow-up studies are published elsewhere (22).

Of the 2,392 participants in the original study, 1,680 (70.2%) of the original study participants were alive and living in Guatemala in 2015, and of those, 1,232 resided in rural towns or villages. As of August 2016, 896 (72.7%) consented to participate (37.4% of the original cohort). We excluded participants from analyses if they were pregnant/lactating in 2015-16 (n=5) or if they were missing BMI trajectory (n=202). The final analytic sample included 689 participants (408 women and 281 men) ages 37-53y.

All data collection followed protocols that were approved by the institutional review boards of INCAP (Guatemala City, Guatemala) and Emory University (Atlanta, GA). All participants gave written informed consent.

BMI Trajectories

In 1969-77, 1988-89, 1997-99, and 2002-04, participant weight and length/height were measured by trained personnel using standard procedures (23). BMI was calculated as weight (kg) divided by height squared (m^2). Using LCGA, we derived sex-specific BMI latent class trajectories from up to 22 possible measures of height and weight: five from 1-12 months; three from 13-23 months; five from 24-50 months; three from 51-84 months; two from 10-20y; and four from 21-42y. Because a minimum of three BMI values are needed for model stability in LCGA (24), trajectories were derived for participants with ≥2 BMI values in childhood (0-84 months) from 1969-77 and ≥1 non-pregnant BMI value in adolescence/adulthood (10-42y) from 1988-2004. We developed models using all available data and robust maximum likelihood estimation. Overall model fit was assessed using the Bayesian Information Criterion, the Bootstrap Likelihood Ratio Test, the Lo–Mendell–Rubin Likelihood Ratio Test, and the quality of classification was based on the entropy statistic and posterior probabilities (9,24,25). Full details on the methodology used to derive the latent class trajectories are available elsewhere (26).

We identified two BMI latent classes for women: low (*n* = 238, 58%) and high (*n* = 170, 42%); and three classes for men: low (*n* = 113, 40%), medium (*n* = 133, 47%), and high (*n* = 35, 13%) (**Figure 5.1**). Given the small percentage of men in the high BMI latent class, we collapsed the medium and high BMI latent classes for men (*n* = 168, 60%).

Assessment of Anthropometric, Biochemical, and Clinical Measures

In 2015-16, trained field workers collected all anthropometric measurements. Height and waist circumference were measured to the nearest 0.1 cm and weight to the nearest 0.01 kg. All measurements were taken in duplicate; if the difference exceeded 0.5 kg for weight or 0.5 cm for height or 1.0 cm for waist circumference (WC), a third measurement was taken and the average of the two closest measurements was used. BMI was classified according to current National Heart, Lung, and Blood Institute (NHLBI) guidelines: underweight/normal (<25.0 kg/m^2), overweight (25.0 – 29.9 kg/m^2), and obese (≥30.0 kg/m^2) (27). Abdominal obesity was defined according to the NHLBI's 2005 National Cholesterol Education Program Adult Treatment Panel III (NCEP ATP III) cut-point of WC ≥88 cm for women and ≥102 cm for men (28). Waist—height ratio (WHtR) was calculated as WC (cm) divided by height (cm). Abdominal obesity by waist—height ratio was defined as WHtR >0.50 (29). Body fat was calculated by subtracting fat-free mass (estimated from total body water using deuterium oxide (D_2O) dilution) from total body mass (30). Obesity by body fat percentage was defined as body fat percentage ≥32% for women and ≥25% for men (31). Medication use, and self-reported diabetes, dyslipidemia, and hypertension status were ascertained by clinical interview.

For CMD risk profiles in 2015-16, trained phlebotomists drew venous blood samples in the fasted state (>9 hours) and 120 minutes after a prandial challenge. Lipids (total cholesterol, high density lipoprotein cholesterol [HDL-c], and triglycerides) and glucose concentrations were measured by enzymatic peroxidase

dry chemistry methods (Cholestech LDX System, Hayward, CA, USA). Elevated triglycerides were defined as triglycerides ≥150 mg/dL (28). Low HDL-c was defined as <40 mg/dL for men and <50 mg/dL for women (28). Total cholesterol-to-HDL-c ratio was calculated as total cholesterol (mg/dL) divided by HDL-c (mg/dL). American Diabetes Association standards were used to classify pre-diabetes (fasting plasma glucose 100-125 mg/dL and/or post-challenge glucose 140-199 mg/dL among participants without self-reported diabetes) and diabetes (fasting plasma glucose ≥126 mg/dL, and/or post-challenge glucose ≥200 mg/dL, and/or self-reported diabetes) (32).

Seated blood pressure was measured by a physician three times at three-minute intervals on the left arm resting on a table at heart level using a digital blood pressure monitor (Omron, Schaumburg, IL, USA) after a five minute rest (33). Three cuff sizes were available and selected based on participant arm circumference. If systolic or diastolic blood pressure measurements differed by >10 mmHg, then a fourth measure was taken. Otherwise, the second and third measurements were recorded and the average of these two measures used. Pre-hypertension was defined as systolic blood pressure 120-129 mmHg and/or diastolic blood pressure 80-89 mmHg among participants without self-reported hypertension or anti-hypertensive medication use. Hypertension was defined as systolic blood pressure >130 mmHg and/or diastolic blood pressure >90 mmHg and/or self-reported hypertension and/or anti-hypertensive medication use.

Metabolic syndrome (MetS) was defined according to the NCEP ATP III diagnostic criteria based on presence of at least three of the following: abdominal obesity (WC ≥88 cm for women; ≥102 cm for men); fasting glucose ≥ 100 mg/dL or medication; triglycerides ≥150 mg/dL or medication; HDL-c <40 mg/dL in men or <50 mg/dL in women; and blood pressure >130 mmHg systolic, >85 mmHg diastolic, and/or medication use (28). The number of MetS components (0-5 of the above criteria) was also included as an ordinal variable. Due to the low proportion of women with zero MetS components and men with 5 MetS components, we collapsed the 0 and 1 components categories for women and the 4 and 5 components categories for men.

Assessment of Lifestyle and Socioeconomic Characteristics

Data on lifestyle and socioeconomic factors were collected by interview in 2015-16. Socioeconomic status (SES) in 2015-16 was a cumulative score developed from principal components analysis of household characteristics and consumer durable goods for rural participant households (34,35). Parity was included as a continuous variable. Smoking status (current, former, never smoker) and multivitamin use were classified as yes or no. In 2002-04 study wave, physical activity level was ascertained using a questionnaire asking about the frequency and duration of activities performed on a typical day over the preceding year (36). We calculated participant physical activity level (PAL by averaging metabolic equivalents (MET) per hour over 24 hours; participants with PAL <1.7, the minimum level recommended to prevent obesity, were classified as physically

inactive (37). At the time of writing, physical activity data were not available in 2015-16.

Statistical Analyses

To assess differences in sociodemographic and health characteristics across BMI trajectory class, we used chi-square tests for categorical variables and ANOVA for continuous variables. To characterize the relationship between BMI trajectory class and CMD risk factors we used sex-stratified log binomial models to regress dichotomous CMD risk outcomes (obesity by BMI, obesity by body fat percentage, abdominal obesity by WC, elevated triglycerides, low HDL-c, and MetS) on BMI trajectory class and used sex-stratified ordinal logistic regression models to regress ordered CMD risk outcomes (elevated blood pressure, dysglycemia, and number of MetS components) on BMI trajectory class. Model 1 included BMI trajectory class and age. Model 2 additionally controlled for SES in 2015-16. Model 3 additionally controlled for other lifestyle covariates (physical inactivity in 2002-04, smoking status in 2015-16). To evaluate the mediating role of current BMI on CMD risk, Model 4 included BMI trajectory class, age, and BMI in 2015-16. Model 5 additionally controlled for SES in 2015-16. Model 6 additionally controlled other lifestyle covariates (physical inactivity in 2002-04, smoking status in 2015-16).

In sensitivity analyses, we reanalyzed the data including the 202 participants who were missing BMI latent class group by assigning them to a "missing trajectory" class. We also evaluated the association between CMD risk factors and a single measure of adiposity in childhood (weight-for-height Z score [WHZ] at age 18-42

months) and in adolescence/young adulthood (BMI in 1988-89 at age 10-27y). We used the 2006 World Health Organization Multicentre Growth Reference child growth standards to calculate each child's WHZ, standardized to the reference population for the child's age and sex (38).

Statistical significance was set *a priori* at $P < 0.05$. All *P*-values were two-sided. All analyses were performed using SAS v.9.4 (SAS Institute, Cary, NC, USA).

Results

The study sample was 59% female (**Table 5.1**). Fifty-eight percent of women and 40% of men were in the low BMI trajectory class.

Median age at onset of overweight among women was 30y and 24y for the low and high BMI latent classes, respectively. Among men, median age at onset of overweight was 33y for the high/medium BMI latent class. At 42y, the mean difference in mean BMI between the low and high/medium BMI latent classes was 7.3 kg/m^2 for women and 2.3 kg/m^2 for men. The mean age is younger in the higher BMI classes ($P < 0.0001$ for women and men) suggesting a secular trend of earlier onset of high BMI among younger cohort members.

The most prevalent risk factors were abdominal obesity by WHtR (99.4% of women and 87% of men), low HDL-c (90.7% of women and 74.7% of men), elevated triglycerides (78.0% of women and 71.6% of men), and MetS (80.6% of women and 40.0% of men). In bivariate analyses, current BMI was highly associated with CMD risk factors ($P < 0.001$ for all comparisons; results not presented).

Relative to the low BMI latent class, high (women) and high/medium (men) BMI latent classes had higher unadjusted mean BMI and higher unadjusted prevalence of obesity ($P = 0.005$ and $P = 0.001$, respectively). Relative to men in the low BMI latent class, men in the high/medium BMI latent class had higher unadjusted BMI, waist circumference, WHtR, total cholesterol-HDL-c ratio, and higher unadjusted prevalence of abdominal obesity (by WC and by WHtR), and obesity by body fat percentage ($P < 0.05$ for all comparisons).

Among women, high BMI latent class was positively associated with obesity (PR 2.17, 95% CI 1.37, 3.41) relative to low BMI latent class (**Table 5.2**). Among men, high/medium BMI latent class was positively associated with elevated triglycerides (PR 2.01, 95% CI 1.08, 3.71) relative to the low BMI latent class in fully adjusted models without BMI in 2015-16; however, the association was not significant after adjusting for current BMI. Among men, relative to low BMI latent class, high/medium BMI latent class was negatively associated with MetS (PR 0.44, 95% CI 0.21, 0.94) and dysglycemia (PR 0.55, 95% CI 0.31, 0.99) in fully adjusted models controlling for current BMI (**Table 5.3**).

In sensitivity analyses which included participants excluded from the primary analyses due to missing BMI trajectory class, findings for models including the "missing" trajectory class and those using WHZ from 18-42 months as the exposure and models using BMI in 1988-89 as the exposure were similar to those in the primary analyses (**Supplemental Tables 9.3-9.5**).

Discussion

With data from a longitudinal cohort with > 40 years of follow-up, we examined the role of life course BMI trajectories on CMD risk in rural Guatemalan adults. We identified two BMI latent classes in women and three in men which diverged in infancy and tracked through adulthood. Life course BMI trajectory class was not associated with most CMD risk factors after controlling for current BMI. In men only, high/medium BMI latent class was negatively associated with MetS and with dysglycemia in fully adjusted models. For all other CMD risk factors we analyzed, however, the role of early life growth on later life CMD appeared to be mediated through adult BMI, highlighting the importance of keeping a healthy BMI throughout life.

It is not clear why higher BMI trajectory from birth or early childhood through mid-adulthood was independently associated with MetS and dysglycemia in men after controlling for current BMI. In the context of a LMIC population in the 1960-70s when childhood undernutrition was prevalent, we hypothesize that higher BMI in childhood might represent growth that is closer to international growth reference standard averages rather than excessive adiposity. Among men in the higher BMI latent class group, mean WHZ from 18-42 months of age was 0.38 relative to -0.69 among men in the low BMI latent class group. Thus, body size at 18-82 months among the men in the higher BMI latent class group was slightly higher than the average value for children growing according to international growth reference standards but not near the threshold for overweight. Conversely, the men in the low BMI latent class group had smaller than average body size at 18-42

months relative to the WHO standard. Increased risk for CMD among people with poor early life growth would be consistent with findings from studies where early life undernutrition was positively associated with hypertension and diabetes later in life (40). However, men in the higher BMI trajectory class also had higher adult adiposity (BMI, abdominal obesity, and obesity by body fat percentage) relative to men in the low BMI trajectory class which is associated with CMD risk (41).

BMI in 2015-16 was highly associated with all CMD risk factors in bivariate analyses. In this Guatemalan cohort, adult BMI was strongly predicted by childhood BMI. Trajectory differences were large, established in early infancy, and maintained throughout the life course, suggesting that early life or pre-conceptual factors may influence BMI trajectory. Data from children in the United States has also shown that BMI tracks from childhood into adulthood (42). Further, the propensity for obesity begins as early as six months of age (43,44). The role of early life nutrition on later life CMD appears to be mediated through adult BMI.

In populations with high prevalence of early life undernutrition, maintaining healthy weight throughout the life course could be especially important in preventing adult CMD. In a prospective cohort of health professionals in the United States, participants who maintained a stably lean body shape over the life course (age 5-50y) had the lowest risk of mortality while people who were lean in early life but had marked increase in body weight in middle age had mortality risk similar to participants who had been heavy throughout life (14). Weight gain in early and mid-adulthood has been associated with increased risk of many NCDs, including

diabetes, CVD, and certain cancers (45,46). In our study, despite low levels of childhood overweight in this rural Guatemalan population, only men in the low BMI trajectory class had mean BMI in the normal range (24.8 kg/m^2) in 2015-16.

High levels of adiposity might explain the lack of association between BMI trajectory class and CMD risk in women. In 2015-16, 34.4% of women in the low BMI trajectory class and 50.0% of women in the high BMI trajectory class were obese by BMI, and >90% of women in both BMI trajectory classes were obese by body fat percentage and had abdominal obesity (by either WC or WHtR). Further, body fat percentage, WC, WHtR, did not vary by BMI trajectory class in women, suggesting a possible ceiling effect. Meaning, women in the low BMI were still largely obese despite having lower adiposity than women in the high BMI trajectory class. Considering BMI > 23 kg/m^2 increases risk of CMD (41) and neither of the women's BMI trajectory classes a mean BMI in the normal range, high levels of and lack of variation in adiposity in women could explain our inability to detect associations between BMI trajectory class and CMD risk.

It is also possible that BMI, an overall measure of excessive body fat, may not capture the type of adiposity that is important for CMD risk in this cohort. The risk of developing diabetes rises with increases in BMI; however, within a narrow range of BMI levels, there is high inter-individual variation in systemic inflammation and insulin resistance, possibly attributable to differences in the distribution and type of body fat (i.e. subcutaneous, visceral, ectopic) which are thought to have varied local and/or systemic effects on metabolic dysfunction (47). A systematic review using

data from fourteen different countries and including Central American participants found that current WHtR independently and more strongly predicted diabetes and cardiovascular disease than did BMI (29). A meta-analysis of WHtR, BMI, and NCDs had similar findings with respect to MetS (48) and mortality (49). In our study, among participants with BMI <30 kg/m^2, 92% of women and 67% of men were considered obese by body fat percentage, 84% of women and 6% of men were considered obese by WC, and 99% of women and 84% of men were considered obese by WHtR (**Supplemental Table 9.6**). The disparate classification of obesity by different methods (BMI vs. waist-based measures vs. directly assessed body fat), suggests that BMI may not adequately identify adiposity in this stunted population in a way that is meaningful for predicting CMD risk.

Further, the mechanisms linking early life weight to adult CMD risk could be different than those linking early life weight to adult weight – especially considering weight varies in its type (i.e. organs, adipose tissue, lean mass, etc.) and location on the body (50). Data from Brazil suggests that BMI and body fat topography behave differently in stunted vs normal stature individuals, especially women (51).

There was a high burden of CMD risk in this cohort – particularly among women. The most prevalent risk factors were abdominal obesity by WHtR, low HDL-c, elevated triglycerides, and MetS. Further, less than half of the women and less than two-thirds of men in the cohort were normoglycemic. Beyond its effects on quality of life, CMD's toll on the health system and society is high. In LMICs, CMD affects people during productive working years, reducing economic contributions to

both households and society (52). According to the World Bank, the Latin America and the Caribbean region will lose US$8 billion to chronic diseases by 2015 (53). Thus, there is a strong need for chronic disease risk factor prevention and management in this population.

Strengths and Limitations

This research is innovative in several respects. The INCAP cohort is distinctive in that its participants have been followed for >40 years and have serial, clinically measured anthropometry and CMD risk. To our knowledge, we are the first study to explore the role of BMI trajectories from birth through mid-adulthood and CMD risk in a LMIC population. The 12-year lag between when the final weight/height in the BMI trajectory and the CMD risk factors attempted to control the influence of potential reverse causation between adult BMI and CMD risk. Finally, our findings were robust in models using WHZ from 18-42 months and BMI in 1988-89 as the primary exposures in sensitivity analyses, likely because BMI tracked over time in this cohort.

There are a few limitations to this study. Life course analyses are threatened by bias owing to missing data; however, the results of the sensitivity analyses which included participants who were missing BMI trajectory class were consistent with the findings of the primary analyses. Further, prior work has indicated that attrition has not biased estimates of early life exposures and later-life outcomes (54). Finally, while LCGA helps identify heterogeneity in body size over life course, the classes are not “real” but instead reflecting a continuum of growth in the population and

should be considered a tool to help visualize variability within the global distribution of BMI gain (55).

Conclusion

In men only, high/medium BMI latent class was negatively associated with MetS and with dysglycemia. Because BMI trajectory class was not associated with most other CMD risk factors after controlling for current BMI and given that early life BMI tracked into adulthood, our findings highlight the importance of healthy growth early in life and preventing weight gain in adulthood.

Chapter 5 References

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Table 5.1. Select sociodemographic and health characteristics in 2015-16 by BMI trajectory class and sex, INCAP Nutrition Supplementation Trial Longitudinal Cohort (n=408 women, n=281 men).

	Women			Men		
	Low Class (n=238)	High Class (n=170)	P-value[13]	Low Class (n=113)	Medium/High Class (n=168)	P-value[13]
Age, years	45.0 (3.9)	41.9 (3.1)	<0.0001	45.0 (3.7)	42.3 (3.5)	<0.0001
SES tertile, %						
Poorest	29.8	35.2		32.7	29.1	
Middle	38.2	36.4		30.0	36.3	
Wealthiest	31.9	28.2		37.1	34.5	
Parity, n	3.4 (2.0)	3.5 (2.2)	0.4			
Alcohol use, %	4.6	4.1	0.8	46.9	35.7	0.06
Ever smoker, %	4.2	3.5	0.7	64.6	66.0	0.7
Physically inactive[1], %	97.3	98.1	0.6	54.5	54.1	0.9
Vitamin use, %	12.6	10.5	0.5	21.2	8.9	0.003
BMI, kg/m^2	28.7 (4.9)	30.2 (5.6)	0.005	24.8 (3.6)	27.0 (3.8)	<0.0001
Obese by BMI[2], %	34.4	50.0	0.001	7.0	18.4	0.006
Waist circumference, cm	101.7 (12.1)	103.6 (13.0)	0.1	91.1 (9.3)	94.6 (9.6)	0.002
Abdominal obesity[3], %	91.1	90.0	0.6	10.6	22.0	0.01
Waist-height ratio	0.67 (0.08)	0.68 (0.08)	0.1	0.55 (0.05)	0.57 (0.05)	0.0002
Waist-height ratio obesity[4], %	99.5	99.4	0.8*	78.7	91.6	0.001
Body fat, %	42.0 (6.2)	42.1 (5.2)	0.8	27.3 (6.8)	28.8 (6.0)	0.05
Obese by body fat %[5], %	93.7	95.8	0.3	63.7	75.0	0.04
Elevated triglycerides[6], %	78.0	80.2	0.1	65.4	75.9	0.05
Low HDL-c[7], %	89.0	92.8	0.1	70.0	80.2	0.05
TC:HDL-c ratio	5.5 (1.7)	5.7 (2.1)	0.2	5.3 (1.7)	5.9 (2.6)	0.01
Blood pressure			0.1			0.5
Pre-hypertension[8], %	16.8	15.8		20.3	25.6	
Hypertension[9], %	28.9	20.5		9.7	8.3	
Dysglycemia			0.2			0.2
Pre-diabetes[10], %	35.2	27.0		36.2	27.7	
Diabetes[11], %	15.4	17.0		8.8	8.4	
MetS risk factors	3.4 (1.0)	3.2 (1.0)	0.2	2.2 (1.2)	2.3 (1.2)	0.1
MetS[12], %	83.1	77.6	0.1	40.7	43.4	0.6

Values presented are mean (SD) or percent. [1]Low physical activity defined as 24-h average physical activity <1.7 MET/hour. [2]Obesity by BMI defined as BMI ≥30 kg/m^2. [3]Abdominal obesity defined as waist circumference ≥88 cm for women and ≥102 cm for men. [4]Abdominal obesity by waist-height ration defined as waist-height >0.50. [5]Obesity by body fat% defined as body fat % ≥32% for women and ≥25% for men. [6]Elevated triglycerides defined as ≥150 mg/dL or medication. [7]Low HDL-c defined as HDL-c <50 mg/dL for women and <40 mg/dL for men. [8]Pre-hypertension is defined as systolic blood pressure 120-129 mmHg and/or diastolic blood pressure 80-89 mmHg among participants without self-reported hypertension and/or anti-hypertensive medication use. [9]Hypertension is defined as systolic blood pressure >130 mmHg and/or diastolic blood pressure >90 mmHg and/or self-reported hypertension and/or anti-hypertensive medication use. [10]Pre-diabetes is defined according to the ADA diagnostic criteria: impaired fasting glucose (fasting plasma glucose 100-125 mg/dL) and/or impaired glucose tolerance (post challenge glucose 140-199 mg/dL) among participants without self-reported diabetes. [11]Diabetes is defined according to the ADA diagnostic criteria: fasting plasma glucose ≥126 mg/dL, and/or post-challenge glucose ≥200 mg/dL, and/or self-reported diabetes. [12]Metabolic syndrome defined according to 2005 NCEP ATP III diagnostic criteria based on presence ≥3 of the following: abdominal obesity (waist circumference ≥88 cm for women and ≥102 cm for men); fasting plasma glucose ≥100 mg/dL or medication; triglycerides ≥150 mg/dL or medication; HDL-c <50 mg/dL); and blood pressure >130 mmHg systolic, >85 mmHg diastolic and/or medication use. [13]P was calculated using ANOVA (continuous) and Chi-square tests (categorical variables). *Expected cell count <5. Abbreviations: ADA, American Diabetes Association; BMI, body mass index; HDL-c. high density lipoprotein cholesterol; INCAP, Institute of Nutrition for Central America and Panama; MET, metabolic equivalents; MetS, metabolic syndrome; NCEP ATP III, National Cholesterol Education Program Adult Treatment Panel III; TC, total cholesterol.

Table 5.2. Multivariable logistic regression models to predict cardiometabolic risk factors based on BMI latent class trajectory (high vs. low in women and high/medium vs. low in men) in the INCAP Nutrition Supplementation Trial Longitudinal Cohort (n=408 women, n=281 men).

	Women High vs. low		Men High/medium vs. low	
Cardiometabolic risk factor	Prevalence Ratio	95% CI	Prevalence Ratio	95% CI
Obesity by BMI[1]				
Model 1	2.05	1.32, 3.19	2.25	0.96, 5.30
Model 2	2.06	1.32, 3.22	2.18	0.92, 5.15
Model 3	2.17	1.37, 3.41	1.90	0.77, 4.65
Model 4	-	-	-	-
Model 5	-	-	-	-
Model 6	-	-	-	-
Abdominal obesity[2]				
Model 1	0.98	0.47, 2.02	1.96	0.94, 4.11
Model 2	0.95	0.46, 1.97	1.93	0.84, 4.06
Model 3	0.97ǂ	0.46, 2.03	1.58	0.73, 3.14
Model 4	0.83	0.28, 2.47	0.76	0.23, 2.47
Model 5	0.74	0.23, 2.29	0.77	0.22, 2.61
Model 6	0.58ǂ	0.17, 1.94	0.59	0.16, 2.19
Obesity by body fat % [3]				
Model 1	1.12	0.40, 3.10	1.74	1.00, 3.04
Model 2	1.15	0.41, 3.21	1.72	0.97, 3.03
Model 3	1.03	0.35, 2.99	1.74	0.94, 3.20
Model 4	0.90	0.31, 2.63	0.97	0.50, 1.90
Model 5	0.90	0.31, 2.66	0.97	0.49, 1.92
Model 6	0.83	0.26, 2.62	0.83	0.39, 1.76
Elevated triglycerides[4]				
Model 1	1.27	0.75, 2.15	1.81	1.02, 3.23
Model 2	1.28	0.75, 2.18	1.76	0.98, 3.14
Model 3	1.29	0.75, 2.24	2.01	1.08, 3.71
Model 4	1.18	0.69, 2.02	1.21	0.65, 2.28
Model 5	1.20	0.70, 2.06	1.21	0.64, 2.27
Model 6	1.20	0.69, 2.10	1.41	0.72, 2.73
Low HDL-c[5]				

Model 1	1.51	0.70, 3.27	1.70	0.93, 3.12
Model 2	1.49	0.69, 3.23	1.70	0.93, 3.11
Model 3	1.55ǂ	0.67, 3.58	1.74	0.91, 3.35
Model 4	1.36	0.62, 2.95	0.90	0.44, 1.83
Model 5	1.31	0.60, 2.88	0.95	0.46, 1.93
Model 6	1.35ǂ	0.58, 3.16	0.97	0.46, 2.04
Metabolic syndrome[6]				
Model 1	0.86	0.51, 1.48	1.16	0.69, 1.95
Model 2	0.90	0.52, 1.54	1.16	0.69, 1.94
Model 3	0.98	0.51, 1.55	1.16	0.66, 2.04
Model 4	0.70	0.40, 1.23	0.49	0.25, 0.96
Model 5	0.72	0.41, 1.28	0.48	0.24, 0.95
Model 6	0.70	0.39, 1.25	0.44	0.21, 0.94

Values presented are prevalence ratios and 95% confidence intervals. [1]Obesity by BMI defined as BMI ≥30 kg/m^2. [2]Abdominal obesity defined as waist circumference ≥88 for women and ≥102 cm for men. [3]Obesity by body fat% defined as body fat ≥32% for women and ≥25% for men. [4]Elevated triglycerides defined as ≥150 mg/dL or medication. [5]Low HDL-c defined as HDL-c <50 mg/dL for women and <40 mg/dL for men. [6]Metabolic syndrome defined according to 2005 NCEP ATP III diagnostic criteria based on presence ≥3 of the following: abdominal obesity (waist circumference ≥102 cm); fasting plasma glucose ≥100 mg/dL or medication; triglycerides ≥150 mg/dL or medication; HDL-c <50 mg/dL for women and <40 mg/dL for men); and blood pressure >130 mmHg systolic, >85 mmHg diastolic and/or medication use. ǂ Modeled without smoking status due to non-convergence.

Abbreviations: BMI, body mass index; HDL-c, high density lipoprotein cholesterol; INCAP, Institute of Nutrition for Central America and Panama; NCEP ATP III, National Cholesterol Education Program Adult Treatment Panel III; SES, socioeconomic status.

Model 1 = BMI trajectory latent class + age

Model 2 = Model 1 + SES in 2015

Model 3 = Model 2 + physical inactivity in 2004 + smoking status in 2015

Model 4 = Model 1 + BMI in 2015

Model 5 = Model 4 + SES in 2015

Model 6 = Model 5 + physical inactivity in 2004 + smoking status in 2015

Table 5.3. Ordinal logistic regression models to predict cardiometabolic risk factors based on BMI latent class trajectory (high vs. low in women and high/medium vs. low in men) in the INCAP Nutrition Supplementation Trial Longitudinal Cohort (n=408 women, n=281 men).

	Women		Men	
	High vs. low BMI trajectory		High/medium vs. low BMI trajectory	
Cardiometabolic risk factor	Proportional Odds	95% CI	Proportional Odds	95% CI
Elevated blood pressure (pre-hypertension[1] and hypertension[2])				
Model 1	0.91	0.59, 1.39	1.30	0.76, 2.24
Model 2	0.90	0.59, 1.39	1.31	0.76, 2.26
Model 3	0.90	0.58, 1.41	1.36	0.76, 2.42
Model 4	0.77ǂ	0.49, 1.20	0.99	0.56, 1.75
Model 5	0.76	0.49, 1.20	0.97	0.55, 1.72
Model 6	0.75ǂ	0.48, 1.19	0.97	0.53, 1.78
Dysglycemia (pre-diabetes[3] and diabetes[4])				
Model 1	1.06	0.70, 1.60	0.77	0.46, 1.28
Model 2	1.07	0.71, 1.62	0.76	0.46, 1.27
Model 3	1.09	0.71, 1.66	0.75	0.43, 1.29
Model 4	0.95ǂ	0.62, 1.44	0.59	0.34, 1.00
Model 5	0.96	0.63, 1.46	0.58	0.34, 1.00
Model 6	0.96ǂ	0.62, 1.48	0.55	0.31, 0.99
Number of metabolic syndrome risk factors[5]				
Model 1	1.02	0.69, 1.50	1.42	0.90, 2.24
Model 2	1.02	0.69, 1.51	1.40	0.89, 2.20
Model 3	1.02	0.68, 1.51	1.46	0.90, 2.38
Model 4	0.83	0.56, 1.23	0.74	0.46, 1.21
Model 5	0.83	0.56, 1.24	0.74	0.49, 1.21
Model 6	0.82	0.55, 1.23	0.72	0.43, 1.22

Values presented are proportional odds ratios and 95% confidence intervals. [1]Pre-hypertension is defined as systolic blood pressure 120-129 mmHg and/or diastolic blood pressure 80-89 mmHg among participants without self-reported hypertension and/or anti-hypertensive medication use. [2]Hypertension is defined as systolic blood pressure >130 mmHg and/or diastolic blood pressure >90 mmHg and/or self-reported hypertension and/or anti-hypertensive medication use. [3]Pre-diabetes is defined according to the ADA diagnostic criteria: impaired fasting glucose (fasting plasma glucose 100-125 mg/dL) and/or impaired glucose tolerance (post challenge glucose 140-199 mg/dL) among participants without self-reported diabetes. [4]Diabetes is defined according to the ADA diagnostic criteria: fasting plasma glucose ≥126 mg/dL, and/or post-challenge glucose ≥200 mg/dL, and/or self-reported diabetes. [5]Metabolic syndrome risk factors were defined according to 2005 NCEP ATP III diagnostic criteria: abdominal obesity (waist circumference ≥88 cm in women and ≥102 cm in men); fasting plasma glucose ≥100 mg/dL or medication; triglycerides ≥150 mg/dL or medication; HDL-c <50 mg/dL in women and <40 mg/dLin men); and blood pressure >130

mmHg systolic, >85 mmHg diastolic and/or medication use. Women with 0 or 1 metabolic syndrome risk factor(s) have been combined into a single group. Men with 4 or 5 metabolic syndrome risk factors have been combined into a single group. ǂResults are partial proportional odds due to violation of proportional odds assumption. Smoking allowed to have unequal slopes. Abbreviations: ADA, American Diabetes Association; BMI, body mass index; INCAP, Institute of Nutrition for Central America and Panama; NCEP ATP III, National Cholesterol Education Program Adult Treatment Panel III; SES, socioeconomic status.
Model 1 = BMI trajectory latent class + age
Model 2 = Model 1 + SES in 2015
Model 3 = Model 2 + physical inactivity in 2004 + smoking status in 2015
Model 4 = Model 1 + BMI in 2015
Model 5 = Model 4 + SES in 2015
Model 6 = Model 5 + physical inactivity in 2004 + smoking status in 2015

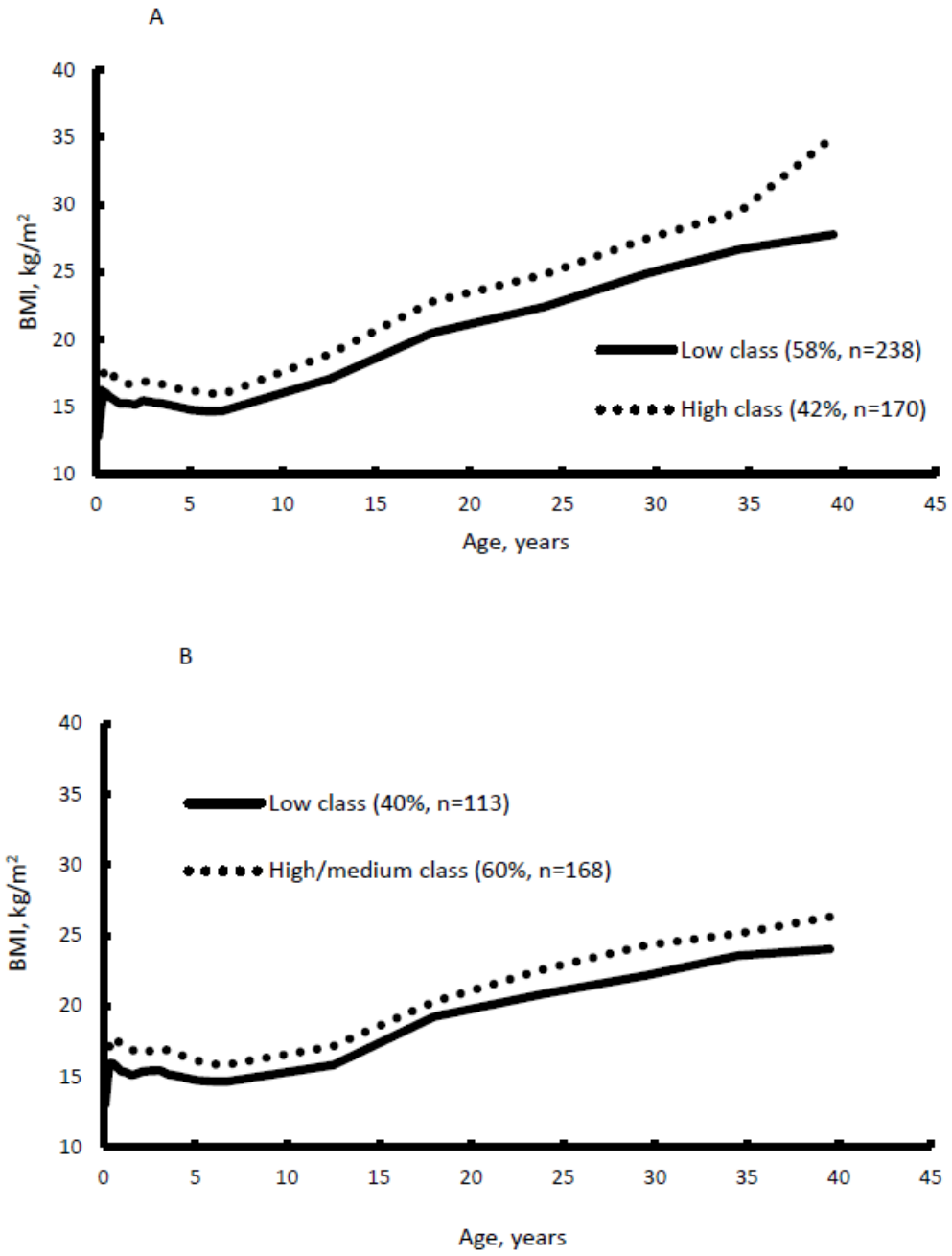

Figure 6.1. Mean body mass index (BMI) by latent class group in females (A) and males (B) in the INCAP Nutrition Supplementation Trial Longitudinal Cohort. Sex-specific BMI latent class trajectories were derived from 22 possible measures of height and weight from 1969-2004.

Chapter 6 - The Nutrition Transition in Rural Guatemala: 12 Year Changes in Adult Diet -

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The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

Abbreviations used: BMI, body mass index; FFQ, food frequency questionnaire; IOM, Institute of Medicine; INCAP, Institute of Nutrition of Central America and Panama; MET, metabolic equivalent; NHLBI, National Heart Lung and Blood Institute; NCD, non-communicable disease; PAL, physical activity level; PCA, principal components analysis; SES, socioeconomic status; SSB, sugar-sweetened beverages; USDA, United States Department of Agriculture; WHO, World Health Organization.

Abstract

Objective: Latin America is undergoing a nutrition transition marked by shifts from traditional to high-fat, high-sugar, processed foods. Despite documented changes to the food environment, including proliferation of supermarkets in urban areas, the extent to which rural Guatemalans have adopted Western diets is unclear. Our study explored 12y changes in diet in a cohort of rural Guatemalan adults.

Methods: Study participants were born in eastern Guatemala from 1962-77 and are members of the INCAP Nutrition Supplementation Trial Longitudinal Cohort. Data on typical dietary intake were collected using a previously-validated, semi-quantitative 52-item food frequency questionnaire (FFQ) in 2002-04 and in 2015-16. We categorized food intake into 19 mutually exclusive food groups and compared dietary composition change over 12 years using Wilcoxon signed-rank tests. We also derived dietary patterns using principal components analysis and assessed differences in sociodemographic and health characteristics, and in dietary factors. The final sample included all non-pregnant/lactating participants with complete dietary data in both study waves (479 women and 303 men).

Results: We identified two dietary patterns in each study wave: a Western pattern and a traditional pattern, collectively explaining ~30% of variance in the diet at each time point. In 2002-04 and in 2015-16, the two dietary patterns were largely similar in terms of food groups and food group factor loadings. In 2002-04, the top contributors to diet as a percentage of total energy were corn tortillas (50.7%), refined grains (e.g. French bread, sweet rolls, pastries) (12.6%), and sugar-

sweetened beverages (SSBs) (4.9%). In 2015-16, participants consumed fewer corn tortillas (46.3% of total energy) and traditional Guatemalan foods (tamales and tacos) (1.9% of total energy vs. 2.4% in 2002/04). Participants' diets diversified through small but significant increases in baked/roasted meat and fish (from 3.9% to 5.0%), fried/processed meats (from 3.0% to 4.0%), and vegetables (from 2.3% to 3.4%). SSBs had the largest change of any food group with intake nearly doubling from 4.9% of total energy in 2002/04 to 7.2% in 2015/16. Finally, the macronutrient composition of the diet changed significantly over the 12y period: carbohydrate as a percentage of total energy decreased from 69.6% to 67.8% while fat and protein increased from 18.3% to 19.1% and from 12.0% to 12.9%, respectively.

Conclusion: We found two dietary patterns at each time point –Western and traditional. While diets remained largely reliant on starches and simple sugars over time, there was evidence of diet diversification characterized by decreased consumption of corn tortillas and traditional foods and by increased consumption of both healthy (e.g. vegetables and baked/roasted meats and fish) and less healthy food groups (e.g. fried/processed meats and SSBs). To help mitigate risks associated with nutrition-related non-communicable disease, further research should explore approaches to encourage adoption of healthier foods while minimizing the addition of energy-dense, nutrient-poor foods.

Introduction

Latin America has been experiencing an increasing burden of non-communicable diseases (NCD) which account for 77% of deaths in the region (1). In 2015, 64% of cardiovascular disease-related deaths were attributable to dietary risk factors including high intake of unhealthy food groups like red and processed meats and sugar-sweetened beverages (SSBs) and low intakes of healthful food groups like fruits, vegetables, and whole grains (2). Because diet is a major modifiable determinant of NCD risk, understanding diet and how diets are changing is important for informing NCD prevention and mitigation strategies.

Latin America is undergoing a nutrition transition marked by shifts from traditional to high-fat, high-sugar, processed foods (3). The nutrition transition has been well-documented in Mexico, Brazil, and Chile (4–6); however, little is known about dietary change in less economically developed countries in Latin America. The "modernization" of the diet is influenced by urbanization and other macro-level factors (7). Over the last 20 years, the food environment at the national-level in Guatemala has changed including availability of and access to packaged and ultra-processed foods. Food imports (U.S. millions $) increased from $1,706 in 2002 to $3,944 in 2012 (8), and the number of supermarkets doubled between 1990 and 2008 (9). Despite changes in availability and access to high-fat, high-sugar foods, the extent to which adults in rural Guatemala have transitioned from traditional to Western diets is not well understood. While some studies have explored individual diets in Guatemala (10–15), to our knowledge, none have examined individual dietary change over time.

The objectives of this study were: (a) to describe food group intake as a percentage of total caloric intake in 2002-04 and in 2015-16; (b) to characterize dietary patterns at both time points using principal components analysis (PCA); (c) to examine the association between dietary patterns and sociodemographic characteristics; and (d) to explore 12y change in food group intake, dietary factors, and PCA-derived dietary patterns in a population of rural Guatemalan adults.

Methods

Study Population

Participants in this study are part of the Institute of Nutrition of Central America and Panama (INCAP) Nutrition Supplementation Trial Longitudinal Study cohort. They were born in four villages in *El Progreso* department in Guatemala from 1962-77 and have been followed-up periodically since the original trial ended in 1977 (16). This analysis is based on the 2002-04 and 2015-16 follow-up studies – henceforth referred to as 2003 and 2015. Full details of the original trial and its follow-up studies are published elsewhere (17). Of the 2,392 participants in the original study, 1,680 (70.2%) of the original study participants were alive and living in Guatemala in 2015, and of those, 1,232 resided in rural towns or villages. As of August 2016, 896 (72.7%) consented to participate, all of whom (37.4% of the original cohort) had complete dietary data.

Participants were excluded from analyses if they were missing dietary data in 2003 (n=71), were pregnant/lactating (n=33 in 2003 and n=1 in 2015), or had total energy intake that exceeded 3 SD from the median total energy intake in either

2003 (2,603 kcal) (n=5) or in 2015 (2,583 kcal) (n=4). The final analytic sample included 782 participants (479 women and 303 men) ages 37-53y in 2015.

All data collection followed protocols that were approved by the institutional review boards of INCAP (Guatemala City, Guatemala) and Emory University (Atlanta, GA). All participants gave written informed consent.

Assessment of Dietary Intake

Data on typical dietary intake were collected using a previously validated, 52-item, semi-quantitative food frequency questionnaire (FFQ) (18). Participants were asked about their consumption over the three months prior to the survey. The questionnaire included both traditional foods (corn tortillas, beans, etc.) and "transitional" foods such as pizza, hot dogs, and ice cream. To capture seasonality in consumption, the FFQ also included open-ended sections for fruits and vegetables. Consumption frequency categories were never/rarely, daily, days per week, and days per month. Portion sizes were determined by selecting from a range of serving sizes (e.g. three different serving spoons; small, medium, or large tortillas) or standard serving units (e.g. a chicken wing; a standard-sized beverage glass). We converted frequency of consumption for each food to servings per day, summed the servings for food items, and converted servings of food items to grams per day consumed. Assuming standard weights based on reported serving sizes, nutrient intake at each time point was estimated using the INCAP nutrient database of foods typically consumed in Guatemala (updated in 2015 to account for reformulation of

foods) supplemented with data from the United States Department of Agriculture (USDA) Nutrient Database.

We then categorized food items into 19 mutually exclusive food groups intended to capture consumption of both traditional and transitional food groups (i.e. processed/fried vs. baked/roasted meats) (**Supplemental Table 9.7**) (19).

Derivation of Dietary Patterns

Dietary patterns were derived separately for each study wave using principal components analysis (PCA) with orthogonal rotation of total grams of food groups consumed. Because <10% of participants reported any consumption of "Nuts" and "Whole Grains" and because "Alcohol" contributed <0.5% of total caloric intake, we removed these food groups to improve statistical robustness (20,21). Because the "Coffee" and "Sugar Added to Coffee" were highly correlated (R^2=0.82 in 2003; R^2=0.76 in 2015) and coffee contributes no calories, we removed "Coffee" from the PCA analyses at both time points. We used minimum absolute factor loading of 35, eigenvalues >1.4, scree plots, and interpretability to guide the final selection of the dietary patterns (22). We explored gender-specific patterns; however, the results were largely consistent, so we conducted the final PCA for men and women together. However, we categorized the dietary pattern scores into gender-specific tertiles due to large differences in energy intake by gender.

Assessment of Lifestyle and Socioeconomic Characteristics

Data on lifestyle and socioeconomic factors were collected by interview. For both time points, socioeconomic status (SES) was a cumulative score developed from PCA for rural participant households based on participant household characteristics and consumer durable goods (23). Smoking status (current, former, ever smoking) and multivitamin use in 2003 and 2015 were classified as yes or no. In the 2003 study wave, physical activity level was ascertained using a questionnaire asking about the frequency and duration of activities performed on a typical day over the preceding year (24). We calculated participant physical activity level (PAL by averaging metabolic equivalents (MET) per hour over 24 hours; participants with PAL <1.7, the minimum level recommended to prevent obesity, were classified as physically inactive (25). At the time of writing, physical activity data were not available in 2015.

Trained field workers collected all anthropometric measurements in duplicate. Height was measured to the nearest 0.1 cm and weight to the nearest 0.01 kg. A third measurement was taken and the average of the two closest measurements was used if the difference between the first and second measurements exceeded 0.5 kg for weight or 0.5 cm for height. Body mass index (BMI) was calculated as weight (kg) divided by height-squared (m^2).

Statistical Analyses

We compared dietary composition change including food groups and macro- and micronutrients over 12 years using Wilcoxon signed-rank due to the non-normality of the dietary intake. To assess differences in sociodemographic, health characteristics, and in dietary factors such as percent of energy from macronutrients across dietary pattern tertiles, we used Mantel-Haenzel chi-square tests for categorical variables and Spearman rank tests for continuous variables. Statistical significance was set at $P < 0.05$. All *P*-values were two-sided. All analyses were performed using SAS v.9.4 (SAS Institute, Cary, NC, USA).

Results

Food Groups as a Percentage of Total Caloric Intake

In 2003, the top five contributors to diet as a percentage of total energy were corn tortillas (49.5% for women and 52.5% for men), refined grains (e.g. French bread, sweet rolls, pastries) (12.9% for women and 12.1% for men), and SSBs (5.1% for women and 4.5% for men) (**Table 6.1**). All participants reported daily consumption of corn tortillas and refined grains. No participants reported daily intake of nuts or whole grains. Relative to women, men in 2003 consumed higher proportion of total energy from corn tortillas, transitional foods (2.6% vs. 1.7%), eggs (1.7% vs. 1.5%), and alcohol (0.8% vs. 0.03%) while women consumed higher proportion of total energy from SSBs, baked/roasted meat and fish (4.2% vs. 3.6%), traditional Guatemalan foods (2.6% vs. 2.0%), vegetables (2.5% vs. 2.1%), sugar

added to coffee (1.8% vs. 1.2%), and dairy (1.9% vs. 1.2%) ($P < 0.01$ for all comparisons).

In 2015, the top contributors to diet as a percentage of total energy intake were the same as in 2003; however, corn tortillas comprised a smaller proportion of total energy (44.7% for women and 48.8% for men) while SSBs comprised a larger proportion (7.5% for women and 6.5% for men) relative to 2002/04. Consumption of traditional Guatemalan foods also decreased from 2.6% to 2.2% of total energy in women and from 2.0% to 1.6% of total energy in men. All participants reported consuming corn tortillas daily in 2015, all men reported daily consumption of refined grains. No participants reported daily intake of nuts or whole grains. Relative to women in 2015, men consumed higher proportion of total energy from and corn tortillas, processed/fried meats (4.3% vs. 3.8%), transitional foods (2.5% vs. 1.5%), eggs (1.9% vs. 1.5%, and alcohol (1.1% vs. 0.04%) ($P < 0.03$ for all comparisons). Women consumed higher proportion of total energy from baked/roasted meat and fish (5.4% vs. 4.5%), fruit (4.1% vs. 2.7%), vegetables (3.9% vs. 2.6%), traditional Guatemalan foods (2.2% vs. 1.6%), dairy (2.1% vs. 1.4%), and sugar added to coffee (1.8% vs. 1.2%) relative to men ($P < 0.001$ for all comparisons).

Participants' diets diversified through small but significant increases in vegetables (+56.0% in women and +23.8% in men), baked/roasted meat and fish (+28.5% in women and +22.2% in men), and processed/fried meats (+26.3% in women and +43.3% in men) as a percentage of total caloric intake. SSBs had the

largest 12y change of any food group with intake as a percentage of total energy intake increasing by 47.0% in women and by 51.1% in men. Additionally, men reduced intake of fruit from 3.8% to 2.7% of energy intake.

Carbohydrates provided the majority of energy in both study waves (69.6% in 2003 and 67.8% in 2015). The macronutrient composition of the diet changed significantly over the 12y period: carbohydrate as a percentage of total energy decreased ($P < 0.0001$) while fat and protein increased (from 18.3% to 19.1% and from 12.0% to 12.9% of total calories, respectively) ($P < 0.0001$ for both comparisons). Fiber intake decreased over the study period from 28.3 to 26.7 g/day in women ($P = 0.001$) and from 39.8 to 38.3 g/day in men ($P = 0.03$). Among women, total energy intake decreased from 2,251 ±677 kcal/day in 2003 to 2,183 ±717 kcal/day in 2015 ($P = 0.04$).

Dietary Patterns

In 2003, we identified two dietary patterns which we labeled Western and traditional. Collectively these dietary patterns explained 28.6% of dietary variance (**Tables 6.2-6.3 and Supplemental Tables 9.8-9.9**). The Western dietary pattern was characterized by consumption of refined grains, vegetables, fried starches, roasted/baked meats and fish, processed/fried meats, eggs, dairy, oils/fats, SSBs, traditional Guatemalan foods, and transitional foods. The traditional dietary pattern was characterized by consumption of corn tortillas, beans, and sugar added to coffee.

In 2015, we also identified two dietary patterns that were largely similar to the patterns derived in 2003 in terms of food groups and the food group factor. In 2015, the same food groups loaded onto each pattern with a few exceptions: fruits loaded onto the Western dietary pattern, eggs moved from the Western dietary pattern to the traditional dietary pattern, and sugar added to coffee no longer loaded on the traditional dietary pattern. Collectively, the Western and traditional dietary patterns explained 29.0% of variance in the diet in 2015.

Within and across dietary patterns at both time points, carbohydrates provided the majority of energy ranging from 65% among participants in the highest tertile of the 2015 Western pattern to 73% among participants in the lowest tertile of the 2003 Western pattern (**Tables 6.4**). Higher traditional pattern tertile in 2003 was associated with increased percentage of total energy from carbohydrates for both genders (P <0.0001 for all comparisons) while higher traditional pattern in 2015 was associated with increased proportion of total energy from carbohydrates in women only (P = 0.0002).

In 2003, fat as a proportion of total energy ranged from 15.0% among women in the lowest tertile of the Western pattern to 21.4% among women in the highest tertile of the Western pattern. In 2015, fat as a proportion of total energy ranged from 16.3% among women in the lowest tertile of the Western pattern to 21.9% among women in the highest tertile of the Western pattern. Higher Western pattern tertile in 2003 and in 2015 were both associated with increased percentage of total energy from total fat and from saturated fat for both genders (P <0.0001 for

all comparisons). Percent of total energy from protein did not vary by dietary pattern tertile for either dietary pattern at either time point.

In 2003, higher Western pattern tertile was associated with alcohol use (p trend 0.05) and former smoking (p trend 0.04) among men, and vitamin use among both women and men (p trend 0.01 and p trend 0.009, respectively) (**Table 6.5**). In 2015, higher Western pattern tertile was associated with higher household SES (p trend <0.0001 in women and p trend 0.004 in men), with vitamin use in men (p trend 0.04) and with BMI in women (p trend 0.04). In 2003, higher traditional pattern tertile was associated with former smoking among men (p trend 0.008). In 2015, higher traditional pattern tertile was associated with lower household SES (p trend <0.0001 in women and p trend 0.03 in men) current smoking among men (p trend 0.04), and with less vitamin use and with younger age in women (p trend 0.01 and p trend 0.008, respectively).

Discussion

In this rural Guatemalan population, we found evidence of two dietary patterns at both time points – a traditional pattern and a Western pattern characterized by a mixture of healthy, unprocessed foods and processed less healthy foods. Collectively, these dietary patterns explained ~30% of variation in the diet in each study wave. While diets remained largely reliant on starches and simple sugars, there was evidence of dietary diversification over the 12y study period through decreased consumption of corn tortillas and traditional Guatemalan foods

and increased consumption of both healthy (e.g. vegetables, baked/roasted meats and fish) and less healthy (e.g. processed/fried meats and SSBs) food groups.

The traditional patterns were based on foods traditionally consumed in Guatemala: corn tortillas, beans, table sugar added to coffee (2003), and eggs (2015). These traditional patterns are similar to findings from another study in Guatemala where tortillas, table sugar, and sweet rolls (*pan dulce*) were the top contributors to total energy among rural populations (10). The Western patterns were more nutritionally diverse relative to the traditional dietary patterns, and they included healthy and unhealthy food groups. The Western pattern was based on consumption of refined grains, fried starches, vegetables, baked/roasted meat and fish, processed/fried meats, dairy, oils/fats, SSBs, traditional Guatemalan foods, transitional foods, eggs (2003), and fruits (2015). While the nutrition transition is generally characterized by the adoption of unhealthy high fat, high sugar, and processed foods (3,4), one study from China found the nutrition transition improved dietary diversity through greater inclusion of fruits and vegetables, eggs, dairy, and meat (3).

Despite deriving two distinctive dietary patterns, diets in this rural Guatemala cohort were monotonous and highly reliant on carbohydrates and simple sugars. At both time points, diets were characterized by high carbohydrate consumption (69.6% in 2003 and 67.8% in 2015) with corn tortillas as the primary contributor. Traditionally, corn and corn products (tortillas and tamales) have dominated the Guatemalan diet, accounting for 40% of total caloric availability at

the national level in 2008 (9). Across all tertiles of both dietary patterns at both time points, percent energy from carbohydrates was above levels recommended by the National Heart, Lung, and Blood Institute (NHLBI) (<60%) and the Institutes of Medicine (IOM) (<65%) to prevent cardiovascular disease risk factors such as dyslipidemia (26,27). While corn tortillas are a good source of dietary fiber (~6 g per 2 oz. serving), refined grains were the secondary contributor to total energy at both time points (12.6% in 2003 and 12.3% in 2015). Refined grains, beneficial insofar as wheat flour is fortified with micronutrients such as iron (28), have little fiber and are unlikely to lead to improved nutritional status.

Furthermore, foods with high sugar content (SSBs, table sugar added to coffee, jelly, and candies/caramels/chocolates) accounted for approximately 14.6% of total energy in 2003 and 15.9% in 2015 - similar to findings from a nationally-representative study in Mexico where added sugars contributed to 12.5% of total energy in 2012 (29). While we were unable to estimate total added sugar in the diet, the percentage of total calories from the high-sugar foods/beverages listed above exceed WHO's upper limit for added sugars (10% of total energy) to prevent chronic disease (105,106). The World Health Organization (WHO) set an upper limit for added sugars (10% of total energy) to prevent chronic disease (30,31). In addition to being the third largest contributor to total energy and the main driver of added sugar intake at both time points, SSBs had the largest change of any food group with intake nearly doubling over the study period (from 4.9% of total energy in 2003 to 7.2% in 2015). SSB consumption trends in this Guatemalan population were similar to those found in Mexico where SSBs were also the largest contributor to added

sugars and accounted for 9.8% of total energy in 2012 (32). Heavy reliance on carbohydrates and high intake of SSBs likely contributes to deficient micronutrient intake. Displacement of nutrient-rich, whole foods by highly processed foods has been cited as a main cause of the double-burden of malnutrition in Mexico (33).

In 2003 and 2015, the Western and traditional dietary patterns remained stable in terms of food groups and food group factor loadings, suggesting little dietary change over the study period. While still reliant on carbohydrates in 2015, we found some evidence of some dietary diversification due to small but significant displacement of corn tortillas and traditional Guatemalan foods by both healthy and energy-dense, nutrient-poor foods. Healthier changes included increased consumption of vegetables and baked/roasted meats and fish while less healthy changes included an increase in processed/fried meats and SSBs in both genders and decreased fruit intake among men. In contrast to other diet studies in Guatemala, we did not find evidence that corn tortillas and tamales were replaced by refined carbohydrates (34,35). Consumption of refined carbohydrates remained stable over the study period suggesting that corn tortilla and tamales intake was displaced by other types of food groups, such as vegetables.

The macronutrient composition of the diet changed significantly over the 12y period; as a percentage of total energy, carbohydrate intake decreased while fat and protein intake increased**.** This shift in macronutrient composition of the diet is a hallmark of the nutrition transition (3). The shifts, though small, were similar to those reported in southern Mexico (a poorer and more rural region of the country

which borders Guatemala) where carbohydrate intake decreased from 61.4% to 60.8% of total energy while total energy from fat increased from 22.1% to 26.9% between 1988 and 1999 (36). Despite the small magnitude of change as a percentage of total energy, based on their consistency with similar populations in the region, the shifts are likely reflective of the slow but meaningful changes in dietary composition.

While still above recommended levels, diets in the Guatemalan cohort moved closer to meeting NHBLI and IOM guidelines for maximum carbohydrate intake. However, fiber intake declined significantly over the study period (from 28.3 to 26.7 g/day in women and from 39.8 to 38.3 g/day in men) – likely due to reduced intake of corn tortillas. While fiber intakes for most participants were adequate relative to U.S. Dietary Reference Intakes (25g for women and 38g for men) (27), a downward trend in fiber intake should be monitored due to its association with cholesterol and certain cancers (37,38).

The observed changes in the diet between 2003 and 2015 were in line with our prior expectations based on (a) documented macro-level alterations to food availability and food access in Guatemala; and (b) dietary shifts seen in other low- and middle-income countries (LMIC) undergoing nutrition transition. Guatemala ratified the Central American Free Trade Agreement (CAFTA) in 2006 which eliminated tariffs on ultra-processed foods including sweet pastries, corn chips, frozen pizzas, baked crackers, chocolate products, and sugar confectionery (39). As a result, processed food imports increased substantially (40). By 2008, partially and

highly processed foods each accounted for 20% of total calorie availability (41). According to a WHO report on ultra-processed food and drink products in Latin America, consumption of ultra-processed foods and beverages in Guatemala increased in tandem with increased availability (90.7 kg per capita in 2000 vs. 113.5 kg per capita in 2013) (42). The WHO reported similar trends throughout Latin America.

There were a few notable associations between sociodemographic and health behaviors and the dietary patterns. The Western dietary patterns were associated with both healthy (vitamin use in both genders in 2003 and in men only in 2015) and unhealthy behaviors (smoking and alcohol use in men in 2003). Lack of variation in smoking and physical inactivity in women limited our ability to detect any trends in this group. Previous studies on diet in Guatemala reported that higher household annual expenditures were associated with increased likelihood of consuming a Western diet (13) and that higher SES was associated with increased household-level calorie and processed food intake (43). We found a positive association between higher household SES and increased likelihood of consuming a Western diet in 2015 (13,43). Westernized diets are thought to track with income in LMICs where higher income households benefit from increased access to market foods (44). Similarly, lower household SES was associated with increased likelihood of consuming the traditional dietary pattern in 2015.

The diversification of the diet in Guatemala may have public health implications for NCD risk. Diversification of the diet through healthy foods would be

beneficial to health because balanced diets high in fruits and vegetables, whole grains, and healthy fats have been associated with reduced obesity and diabetes (45,46); however, adoption of unhealthy foods is likely to worsen Guatemala's NCD burden. Studies from Mexico and Brazil have found strong associations between adoption of Western dietary patterns and health outcomes including overweight/obesity and metabolic syndrome (47–49). Nutrition transition is especially pressing in Guatemala given its high prevalence of stunting. In 2015, 46.5% of children under 5y old were stunted (HAZ < -2 SD), suggesting widespread and chronic early life undernutrition (50). Data from animal studies suggest that hyper-caloric nutrition amplifies metabolic abnormalities due to early life growth retardation (51). Thus, more research should be done on how to encourage adoption of healthy modern foods without introducing energy-dense, nutrient-poor foods. Countries including Mexico and Brazil are implementing a number of schemes including fiscal policies to address the double burden of malnutrition (52); however, to date, their impact on diet and overall health have not been evaluated.

Strengths and Limitations

There are a few limitations to this study. The FFQ did not fully capture processing (e.g. commercially-processed tortillas versus those made in the home or a local bakery) or certain differences within food groups (e.g. low- versus high-fat dairy) which might help distinguish between healthy and less healthy additions to the traditional diet. However, the FFQ was designed to capture transitional foods typically associated with Western diets such as ice cream, pizza, and hamburgers.

There may have been differential misreporting of intake by BMI status. Studies in high income country populations have shown that overweight/obese people tend to under-report food intake relative to normal weight people (53,54); however, one study from Brazil found that total energy underreporting was differential by overweight/obesity status for diet journals and 24-hour recalls but not FFQ (55). Misreporting could help explain the finding that total caloric intake decreased in women over the study period while mean BMI increased by 2.5 kg/m^2. Finally, these analyses are specific to a rural population; urban populations in Guatemala may have different diets and/or different patterns of change because behaviors associated with the nutrition transition tend to appear first in urban populations (7). Our findings contribute to the limited literature on individual diet and dietary change over time in a developing country.

This study also has a number of strengths. The FFQ was developed for and previously validated in this cohort (18). The FFQ included a number of "transitional foods" relevant to identifying modern diets like SSBs and hot dogs and had open-ended sections for fruit and vegetable consumption to capture potential seasonality in the diet. We used a data-driven approach to dietary pattern analysis which goes beyond intake and adequacy of individual nutrients and attempts to characterize dietary behavior (56–58). Assessing overall food group intake and dietary patterns help provide a more complete picture of Guatemalan dietary habits. To our knowledge, this is the first study to assess longitudinal change in individual diet in Guatemala.

Conclusion

Our findings suggest that, while diets remained largely reliant on starches and disaccharides, there is some evidence of diet diversification characterized by decreased intake of traditional foods and a mixture of consumption trends for Western foods. To help mitigate risks associated with nutrition-related NCD, further research should explore approaches to encourage adoption of healthier foods while minimizing the addition of energy-dense, nutrient-poor foods. Future research should include urban populations and show how dietary patterns and dietary change are associated with health outcomes.

Chapter 6 References

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Table 6.1. Absolute and relative 12 year changes in food group intake (% of total caloric intake) by sex for rural Guatemalan adults. INCAP Nutrition Supplementation Trial Longitudinal Cohort, 2002-04 and 2015-16 (n=479 women, n=303 men).

	Women (n=479)			Men (n=303)		
	2002-04 Mean (% of total caloric intake)[1]	Absolute 12y change (% points)	Relative 12y change (%)	2002-04 Mean (% of total caloric intake)[1]	Absolute 12y change (% points)	Relative 12y change (% change)
Corn tortilla	49.5 (14.2)	-4.7 (14.8)	-9.4***	52.5 (11.7)	-3.7 (13.1)	-7.0***
Whole grains	0 (0)	0 (0)	0	0 (0)	0 (0)	0
Refined grains	12.9 (7.4)	-0.4 (9.2)	-3.1	12.1 (6.6)	-0.1 (8.2)	-0.8
Vegetables	2.5 (2.7)	1.4 (3.8)	56.0***	2.1 (1.7)	0.5 (2.6)	23.8**
Fried starches	2.8 (3.2)	-0.2 (4.5)	-7.1	2.5 (2.5)	-0.4 (3.2)	-16.0
Fruits	3.9 (3.5)	0.1 (4.7)	2.5	3.8 (4.0)	-1.1 (4.6)	-28.9**
Baked/roasted meat and fish	4.2 (3.1)	1.2 (3.9)	28.5***	3.6 (2.6)	0.8 (3.9)	22.2***
Processed and fried meat	3.0 (2.6)	0.8 (3.8)	26.3***	3.0 (2.3)	1.3 (3.6)	43.3***
Eggs	1.5 (1.3)	0.05 (1.8)	3.3	1.7 (1.2)	0.2 (2.0)	11.7
Dairy	1.9 (2.4)	0.1 (3.0)	5.2	1.2 (1.3)	0.1 (1.9)	8.3
Nuts	0 (0)	0 (0)	0	0 (0)	0 (0)	0
Beans	4.5 (3.6)	-0.2 (4.3)	-4.4	4.4 (3.2)	0.2 (4.1)	4.5
Oils/fats	1.2 (1.5)	0.01 (1.9)	0.8	1.2 (1.4)	-0.08 (1.6)	-6.6
Coffee	0.2 (0.1)	-0.006 (0.2)	-3.0	0.1 (0.1)	-0.01 (0.1)	-10.0
Sugar added to coffee	1.8 (1.7)	0.02 (2.1)	1.1	1.2 (1.1)	0.03 (1.3)	2.5
Alcohol	0.03 (0.4)	0.01 (0.5)	33.3	0.8 (1.8)	0.2 (3.5)	25.0
SSB[2]	5.1 (4.7)	2.4 (6.5)	47.0***	4.5 (3.5)	2.3 (5.2)	51.1***
Traditional Guatemalan foods[2]	2.6 (2.3)	-0.4 (3.0)	-15.3**	2.0 (1.6)	-0.4 (1.9)	-20.0**
Transitional foods[3]	1.7 (2.6)	-0.1 (3.0)	-5.8	2.6 (2.7)	-0.09 (3.3)	-3.4

Values presented are mean (SD). [1]Mean intake of food groups (g). [2]Soft drinks, lemonade, sweetened juice-flavored drinks. [3]Tamales and tacos.[4]Pizza, hamburgers, salty snacks, processed soup, candy, jelly. [5]P was calculated using Wilcoxon signed-rank tests.

*** P <0.0001

** P <0.01

* P <0.05

Abbreviations: INCAP, Institute of Nutrition for Central America and Panama; SSB, sugar-sweetened beverages.

Table 6.2. Food group factor loadings and mean intake (g) by PCA-derived dietary pattern tertile for rural Guatemalan adults. INCAP Nutrition Supplementation Trial Longitudinal Cohort, 2002-04 (n=479 women, n=303 men).

	Western 2002-04				Traditional 2002-04			
Food Groups	Factor loading	T1[1] (g)	T2 (g)	T3 (g)	Factor loading	T1 (g)	T2 (g)	T3 (g)
WOMEN								
Corn tortilla					79	269.6	383.4	512.3
Refined grains	48	81.7	121	154				
Vegetables	50	14.4	28.8	65.7				
Fried starches	60	14.1	28.7	80.2				
Fruits								
Baked/roasted meat, fish	57	32.0	49.7	91.2				
Processed and fried meats	58	11.9	27.1	43.4				
Eggs	38	17.6	28.1	39.7				
Dairy	37	28.5	70.2	130				
Beans					73	57.1	90.9	218.6
Oils/fats	36	4.6	9.9	14.7				
Sugar added to coffee					46	6.3	11.8	20.5
SSB[2]	56	214	411	575				
Traditional Guatemalan foods[3]	40	30.2	48.5	69.8				
Transitional foods[4]	51	8.9	22.5	42.9				
MEN								
Corn tortilla					79	414.9	558.9	732.5
Refined grains	48	106.4	154.5	198.5				
Vegetables	50	21.6	36.7	64.5				
Fried starches	60	24.1	38.2	87.9				
Fruits								
Baked/roasted meats, fish	57	37.8	60.5	104.0				
Processed and fried meats	58	18.1	35.1	61.1				
Eggs	38	31.8	44.5	56.5				
Dairy	37	27.5	67.1	97.5				
Beans					73	78.1	126.2	259.5
Oils/fats	36	6.6	14.4	19.4				

Sugar added to coffee					46	7.2	11.7	17.5
SSB[2]	56	357.9	638.2	795.5				
Traditional Guatemalan foods[3]	40	31.2	52.6	76.3				
Transitional foods[4]	51	19.6	36.1	63.1				

[1]Mean intake of food groups (g) across tertiles. Tertiles are sex-specific. [2]Soft drinks, lemonade, sweetened juice-flavored drinks. [3]Tamales and tacos. [4]Pizza, hamburgers, salty snacks, processed soup, candy, jelly. Whole grains and nuts were excluded from analyses due to low (<10%) consumption. Alcohol was excluded from analyses due to low frequency of consumption (<0.5g/day). Abbreviations: INCAP, Institute of Nutrition for Central America and Panama; SSB, sugar-sweetened beverages; T, tertile.

Total variance explained in 2004: 28.6%

Table 6.3. Food group factor loadings and mean intake (g) by PCA-derived dietary pattern tertile for rural Guatemalan adults. INCAP Nutrition Supplementation Trial Longitudinal Cohort, 2015-16 (n=479 women, n=303 men).

	Western 2015-16				Traditional 2015-16			
Food Groups	Factor loading	T1[1] (g)	T2 (g)	T3 (g)	Factor loading	T1 (g)	T2 (g)	T3 (g)
WOMEN								
Corn tortilla					69	237.9	333.7	437.5
Refined grains	50	80.7	107.8	152.6				
Vegetables	47	25.0	47.6	85.2				
Fried starches	50	13.9	31.1	63.4				
Fruits	46	112.9	216.2	325.9				
Baked/roasted meat, fish	58	40.8	72.0	105.5				
Processed and fried meats	46	21.6	30.0	49.8				
Eggs					44	19.1	26.9	41.0
Dairy	40	28.6	62.9	138.2				
Beans					72	49.9	84.7	181.8
Oils/fats	45	4.8	9.1	15.6				
Sugar added to coffee								
SSB[2]	48	293.8	430.2	631.8				
Traditional Guatemalan foods[3]	42	24.0	37.0	63.8				
Transitional foods[4]	45	17.2	25.0	48.3				
MEN								
Corn tortilla					69	410.9	507.9	710.6
Refined grains	50	115.5	143.9	213.9				
Vegetables	47	23.2	43.1	77.4				
Fried starches	50	14.7	38.8	80.6				
Fruits	46	125.9	216.7	316.7				
Baked/roasted meats, fish	58	52.4	77.4	126.2				
Processed and fried meats	46	34.4	53.3	87.0				
Eggs					44	33.6	53.0	71.7
Dairy	40	31.2	76.0	102.3				
Beans					72	85.5	139.5	288.2
Oils/fats	45	6.8	12.3	20.7				

Sugar added to coffee				
SSB[2]	48	357.5	638.9	882.5
Traditional Guatemalan foods[3]	42	26.8	37.7	67.7
Transitional foods[4]	45	24.7	41.2	65.4

[1]Mean intake of food groups (g) across tertiles. Tertiles are sex-specific. [2]Soft drinks, lemonade, sweetened juice-flavored drinks. [3]Tamales and tacos. [4]Pizza, hamburgers, salty snacks, processed soup, candy, jelly. Whole grains and nuts were excluded from analyses due to low (<10%) consumption. Alcohol was excluded from analyses due to low frequency of consumption (<0.5g/day). Abbreviations: INCAP, Institute of Nutrition for Central America and Panama; SSB, sugar-sweetened beverages; T, tertile.

Total variance explained in 2015: 29.0%

Table 6.4. Nutrient intakes by PCA-derived dietary pattern tertile for rural Guatemalan adults. INCAP Nutrition Supplementation Trial Longitudinal Cohort, 2002-04 and 2015-16 (n=479 women, n=303 men).

	Western 2002-04				Western 2015-16			
	T1	T2	T3	*P*-trend[2]	T1	T2	T3	*P*-trend[2]
WOMEN								
n	159	160	160		160	159	160	
Mean factor score	-1.1 (0.3)	-0.3 (0.2)	0.8 (0.7)		-1.0 (0.3)	-0.2 (0.2)	0.8 (0.6)	
Total energy (kcal/day)	1797 (523)	2170 (494)	2784 (602)	<0.0001	1696 (480)	2086 (476)	2767 (708)	<0.0001
Carbohydrate (% energy)	72.9 (4.6)	68.7 (4.8)	66.0 (4.9)	<0.0001	70.7 (5.7)	67.4 (5.9)	65.0 (5.6)	<0.0001
Protein (% energy)	12.0 (1.4)	12.1 (1.5)	12.4 (1.7)	0.01	12.8 (1.8)	12.9 (2.0)	13.0 (2.0)	0.8
Fat (% energy)	15.0 (4.2)	19.0 (4.2)	21.4 (4.2)	<0.0001	16.3 (5.1)	19.5 (4.7)	21.9 (4.5)	<0.0001
Saturated fat (% energy)	3.4 (1.5)	5.0 (1.7)	6.0 (1.7)	<0.0001	3.9 (1.7)	5.3 (2.2)	6.2 (1.7)	<0.0001
Fiber (g/day)	25.7 (8.3)	27.1 (8.9)	32.0 (9.2)	<0.0001	22.4 (7.4)	26.3 (8.5)	31.4 (9.2)	<0.0001
	Traditional 2002-04				Traditional 2015-16			
n	159	161	159		159	160	160	
Mean factor score	-1.1 (0.3)	-0.4 (0.1)	0.7 (0.7)		-1.2 (0.4)	-0.4 (0.1)	0.5 (0.5)	
Total energy (kcal/day)	1973 (624)	2161 (519)	2622 (706)	<0.0001	1930 (611)	2126 (679)	2492 (743)	<0.0001
Carbohydrate (% energy)	66.9 (5.3)	69.4 (5.4)	71.2 (507)	<0.0001	66.7 (6.4)	67.4 (6.2)	69.0 (572)	0.0002
Protein (% energy)	12.3 (1.8)	12.1 (1.6)	12.1 (1.2)	0.3	13.1 (2.0)	12.8 (1.9)	12.9 (1.8)	0.3
Fat (% energy)	20.6 (4.4)	18.4 (4.8)	16.5 (4.7)	<0.0001	20.1 (5.2)	19.6 (5.4)	18.0 (5.0)	<0.0001
Saturated fat (% energy)	5.8 (1.9)	4.7 (1.8)	4.1 (1.8)	<0.0001	5.7 (1.9)	5.2 (2.4)	4.5 (1.8)	<0.0001
Fiber (g/day)	25.5 (6.5)	26.9 (6.3)	34.4 (10.3)	<0.0001	24.5 (9.0)	25.8 (8.7)	29.9 (8.9)	<0.0001
	Western 2002-04				Western 2015-16			
MEN								
n	101	102	100		100	102	101	
Mean factor score	-0.6 (0.3)	0.2 (0.2)	1.4 (0.7)		-0.8 (0.3)	0.09 (0.2)	1.4 (0.7)	
Total energy (kcal/day)	2433 (630)	3066 (568)	3815 (714)	<0.0001	2452 (752)	3067 (646)	3939 (732)	<0.0001
Carbohydrate (% energy)	73.1 (3.7)	69.8 (5.0)	67.7 (4.6)	<0.0001	70.4 (5.0)	68.7 (4.7)	65.0 (5.4)	<0.0001
Protein (% energy)	11.6 (1.3)	11.5 (1.5)	11.9 (1.4)	0.2	12.8 (1.8)	12.7 (1.9)	13.0 (2.2)	0.6
Fat (% energy)	15.1 (3.4)	18.5 (4.6)	20.3 (3.9)	<0.0001	17.2 (3.9)	17.8 (5.2)	18.9 (4.2)	<0.0001
Saturated fat (% energy)	3.4 (1.0)	5.1 (3.5)	5.5 (1.5)	<0.0001	4.0 (1.6)	4.8 (1.2)	5.8 (1.6)	<0.0001
Fiber (g/day)	34.6 (10.8)	38.6 (10.5)	46.1 (13.5)	<0.0001	32.6 (10.8)	38.0 (11.9)	44.1 (12.8)	<0.0001

	Traditional 2002-04				Traditional 2015-16			
n	100	103	100		100	103	100	
Mean factor score	-0.5 (0.3)	0.3 (0.2)	1.5 (0.6)		-0.4 (0.4)	0.4 (0.1)	1.6 (0.6)	
Total energy (kcal/day)	2588 (750)	3039 (652)	3681 (777)	<0.0001	2586 (897)	3058 (699)	3821 (758)	<0.0001
Carbohydrate (% energy)	68.7 (5.0)	70.5 (4.3)	71.4 (5.2)	<0.0001	68.0 (6.6)	68.0 (5.0)	68.1 (4.9)	0.6
Protein (% energy)	11.9 (1.5)	11.4 (1.3)	11.8 (1.4)	0.8	12.9 (2.4)	12.6 (1.6)	13.1 (1.8)	0.1
Fat (% energy)	19.3 (4.4)	17.9 (3.7)	16.7 (5.0)	<0.0001	18.6 (4.7)	17.7 (3.7)	17.6 (5.0)	0.3
Saturated fat (% energy)	5.0 (1.5)	4.5 (1.5)	4.4 (3.6)	<0.0001	5.2 (1.9)	4.9 (1.5)	4.5 (1.4)	0.004
Fiber (g/day)	31.0 (7.9)	38.8 (8.6)	49.5 (13.0)	<0.0001	32.1 (10.6)	35.5 (8.8)	47.3 (12.8)	<0.0001

Values presented are mean (SD) or percent. [1]Low physical activity defined as 24-h average physical activity <1.7 MET/hr. [2]P for trend was calculated using Spearman correlation (continuous) and Mantel-Hansel Chi-square tests (categorical variables). Abbreviations: INCAP, Institute of Nutrition for Central America and Panama; SES, socioeconomic status; T, tertile.

Table 6.5. Sociodemographic and health characteristics by PCA-derived dietary pattern tertile for rural Guatemalan adults. INCAP Nutrition Supplementation Trial Longitudinal Cohort, 2002-04 and 2015-16 (n=479 women, n=303 men).

	Western 2002-04				Western 2015-16			
	T1	T2	T3	*P*-trend[2]	T1	T2	T3	*P*-trend[2]
WOMEN								
n	159	160	160		160	159	160	
Age	32.8 (4.0)	32.8 (4.4)	32.7 (4.4)	0.9	44.2 (4.3)	44.4 (4.4)	44.1 (4.3)	0.8
SES tertile				0.5				<0.0001
Poorest	32.7	33.1	35.6		43.5	28.5	25.0	
Middle	26.4	25.0	25.6		37.6	32.4	30.7	
Richest	40.8	41.8	38.7		18.8	38.9	44.2	
Alcohol use, %	28.5	31.1	29.3	0.8	1.8	4.4	3.8	0.3
Ever smoking, %	3.4	3.2	6.3	0.2	3.7	2.5	5.1	0.5
Low physical activity[1], %	97.4	96.8	98.1	0.7*				
Vitamin use, %	15.6	18.8	27.3	0.01	8.4	12.9	14.1	0.2
BMI (kg/m^2)	27.1 (5.3)	27.1 (4.6)	26.6 (5.0)	0.4	28.8 (5.4)	29.2 (5.0)	30.1 (5.5)	0.04
	Traditional 2002-04				Traditional 2015-16			
n	159	161	159		159	160	160	
Age	32.8 (4.1)	32.8 (4.4)	32.8 (4.3)	0.8	44.9 (4.2)	44.2 (4.3)	43.7 (4.3)	0.008
SES tertile				0.8				<0.0001
Poorest	32.7	34.1	34.5		22.5	33.1	41.4	
Middle	25.1	29.1	22.6		30.9	33.1	36.8	
Richest	42.1	36.6	42.7		46.4	33.7	21.7	
Alcohol use, %	24.3	34.6	30.0	0.2	3.8	3.1	3.2	0.7
Ever smoking, %	3.2	2.6	7.1	0.09	5.7	2.5	3.2	0.2
Low physical activity[1], %	96.8	99.3	96.2	0.7*				
Vitamin use, %	17.1	22.1	22.8	0.2	16.7	10.8	7.9	0.01
BMI (kg/m^2)	26.6 (4.8)	27.0 (5.2)	27.2 (4.9)	0.2	29.9 (5.6)	29.3 (5.3)	28.9 (5.0)	0.1
	Western 2002-04				Western 2015-16			
MEN								
n	101	102	100		100	102	101	
Age	32.8 (4.2)	32.3 (4.5)	32.0 (4.0)	0.2	43.4 (4.4)	43.9 (4.1)	44.0 (4.1)	0.2
SES tertile				0.7				0.004
Poorest	33.6	26.4	39.0		44.7	23.0	33.6	
Middle	36.6	21.5	23.0		29.1	43.0	25.7	

Richest	29.7	51.9	38.0		26.0	34.0	40.5	
Alcohol use, %	69.8	80.2	82.0	0.05	31.9	40.2	43.5	0.09
Current smoking, %	38.5	50.0	43.3	0.5	31.9	31.3	39.6	0.2
Former smoking, %	35.2	46.5	54.9	0.04	42.4	54.2	54.1	0.1
Low physical activity[1], %	53.4	56.8	51.0	0.7				
Vitamin use, %	14.4	23.2	31.1	0.009	5.2	16.0	17.8	0.01
BMI (kg/m^2)	23.6 (3.5)	24.3 (3.3)	23.9 (3.1)	0.3	25.4 (4.2)	26.1 (4.1)	25.9 (3.8)	0.2
	Traditional 2002-04				Traditional 2015-16			
n	100	103	100		100	103	100	
Age	33.0 (4.2)	32.1 (4.3)	32.0 (4.1)	0.1	44.1 (4.3)	43.7 (4.2)	43.6 (4.1)	0.4
SES tertile				0.8				0.03
Poorest	31.0	32.0	36.0		27.8	31.0	42.2	
Middle	32.0	25.2	24.0		29.9	32.0	36.0	
Richest	37.0	42.7	40.0		42.2	36.8	21.6	
Alcohol use, %	71.6	82.2	78.1	0.3	42.8	30.1	43.4	0.9
Current smoking, %	40.2	50.0	41.3	0.9	29.5	30.1	43.4	0.04
Former smoking, %	34.6	40.0	60.7	0.008	47.8	47.2	57.1	0.3
Low physical activity[1], %	56.0	52.4	53.0	0.6				
Vitamin use, %	25.6	25.5	18.3	0.2	15.6	10.6	13.4	0.5
BMI (kg/m^2)	23.7 (2.8)	24.1 (3.5)	24.0 (3.6)	0.8	25.7 (3.9)	25.6 (4.0)	26.1 (4.2)	0.7

Values presented are mean (SD) or percent. [1]Low physical activity defined as 24-h average physical activity <1.7 MET/hr. [2]P for trend was calculated using Spearman correlation (continuous) and Mantel-Hansel Chi-square tests (categorical variables).*Expected cell count <5. Abbreviations: BMI, body mass index; INCAP, Institute of Nutrition for Central America and Panama; T, tertile.

Table 6.6. Sociodemographic and health characteristics by PCA-derived dietary pattern tertile for rural Guatemalan adults. INCAP Nutrition Supplementation Trial Longitudinal Cohort, 2002-04 and 2015-16 (n=479 women, n=303 men).

	Western 2002-04				Western 2015-16			
	T1	T2	T3	*P*-trend[2]	T1	T2	T3	*P*-trend[2]
WOMEN								
n	159	160	160		160	159	160	
Age	32.8 (4.0)	32.8 (4.4)	32.7 (4.4)	0.9	44.2 (4.3)	44.4 (4.4)	44.1 (4.3)	0.8
SES tertile				0.5				<0.0001
Poorest	32.7	33.1	35.6		43.5	28.5	25.0	
Middle	26.4	25.0	25.6		37.6	32.4	30.7	
Richest	40.8	41.8	38.7		18.8	38.9	44.2	
Alcohol use, %	28.5	31.1	29.3	0.8	1.8	4.4	3.8	0.3
Ever smoking, %	3.4	3.2	6.3	0.2	3.7	2.5	5.1	0.5
Low physical activity[1], %	97.4	96.8	98.1	0.7*				
Vitamin use, %	15.6	18.8	27.3	0.01	8.4	12.9	14.1	0.2
BMI (kg/m^2)	27.1 (5.3)	27.1 (4.6)	26.6 (5.0)	0.4	28.8 (5.4)	29.2 (5.0)	30.1 (5.5)	0.04
	Traditional 2002-04				Traditional 2015-16			
n	159	161	159		159	160	160	
Age	32.8 (4.1)	32.8 (4.4)	32.8 (4.3)	0.8	44.9 (4.2)	44.2 (4.3)	43.7 (4.3)	0.008
SES tertile				0.8				<0.0001
Poorest	32.7	34.1	34.5		22.5	33.1	41.4	
Middle	25.1	29.1	22.6		30.9	33.1	36.8	
Richest	42.1	36.6	42.7		46.4	33.7	21.7	
Alcohol use, %	24.3	34.6	30.0	0.2	3.8	3.1	3.2	0.7
Ever smoking, %	3.2	2.6	7.1	0.09	5.7	2.5	3.2	0.2
Low physical activity[1], %	96.8	99.3	96.2	0.7*				
Vitamin use, %	17.1	22.1	22.8	0.2	16.7	10.8	7.9	0.01
BMI (kg/m^2)	26.6 (4.8)	27.0 (5.2)	27.2 (4.9)	0.2	29.9 (5.6)	29.3 (5.3)	28.9 (5.0)	0.1
	Western 2002-04				Western 2015-16			
MEN								
n	101	102	100		100	102	101	
Age	32.8 (4.2)	32.3 (4.5)	32.0 (4.0)	0.2	43.4 (4.4)	43.9 (4.1)	44.0 (4.1)	0.2
SES tertile				0.7				0.004
Poorest	33.6	26.4	39.0		44.7	23.0	33.6	
Middle	36.6	21.5	23.0		29.1	43.0	25.7	

Richest	29.7	51.9	38.0		26.0	34.0	40.5	
Alcohol use, %	69.8	80.2	82.0	0.05	31.9	40.2	43.5	0.09
Current smoking, %	38.5	50.0	43.3	0.5	31.9	31.3	39.6	0.2
Former smoking, %	35.2	46.5	54.9	0.04	42.4	54.2	54.1	0.1
Low physical activity[1], %	53.4	56.8	51.0	0.7				
Vitamin use, %	14.4	23.2	31.1	0.009	5.2	16.0	17.8	0.01
BMI (kg/m^2)	23.6 (3.5)	24.3 (3.3)	23.9 (3.1)	0.3	25.4 (4.2)	26.1 (4.1)	25.9 (3.8)	0.2
	Traditional 2002-04				Traditional 2015-16			
n	100	103	100		100	103	100	
Age	33.0 (4.2)	32.1 (4.3)	32.0 (4.1)	0.1	44.1 (4.3)	43.7 (4.2)	43.6 (4.1)	0.4
SES tertile				0.8				0.03
Poorest	31.0	32.0	36.0		27.8	31.0	42.2	
Middle	32.0	25.2	24.0		29.9	32.0	36.0	
Richest	37.0	42.7	40.0		42.2	36.8	21.6	
Alcohol use, %	71.6	82.2	78.1	0.3	42.8	30.1	43.4	0.9
Current smoking, %	40.2	50.0	41.3	0.9	29.5	30.1	43.4	0.04
Former smoking, %	34.6	40.0	60.7	0.008	47.8	47.2	57.1	0.3
Low physical activity[1], %	56.0	52.4	53.0	0.6				
Vitamin use, %	25.6	25.5	18.3	0.2	15.6	10.6	13.4	0.5
BMI (kg/m^2)	23.7 (2.8)	24.1 (3.5)	24.0 (3.6)	0.8	25.7 (3.9)	25.6 (4.0)	26.1 (4.2)	0.7

Values presented are mean (SD) or percent. [1]Low physical activity defined as 24-h average physical activity <1.7 MET/hr. [2]P for trend was calculated using Spearman correlation (continuous) and Mantel-Hansel Chi-square tests (categorical variables).*Expected cell count <5. Abbreviations: BMI, body mass index; INCAP, Institute of Nutrition for Central America and Panama; T, tertile.

Chapter 7 – Dietary patterns and Cardio-metabolic Risk in a Population of Guatemalan Young Adults

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The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

Abbreviations used: BMI, body mass index; CMD, cardio-metabolic disease; CI, confidence interval; FFQ, food frequency questionnaire; HDL-c, high density lipoprotein cholesterol; Institute of Nutrition of Central America and Panama (INCAP); LMIC, low- and middle-income countries; NCEP ATP III, National Cholesterol Education Program Adult Treatment Panel III; NCD, non-communicable disease; PAL, physical activity level; PCA, principal components analysis; RR, risk ratio; SES, socioeconomic status.

Abstract

Background: Latin America is facing an increasing burden of nutrition-related non-communicable disease. Little is known about dietary patterns in Guatemalan adults and how dietary patterns are associated with cardio-metabolic disease (CMD) risk.

Methods: This analysis is based on data from a 2002-04 follow-up study of the INCAP Nutrition Supplementation Trial Longitudinal Cohort. Diet data were collected using a validated, semi-quantitative food frequency questionnaire. We derived dietary patterns using principal components analysis. CMD risk was assessed by anthropometry (body mass index, waist circumference), biochemistry (fasting blood glucose and lipids), and clinical (blood pressure) measures. We used sex-stratified multivariable log binomial models to test associations between dietary pattern tertile and CMD risk factors. The sample included 1,428 participants (681 men and 747 women) ages 25-43 years.

Results: We derived 3 dietary patterns (traditional, meat-based modern, and starch-based modern), collectively explaining 24.2% of variance in the diet. Dietary patterns were not associated with most CMD risk factors; however, higher starch-based modern tertiles were associated with increased prevalence of low high density lipoprotein cholesterol (HDL-c) in men (Prevalence Ratio (PR) 1.17, 95% Confidence Interval (CI) 1.01, 1.20 for tertile 2; PR 1.20, 95% CI 1.00, 1.44 for tertile 3; p trend 0.04). Higher traditional tertile was associated with increased prevalence of abdominal obesity in women (PR 1.24, 95% CI 1.07, 1.43 for tertile 2; PR 1.19, 95% CI 1.02, 1.39 for tertile 3; p trend 0.02) but marginally significant reduced

prevalence of low HDL-c in men (PR 0.88, 95% CI 0.76, 1.00 for tertile 2; PR 0.85, 95% CI 0.72, 1.00 for tertile 3; p trend 0.05).

Conclusion: Our findings suggest the presence of two 'modern diet' patterns in Guatemala – one of which was associated with increased prevalence of low HDL-c in men. The association between the traditional dietary pattern and some CMD risk factors may vary by sex.

Introduction

Latin America has experienced large increases in non-communicable diseases (NCDs) over the past 20 years, which now account for 34% of deaths in the region (1). These increases are a direct result of demographic, social, and economic changes influencing dietary and physical activity patterns, among other factors (2). The nutrition transition is marked by changes in diet from staple foods to high-fat, high-sugar, processed foods (3). Despite documented changes to the food environment in Guatemala, such as doubling of the number of supermarkets from 1990-2008 (4) and increased imports of processed foods (5), the extent to which Guatemalans have adopted modern diets is unclear. To date, little has been published about individual diets in Guatemala (6–9).

Furthermore, there is little information about how Guatemalan dietary habits influence NCD risk. One previous study of diet scores and cardio-metabolic disease (CMD) risk found that neither score-based indices of diet quality nor single nutrients were consistently associated with CMD risk factors (10–12); however, individuals with identical diet scores can have diverse consumption patterns (13). Data-driven dietary pattern analysis goes beyond intake and adequacy of individual nutrients and attempts to characterize dietary behavior and link patterns of consumption of foods and beverages to health outcomes, including adult anthropometry, metabolic syndrome, and diabetes (14–16). Because diet is a major modifiable determinant of NCD risk (17), understanding how dietary patterns are associated with CMD risk is important for informing public health strategies.

The objectives of this study were: (a) to characterize dietary patterns using principal components analysis (PCA); and (b) to examine the association between dietary patterns and CMD risk in a population of Guatemalan adults.

Methods

Study Population

Individuals in this study were born in four villages in *El Progreso* department in Guatemala from 1962-77 and are participants in the Institute of Nutrition of Central America and Panama (INCAP) Nutrition Supplementation Trial Longitudinal Study cohort (18). This analysis is based on the 2002-04 follow-up. Full details of the original nutrition supplementation trial and its follow-up waves are published elsewhere (19). Of the 2,392 participants in the original study, 1,855 (77.5%) were alive and living in Guatemala for the 2002-04 follow-up, of which 1,571 (85%) consented to participate and provided at least some data. Data were collected in four sessions over the course of one year. Dietary data were acquired during one of these sessions. We obtained dietary data from 1,488 (62.2% of the original cohort) adults ages 25-43 years. The cohort members who consented to participate and who provided at least partial information but were missing dietary data (n=83) were more likely to be male.

Participants were excluded from analyses if they had total energy intake that exceeded 3 SD from the median total energy intake (2,544 kcal) (n=19) or if they were pregnant or within six months post-partum (n=41). The final analytic sample

included 1,428 participants (681 men and 747 women); of these 1,283 had anthropometric measures, 1,141 had blood data, and 1,355 had blood pressure.

All data collection followed protocols that were approved by the institutional review boards of Emory University (Atlanta, GA) and INCAP (Guatemala City, Guatemala). All participants gave written informed consent.

Assessment of Dietary Intake

Data on typical dietary intake were collected using a validated, semi-quantitative 52- item food frequency questionnaire (FFQ) (20). Participants were asked about their consumption over the last three months of traditional and "transitional" foods such as pizza and hamburgers. The FFQ also included open-ended sections for fruits and vegetables to capture potential seasonality in consumption of these foods. The frequency categories were never/rarely, daily, days per week, and days per month. Portion sizes were determined by selecting from a range of serving sizes (e.g. small, medium, or large tortillas; three different serving spoons) or standard serving units (e.g. a medium-sized apple). We converted frequency of consumption for each food to servings per day and then summed the servings for food items. We estimated nutrient intake using the INCAP nutrient database, which is based on foods commonly consumed in Guatemala, supplemented with data from the United States (U.S.) Department of Agriculture Nutrient Database, assuming standard weights based on the reported serving sizes. Servings of food items were converted to grams per day consumed.

Derivation of Dietary Patterns

We categorized food items into 27 mutually exclusive food groups adapted from food group categories developed in Mexico (**Supplemental Table 9.10**) (21). Because <10% of participants reported any consumption of "Nuts" and "Whole Grains", we removed these food groups to improve statistical robustness (22,23). We also removed "Coffee" from the analyses owing to its high correlation with "Sugar Added to Coffee" (R^2=0.89) which led to instability in the factor solutions. Because coffee contributes few calories per mL relative to each gram of sugar, we chose to retain "Sugar Added to Coffee" in analyses.

To derive the dietary patterns, we used PCA with orthogonal rotation of total grams of food groups consumed. We used scree plots, eigenvalues >1.4, minimum absolute factor loading of 35, and the interpretability of factors to guide the final selection of dietary patterns (24). We also explored dietary patterns for men and women separately; however, the patterns (i.e. food groups and factor loadings) were largely consistent, so we conducted the final PCA on the entire sample. Individual dietary pattern scores were calculated by multiplying food group factor loadings by individual intake of the food group (in grams) and then summing for each dietary pattern (24). Due to large differences in energy intake by sex, we categorized the resulting dietary pattern scores into sex-specific tertiles. To assess the stability of the factor solutions, we randomly split the study sample and repeated the analyses (25–27).

Assessment of Anthropometric, Biochemical, and Clinical Measures

Trained field workers collected all anthropometric measurements. Height and waist circumference were measured to the nearest 0.1 cm and weight to the nearest 0.01 kg. All measurements were taken in duplicate; if the difference exceeded 0.5 kg for weight or 0.5 cm for height or 1.0 cm for waist circumference, a third measurement was taken and the average of the two closest measurements was used. Body mass index (BMI) was calculated as weight (kg) divided by height-squared (m^2) and was classified according to current National Heart, Lung, and Blood Institute (NHLBI) guidelines: underweight/normal (<25.0 kg/m^2) and overweight/obese (≥25.0 kg/m^2) (28). Abdominal obesity was defined according to the NHLBI's 2005 National Cholesterol Education Program Adult Treatment Panel III (NCEP ATP III) cut-point of waist circumference of ≥102 cm for men and ≥88 cm for women (29).

For blood lipids and glucose, trained field staff drew fasted (>9 hours) capillary blood samples. Lipids (total cholesterol, high density lipoprotein cholesterol [HDL-c], and triglycerides) and glucose concentrations were measured by enzymatic peroxidase dry chemistry methods (Cholestech LDX System, Hayward, CA, USA). Elevated triglycerides were defined as triglycerides ≥150 mg/dL (29). Low HDL-c was defined as <40 mg/dL for men and <50 mg/dL for women (29). Dysglycemia was defined as having either impaired fasting glucose (fasting blood glucose 100-125 mg/dL) or diabetes (fasting blood glucose ≥126 mg/dL and/or self-reported diabetes and/or reported diabetes medication use).

Seated blood pressure was measured by a physician three times at three-minute intervals on the left arm resting on a table at heart level using a digital blood pressure monitor (Omron, Schaumburg, IL, USA) after a five minute rest (30). Three cuff sizes were available and selected based on participant arm circumference. If systolic or diastolic blood pressure measurements differed by >10 mmHg, then a fourth measure was taken. Otherwise, the second and third measurements were recorded and the average of these two measures used. Medication use for hypertension was ascertained by interview.

Metabolic syndrome was defined according to 2005 NCEP ATP III diagnostic criteria based on presence of at least three of the following: abdominal obesity (waist circumference ≥102 cm for men; ≥88 cm for women); fasting glucose ≥ 100 mg/dL or medication; triglycerides ≥150 mg/dL or medication; HDL-c <40 mg/dL in men or <50 mg/dL in women; and blood pressure >130 mmHg systolic, >85 mmHg diastolic, and/or medication use (29).

Assessment of Covariates

Data on lifestyle and socioeconomic factors were collected by interview. Potential covariates were identified *a priori* and include age, socioeconomic status (SES), urban residence, smoking, multivitamin use, and physical activity. SES was a cumulative score developed from PCA of participant household characteristics and consumer durable goods (31). Urban residence was based on residence location, neighborhood, and amenities (11). Current smoking and daily multivitamin intake were classified as yes or no. Average physical activity was ascertained using a

physical activity questionnaire asking about the frequency and duration of activities performed on a typical day over the preceding year (32). Participant physical activity level (PAL) was calculated by averaging metabolic equivalents (MET) per hour over 24 hours. Participants were classified as physically inactive if their PAL was <1.7 – the minimum level recommended to prevent obesity (33).

Statistical Analyses

To assess differences in sociodemographic, health characteristics, and in dietary factors such as percent of energy from macronutrients across dietary pattern tertiles, we used Mantel-Haenszel chi-square tests for categorical variables and Spearman rank tests for continuous variables. To characterize the relationship between dietary pattern and CMD risk factors, we used sex-stratified log binomial models to regress CMD risk outcomes on dietary pattern score tertiles. Model 1 controlled for age. Model 2 additionally controlled for total energy intake to account for absolute differences in food intake (34). Model 3 additionally controlled for other covariates (urban residence, SES, and multivitamin use). We also controlled for smoking and physical inactivity in Model 3 in men; too few women smoked or were physically active to include these variables in the model. Each dietary pattern was modeled separately. We also assessed effect modification by stratifying the data by urban residence and comparing stratum-specific and pooled prevalence ratio estimates (12).

Statistical significance was set *a priori* at $P < 0.05$. For statistical interactions, $P < 0.10$ was considered significant. All *P*-values were two-sided. All analyses were performed using SAS v.9.4 (SAS Institute, Cary, NC, USA).

Results

We identified three dietary patterns which we label as meat-based modern, starch-based modern, and traditional, which collectively explained 24.2% of the dietary variance (**Table 7.1 and Supplemental Tables 9.11-12**). The meat-based modern pattern was characterized by consumption of salty snacks, processed and fried meats, sweets/candies, alcohol, soda, traditional Guatemalan foods (e.g. tamales and tacos), and transitional foods (e.g. hamburgers and pizza). The starch-based modern pattern was characterized by consumption of refined grains, starchy and non-starchy vegetables, fried starches, juices, fruit, oils/fats, giblets, and packaged soups. The traditional pattern was characterized by consumption of corn tortillas, beans, sugar added to coffee, and was negatively associated with consumption of dairy and transitional foods.

Higher meat-based modern pattern tertile was associated with lower SES in women (p trend 0.001) (**Table 7.2**) and younger age (p trend 0.002), smoking (p trend 0.001), and alcohol consumption (p trend <0.001) in men (**Table 7.3**). Higher starch-based modern pattern tertile was associated with multivitamin use in both sexes (p trend <0.001 for men and p trend 0.02 for women), and with physical inactivity (p trend 0.002) and higher BMI (p trend 0.02) in men. In both men and women, higher traditional pattern tertile was inversely associated with urban

residence (p trend 0.008 and p trend <0.001, respectively). In men, higher traditional pattern tertile was also associated with lower SES (p trend 0.05), smoking (p trend 0.04), less physical inactivity (p trend <0.0001), lower BMI (p trend 0.003), less overweight (p trend 0.01), and less low HDL-c (p trend 0.009). Conversely, in women, higher traditional pattern tertile was associated with higher BMI (p trend 0.04).

Within and across the three dietary patterns, carbohydrates provided the majority of energy intake ranging from 66-67% among participants in the highest tertile of the meat-based modern pattern to 72% among participants in the lowest tertile of this pattern (**Tables 7.2 and 7.3**). Participants in the lowest tertile of the traditional pattern had significantly lower fiber consumption (23.5 g for women and 32.3 g for men) compared to participants in the highest tertile (33.9 g for women and 48.1 g for men). Fat as a proportion of total energy intake ranged from 16.0% among men in the lowest tertile of the meat-based modern pattern to 21.6% among women in the highest tertile of the meat-based modern pattern. There were small but significant differences in protein consumption as a percentage of total energy intake (11.6% to 12.6%).

In women, relative to tertile 1, higher traditional diet pattern tertile was associated with increased prevalence of abdominal obesity (Prevalence Ratio (PR) 1.24, 95% Confidence Interval (CI) 1.07, 1.43 for tertile 2; PR 1.19, 95% CI 1.02, 1.39 for tertile 3; p trend 0.02) (**Table 7.4**). In men, relative to tertile 1, higher starch-based modern pattern tertile was associated with increased prevalence of low HDL-

c (PR 1.17, 95% CI 1.01, 1.20 for tertile 2; PR 1.20, 95% CI 1.00, 1.44 for tertile 3; p trend 0.04) whereas higher traditional pattern tertile was marginally associated with reduced prevalence of low HDL-c (PR 0.88, 95% CI 0.76, 1.00 for tertile 2; PR 0.85, 95% CI 0.72, 1.00 for tertile 3; p trend 0.05) (**Table 7.5**). In men, higher traditional pattern tertile was also associated with decreased prevalence of overweight in models adjusting for age and total energy intake (Model 2 PR 0.94, 95% CI 0.75, 1.18 for tertile 2; PR 0.68, 95% CI 0.52, 0.88 for tertile 3; p trend 0.004) but there was no association after adjusting for physical inactivity, smoking, and multivitamin use in Model 3.

We did not find evidence of effect modification between dietary pattern tertile and urban residence on any CMD risk factors ($P > 0.1$ for all comparisons).

Discussion

We identified three dietary patterns in this population: a traditional pattern and two modern patterns (meat-based and starch-based), collectively explaining one-quarter of variation in the diet. Variation explained is slightly higher in our study relative to dietary pattern analyses in other Latin American populations where percent variance explained was reported (20.4% in a population of urban Mexican adults) (35). All three dietary patterns were characterized by high carbohydrate consumption (66-72% of total energy intake) with corn tortillas being the principal contributor, even among participants with high modern diet pattern scores. The traditional diet was associated with rural residence in both sexes and with lower SES, smoking, and physical activity in men. In fully adjusted models,

higher traditional diet tertile was associated with increased prevalence of abdominal obesity in women but marginally reduced prevalence of low HDL-c in men. Higher starch-based modern diet tertile was associated with increased prevalence of low HDL-c in men.

The nutrition transition is characterized by a shift from traditional diets comprised of whole foods including pulses and whole grains to a modern diet comprised of refined carbohydrates, high fat, and processed foods (3,36,37). In this Guatemalan population, we found evidence of two dominant modern dietary patterns – one related to energy-dense, nutrient-poor foods (meat-based) and a second with a mixture of processed less healthy foods and more healthy foods (starch-based). The meat-based modern pattern was characterized by consumption of salty snacks, processed and fried meats, soda, alcohol, candies, and transitional foods. While the meat-based modern pattern typifies the unhealthy modern diet associated with the nutrition transition, shifts to modern diets do not necessarily exclude additions of healthy foods. The starch-based modern pattern was characterized by both less healthy modern foods including refined grains and fried starches, but also healthy foods such as non-starchy vegetables and fruits, which are not typically consumed in large quantities in the traditional Guatemalan diet. Thus, the starch-based modern pattern is an example of a transitional diet that is not wholly unhealthy. Studies from China found improved dietary diversity with the nutrition transition through greater inclusion of fruits and vegetables, eggs, dairy, and meat (3) while data from the Food and Agriculture Organization national food

balance sheets in low- and middle-income countries (LMICs) show increased availability of processed foods and beverages (38).

The traditional pattern appeared to be associated with reduced CMD prevalence in men for low HDL-c but increased prevalence in women for abdominal obesity. Associations between traditional pattern in men and reduced prevalence of obesity were attenuated after controlling for lifestyle factors. Other studies in Latin American populations have not yielded consistent findings concerning traditional diets and CMD risk - possibly due to differences in fruit and vegetable consumption. The traditional rice and beans dietary pattern was associated with higher risk of metabolic syndrome and lower HDL-c in a cohort of Puerto Rican adults residing in Massachusetts (39). Among women of Mexican descent living in the U.S., the traditional Mexican diet was associated with lower C-reactive protein and insulin concentrations (21). Comparing these studies is complicated because the concept of "traditional" and "modern" diets varies across cultures and regions. The traditional rice and beans pattern in the study of Puerto Rican adults was characterized by oils, rice, beans/legumes, and vegetables (39). The traditional Mexican diet was characterized by high intake of fresh fruits and vegetables, whole grains, and legumes and low intakes of refined carbohydrates and sugars (21). Balanced diets high in fruits and vegetables, whole grains, and healthy fats have been associated with reduced obesity and diabetes (40,41). However, the traditional diet in Guatemala is characterized by consumption of corn tortillas, beans, and sweetened coffee with relatively low intake of vegetables, fruit, and healthy fats. Thus, the

traditional Guatemalan diet would not necessarily be expected to be associated with reduced CMD risk.

The study population's relatively homogenous diet with high reliance on carbohydrates (66-72% of total energy intake) could explain why we detected few associations between dietary patterns and CMD risk. Corn tortillas are the primary source of carbohydrates and constitute a large proportion of the diet - even among participants with high modern diet pattern scores. Corn tortillas are a good source of fiber (approximately 6 g per 2 oz serving) – likely explaining adequate fiber intakes for most participants relative to U.S. Dietary Reference Intakes (25g for women and 38g for men) (42)**.** While fiber is associated with reduced cardiovascular risk (43), NHLBI recommends consuming <60% of calories from carbohydrates to help prevent dyslipidemia while the Institutes of Medicine recommends no more than 65% (29,42). Minor differences in the macronutrient composition of the traditional and modern diet patterns were due to small substitutions of corn tortillas for wheat-based breads, crackers, and other refined carbohydrates. This "modernization" of the diet has been seen elsewhere in Guatemala (44,45). Because of the way in which they are metabolized, corn tortillas and refined grains have similar effects on blood glucose and triglycerides (46), potentially diminishing differences in CMD risk by dietary pattern.

The absolute intake of modern foods in this population was relatively low – even in the highest tertiles of the two modern diet patterns. For example, men and women in the highest tertile of the meat-based modern diet pattern consumed an

average of 19 g and 11 g of salty snack foods per day, respectively, or less than a typical single-serving bag of potato chips (about 28 g). However, there was high added sugar consumption. Sweets and powdered drink/sugar-sweetened beverage consumption accounted for approximately 17% of energy intake – nearly double the 10% limit for free sugars recommended by the World Health Organization to prevent chronic disease (17,47). While not a "modern" food, **c**offee, through its association with added sugars, could be an important driver of poor nutrition. In the highest tertile of the traditional pattern, women and men added an average of 4.8 tsp and 4.1 tsp of sugar, respectively, to their coffee. Sugar-sweetened beverages are positively associated with body weight (54), and added sugars from liquid sources are associated with higher fasting glucose, higher fasting insulin, and higher β-cell dysfunction and insulin resistance (48).

Sociodemographic and health behaviors tracked as expected with the dietary patterns; however, a few observations are worth highlighting here. First, both modern dietary patterns were associated with unhealthy behaviors (alcohol consumption and smoking with the meat-based modern pattern and physical inactivity with the starch-based modern pattern) in men but not women; however, lack of variation in smoking and physical inactivity in women limited our ability to detect any trends. Second, modern dietary patterns are thought to track with income in LMICs where higher income households benefit from increased access to market foods (49). In Guatemala, higher household annual expenditures were associated with increased likelihood of consuming a Western diet (9) and higher SES was associated with increased household-level calorie and processed food

intake (50). Conversely, we found that the meat-based modern pattern was associated with lower SES among women. These women might be purchasing cheap, processed foods rather than items typically associated with higher income such as dairy and unprocessed meats. Finally, at the beginning of the nutrition transition, dietary changes first appear in urban populations (2), likely due to differences in infrastructure, employment, income, and food access (49). We found that while the traditional pattern was more dominant in rural areas, neither of the modern diet patterns varied by urban residence, suggesting that while urban residents are less likely to eat a traditional diet, there is considerable variation in dietary patterns among urban dwellers.

There are several possible explanations for the apparent sex differences in the different physiological responses to dietary components, sex-specific nutrient-gene interactions (51), the influence of sex hormones on metabolic risk factors (triglycerides and HDL-c) (52), or differences in dietary intake not captured by our patterns. One limitation of dietary pattern analysis is the inability to detect the biologic effects of specific nutrients (53), thus our study cannot draw conclusions about the biologic mechanisms responsible for the sex differences. However, studies from European and Korean populations have shown that dietary patterns might influence CMD risk (BMI, metabolic syndrome, metabolic syndrome components) differently in men and women (54–56).

Strengths and Limitations

There are some limitations to the dietary data. FFQs can obscure food choice-differences within food groups; for example, low- versus high-fat dairy (13). We also may not have fully captured processed food consumption; however, the FFQ was designed to capture consumption of "transitional" foods, sweets, and sugar-sweetened beverages typically associated with modern diets. As Guatemala continues to develop, the rural/urban dichotomy is likely more nuanced than we present here. Nevertheless, because urban residence was based on residence location, neighborhood, and amenities, we expect it captures more than simple census-based classifications.

This study also has a number of strengths. The FFQ was developed for and validated in this population (20). It had open-ended sections for fruit and vegetable consumption to capture potential seasonality in the diet and included a number of "transitional" foods relevant to identifying modern diets. The study used clinically measured anthropometry and biomarkers of CMD risk. The dietary patterns were relatively stable when the study sample was randomly reduced from 1,428 to 717 participants in terms of percent variance explained (25.7%, collectively) and similarity of food groups and food group factor loadings (**Supplemental Table 9.13**). Even though the population is not nationally or provincially representative, results contribute to the very limited literature on dietary patterns in a Latin American country. Few studies report dietary patterns outside of high-income countries, yet populations in LMICs likely have different dietary patterns (57–61).

To our knowledge, this is the first paper to explore the association between PCA-derived dietary patterns and CMD risk in Central American adults.

Conclusion

Our findings suggest the emergence of two modern diet patterns in Guatemala – one of which was associated with increased prevalence of low HDL-c in men The traditional diet appeared to have a differential association with some CMD risk factors by sex. All three dietary patterns were characterized by carbohydrate consumption in excess of recommended levels – possibly explaining why we detected few associations between diet pattern and CMD risk factors. Future research will explore longitudinal diet and CMD risk in this population and quantify the contribution of other risk factors relative to diet in predicting CMD risk.

References for Chapter 7

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Table 7.1. Food group factor loadings and mean intake (g) by PCA-derived dietary pattern tertile for Guatemalan adults. INCAP Nutrition Supplementation Trial Longitudinal Cohort, 2002-2004 (n=747 women, n=681 men).

Food Groups	Meat-based Modern				Starch-based Modern				Traditional			
	Factor loading	T1[1] (g)	T2 (g)	T3 (g)	Factor loading	T1 (g)	T2 (g)	T3 (g)	Factor loading	T1 (g)	T2 (g)	T3 (g)
Women												
Corn tortilla									70	252.4	369.0	510.2
Refined grains					39	46.2	73.3	96.8				
Salty snacks	49	1.0	3.9	11.3								
Non-starchy vegetables					52	34.7	73.1	154.0				
Starchy vegetables					56	12.5	29.1	73.3				
Fried starches					44	18.4	35.6	73.7				
Fruits					39	126.2	202.6	325.9				
Processed meats	39	4.7	8.1	15.2								
Giblets					47	5.3	10.4	29.7				
Fried meats	51	8.7	17.2	30.8								
Dairy									-36	141.3	65.4	41.0
Beans									63	53.3	85.7	193.3
Oils/fats					37	5.2	9.1	15.9				
Sugar added to coffee									36	7.5	11.6	19.4
Sweets	48	1.2	3.1	8.6								
Alcohol	39	0.1	0.3	5.7								
Juice					45	153.4	316.5	438.4				
Soda	70	24.1	70.1	206.3								
Packaged soup					37	3.5	12.1	27.1				
Traditional Guatemalan foods[2]	36	25.9	39.7	69.2								

Transitional foods[3]	55	1.0	1.4	8.4					-36	8.0	1.9	0.8
Men												
Corn tortilla									70	406.3	547.0	728.5
Refined grains					39	61.7	88.4	125.4				
Salty snacks	49	3.0	9.4	19.2								
Non-starchy vegetables					52	56.4	92.0	186.7				
Starchy vegetables					56	22.1	36.1	67.1				
Fried starches					44	30.0	50.7	76.3				
Fruits					39	146.9	267.4	396.4				
Processed meats	39	7.0	15.0	25.5								
Giblets					47	6.5	13.6	27.3				
Fried meats	51	12.8	24.8	40.5								
Dairy									-36	99.6	56.2	50.8
Beans									63	78.7	111.4	240.3
Oils/fats					37	8.3	13.3	21.1				
Sugar added to coffee									36	7.5	11.4	16.5
Sweets	48	2.7	6.5	12.7								
Alcohol	39	12.5	55.1	124.1								
Juice					45	194.8	377.5	563.4				
Soda	70	79.3	206.5	404.7								
Packaged soup					37	6.8	9.9	23.6				
Traditional Guatemalan foods[2]	36	29.2	48.1	79.6								
Transitional foods[3]	55	2.3	5.3	20.8					-36	20.0	4.8	3.5

[1]Mean intake of food groups (g) across tertiles. [2]Tamales and tacos. [3]Pizza and hamburgers. Whole grains and nuts were excluded from analyses due to low (<10%) consumption.Abbreviations: T, tertile.

Table 7.2. Sociodemographic characteristics, clinical outcomes, and nutrient intake by PCA-derived dietary pattern tertile for Guatemalan women. INCAP Nutrition Supplementation Trial Longitudinal Cohort, 2002-2004 (n=747)

		Meat-based Modern				Starch-based Modern				Traditional			
	n	T1	T2	T3	*P*-trend[8]	T1	T2	T3	*P*-trend[8]	T1	T2	T3	*P*-trend[8]
Participants, n	747	252	247	248		252	247	248		251	246	250	
Mean factor score	747	-0.9 (0.2)	-0.5 (0.1)	0.3 (0.7)		-0.9 (0.2)	-0.2 (0.2)	1.0 (0.8)		-1.1 (0.4)	-0.3 (0.1)	0.6 (0.6)	
Age, y	747	33.4 (4.1)	32.6 (4.2)	32.8 (4.4)	0.1	32.7 (4.3)	32.7 (4.0)	33.3 (4.0)	0.1	32.0 (4.1)	33.0 (4.3)	32.7 (4.3)	0.5
SES tertile	747				0.001				0.6				0.6
Poorest		28.9	34.4	41.5		32.9	34.0	37.9		32.2	35.7	36.8	
Middle		23.8	29.7	22.9		27.7	25.9	20.9		27.4	24.8	22.4	
Richest		47.2	37.6	35.4		39.2	40.0	41.1		40.2	39.4	40.8	
Urban, %	747	28.5	29.9	29.8	0.7	25.4	30.7	32.2	0.09	44.6	26.4	17.2	<0.001
Alcohol use, %	692	20.4	30.2	23.5	0.4	26.2	26.4	21.5	0.2	17.5	31.1	25.4	0.05
Current smoking, %	692	0.8	1.3	3.0	0.06*	2.1	2.1	0.8	0.2*	1.7	1.3	2.1	0.7*
Low physical activity[1], %	747	97.2	97.9	95.5	0.2	98.0	95.1	97.5	0.7	96.4	98.3	96.0	0.7
Vitamin use, %	695	17.8	20.4	23.5	0.1	17.4	18.4	25.7	0.02	22.6	18.3	20.7	0.6
BMI (kg/m^2)	683	26.8 (4.8)	26.8 (4.4)	26.9 (5.0)	0.6	27.1 (5.1)	26.9 (4.5)	26.7 (4.6)	0.4	26.4 (4.8)	27.0 (4.5)	27.3 (4.9)	0.04
Overweight[2], %	683	59.3	61.7	65.6	0.1	60.7	63.4	62.3	0.7	58.5	64.2	63.7	0.2
Abdominal obesity[3], %	683	61.5	63.0	62.0	0.9	63.0	61.3	62.3	0.8	55.9	66.5	64.2	0.06
Elevated triglycerides[4], %	647	52.8	51.6	49.7	0.5	51.6	49.3	53.4	0.7	48.8	53.8	51.8	0.5
Low HDL-c[5]	647	82.6	87.2	87.2	0.1	84.8	85.3	86.6	0.5	82.4	86.5	87.8	0.1
Dysglycemia[6]	726	16.2	21.9	20.0	0.2	18.5	18.6	21.1	0.4	16.8	23.0	18.5	0.6
Metabolic Syndrome[7]	747	38.1	38.0	36.2	0.6	35.3	37.2	39.9	0.2	32.2	41.0	39.2	0.1
Dietary Intakes													
Total energy (kcal/day)	747	1864 (584)	2243 (582)	2646 (715)	<0.001	1813 (542)	2220 (559)	2722 (689)	<0.001	2010 (668)	2144 (591)	2593 (717)	<0.001
Carbohydrate (% of total energy)	747	71.7 (5.6)	68.9 (4.9)	65.8 (5.2)	<0.001	71.3 (5.3)	68.9 (5.2)	66.3 (5.7)	<0.001	66.1 (6.0)	69.2 (4.8)	71.3 (5.1)	<0.001

Protein (% of total energy)	747	12.1 (1.7)	12.1 (1.7)	12.4 (1.7)	0.05	12.0 (1.4)	12.2 (1.6)	12.6 (2.0)	<0.001	12.6 (2.1)	12.1 (1.5)	12.1 (1.3)	0.03
Fat (% of total energy)	747	16.0 (4.7)	18.7 (4.1)	21.6 (4.4)	<0.001	16.5 (4.9)	18.7 (4.3)	20.9 (4.6)	<0.001	21.2 (4.8)	18.6 (4.2)	16.4 (4.6)	<0.001
Cholesterol (mg/day)	747	194.3 (141.3)	274.6 (138.7)	367.8 (217.7)	<0.001	186.6 (135.8)	267.7 (159.0)	382.5 (196.5)	<0.001	246.4 (151.6)	284.0 (177.9)	305.2 (212.8)	0.002
Fiber (g/day)	747	25.3 (8.7)	28.3 (8.6)	30.8 (10.3)	<0.001	24.5 (8.0)	27.6 (8.8)	32.2 (10.0)	<0.001	23.5 (7.8)	26.8 (7.1)	33.9 (10.2)	<0.001
Iron (mg/day)	747	11.5 (5.3)	12.9 (4.5)	15.2 (5.3)	<0.001	9.5 (3.2)	12.7 (3.8)	17.4 (5.2)	<0.001	12.2 (4.9)	12.2 (4.9)	15.1 (5.5)	<0.001
Vitamin C		289.7 (217.5)	268.6 (186.4)	286.6 (183.7)	0.5	151.2 (105.6)	277.7 (146.3)	418.4 (218.8)	<0.001	291.9 (195.7)	258.2 (173.5)	294.5 (216.4)	0.7

Values presented are mean (SD) or percent. [1]Low physical activity defined as 24-h average physical activity <1.7 MET/hr. [2]Overweight defined as BMI ≥25 kg/m^2. [3]Abdominal obesity defined as waist circumference ≥88 cm. [4]Elevated triglycerides defined as ≥150 mg/dL or medication. [5]Low HDL-c defined as HDL-c <50 mg/dL. [6]Dysglycemia defined as impaired fasting glucose (fasting plasma glucose 100-125 mg/dL) or diabetes (self-report, fasting plasma glucose ≥126 mg/dL, and/or use of diabetes medication). [7]Metabolic syndrome defined according to 2005 NCEP ATP III diagnostic criteria based on presence ≥3 of the following: abdominal obesity (waist circumference ≥88 cm); fasting plasma glucose ≥100 mg/dL or medication; triglycerides ≥150 mg/dL or medication; HDL-c <50 mg/dL); blood pressure >130 mmHg systolic, >85 mmHg diastolic and/or medication use. [8]P for trend was calculated using Spearman correlation (continuous) and Mantel-Haenszel Chi-square tests (categorical variables). *Expected cell count <5. Abbreviations: BMI, body mass index; HDL-c, high density lipoprotein cholesterol; INCAP, Institute of Nutrition for Central America and Panama; National Cholesterol Education Program Adult Treatment Panel III, NCEP ATP III; PCA, principal component analysis; SES, socioeconomic status; T, tertile.

Table 7.3. Sociodemographic characteristics, clinical outcomes, and nutrient intake by PCA-derived dietary pattern tertile for Guatemalan men. INCAP Nutrition Supplementation Trial Longitudinal Cohort, 2002-2004 (n=681)

		Meat-based Modern				Starch-based Modern				Traditional			
	n	T1	T2	T3	*P*-trend[8]	T1	T2	T3	*P*-trend[8]	T1	T2	T3	*P*-trend[8]
Participants, n	681	227	228	226		226	228	227		227	227	227	
Mean factor score	681	-0.5 (0.3)	0.2 (0.2)	1.6 (0.9)		-0.9 (0.4)	-0.06 (0.2)	1.2 (0.7)		-0.7 (0.6)	0.2 (0.2)	1.4 (0.6)	
Age, y	681	33.1 (4.2)	32.7 (4.3)	31.7 (3.9)	0.002	32.5 (4.3)	32.5 (4.1)	32.5 (4.2)	0.9	32.8 (4.4)	32.2 (4.1)	32.5 (4.0)	0.7
SES tertile	681				0.7				0.6				0.05
Poorest		36.5	31.1	33.6		32.7	30.2	38.3		28.6	37.0	35.6	
Middle		26.8	30.7	30.0		33.6	27.6	26.4		29.9	26.4	31.2	
Richest		36.5	38.1	36.2		33.6	42.1	35.2		41.4	36.5	33.0	
Urban, %	680	26.9	20.6	19.9	0.07	22.1	21.5	23.7	0.6	29.5	21.6	16.3	<0.001
Alcohol use, %	552	65.2	77.6	82.5	<0.001	73.9	76.8	74.3	0.9	72.2	75.1	77.5	0.2
Current smoking, %	554	32.1	43.8	48.3	0.001	46.8	36.6	40.4	0.2	36.2	41.0	46.5	0.04
Low physical activity[1], %	681	61.2	56.5	53.5	0.09	49.1	58.7	63.4	0.002	66.9	56.8	47.5	<0.001
Vitamin use, %	554	24.2	21.6	26.0	0.6	15.9	24.0	32.2	<0.001	28.5	21.6	21.9	0.1
BMI (kg/m^2)	589	24.5 (3.6)	24.5 (3.5)	24.7 (3.6)	0.5	24.3 (3.5)	24.5 (3.5)	25.0 (3.6)	0.02	25.0 (3.8)	24.8 (3.5)	24.1 (3.3)	0.003
Overweight[2], %	589	38.9	41.6	42.3	0.4	38.2	37.5	47.1	0.07	46.7	42.6	34.1	0.01
Abdominal obesity[3], %	589	4.9	6.6	6.3	0.5	6.1	4.5	7.2	0.6	7.0	6.0	4.8	0.3
Elevated triglycerides[4], %	456	53.0	58.1	52.7	0.9	52.9	49.3	61.7	0.1	58.3	52.3	53.0	0.3
Low HDL-c[5], %	456	74.3	76.3	72.2	0.6	68.3	78.2	76.5	0.1	82.6	70.2	69.8	0.009
Dysglycemia[6], %	456	15.1	14.6	15.2	0.9	14.4	14.8	15.8	0.6	17.7	13.3	14.0	0.2
Metabolic syndrome[7], %	681	14.5	15.7	14.6	0.9	15.9	14.4	14.5	0.6	18.0	12.7	14.1	0.2
Dietary Intakes													
Total energy (kcal/day)	681	2626 (676)	3059 (760)	3627 (839)	<0.001	2578 (733)	3064 (690)	3666 (796)	<0.001	2775 (862)	2945 (717)	3590 (784)	<0.001

Carbohydrate (% of total energy)	681	72.2 (4.5)	69.6 (4.4)	67.3 (5.4)	<0.001	71.2 (5.1)	70.0 (4.4)	67.9 (5.5)	<0.001	67.5 (5.1)	70.2 (4.9)	71.3 (4.9)	<0.001
Protein (% of total energy)	681	11.6 (1.6)	11.9 (1.4)	12.1 (1.6)	<0.001	11.6 (1.4)	11.8 (1.4)	12.3 (1.7)	<0.001	12.1 (1.6)	11.6 (1.5)	11.9 (1.5)	0.4
Fat (% of total energy)	681	16.0 (3.9)	18.4 (3.7)	20.5 (4.5)	<0.001	17.1 (4.6)	18.1 (3.8)	19.7 (4.5)	<0.001	20.2 (4.2)	18.0 (4.0)	16.6 (4.4)	<0.001
Cholesterol (mg/day)	681	280.9 (157.6)	396.8 (201.6)	501.6 (236.2)	<0.001	294.6 (174.3)	383.8 (195.6)	500.0 (236.0)	<0.001	365.9 (204.5)	361.5 (199.8)	451.3 (242.3)	<0.001
Fiber (g/day)	681	36.2 (11.6)	39.1 (13.0)	43.0 (13.1)	<0.001	33.5 (10.1)	39.3 (11.4)	45.4 (13.9)	<0.001	32.3 (10.6)	37.9 (9.8)	48.1 (12.7)	<0.001
Iron (mg/day)	681	14.6 (5.2)	17.1 (6.3)	19.8 (6.3)	<0.001	12.9 (4.7)	16.7 (4.3)	21.8 (6.3)	<0.001	15.7 (6.0)	15.7 (5.7)	20.0 (6.3)	<0.001
Vitamin C (mg/day)	681	352.5 (289.7)	362.2 (266.0)	352.0 (232.6)	0.6	191.2 (125.6)	351.2 (177.3)	523.7 (325.9)	<0.001	327.5 (212.1)	328.2 (215.0)	411.0 (336.2)	0.01

Values presented are mean (SD) or percent. [1]Low physical activity defined as 24-h average physical activity <1.7 MET/hr. [2]Overweight defined as BMI ≥25 kg/m^2. [3]Abdominal obesity defined as waist circumference ≥102 cm. [4]Elevated triglycerides defined as ≥150 mg/dL or medication. [5]Low HDL-c defined as HDL-c <40 mg/dL. [6]Dysglycemia defined as impaired fasting glucose (fasting plasma glucose 100-125 mg/dL) or diabetes (self-report, fasting plasma glucose ≥126 mg/dL, and/or use of diabetes medication). [7]Metabolic syndrome defined according to 2005 NCEP ATP III diagnostic criteria based on presence ≥3 of the following: abdominal obesity (waist circumference ≥88 cm); fasting plasma glucose ≥100 mg/dL or medication; triglycerides ≥150 mg/dL or medication; HDL-c <50 mg/dL); blood pressure >130 mmHg systolic, >85 mmHg diastolic and/or medication use. [8]P for trend was calculated using Spearman correlation (continuous) and Mantel- Haenszel Chi-square tests (categorical variables). *Expected cell count <5. Abbreviations: BMI, body mass index; HDL-c, high density lipoprotein cholesterol; INCAP, Institute of Nutrition for Central America and Panama; National Cholesterol Education Program Adult Treatment Panel III, NCEP ATP III; PCA, principal component analysis; SES, socioeconomic status; T, tertile.

Table 7.4. Log binomial models predicting cardio-metabolic risk by PCA-derived dietary pattern tertile for Guatemalan women. INCAP Nutrition Supplementation Trial Longitudinal Cohort, 2002-2004. (n=747)

	Meat-based Modern			Starch-based Modern			Traditional		
	T2 PR (95% CI)	T3 PR (95% CI)	P-trend	T2 PR (95% CI)	T3 PR (95% CI)	P-trend	T2 PR (95% CI)	T3 PR (95% CI)	P-trend
Overweight[1]									
Model 1	1.05 (0.90, 1.21)	1.10 (0,96, 1.27)	0.1	1.03 (0.89, 1.19)	1.00 (0.87, 1.16)	0.8	1.09 (0.94, 1.26)	1.07 (0.92, 1.23)	0.3
Model 2	1.03 (0.88, 1.20)	1.07 (0.92, 1.25)	0.3	0.98 (0.84, 1.14)	0.92 (0.77, 1.10)	0.3	1.08 (0.93, 1.25)	1.04 (0.89, 1.21)	0.5
Model 3	1.03 (0.89, 1.20)	1.08 (0.92, 1.25)	0.3	0.97 (0.84, 1.12)	0.89 (0.76, 1.05)	0.1	1.11 (0.96, 1.28)	1.11 (0.96, 1.30)	0.1
Abdominal obesity[2]									
Model 1	1.02 (0.88, 1.17)	0.97 (0.84, 1.12)	0.9	0.96 (0.83, 1.10)	0.97 (0.84, 1.12)	0.7	1.18 (1.02, 1.37)	1.14 (0.98, 1.32)	0.07
Model 2	0.99 (0.85, 1.14)	0.95 (0.81, 1.12)	0.5	0.91 (0.78, 1.06)	0.88 (0.74, 1.05)	0.1	1.18 (1.07, 1.37)	1.11 (0.95, 1.30)	0.1
Model 3	1.00 (0.87, 1.16)	0.97 (0.83, 1.13)	0.7	0.90 (0.78, 1.05)	0.85 (0.72, 1.00)	0.06	1.24 (1.07, 1.43)	1.19 (1.02, 1.39)	0.02
Elevated triglycerides[3]									
Model 1	0.97 (0.81, 1.17)	0.94 (0.78, 1.13)	0.5	0.97 (0.80, 1.17)	1.04 (0.86, 1.25)	0.6	1.09 (0.91, 1.32)	1.04 (0.86, 1.25)	0.1
Model 2	0.96 (0.80, 1.16)	0.92 (0.75, 1.13)	0.4	0.97 (0.80, 1.19)	1.05 (0.85, 1.30)	0.6	1.09 (0.91, 1.32)	1.04 (0.85, 1.27)	0.6
Model 3	0.98 (0.81, 1.19)	0.94 (0.76, 1.15)	0.5	0.99 (0.81, 1.20)	1.08 (0.87, 1.34)	0.4	1.06 (0.87, 1.19)	1.01 (0.82, 1.24)	0.8
Low HDL-c[4]									
Model 1	1.05 (0.99, 1.12)	0.99 (0.90, 1.90)	0.8	0.99 (0.92, 1.07)	1.02 (0.94, 1.10)	0.6	1.02 (0.94, 1.11)	1.05 (0.98, 1.14)	0.1
Model 2	1.08 (1.00, 1.17)	1.08 (0.99, 1.19)	0.07	1.00 (0.92, 1.08)	1.03 (0.94, 1.13)	0.4	1.03 (0.95, 1.11)	1.06 (0.98, 1.14)	0.1
Model 3	1.09 (1.01, 1.18)	1.09 (0.99, 1.20)	0.06	1.00 (0.92, 1.08)	1.03 (0.93, 1.14)	0.5	1.04 (0.94, 1.11)	1.06 (0.98, 1.15)	0.1

Dysglycemia[5]									
Model 1	1.46	1.28	0.2	1.01	1.07	0.7	1.28	1.03	0.8
	(1.00, 2.12)	(0.86, 1.89)		(0.69, 1.47)	(0.74, 1.54)		(0.89, 1.80)	(0.70, 1.51)	
Model 2	1.48	1.30	0.2	1.00	1.04	0.8	1.27	1.00	0.9
	(1.00, 2.17)	(0.85, 2.00)		(0.68, 1.47)	(0.68, 1.60)		(0.88, 1.83)	(0.66, 1.50)	
Model 3	1.46	1.26	0.2	0.99	1.04	0.8	1.29	1.03	0.8
	(0.99, 2.14)	(0.82, 1.94)		(0.67, 1.45)	(0.68, 1.59)		(0.89, 1.87)	(0.68, 1.56)	
Metabolic syndrome[6]									
Model 1	1.00	0.97	0.8	1.01	1.08	0.4	1.23	1.15	0.2
	(0.80, 1.24)	(0.78, 1.21)		(0.81, 1.27)	(0.87, 1.34)		(0.98, 1.55)	(0.91, 1.45)	
Model 2	0.98	0.94	0.6	1.01	1.07	0.5	1.23	1.14	0.2
	(0.78, 1.22)	(0.73, 1.20)		(0.80, 1.28)	(0.83, 1.38)		(0.98, 1.54)	(0.90, 1.46)	
Model 3	1.00	0.95	0.6	1.00	1.04	0.7	1.27	1.18	0.1
	(0.80, 1.25)	(0.74, 1.21)		(0.79, 1.26)	(0.81, 1.35)		(1.01, 1.59)	(0.93, 1.51)	

Values presented are prevalence ratios and 95% confidence intervals. Tertile 1 is the reference group. [1]Overweight defined as BMI ≥25 kg/m^2. [2]Abdominal obesity defined as waist circumference ≥88 cm. [3]Elevated triglycerides defined as ≥150 mg/dL or medication. [4]Low HDL-c defined as HDL-c <50 mg/dL. [5]Dysglycemia defined as impaired fasting glucose (fasting plasma glucose 100-125 mg/dL) or diabetes (self-report, fasting plasma glucose ≥126 mg/dL, and/or use of diabetes medication). [6]Metabolic syndrome defined according to 2005 NCEP ATP III diagnostic criteria based on presence ≥3 of the following: abdominal obesity (waist circumference ≥88 cm); fasting plasma glucose ≥100 mg/dL or medication; triglycerides ≥150 mg/dL or medication; HDL-c <50 mg/dL); blood pressure >130 mmHg systolic, >85 mmHg diastolic and/or medication use. Abbreviations: BMI, body mass index; CI, confidence interval; HDL-c. high density lipoprotein cholesterol; INCAP, Institute of Nutrition for Central America and Panama; National Cholesterol Education Program Adult Treatment Panel III, NCEP ATP III; PCA, principal component analysis; RR, risk ratio; SES, socioeconomic status; T, tertile.

Model 1 = dietary pattern tertile + age

Model 2 = model 1 + kcal/day

Model 3 = model 2 + SES + urban residence + multivitamin use

Table 7.5. Log binomial models predicting cardio-metabolic risk by PCA-derived dietary pattern tertile for Guatemalan men. INCAP Nutrition Supplementation Trial Longitudinal Cohort, 2002-2004. (n=681)

	Meat-based Modern			Starch-based Modern			Traditional		
	T2 PR (95% CI)	T3 PR (95% CI)	P-trend	T2 PR (95% CI)	T3 PR (95% CI)	P-trend	T2 PR (95% CI)	T3 PR (95% CI)	P-trend
Overweight[1]									
Model 1	1.07 (0.84, 1.37)	1.15 (0.90, 1.47)	0.2	1.03 (0.80, 1.32)	1.24 (0.98, 1,57)	0.06	0.96 (0.76, 1.20)	0.78 (0.61, 0.99)	0.04
Model 2	1,05 (0.82, 1.34)	1.07 (0.82, 1.41)	0.5	1.01 (0.78, 1.31)	1.18 (0.89, 1.56)	0.2	0.94 (0.75, 1.18)	0.68 (0.52, 0.88)	0.004
Model 3	1.08 (0.87, 1.33)	1.15 (0.91, 1.45)	0.9	0.91 (0.72, 1.16)	0.98 (0.75, 1.27)	0.9	0.98 (0.80, 1.19)	0.84 (0.67, 1.05)	0.9
Abdominal obesity[2]									
Model 1	1.35 (0.56, 3.24)	1.53 (0.63, 3.71)	0.6	0.74 (0.30, 1.81)	1.15 (0.50, 2.62)	0.6	0.94 (0.41, 2.16)	0.64 (0.26, 1.54)	0.5
Model 2	1.25 (0.55, 2.84)	1.26 (0.49, 3.24)	0.6	0.68 (0.29, 1.61)	0.92 (0.39, 2.17)	0.8	0.95 (0.76, 1.20)	1.13 (0.90, 1.42)	0.2
Model 3	1.36 (0.53, 3.45)	1.75 (0.60, 5.15)	0.5	0.58 (0.22, 1.54)	0.56 (0.19, 1.61)	0.4	1.19 (0.49, 2.84)	0.61 (0.21, 1.73)	0.4
Elevated triglycerides[3]									
Model 1	1.11 (0.91, 1.36)	1.03 (0.83, 1.29)	0.7	0.96 (0.77, 1.20)	1.16 (0.95, 1.42)	0.1	0.91 (0.74, 1.11)	0.92 (0.75, 1.,13)	0.4
Model 2	1.10 (0.89, 1.34)	0.97 (0.76, 1.23)	0.8	0.95 (0.76, 1.20)	1.13 (0.90, 1.42)	0.1	0.89 (0.72, 1.09)	0.85 (0.68, 1.06)	0.1
Model 3	1.12 (0.91, 1.37)	1.03 (0.81, 1.31)	0.7	0.92 (0.73, 1.16)	1.05 (0.83, 1.33)	0.6	0.88 (0.74, 1.11)	0.79 (0.62, 1.01)	0.06
Low HDL-c[4]									
Model 1	1.02 (0.89, 1.16)	0.96 (0.83, 1.11)	0.6	1.15 (1.00, 1.32)	1.11 (0.96, 1.28)	0.1	0.86 (0.76, 0.98)	0.85 (0.74, 0.97)	0.01
Model 2	1.03 (0.90, 1.17)	0.99 (0.84, 1.17)	0.9	1.18 (1.03, 1.37)	1.21 (1.01, 1.44)	0.03	0.85 (0.74, 0.98)	0.83 (0.71, 0.97)	0.02
Model 3	1.07 (0.94, 1.23)	1.02 (0.86, 1.20)	0.7	1.17 (1.01, 1.35)	1.20 (1.00, 1.44)	0.04	0.88 (0.76, 1.00)	0.85 (0.72, 1.00)	0.05

Dysglycemia[5]									
	Model 1	0.93 (0.57, 1.49)	1.08 (0.68, 1.72)	0.7	0.95 (0.59, 1.54)	1.10 (0.69, 1.75)	0.6	0.84 (0.52, 1.34)	0.84 (0.53, 1.33)	0.4
	Model 2									
	Model 3	0.98 (0.60, 1.57)	1.19 (0.70, 2.02)	0.5	1.03 (0.62, 1.70)	1.13 (0.65, 1.98)	0.6	0.83 (0.52, 1.33)	0.79 (0.47, 1.33)	0.3
Metabolic syndrome[6]										
	Model 1	1.21 (0.78, 1.88)	1.17 (0.74, 1.84)	0.4	0.88 (0.56, 1.36)	0.94 (0.61, 1.46)	0.8	0.77 (0.49, 1.19)	0.76 (0.49, 1.17)	0.2
	Model 2	0.94 (0.58, 1.53)	1.14 (0.67, 1.93)	0.6	0.98 (0.60, 1.61)	1.17 (0.69, 1.98)	0.5	0.84 (0.52, 1.34)	0.83 (0.50, 1.38)	0.4
	Model 3	1.35 (0.88, 2.06)	1.48 (0.89, 2,.46)	0.1	0.89 (0.56, 1.41)	0.88 (0.53, 1.47)	0.6	0.79 (0.51, 1.21)	0.82 (0.51, 1.32)	0.4

Values presented are prevalence ratios and 95% confidence intervals. Tertile 1 is the reference. [1]Overweight defined as BMI ≥25 kg/m^2. [2]Abdominal obesity defined as waist circumference ≥102 cm. [3]Elevated triglycerides defined as ≥150 mg/dL or medication. [4]Low HDL-c defined as HDL-c <40 mg/dL.[5]Dysglycemia defined as impaired fasting glucose (fasting plasma glucose 100-125 mg/dL) or diabetes (self-report, fasting plasma glucose ≥126 mg/dL, and/or use of diabetes medication). [6]Metabolic syndrome defined according to 2005 NCEP ATP III diagnostic criteria based on presence ≥3 of the following: abdominal obesity (waist circumference ≥88 cm); fasting plasma glucose ≥100 mg/dL or medication; triglycerides ≥150 mg/dL or medication; HDL-c <50 mg/dL); blood pressure >130 mmHg systolic, >85 mmHg diastolic and/or medication use. Abbreviations: BMI, body mass index; CI, confidence interval; HDL-c. high density lipoprotein cholesterol; INCAP, Institute of Nutrition for Central America and Panama; National Cholesterol Education Program Adult Treatment Panel III, NCEP ATP III; PCA, principal component analysis; RR, risk ratio; SES, socioeconomic status; T, tertile.

Model 1 = dietary pattern tertile + age

Model 2 = model 1 + kcal/day

Model 3 = model 2 + SES + urban residence + multivitamin use + smoking status (current vs. other) + low physical activity physical activity

Chapter 8 – – Summary, Discussion, and Conclusion

The table below (**Table 8.1**) is a summary of the key findings of this dissertation, in relation to the stated aims of the research.

Table 8.1. Summary of Key Findings in Relation to Specific Aims

Specific Aims	Key Findings
Specific Aim 1 To investigate BMI trajectories from birth/early childhood through mid-adulthood and assess early life factors associated with these trajectories, including childhood household socioeconomic status and nutrition supplementation during the first 1,000 days; and	Chapter 4 • We identified two BMI latent classes in women (low (57%) and high (43%)) and three classes in men (low (38%), medium (47%), and high (15%)). • Nutrition supplementation during the first 1,000 days was not associated with BMI latent class membership. • Higher childhood household SES was associated with increased odds of high BMI latent class membership in both men and women for highest relative to lowest tertile households – the pathways through which this operates still need to be explored.
To investigate an association between BMI trajectories from birth/early childhood to mid-adulthood with markers of CMD risk including body composition, fasting blood glucose, blood lipids, blood pressure, and metabolic syndrome.	Chapter 5 • Abdominal obesity by waist—height ratio, low HDL-c, and elevated triglycerides were the most prevalent CMD risk factors**.** • BMI trajectory class was not associated with most CMD risk factors after controlling for current BMI. • Among men, relative to low BMI latent class, high/medium BMI latent class was negatively associated with metabolic syndrome and dysglycemia in fully adjusted models. • The role of early life growth on most adult CMD risk factors was mediated by adult BMI –

Specific Aims	Key Findings
	highlighting the need to establish and maintain healthy body weight over the life course.
Specific Aim 2 To describe changes in diet over time and the extent to which changes are consistent with nutrition transition; and	Chapter 6 • We identified two dietary patterns in each study wave: a Western pattern and a traditional pattern. • In 2002-04 and in 2015-16, the two dietary patterns were largely similar in terms of food groups and food group factor loadings. In 2002-04, the top contributors to diet as a percentage of total energy were corn tortillas, refined grains, and SSB. In 2015-16, participants consumed fewer corn tortillas and traditional Guatemalan foods. • Participants' diets were diversified through small but significant increases in baked/roasted meat and fish, fried/processed meats, and vegetables. SSB had the largest change of any food group with intake nearly doubling from 2002/04 to 2015/16. • The macronutrient composition of the diet changed significantly over the 12y period: carbohydrate as a percentage of total energy decreased while fat and protein increased. • While diets remained largely reliant on starches and simple sugars over time, there was evidence of diet diversification characterized by decreased consumption of corn tortillas and traditional foods and by increased consumption of both healthy and less healthy food groups.
To characterize dietary patterns and to examine the association between dietary pattern and CMD risk.	Chapter 7 • We derived 3 dietary patterns (traditional, meat-based modern, and starch-based modern). • Dietary patterns were not associated with most CMD risk factors; however, higher starch-based modern tertiles were associated with increased prevalence of low high-density lipoprotein cholesterol (HDL-c) in men.

Specific Aims	Key Findings
	• Higher traditional tertile was associated with increased prevalence of abdominal obesity in women but marginally significant reduced prevalence of low HDL-c in men. • Our findings suggest the presence of two modern dietary patterns in Guatemala – one of which was associated with increased prevalence of low HDL-c in men.

Discussion of Main Findings and Public Health Implications

In this section, we discuss the main findings of the dissertation, public health implications, and future areas of research.

Cardio-metabolic disease risk

NCDs represent a growing proportion of disease burden in Latin America (1). In the coming decades, the NCD burden is projected to increase due to a rise in risk factors. Obesity, hypertension, and dyslipidemia are the most widespread risk factors in the region (2). Dyslipidemia is prevalent– notably, low levels of HDL and high triglycerides (3,4). Despite being the main cause of mortality, there is a paucity of data on NCDs in Guatemala (5). Several multi-country studies have explored NCDs in Latin America; however, Guatemala was only included in one, the INTERHEART STUDY (6). Thus, this dissertation adds to the limited evidence base on CMD in Guatemala.

Despite the relatively young age of this cohort, the rural INCAP participants had a high burden of CMD risk– particularly the women. The most prevalent risk

factors in 2015-16 were abdominal obesity by WHtR (99% of women and 87% of men), low HDL-c (91% of women and 75% of men), and elevated triglycerides (78% of women and 72% of men). Prevalence of these conditions in our population were considerably higher than estimates from the Latin American Consortium Studies in Obesity (LASO) which found prevalences of 36%, 53%, and 27% for abdominal obesity, low HDL-c, and elevated triglycerides, respectively (7). Women in our study also had a high prevalence of MetS (81% of vs. 40% in men). Furthermore, less than half of the women and less than two-thirds of men in the cohort were normoglycemic. Current BMI was highly associated with all of the CMD risk factors we analyzed, suggesting elevated levels of adiposity could be driving the CMD burden in this rural population. Given that 40% of NCD deaths in Guatemala are among people under 60y old, the high burden of chronic disease in this aging population is alarming (8).

If past trends are indicative of future trends, the CMD burden will likely continue to rise in this population. From 1997 to 2004, 42% of men and 56% of women gained more than five kilograms (9). Triglycerides, total cholesterol, glucose, and prevalence of the metabolic syndrome also increased during the same time period (9). In analyses exploring change in CMD risk from 2002-2016 among rural participants in the INCAP cohort, there were large relative and absolute 12y increases in CMD risk factor prevalence – especially for diabetes (from 2.8% to 17.5% in women and from 1.6% to 7.6% in men), metabolic syndrome (from 34.7% to 80.6% in women and from 13.2% to 40.0% in men), abdominal obesity in men (from 5.3% to 16.6%) and pre-diabetes in women (from 17.2% to 33.0%).

Projections for the Latin American region also predict increases in NCDs in the coming years – and are even expected to double in the next 40 years in countries like Mexico (10). In 2015, 29.6 million people in central and south America had diabetes, and the number is expected to increase to 48.8 million by 2040 (11). Changing disease patterns are a consequence of demographic, social, and economic shifts (12). This dissertation research examined the roles of life-course BMI trajectories and adult diet on CMD risk, and our conclusions, public health implications, and future areas of research are discussed with greater depth throughout this discussion chapter.

High levels of CMD will be costly for the health care system but also individual households and the economy as a whole. In LMICs like Guatemala, CMD affects people during productive working years, reducing economic contributions to both households and society (3). According to the World Bank, the Latin America and the Caribbean region will lose US$8 billion to chronic diseases by 2015 (13). NCDs also threaten to widen existing economic and health equity gaps both within and across countries because vulnerable people and households may be less able to weather stressors like disruptions to income or increased healthcare-related expenditure (14). Given that 54% of the population lives below the national poverty line, and 14% live on less than $1.25 per day, NCD could have a devastating effect on vulnerable populations in Guatemala (15). In addition to the clear toll on human health and well-being, there is also a strong economic case to make chronic disease prevention and management a national health care priority.

Data gaps could be contributing to limited action on NCDs. National-level surveillance data on overweight/obesity and obesity-related outcomes (e.g. diabetes, hypertension) in both genders at all ages will help guide evidence-based healthcare decision-making. Much of the existing data in Guatemala is from children under 5y and women of reproductive age; however, population subgroups such as men, adolescents, and older adults in should be included in existing surveys. Moreover, routine surveillance of BMI and CMD risk factors should be built into national health programming. Consolidating existing information and improving routine data collection could help Guatemala justify prioritizing NCD prevention and treatment while also creating an evidence base for program development. Despite causing 60% of DALYs, NCDs receive relatively little global health funding. In 2015, NCDs received <2% of international development assistance allocated to health while 30% was allocated to HIV/AIDS, which accounted for 3% of global DALYs (16).

NCDs receive relatively little attention in many national health plans in LMICs where health systems developed to attend to infectious disease and maternal and child undernutrition. These systems must be re-designed to contend with the dual burden of disease (17). While NCD prevention is optimal, Guatemala should also invest in management and treatment to improve the health and quality of life of those living with chronic diseases. To our knowledge, routine metabolic screenings are not carried out at health posts or health centers. People learn about their disease status either by chance or after seeking care for disease complications (Ramirez-Zea, personal communication, 2017). In our study population, half of participants

with diabetes were newly diagnosed at the time of the clinical exam, and 85% of participants with elevated triglycerides were not aware of their condition. Strategies for obesity prevention and management in Guatemala are discussed later in this chapter.

Early life nutrition, life-course BMI trajectories, and cardio-metabolic disease risk

In Chapter 4, we explored the timing and rate of BMI gain from infancy through mid-adulthood using LCGA. To our knowledge, we are the first study to do so in a LMIC population. In non-latent class type growth modeling, a single curve is used to describe average growth patterns (18); however, LCGA can identify distinct growth patterns in cohort sub-groups not readily identifiable using other modeling techniques (19).

We identified two BMI latent classes in women (low and high) and three classes in men (low, medium, and high). Given that the "Developmental Origins of Health and Disease" hypothesizes early life undernutrition combined with an obesogenic environment outside the womb predisposes an individual to obesity (20), we had expected children with lower BMI in early life to exhibit higher BMI later in life compared to the children with relatively higher BMI in early life. However, the trajectories separated early in infancy and did not overlap over the life-course. Our findings are consistent with those from studies in high-income countries which show BMI tracking from childhood into adulthood (21). This finding highlights the need to establish optimal growth during the first 1,000 days.

Early separation of the latent classes and lack of overlapping trajectories over the life-course suggest that pre-conceptional or early life factors were important in establishing BMI trajectories. The first 1,000 days after conception is a critical window to prevent stunting and to achieve optimal growth for health and cognitive development (22,23). Conversely, in high income countries, rapid weight gain during the first two years increased the risk of childhood overweight and adiposity (24,25). Despite this potential conflict between growth promotion and obesity risk, there is a paucity of data to assess the long term effects of child nutrition interventions on BMI gain in LMICs.

In Chapter 4, we concluded that exposure to *Atole* during the first 1,000 days was not associated with BMI latent class. Our findings were consistent with those from other studies using INCAP cohort data. In the original trial, *Atole* exposure before age 3y was associated positively with linear growth and weight, negatively with fat-folds, and had no association with weight-for-height (26,27). Importantly, nutrition supplementation did not influence physical growth rates after age 3y (28) – highlighting how critical the first 1,000 days are to prevent stunting. Differences in body composition persisted at the 1988-89 follow-up study; in adolescence, participants exposed to *Atole* during the first 3y were taller, weighed more, and had more lean body mass than those exposed to *Fresco* (23). Thus, *Atole* supplementation during the first 1,000 days seems to have improved linear growth in childhood without increasing risk of an overweight/obese trajectory.

Our findings suggest that supplemental feeding programs in the critical developmental window from conception to age 2y are unlikely to adversely affect BMI trajectories. Nevertheless, given the origins of the cohort, these findings may not be generalizable to Guatemala today or to other LMICs. In 1967, the study villages had high levels of malnutrition and of respiratory and gastrointestinal infections (28). No homes were equipped with electricity, < 10% of families had a source of water in the home, few houses had a latrine, and homes had adobe walls and dirt floors (29). In other words, the trial originated prior to the spread of factors consistent with the nutrition transition – which was first documented in LMICs beginning in the 1990s (12). Many countries with persistent burdens of chronic undernutrition are also facing increasingly obesogenic environments. Thus, the potential impact of early life factors on the NCD burden in LMICs could be underestimated where the magnitude of "mismatch" between early life undernutrition and later life over-nutrition is larger than observed in the INCAP trial.

The contextual differences (i.e. underlying nutritional deficits, supplement type) between the original INCAP trial and Latin American countries today could help explain why some nutrition support programs in the region have been associated with excessive weight gain in children. A nutrition supplementation program for pre-school children in Chile was associated with a 50% increase in the number of overweight children and a threefold increase in the number of obese children during the first year of the program (30,31). This national program targeted all children under 6y old – a population with a mean HAZ score close to

zero, meaning children who were not at high risk for nutrition deficiencies received supplementation. Thus, the possible effect of nutrition supplementation on later obesity risk is likely dependent on the underlying nutritional status of the target population. Yet, only 25% of food programs in Latin America used anthropometry to target beneficiaries (32), and only 5-6% of supplementary feeding program beneficiaries in the region were truly underweight (33).

Future actions to combat undernutrition should address food quality rather than food quantity. Some interventions, like those providing food baskets of energy-dense, processed foods, have possibly conflated the "hidden hunger" of micronutrient malnutrition with caloric deficits. For example, the food basket in Mexico's *Oportunidades* program, which contained cookies, powdered chocolate, and whole milk among other items, was associated with excess energy intake (34). Providing energy-dense foods to children, even those who may have stunting and/or low weight-for-age, will likely influence weight gain to exceed normal reference values without appreciable gains in length/height (32,33,35). Ensuring that programs address underlying nutrition deficiencies and focus on healthy growth (appropriate weight gain and linear growth), especially in stunted populations, could help prevent inadvertent increases in child obesity. In a region where compensatory growth is promoted and an estimated 20% of the population receives food assistance (31), understanding how nutrition supplementation is associated with BMI gain is important in Latin America's landscape of stunting and obesity.

Nearly half of Guatemala's population is under 18 years old, so child nutrition plays a central role in the country's current and future disease burden (36). Future research should evaluate interventions to increase length-for-age without disproportionately increasing weight-for-age or weight-for-height. A next step is better understanding of the biological mechanisms underlying the relationships between early life nutrition exposures and adult disease, possibly through high-dimensional data like metabolomics and epigenetics. Beyond its potential role in adult disease risk, improved child nutrition could help stop the inter-generational cycle of malnutrition and poverty (37). Thus, improving child growth in chronically undernourished populations could have sustained long-term benefits.

In addition to nutrition supplementation during the first 1,000 days, we also explored the role of childhood household SES on BMI trajectory in Chapter 4. Little is known about how childhood SES influences adult obesity risk in LMICs. Existing studies of SES and obesity in LMICs have focused on adults (38,39); however, SES likely influences BMI in infancy and early childhood. For adults, high SES is positively associated with obesity in low income countries (40); however, in children, prevalence of overweight (BMI-for-age Z > 2 SD) did not differ by household SES in most LMICs – possibly due to low overall burden of childhood overweight/obesity in many low income countries (41). We found that higher childhood household SES was associated with increased odds of high BMI latent class membership relative to the poorest households. It is possible that we were able to detect a difference by SES tertile because the BMI latent classes encompass a continuum of BMI growth over several decades while Black *et al.* used a

dichotomous measure of childhood overweight in a small age range (children under 5y) (41).

The mechanisms by which childhood SES might influence BMI gain are not well understood. In contrast to our finding where childhood household SES (ascertained in 1967) was positively associated with higher BMI trajectory, children in lower income households may be increasingly exposed to high-calorie diets associated with the nutrition transition. Major dietary shifts have occurred in LMICs in the absence of economic development or increases in income (12). For example, there is evidence that increased consumption of vegetable-source fats is nearly independent of income (42,43). Conversely, socioeconomically disadvantaged households may exhibit different coping strategies (e.g. reducing food intake vs. seeking out cheap, energy-dense foods) to those with greater income (44). For example, during the economic crisis in 2007-2008, average energy intake decreased by 8% across seven countries in Latin America, with the largest decreases seen among poor households (45). In a related study in Guatemala, income-nutrient elasticities in poorer households were four times higher than those in the richest households (46).

While our study found a positive association between higher household SES and higher BMI trajectory class, the relationship between household SES during childhood and BMI gain over the life-course may be different than it was during the 1960-70s. Guatemala was classified as a low income country when childhood household SES was determined during the original trial, but given that Guatemala is

now classified as lower-middle income, the relationship between childhood SES and BMI gain might have changed (15). Studies have shown that the burden of obesity often shifts from the wealthy to the poor as countries move from low to middle income (47,48). To inform obesity prevention in LMICs, more research is needed to understand the mechanisms through which SES influences risk.

Moreover, in contexts where low SES is positively associated with both stunting and obesity, childhood household SES could have serious implications for CMD risk later in life. A 2007 study of pre-school children from rural Mexico found that low SES was positively associated with co-occurrence of stunting and overweight (49). Given the steep income gradient in under-five stunting prevalence in Guatemala (ranging from 65.9% in the lowest quintile of household wealth to 17.4% in the highest) combined with rising overweight (50), understanding how childhood household SES influences child growth is essential for informing child health and nutrition policies.

Beyond identifying distinct growth patterns across the life-course and their early life predictors, this dissertation research also aimed to explore distal health consequences of these trajectories. Existing studies of life course BMI trajectories and CMD risk have focused on HIC populations (51–54); however, these findings are likely not generalizable to LMIC populations owing to high burden of early life undernutrition. Studies from LMIC populations have explored the role of smaller segments of the life course, for example, adolescence, with CMD outcomes (53,55,56) and were thus not also able to capture the continuity of weight gain

through middle age. Despite its potential utility in identifying groups for targeted obesity and CMD prevention, there is little data on the long term consequences of chronic early life undernutrition in countries undergoing nutrition transition. This dissertation research addresses this important gap in the literature.

In Chapter 5, high/medium BMI latent class was negatively associated with MetS and with dysglycemia among men only. It is not clear why higher BMI trajectory from birth or early childhood through mid-adulthood was independently associated with MetS and dysglycemia in men after controlling for current BMI. In the context of a LMIC population in the 1960-70s when childhood undernutrition was prevalent, we hypothesize that higher BMI in childhood might represent growth that is closer to international growth reference standard averages rather than excessive adiposity. Among men in the higher BMI latent class group, mean WHZ from 18-42 months of age was slightly higher than the average value for children growing according to international growth reference standards (0.38) but not near the threshold for overweight. Conversely, men in the low BMI latent class group had smaller than average body size at 18-42 months relative to the WHO standard (0.69). The low prevalence of childhood overweight (< 2%) in this cohort further supports the assertion that childhood high BMI trajectory was within normal limits and does not represent childhood obesity in this context (57). This would be consistent with findings from studies where early life undernutrition was positively associated with hypertension and diabetes later in life (58). However, men in the higher BMI trajectory class also had higher adult adiposity (BMI, abdominal obesity,

and obesity by body fat percentage) relative to men in the low BMI trajectory class which is positively associated with CMD risk (59).

Owing to the rise in childhood obesity in Latin America (60), our finding that higher BMI in childhood was negatively associated with some CMDs may no longer be informative for planning child nutrition programming. An estimated 20-25% of children and adolescents 0-19y in Latin America are overweight (61). Further, findings from studies on the relationship between stunting and risk of overweight have been mixed (62–66). A recent study in Peru reported that stunting in infancy was negatively associated with overweight at age 8y and 12y, suggesting that populations with high burdens of childhood stunting are at decreased risk of overweight (67); however, stunting was positively associated with abdominal adiposity in studies in Brazil and in India (68). It was previously reported in the INCAP cohort that childhood stunting was positively associated with lower BMI and lower body fat percentage in men but with higher abdominal fatness in both men and women (69). Considering that abdominal adiposity is an important predictor of CMD risk, the role of stunting on central obesity is an important consideration beyond its potential influence on BMI in populations with high levels of childhood undernutrition (70).

In Chapter 5, we also concluded that BMI trajectory class was not associated with most CMD risk factors after controlling for current BMI. In populations with high prevalence of early life undernutrition, targeting interventions to promote healthy weight throughout the life course could be especially important in

preventing adult CMD. In a prospective cohort of health professionals in the U.S., participants who maintained a stably lean body shape from age 5-50y had the lowest risk of mortality while people who were lean in early life but had marked increase in body weight in middle age had mortality risk similar to participants who had been heavy throughout life (54). Weight gain in early and mid-adulthood has been associated with increased risk of many NCDs, including diabetes, CVD, and certain cancers (71,72). While the burden of child overweight was low in our study population, INCAP participants have had substantial increases in BMI in young and mid-adulthood. Only men in the low BMI trajectory class had mean BMI in the normal range (24.8 kg/m^2) in 2015-16.

The majority of women in our study population were overweight or obese. Women in the high BMI latent class and low BMI latent class were, on average, overweight by 23y and 29y, respectively. In 2015-16, 50.0% of women in the high BMI trajectory class and 34.4% of women in the low BMI trajectory class were obese by BMI, and >90% of women in both BMI trajectory classes were obese by body fat percentage and had abdominal obesity. Women in LMICs bear a disproportionate burden of obesity in LMICs (60,73); however, the gender differential appears especially high in Latin America (74,75). Gender differences in LMICs typically emerge during adolescence or adulthood (76,77) and could be driven by sex differences in physiological responses to early life nutrition, pregnancy-associated weight gain combined with higher parity (74), hormonal signaling related to energy expenditure (78), physical activity levels (79), depression (80), past and present economic circumstances (81), and sociocultural factors such as perception of ideal

body size and beliefs surrounding acceptability of physical activity in some contexts (82,83). Future research should explore the drivers of the sex differential to prevent widening gender disparities in obesity-related NCDs.

High levels of adiposity among women might explain why we found significant associations between BMI trajectories and CMD risk in men but not women. Body fat percentage, WC, WHtR, did not vary by BMI trajectory class in women, suggesting a possible ceiling effect. Meaning, women in the low BMI were still largely obese despite having lower adiposity than women in the high BMI trajectory class. Considering BMI > 23 kg/m^2 increases risk of CMD (59) and neither of the women's BMI trajectory classes a mean BMI in the normal range, high levels of and lack of variation in adiposity in women could explain our inability to detect associations between BMI trajectory class and CMD risk.

Because BMI is a measure of general obesity, it may not capture the type of adiposity that is important for CMD risk in this population. The risk of developing CMD rises with increases in BMI; however, within a narrow range of BMI levels, there is high inter-individual variation in systemic inflammation and insulin resistance, possibly attributable to differences in the distribution and type of body fat (e.g. subcutaneous, visceral), which are thought to have varied local and/or systemic effects on metabolic dysfunction (84). Further, studies from populations with high burdens of stunting (Brazil and India) found positive associations between stunting and abdominal adiposity (68,85). Thus, measures of central adiposity (waist-based measures such as WC, WHtR, and waist-hip ratio) may be

superior to BMI in stunted populations. Systematic reviews that included data from Central America found that WHtR independently and more strongly predicted diabetes, CVD (86), MetS (87), and mortality (88) than did BMI. The disparate classification of obesity by different methods (BMI vs. waist-based measures) in our study population, suggests that BMI may not adequately identify adiposity in stunted adults.

Our findings in Chapter 5 highlight the importance of establishing and maintaining healthy weight over the life course. As discussed in Part I of Chapter 2, intentional weight loss and weight management are challenging. There is very little data on effective strategies to prevent the onset of obesity and to maintain weight during aging in LMICs like Guatemala. Furthermore, obesity management is especially challenging in countries where health systems were developed to attend to infectious disease and maternal and child undernutrition (17). Poverty and other factors affecting access to healthcare are additional hurdles in obesity management. While bariatric surgery for obesity treatment is advised for individuals with BMI ≥40 or BMI ≥35 with comorbid conditions that have not responded to lifestyle changes, surgery may also not be feasible in very low resource settings like Guatemala. Interventions in Latin America to address obesity prevention and treatment are a key priority for future research.

Children may be the most effective target group for prevention efforts because evidence suggests that propensity for overweight and obesity begins as early as six months of age (89,90), and data from HICs show that overweight tracks

from childhood into adulthood (21). This dissertation contributes to this evidence base given our finding that BMI trajectories separated early in infancy and did not overlap over the life-course. While focusing on obesity prevention in children will have little short-term impact on population prevalence of obesity and obesity-related NCDs, it would support the long term goal of preventing further increases in obesity prevalence. Initiatives to promote healthy diet and weight in children include increases in fruits and vegetables in school meals in Brazil (91), banning sugared soft drinks and whole milk in schools in Mexico and ultra-processed foods in schools in Costa Rica, prohibiting promotional "hooks" such as toys for meals not meeting nutritional guidelines in Chile (92), and school-based nutrition education to improve food literacy (93). These policies are discussed in greater detail later in this chapter.

Nutrition transition, adult diet, and cardio-metabolic disease risk

Despite changes in availability and access to high-fat, high-sugar foods, the extent to which adults in rural Guatemala have transitioned from traditional to Western diets is not well understood. Few published studies have explored individual adult diets in Guatemala (94–98), and, to our knowledge, no published studies have examined changes in individual adult diet. Our analyses in Chapter 6 addressed these gaps in the literature. We explored 12y changes in food group intake and in dietary components including macro- and micronutrients. Because data collection in the Metabolic Study was ongoing at the time of writing, the analyses in Chapter 6 were restricted to cohort members who lived in the original

study villages in 2015-16. Thus, our conclusions about 12y changes are based on rural diets only.

In both 2002-04 and 2015-16, rural diets were largely comprised of starches and simple sugars; however, we found evidence of diet diversification over the 12y study period characterized by decreased intake of traditional foods and a mixture of consumption trends for Western foods. In 2002-04, the top contributors to rural diet as a percentage of total energy were corn tortillas, refined grains, and SSB. In 2015-16, participants consumed fewer corn tortillas and traditional Guatemalan foods. These small reductions in tortilla consumption allowed for dietary diversification through small but significant increases in baked/roasted meat and fish, fried/processed meats, and vegetables.

In Chapter 6, we also identified two dietary patterns in each study wave: a traditional pattern and a Western pattern. The traditional patterns were based on foods traditionally consumed in Guatemala: corn tortillas, beans, table sugar added to coffee (2003), and eggs (2015). The Western patterns were more nutritionally diverse relative to the traditional dietary patterns, containing both healthy and less healthy food groups. The Western pattern was based on consumption of refined grains, fried starches, vegetables, baked/roasted meat and fish, processed/fried meats, dairy, oils/fats, SSB, traditional Guatemalan foods, transitional foods, eggs (2003), and fruits (2015). We found that the two dietary patterns we identified were relatively stable over the 12y study period in terms of food groups and food group factor loadings, with a few exceptions: fruits loaded onto the Western dietary

pattern, eggs moved from the Western dietary pattern to the traditional dietary pattern, and sugar added to coffee no longer loaded on the traditional dietary pattern.

Historically, maize, along with black beans, have been central to the Guatemalan diet (99); however, refined grains and sugar appear to be increasingly important to caloric intake in this population. While corn tortillas were the primary source of energy in both 2002-04 and in 2015-16, refined grains were the second largest contributor to energy intake. Our findings are consistent with diet literature from Guatemala. In 1997, Solomons noted the substitution of wheat-based products for corn in urban populations (100). In a 2011 study by Soto-Méndez *et al.*, corn tortillas, sweet rolls (*pan dulce*), and table sugar were the top contributors to total energy among rural populations (94). Consumption of wheat flour could be beneficial because Guatemala has mandatory wheat flour fortification with micronutrients such as iron (101). However, replacing corn tortillas with wheat-based foods like sweet rolls is unlikely to lead to improvements in nutritional status. Displacement of nutrient-rich, whole foods by ultra-processed foods has been cited as a main cause of the double-burden of malnutrition in Mexico (102) and a driver of obesity in Brazil (103).

Our study also found that a substantial proportion of energy in the Guatemalan diet comes from sugar. Foods with high sugar content (SSB, sugar added to coffee, jelly, and candies/caramels/chocolates) accounted for approximately 15% of energy intake at both time points. While we were unable to

estimate total added sugar in the diet, the percentage of total calories from the high-sugar foods/beverages listed above exceed WHO's upper limit for added sugars (10% of total energy) to prevent chronic disease (104,105). SSBs were the third largest contributor to total energy and the main driver of added sugar intake at both time points. Worryingly, intake nearly doubled over the 12y period – the largest increase of any food group. Our findings were consistent with trends in Latin America. In Mexico in 2012, added sugars contributed to 12.5% of total energy (106) and SSB accounted for 9.8% of total energy (107).

Beyond its contribution to overweight/obesity, dental caries, and other health problems (54), high intake of sugar and SSB could also lead to excessive vitamin A intake. To address micronutrient deficiencies, the government in 1975 mandated fortification of sugar with vitamin A. A 1998 study found that, among pre-school aged children in two poor communities in Guatemala City, table sugar was the single largest contributor to total daily vitamin A intake (25% of total intake) (108), demonstrating the utility of fortified sugar as a source of vitamin A. Yet as sugar consumption increases, there is concern that vitamin A intakes could exceed recommended upper limits, possibly leading to liver damage and birth defects (94,109). Considering a number of foods in Guatemala are also fortified with vitamin A, such as margarine, *Incaparina* (a corn, wheat, and soy-based protein supplement), and wheat-based porridges, balancing micronutrient needs with recommendations to reduce sugar consumption should be explored further both in Guatemala and in other LMICs. Presently, few have explored this topic (110,111). The FFQ for our study population was previously validated; however, the correlation coefficient for

vitamin A was <0.40 when compared to mean intake from three 24-hour dietary recalls, suggesting insensitivity of the FFQ in estimating vitamin A intakes. As a result, we did not present vitamin A intakes in these analyses.

Over the 12y study period, small reductions in tortilla consumption allowed for dietary diversification through small but significant increases in intake of baked/roasted meat and fish, fried/processed meats, and vegetables. Our findings were consistent with those from another study of diet in Guatemala that reported increased food variety, decreased intake of nutrient-dense foods, and increased intake of processed foods from the 1950s to the 2000s (96). The nutrition transition is generally characterized by the adoption of unhealthy high fat, high sugar, and processed foods (42,112); nevertheless, it can also promote dietary diversity through greater intake of fruits and vegetables, eggs, dairy, and meat (42).

Even though diets were characterized by high carbohydrate consumption at both time points, the macronutrient composition of the diet changed significantly over the 12y period. As a percent of total energy, carbohydrates decreased from 69.6% to 67.8% of total calories alongside concomitant increases in fat (from 18.3% to 19.1% of total energy) and protein (from 12.0% to 12.9% of total energy). Decreased reliance on carbohydrates and increased consumption of fat is a hallmark of the nutrition transition (43). The shifts seen in the INCAP study sample were similar to those reported in southern Mexico between 1988 and 1999 (113), suggesting that, while small, decreasing reliance on carbohydrates and increasing

intake of fat are likely reflective of the slow but meaningful changes in dietary composition.

The observed changes in rural diets between 2002 and 2016 were in line with our *a priori* expectations based on (a) national-level shifts in food availability and food access; and (b) dietary changes seen in other LMICs undergoing nutrition transition. Over the last 20 years, the food environment at the national-level in Guatemala has changed including availability of and access to packaged and ultra-processed foods. Food imports (U.S. millions $) increased from $1,706 in 2002 to $3,944 in 2012 (114), and the number of supermarkets doubled between 1990 and 2008 (115). According to a WHO report on ultra-processed food and drink products in Latin America, consumption of ultra-processed foods and beverages in Guatemala have increased in tandem with increased availability (90.7 kg per capita in 2000 vs. 113.5 kg per capita in 2013) (116). The WHO reported similar trends throughout Latin America. Moreover, studies from the anthropology literature showed that elders in Guatemalan communities have witnessed community-level changes in the availability of ultra-processed foods, behaviors such as snacking, and the toll of obesity and obesity-related diseases over the course of a single generation (99).

It's not clear whether observed changes in rural diets were due to food access, food environment, differences in SES, or other factors. In 2015, the Western pattern was associated with higher household SES while the traditional pattern was associated with lower household SES. At the beginning of the nutrition transition, dietary and physical activity changes first appear among high income and urban

populations (12). Higher income households benefit from increased access to market foods, allowing for increased dietary diversity and, often, for nutritional excess (117). In Guatemala, increased buying power was associated with increased calorie and processed food intake (118). A 2008 study of household food purchasing in Guatemala found that poorer households consumed more corn and beans than richer households (115). At the time of writing, we were unable to assess dietary change by rural/urban residence because the 2015-16 study data had only been collected for cohort members living in the original study villages.

Future research should examine rural/urban differences in dietary change in this population. Guatemala has undergone rapid urbanization since the 1970s. As of 2014, 50% of Guatemala's 15.4 million people lived in urban areas (119). In 2015, 21% of the INCAP cohort reported urban residence. Urbanization is thought to accelerate nutrition transition through changes in infrastructure, transportation, employment, income, food access, and physical activity (117). Consequently, changes in diet associated with the nutrition transition typically appear first among urban populations (12). For example, one study in Guatemala found that bakeries and bread truck routes, both associated with greater level of urbanization, were associated with substitution of white bread for corn tortillas and tamales (117). Another found that, controlling for SES, urban households purchased more meat, pastries/cookies/crackers, fats, and processed foods relative to rural households (115). Thus, urban residents in the INCAP cohort may have different patterns of dietary change relative to the rural residents.

On the other hand, as economic development continues and urban centers in Guatemala expand, the distinction between urban and rural residence in the INCAP cohort is likely more nuanced. One of the study villages, Santo Domingo, is close to Guatemala City (36 km) (28). Elements of the nutrition transition that have historically concentrated in urban environments, such as packaged and ultra-processed foods, have spread to rural areas (120). Thus, rural areas may have more access to energy-dense, nutrient-poor, ultra-processed foods than they had in the past. In the future, it may be useful to develop an urbanicity index to better characterize rural/urban residence - similar to the scale Monda *et al.* developed to assess transition in China (121).

Beyond exploring 12y dietary change, this research aimed to determine the association between dietary patterns and CMD risk. There is little information about how Guatemalan dietary habits influence CMD risk. One study of diet scores and CMD risk found that neither score-based indices of diet quality nor single nutrients were consistently associated with CMD risk factors (98,122,123); however, individuals with identical diet scores can have diverse dietary patterns (124). Data-driven dietary pattern analysis goes beyond intake and adequacy of individual nutrients and attempts to characterize dietary behavior and link patterns of consumption of foods and beverages to health outcomes, including anthropometry, metabolic syndrome, and diabetes (125–127). Because diet is a major modifiable determinant of NCD risk (105), understanding how dietary patterns are associated with CMD risk is important for informing public health strategies. However, to our

knowledge, no published studies have explored PCA-derived dietary patterns and CMD risk in Guatemalan adults.

In Chapter 7, we used cross-sectional data from the 2002-04 follow-up study which included both rural and urban cohort members. Our findings suggest the emergence of two Western diet patterns in Guatemala – one of which was associated with increased prevalence of low HDL-c in men. The traditional diet appeared to have a differential association with some CMD risk factors by sex. All three dietary patterns were characterized by carbohydrate consumption in excess of recommended levels – possibly explaining why we detected few associations between diet pattern and CMD risk factors. Future research will explore longitudinal diet and CMD risk in this population and quantify the contribution of other risk factors relative to diet in predicting CMD risk.

In Chapter 7, we identified three dietary patterns: a traditional pattern and two Western patterns (meat-based and starch-based). The traditional pattern was characterized by consumption of corn tortillas, beans, sugar added to coffee, and was negatively associated with consumption of dairy and transitional foods. The meat-based Western pattern was characterized by consumption of salty snacks, processed and fried meats, sweets/candies, alcohol, soda, traditional Guatemalan foods, and transitional foods. The starch-based Western pattern was characterized by consumption of refined grains, starchy and non-starchy vegetables, fried starches, juices, fruit, oils/fats, giblets, and packaged soups. Higher traditional dietary pattern tertile was positively associated with prevalence of abdominal

obesity in women but marginally reduced prevalence of low HDL-c in men. Higher starch-based modern dietary pattern tertile was associated with increased prevalence of low HDL-c in men only.

While analyses of rural diets in Chapter 6 identified one Western pattern, the analyses in Chapter 7, which used data from both rural and urban cohort members, identified two distinct Western patterns. We found that while the traditional pattern was more dominant in rural areas, neither of the Western diet patterns varied by urban residence, suggesting that while urban residents are less likely to eat a traditional diet, there is considerable variation in dietary patterns among urban residents. This highlights that nutrition transition is not monolithic - shifts away from a traditional diet dominated by tortillas and beans are likely more nuanced than a single type of diet characterized by ultra-processed foods. In this population, the meat-based pattern was related to the energy-dense, nutrient-poor foods typifying the unhealthy diet associated with the nutrition transition. The starch-based pattern was characterized by a mixture of both ultra-processed foods and healthy foods such as non-starchy vegetables and fruits, which are not typically consumed in large quantities in the traditional Guatemalan diet. It is possible that we were not able to detect more than one Western pattern in the rural diet at either time point (Chapter 6) due to less transitioned diets relative to the study sample containing rural and urban cohort members.

The diversification of the diet in Guatemala may have public health implications for NCD risk. In 2015, 64% of cardiovascular disease-related deaths

were attributable to dietary risk factors including high intake of SSBs and red and processed meats and low intakes of fruits, vegetables, and whole grains (5). Diversification of the diet through heathy foods would be beneficial to health because balanced diets high in fruits and vegetables, whole grains, and healthy fats have been associated with reduced obesity and diabetes (128,129). However, adoption of unhealthy foods is likely to worsen Guatemala's NCD burden. Studies from Mexico and Brazil have found strong associations between adoption of Western dietary patterns and health outcomes including overweight/obesity and MetS (103,130,131). Furthermore, the adoption of modern diets in our study was associated with other unhealthy behaviors in men (alcohol consumption and smoking with the meat-based modern pattern and physical inactivity with the starch-based modern pattern). However, lack of variation in smoking and physical inactivity in women limited our ability to detect any trends.

Studies in Latin American populations have not yielded consistent findings concerning traditional diets and CMD risk - possibly due to differences in fruit and vegetable consumption. Balanced diets high in fruits and vegetables, whole grains, and healthy fats have been associated with reduced obesity and diabetes (128,129). Comparing across studies is complicated because the concept of a traditional diet varies across cultures. For example, the traditional Guatemalan diet is characterized by corn tortillas, beans, and sweetened coffee, while the traditional Mexican diet is characterized by high intake of fresh fruits and vegetables, whole grains, and legumes and low intakes of refined carbohydrates and sugars (132), and the traditional Puerto Rican diet is characterized by oils, rice, beans/legumes, and

vegetables (133). These differences likely explain why the traditional Mexican diet was associated with lower C-reactive protein and insulin concentrations (132), but the traditional Puerto Rican diet was associated with higher risk of MetS and lower HDL-c (133). Owing to low intake of vegetables, fruit, and healthy fats in the traditional Guatemalan diet, our finding that traditional dietary pattern was positively associated with prevalence of abdominal obesity in women was not unexpected**.**

All three dietary patterns were characterized by high carbohydrate consumption (66-72% of total energy intake). Corn tortillas were the principal contributor of total energy in the diet, even among participants with high Western diet pattern scores. This finding could explain why we detected few associations between dietary patterns and CMD risk. Corn tortillas are a good source of fiber (approximately 6 g per 2 oz serving), which is associated with reduced CVD risk (134); however, some organizations have suggested that excessive carbohydrate intake increases risk of dyslipidemias and should be limited to reduce risk of NCDs (135). Thus, recommendations for carbohydrate consumption have varied by recommending body and range from < 60% of total energy (NHLBI) to ≤ 65% (IOM) to 55-75% (WHO) (105,135,136). We found that higher starch-based modern dietary pattern tertile was associated with increased prevalence of low HDL-c in men, but it is not clear whether high carbohydrate consumption could explain this finding.

While overall intake of transitional foods was low – even in the highest tertiles of the two Western patterns, small dietary changes could have implications for CMD risk. For example, men and women in the highest tertile of the meat-based modern diet pattern consumed an average of 19 g and 11 g of salty snack foods per day, respectively, or less than a typical single-serving bag of potato chips (about 28 g). Conversely, while not a "modern" food, **c**offee, through its association with added sugars, could be an important driver of sugar intake in this rural population. In the highest tertile of the traditional pattern in 2002-04, women and men added an average of 5.1 tsp and 4.3 tsp of sugar, respectively, to their coffee. SSBs are positively associated with body weight (54), and added sugars from liquid sources are associated with higher fasting glucose, higher fasting insulin, and higher β-cell dysfunction and insulin resistance (137). This finding highlights the need to identify all food groups linked to poor health outcomes. The accumulation of singularly minor dietary habits could influence CMD risk. Small but persistent positive energy balance of only 30 kJ per day could explain observed increases in overweight (138).

Thus, identifying risky dietary behavior can help guide nutrition recommendations to mitigate the risks of the nutrition transition while reinforcing any healthy dietary changes. To help mitigate risks associated with nutrition-related NCDs, further research should explore approaches to encourage adoption of healthier foods while minimizing the addition of energy-dense, nutrient-poor foods. For example, no participants reported daily intake of nuts or whole grains. Nuts have been associated with reduced risk of CVD and with incident type 2 diabetes (139,140) and could be a relatively inexpensive addition to the diet.

Given evidence from this dissertation research and mounting evidence from sources like the Pan-American Health Organization (PAHO), Guatemala might consider adopting policies designed to improve food systems and the built environment. In response to rising obesity and NCDs throughout Latin America, in 2014 PAHO approved a five-year Plan of Action on childhood obesity which emphasized the need for more government interventions in the region to set, achieve, and monitor specific, quantifiable targets (141). The plan includes recommendations for trade and agricultural policies, fiscal policies and incentives for increased production of healthy foods, regulation of food marketing, improved labeling of food items, better school food meal guidelines, and taxation policies for SSB and energy-dense snack foods.

Despite limited evidence of their effectiveness in preventing or reducing obesity and obesity-related NCDs, several countries in Latin America (Mexico, Brazil, Costa Rica, Chile, Peru, Ecuador, and Uruguay) have begun implementing policies and regulations to improve the food supply. Perhaps the most well-known example is from Mexico. In January 2014, the government passed an 8% tax on nonessential, energy-dense foods (≥275 kcal/100g), including foods like chips, pastries, and frozen desserts, as well as a 1 peso/liter (~10%) tax on SSB (142). A first year evaluation of the tax found a 25g per capita per month decrease in the mean volume of purchases of taxed foods in 2014, or a 5.1% change beyond what would have been expected based on pre-tax trends (142). Future research will determine if the tax also had an effect on caloric intake, diet quality, or distal health outcomes like overweight/obesity or diabetes.

Because the food environment has been implicated as the primary driver of global obesity (143), public health professionals have urged governments in Latin America to enact strict regulations in spite of industry pushback (141). Transnational food companies have argued against these policies on the basis that they are not evidence-based and restrict freedom of speech, among other reasons (116). Corporations have fought legislation in much of Latin America, and, in some cases, have succeeded in altering or overturning key policies. For example, the Brazilian Association of Food Industries (ABIA) successfully lobbied several transnational food corporations such as PepsiCo, McDonald's, and Kraft Foods from a law to regulate the marketing of ultra-processed products to children in Brazil (92). Self-regulatory options for the food industry on issues from product formulation to advertising and marketing to children have not yielded intended results (i.e. reduced sugar consumption, shift in advertising messaging to children promoting healthy diet and lifestyle, etc.) (144,145).

Policy recommendations

Given the findings in this dissertation combined with the mounting evidence of a rising CMD burden, there is a clear need for both prevention and treatment of CMD in Guatemala. Because the health system in Guatemala was developed to attend to infectious disease and undernutrition, the health system will need to be re-designed to contend with the dual burden of disease. Primordial and primary CMD prevention are optimal for long-term and sustainable reductions in disease burden; however, Guatemala should also invest in management and treatment of NCDs.

Routine metabolic screenings at health posts or health centers could be an important first step. Treatment delays resulting in poorly managed conditions could contribute to chronic disease deaths are younger ages in LMICs relative to HICs, especially among the most vulnerable populations (146). Given that 50% of the participants with diabetes in our study were not aware of their status, instituting routine screening could improve disease awareness and treatment initiation, where required. Moreover, the health ministry should take steps to ensure access to high-quality healthcare services and medications for those diagnosed with NCD.

Owing to limited resources, Guatemala will likely be tradeoffs between screening and treatment of NCDs and prevention programming. However, there are several regulations designed to improve food systems and built environment that the government in Guatemala could enact with little or no cost to the state. Sample initiatives designed to promote healthy diet and weight in children include banning the sale of sugared soft drinks and ultra-processed foods in and near schools, prohibiting promotional "hooks" such as toys for meals not meeting nutritional guidelines, and providing school-based nutrition education to improve food literacy. These regulations are being tested elsewhere in Latin America, and while their impact has not yet been confirmed, there is little evidence to suggest that similar regulations would *negatively* affect public health status.

Finally, while not nationally representative, the descriptive statistics in Chapters 5 and 7 of this dissertation provide evidence about the severity of the CMD burden which can be used to advocate for higher resource allocation for these

diseases. Over the last decades, routine data collection among children under 5y and women of reproductive age has supported evidence-based programming for maternal and child health; however, there is little available data on overweight/obesity and obesity-related outcomes like diabetes and hypertension to inform NCD planning. Thus, data gaps could be contributing to limited action on CMDs. Routine surveillance of BMI and obesity-related outcomes should be built into national health programming in both genders at all ages. Consolidating existing information and improving routine data collection could help Guatemala justify prioritizing CMDs while also creating an evidence base for program development.

Strengths

This research has a number of strengths. We used experimental data from a randomized trial of a nutrition supplement and its follow-up studies. The INCAP cohort has >40 years of follow-up with serial measures of anthropometry, diet, CMD risk factors, and rich sociodemographic and other health variables. The cohort has experienced relatively low attrition, and prior studies have indicated that attrition has not biased estimates of early life exposures and adult outcomes (147).

To our knowledge, we were the first study to explore BMI trajectories from early childhood through mid-adulthood in a LMIC population using LCGA. Most studies of life-course BMI trajectories have focused on high-income country populations (52,148), and studies from other LMIC cohorts have been limited by the relatively young age of the study participants (149,150). Our model selection also appeared to produce robust trajectories. The model fit statistics (Lo–Mendell–Rubin

Likelihood Ratio Test and Bootstrap Likelihood Ratio Test) for the selected models suggest good model fit, and the entropy statistic and posterior probabilities for the selected models indicate high class separation.

Moreover, we conducted a number of sensitivity analyses for the trajectory analyses which serve to improve confidence in our findings. For the analyses on early life exposures and BMI trajectories, *Atole* during the first 1,000 days was not associated with obesity at the oldest age observed, and all findings were robust to restricting trajectories to BMI values after the first 1,000 days. For the analyses on BMI trajectories and CMD risk, our findings were robust in models using WHZ from 18-42 months and BMI in 1988-89 as the primary exposures in sensitivity analyses. Finally, the 12y lag between when the final weight/height in the BMI trajectory and the CMD risk factors were measured attempted to control the influence of potential reverse causation between adult BMI and CMD risk.

To our knowledge, these were also the first studies to assess longitudinal change in individual diet in Guatemala and to explore the association between PCA-derived dietary patterns and CMD risk in Guatemalan adults. The FFQ was developed for and previously validated in this population (151). The FFQ included a number of "transitional foods" relevant to identifying modern diets like SSB and hot dogs and had open-ended sections for fruit and vegetable consumption to capture potential seasonality in the diet. We used a data-driven approach to dietary pattern analysis that goes beyond intake and adequacy of individual nutrients and attempts to characterize dietary behavior (125–127). Assessing overall food group intake and

dietary patterns helps provide a more complete picture of Guatemalan dietary habits. The dietary patterns were relatively stable when the study sample was randomly reduced from 1,428 to 717 participants in terms of percent variance explained (25.7%, collectively) and similarity of food groups and food group factor loadings.

Limitations

There were some limitations to this research. While the cohort has experienced relatively low attrition (147), there is the possibility of selection bias due to migration, though migrants to Guatemala City or other locations within Guatemala have been included in some of the follow-up study waves. Nevertheless, there was high coverage of target population in follow-up studies (73% in the 1988-89 follow-up, 78% in the 1997-99 CVD sub-study, and 85% in the 2002-04 Human Capital study). Coverage rates did not vary significantly between *Atole* and *Fresco* villages, but coverage was greater among women relative to men and lower for blood collection relative to other measurements or interviews, likely owing to anxiety about blood collection (28).

The nutrition supplement was randomized by village, so village-level effects on BMI are not adequately addressed by randomization but are captured within the difference-in-difference design. We did not analyze the quantity of the supplement actually consumed. If the effect of *Atole* during the first 1,000 days on BMI latent class was small, we might have had limited power to detect an association.

However, our findings were robust to restricting trajectories to BMI values after the first 1,000 days.

Life course analyses are threatened by bias owing to missing data; however, the results of the sensitivity analyses, which included participants who were missing BMI trajectory class, were consistent with the findings of the primary analyses. Further, prior work has indicated that attrition has not biased estimates of early life exposures and later-life outcomes (147). Finally, while LCGA helps identify heterogeneity in BMI gain, classes are not "real" but instead are heuristic - reflecting a continuum of growth in the population (152). Thus, the trajectories should be used to help visualize variability within a global distribution.

For dietary analyses, the FFQ did not fully capture processing (e.g. commercially-processed tortillas versus those made in the home or a local bakery) or certain differences within food groups (e.g. low- versus high-fat dairy), which might help distinguish between healthy and less healthy additions to the traditional diet (124). However, the FFQ was designed to capture transitional foods typically associated with Western diets such as ice cream, pizza, and hamburgers. There may have been differential misreporting of intake by BMI status. Studies in high income country populations have shown that overweight/obese people tend to under-report food intake relative to normal weight people (153,154); however, one study from Brazil found that total energy underreporting was differential by overweight/obesity status for diet journals and 24-hour recalls but not FFQ (155).

Misreporting could help explain the finding that total caloric intake decreased in women over the study period while mean BMI increased by 2.5 kg/m^2.

Some of these analyses are specific to a rural population (Chapters 5 and 6). Urban populations in Guatemala may have different diets, different patterns of change, and/or different burden of CMD because behaviors associated with the nutrition transition tend to appear first in urban populations (12). Further, as Guatemala continues to develop, the rural/urban dichotomy is likely more nuanced than we presented here. Nevertheless, because urban residence was based on residence location, neighborhood, and amenities, we expect it captures more than simple census-based classifications. Finally, even though the INCAP cohort is not nationally or provincially representative, results contribute to the limited literature on dietary patterns in a Latin American country.

Conclusions

Guatemala is experiencing an increasing burden of obesity alongside persistent childhood undernutrition. The appearance of dual burdens of child undernutrition and adult over-nutrition may exacerbate risk of obesity and associated CMD through hypothesized fetal programming pathways. Rising levels of CMDs are contributing to poor population health and well-being and threaten to overwhelm the health care system and gains in development. The research in this dissertation aimed to better understand how early life nutrition, BMI gain over the life course, and adult diet are associated with CMD risk.

We found that BMI trajectories diverged in infancy and tracked through mid-adulthood, suggesting that early life factors were important in establishing these trajectories and also highlighting the need to establish optimal growth early in life. Because exposure to improved nutrition (*Atole*) during the first 1,000 days was not associated with trajectory class, supplemental feeding programs during this critical developmental window are unlikely to adversely affect life-course BMI trajectories. Higher childhood household SES, however, was associated with increased odds of high BMI latent class membership relative to the poorest households. The mechanisms through which SES might influence BMI trajectory need to be explored further to better inform obesity prevention, especially as countries move from low to middle income.

Because BMI trajectory class was not associated with most CMD risk factors after controlling for current BMI and given that early life BMI tracked into adulthood, our findings highlight the importance of healthy growth early in life and preventing weight gain in adulthood. While high BMI latent class was negatively associated with metabolic syndrome and with dysglycemia in men, higher childhood BMI was within normal limits and did not represent childhood obesity in this context. Furthermore, the role of stunting on BMI and other measures of adiposity should be explored in future research to better understand the different pathways through which early life undernutrition might influence adult CMD risk.

Because diet is a major modifiable determinant of CMD risk, understanding diets, dietary change, and diet's association with CMD risk is important for

prevention strategies. In nutrition transition, high-fat, high-sugar, processed foods begin to replace traditional diets. Our findings suggest that, while diets remained largely reliant on starches and disaccharides, there is some evidence of diet diversification characterized by decreased intake of traditional foods and increased consumption of both healthy (e.g. vegetables, baked/roasted meats and fish) and less healthy (e.g. processed/fried meats and SSB) food groups. In dietary pattern analyses, the starch-based modern pattern was associated with increased prevalence of low HDL-c in men while the traditional diet appeared to be associated with increased prevalence of abdominal obesity in women but marginally significant reduced prevalence of low HDL-c in men.

To help mitigate risks associated with nutrition-related NCD, further research should explore approaches to encourage adoption of healthier foods while minimizing the addition of energy-dense, nutrient-poor foods. Future research will explore longitudinal diet and CMD risk in this population and quantify the contribution of other risk factors relative to diet in predicting CMD risk.

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Chapter 9 – Supplemental Materials

Table 9.1 - Fit statistics for the candidate latent class growth models, by sex, in the INCAP Nutrition Supplementation Trial Longitudinal Cohort.

	Females (*n* = 711)			Males (*n* = 742)		
Fit Statistics	2 Class	3 Class	4 Class	2 Class	3 Class	4 Class
Log likelihood	-14,164	-13,924	-13,814	-14,481	-14,107	-13,990
BIC	28,390	27,910	27,690	29,025	28,277	28,043
Entropy	0.76	0.74	0.71	0.76	0.77	0.72
LMR test	1,412.7	478.7	220.5	1,847.3	748.2	234.1
LMR, *P* value	0.008	0.1	0.1	0.0002	<0.0001	0.1
BLRT test	1,412.7	478.7	220.5	1,847.3	712.3	234.1
BLRT, *P* value	<0.0001	0.6	0.6	<0.0001	<0.0001	0.9

Abbreviations: BIC, Bayesian Information Criterion; LMR, Lo-Mendell-Rubin Likelihood Ratio Test; BLRT, Bootstrap Likelihood Ratio Test.

Table 9.2. Percentage within class, intercept, and slope for the BMI latent classes, by sex, in the INCAP Nutrition Supplementation Trial Longitudinal Cohort.

	Females (*n* =711)			Males (*n* = 742)		
Outcome	%	Intercept	Slope	%	Intercept	Slope
BMI latent class						
Low	56.6	14.7	0.016	38.3	14.7	0.014
Medium				46.8	16.1	0.013
High	43.3	16.2	0.018	14.7	17.7	0.010

Abbreviations: BMI, body mass index; INCAP, Institute of Nutrition of Central America and Panama.

Table 9.3. Select sociodemographic and health characteristics in 2015-16 by BMI trajectory class and sex, INCAP Nutrition Supplementation Trial Longitudinal Cohort (n=536 women, n=355 men).

	Women				Men			
	Low Class (n=238)	High Class (n=170)	Missing Class (n=128)	P-value[13]	Low Class (n=113)	High/medium Class (n=168)	Missing Class (n=74)	P-value[13]
Age, years	45.0 (3.9)	41.9 (3.1)	45.6 (5.1)	<0.0001	45.0 (3.7)	42.3 (3.5)	44.8 (5.2)	<0.0001
SES tertile, %				0.1				0.1
Poorest	29.8	35.2	35.1		32.7	29.1	47.3	
Middle	38.2	36.4	26.5		30.0	36.3	20.2	
Wealthiest	31.9	28.2	38.2		37.1	34.5	32.4	
Parity, n	3.4 (2.0)	3.5 (2.2)	4.1 (2.0)	0.01	-	-	-	-
Alcohol use, %	4.6	4.1	2.3	0.5	46.9	35.7	35.6	0.08
Ever smoker, %	4.2	3.5	4.7	0.8	64.6	66.0	69.8	0.4
Physically inactive 2004[1], %	97.3	98.1	97.2	0.8*	54.5	54.1	42.8	0.2
Vitamin use, %	12.6	10.5	10.2	0.7	21.2	8.9	9.5	0.0009
BMI, kg/m^2	28.7 (4.9)	30.2 (5.6)	28.7 (5.3)	0.01	24.8 (3.6)	27.0 (3.8)	25.4 (4.1)	<0.0001
Obese by BMI[2], %	34.4	50.0	39.8	0.006	7.0	18.4	12.1	0.02
Waist circumference, cm	101.7 (12.1)	103.6 (13.0)	101.4 (12.7)	0.2	91.1 (9.3)	94.6 (9.6)	91.1 (9.1)	0.003
Abdominal obesity[3], %	91.1	90.0	87.5	0.5	10.6	22.0	12.1	0.03
Waist-height ratio	0.67 (0.08)	0.68 (0.08)	0.66 (0.08)	0.1	0.55 (0.05)	0.57 (0.05)	0.56 (0.05)	0.0005
Abdominal obesity by waist-height ratio[4], %	99.5	99.4	99.2	0.9*	78.7	91.6	87.5	0.0007
Body fat, %	42.0 (6.2)	42.1 (5.2)	41.8 (6.2)	0.8	27.3 (6.8)	28.8 (6.0)	26.4 (6.4)	0.01
Obese by body fat %[5], %	93.7	95.8	91.4	0.2	63.7	75.0	55.4	0.006
Elevated triglycerides[6], %	78.0	80.2	75.2	0.5	65.4	75.9	72.0	0.1
Low HDL-c[7], %	89.0	92.8	91.2	0.4	70.0	80.2	69.1	0.08
TC:HDL-c ratio	5.5 (1.7)	5.7 (2.1)	5.3 (1.6)	0.1	5.3 (1.7)	5.9 (2.6)	5.6 (1.8)	0.04
Blood pressure				0.3				0.8
Pre-hypertension[8], %	16.8	15.8	18.9		20.3	25.6	20.5	

Hypertension[9], %	28.9	20.5	24.4		9.7	8.3	10.9	
Dysglycemia				0.1				0.04
Pre-diabetes[10], %	35.2	27.0	37.0		36.2	27.7	19.1	
Diabetes[11], %	15.4	17.0	21.6		8.8	8.4	4.1	
MetS risk factors	3.4 (1.0)	3.2 (1.0)	3.4 (1.1)	0.4	2.2 (1.2)	2.3 (1.2)	1.9 (1.3)	0.04
MetS[12], %	83.1	77.6	79.6	0.3	40.7	43.4	31.0	0.1

Values presented are mean (SD) or percent. [1]Low physical activity in 2004 defined as 24-h average physical activity <1.7 MET/hour. [2]Obesity by BMI defined as BMI ≥30 kg/m^2. [3]Abdominal obesity defined as waist circumference ≥88 cm for women and ≥102 cm for men. [4]Abdominal obesity by waist-height ration defined as waist-height >0.50. [5]Obesity by body fat% defined as body fat % ≥32% for women and ≥25% for men. [6]Elevated triglycerides defined as ≥150 mg/dL or medication. [7]Low HDL-c defined as HDL-c <50 mg/dL for women and <40 mg/dL for men. [8]Pre-hypertension is defined as systolic blood pressure 120-129 mmHg and/or diastolic blood pressure 80-89 mmHg among participants without self-reported hypertension and/or anti-hypertensive medication use. [9]Hypertension is defined as systolic blood pressure >130 mmHg and/or diastolic blood pressure >90 mmHg and/or self-reported hypertension and/or anti-hypertensive medication use. [10]Pre-diabetes is defined according to the ADA diagnostic criteria: impaired fasting glucose (fasting plasma glucose 100-125 mg/dL) and/or impaired glucose tolerance (post challenge glucose 140-199 mg/dL) among participants without self-reported diabetes. [11]Diabetes is defined according to the ADA diagnostic criteria: fasting plasma glucose ≥126 mg/dL, and/or post-challenge glucose ≥200 mg/dL, and/or self-reported diabetes. [12]Metabolic syndrome defined according to 2005 NCEP ATP III diagnostic criteria based on presence ≥3 of the following: abdominal obesity (waist circumference ≥88 cm for women and ≥102 cm for men); fasting plasma glucose ≥100 mg/dL or medication; triglycerides ≥150 mg/dL or medication; HDL-c <50 mg/dL); and blood pressure >130 mmHg systolic, >85 mmHg diastolic and/or medication use. [13]P was calculated using ANOVA (continuous) and Chi-square tests (categorical variables).*Expected cell count <5. Abbreviations: BMI, body mass index; HDL-c. high density lipoprotein cholesterol; INCAP, Institute of Nutrition for Central America and Panama; MET, metabolic equivalents; MetS, metabolic syndrome; NCEP ATP III, National Cholesterol Education Program Adult Treatment Panel III; TC, total cholesterol.

Table 9.4. Multivariate logistic regression models to predict cardiometabolic risk factors based on body mass index latent class trajectory (high vs. low and missing vs. low in women; high/medium vs. low and missing vs. low in men) in the INCAP Nutrition Supplementation Trial Longitudinal Cohort (n= 535 women, n=355 men).

	Women				Men			
	High vs. Low		Missing vs. Low		High/medium vs. Low		Missing vs. Low	
CMD risk factor	Prevalence Ratio	95% CI	Prevalence Ratio	95% CI	Prevalence Ratio	95% CI	Prevalence Ratio	95% CI
Obesity by BMI[1]								
Model 1	2.03	1.33, 3.12	1.24	0.79, 1.94	2.74	1.18, 6.36	1.79	0.65, 4.89
Model 2	2.09	1.36, 3.22	1.22	0.78, 1.91	2.60	1.11, 6.08	2.03	0.73, 5.60
Model 3	2.16	1.39, 3.35	1.27	0.79, 2.06	2.26	0.93, 5.48	2.00	0.66, 6.06
Model 4	-	-	-	-	-	-	-	-
Model 5	-	-	-	-	-	-	-	-
Model 6	-	-	-	-	-	-	-	-
Abdominal obesity[2]								
Model 1	0.93	0.46, 1.89	0.66	0.33, 1.33	2.31	1.11, 4.78	1.31	0.53, 3.21
Model 2	0.95	0.47, 1.93	0.59	0.29, 1.20	2.25	1.08, 4.67	1.46	0.59, 3.63
Model 3	1.01	0.49, 2.07	0.61	0.28, 1.30	1.88	0.87, 4.04	1.58	0.60, 4.13
Model 4	0.76	0.26, 2.17	1.04	0.33, 3.22	0.81	0.25, 2.60	0.51	0.09, 2.76
Model 5	0.71	0.24, 2.12	0.79	0.24, 2.56	0.83	0.25, 2.75	0.62	0.10, 3.62
Model 6	0.74	0.24, 2.22	0.57	0.15, 2.09	0.66	0.18, 2.46	0.82	0.12, 5.50
Obesity by body fat %[3]								
Model 1	1.19	0.45, 3.15	0.77	0.34, 1.75	1.71	1.00, 2.94	0.70	0.38, 1.28
Model 2	1.24	0.47, 3.30	0.75	0.32, 1.72	1.68	0.96, 2.91	0.79	0.42, 1.45
Model 3	1.08	0.39, 2.95	0.79	0.31, 2.02	1.72	0.95, 3.11	0.81	0.40, 1.63
Model 4	0.96	0.34, 2.67	0.99	0.39, 2.52	0.97	0.51, 1.82	0.58	0.29, 1.17
Model 5	0.99	0.35, 2.78	1.01	0.39, 2.58	0.98	0.51, 1.85	0.62	0.30, 1.25
Model 6	0.85	0.28, 2.58	1.14	0.38, 2.42	0.88	0.43, 1.77	0.54	0.24, 1.23
Elevated triglycerides[4]								
Model 1	1.29	0.77, 2.15	0.83	0.49, 1.38	1.77	1.01, 3.11	1.38	0.71, 2.68
Model 2	1.32	0.79, 2.21	0.84	0.50, 1.41	1.74	0.99, 3.08	1.47	0.75, 2.89
Model 3	1.34	0.78, 2.29	0.80	0.45, 1.40	1.92	1.05, 3.48	1.94	0.90, 4.19
Model 4	1.20	0.71, 2.02	0.83	0.49, 1.39	1.15	0.62, 2.12	1.35	0.67, 2.74
Model 5	1.22	0.73, 2.06	0.84	0.50, 1.42	1.16	0.62, 2.15	1.38	0.68, 2.82

	Model 6	1.24	0.72, 2.13	0.79	0.45, 1.40	1.27	0.66, 2.42	1.78	0.79, 3.99
Low HDL-c[5]									
	Model 1	1.58	0.75, 3.35	1.27	0.60, 2.68	1.72	0.95, 3.11	0.95	0.49, 1.84
	Model 2	1.55	0.73, 3.28	1.28	0.60, 2.70	1.71	0.95, 3.05	0.94	0.49, 1.83
	Model 3	1.58	0.70, 3.54	1.07	0.48, 2.38	1.86	0.99, 3.52	1.18	0.55, 2.53
	Model 4	1.42ǂ	0.66, 3.03	1.30	0.61, 2.75	0.96	0.49, 1.88	0.87	0.42, 1.81
	Model 5	1.35	0.63, 2.90	1.29	0.60, 2.74	1.01	0.52, 1.99	0.86	0.41, 1.79
	Model 6	1.36ǂ	0.59, 3.09	1.05	0.47, 2.35	1.04	0.51, 2.14	0.95	0.41, 2.19
Metabolic syndrome[6]									
	Model 1	0.83	0.49, 1.39	0.77	0.44, 1.34	1.17	0.70, 1.94	0.65	0.35, 1.22
	Model 2	0.86	0.51, 1.45	0.79	0.45, 1.39	1.18	0.71, 1.95	0.66	0.35, 1.23
	Model 3	0.86	0.50, 1.47	0.72	0.39, 1.30	1.17	0.67, 2.02	0.87	0.43, 1.74
	Model 4	0.66	0.38, 1.14	0.80	0.44, 1.45	0.54	0.29, 1.00	0.46	0.21, 0.98
	Model 5	0.67	0.38, 1.17	0.86	0.47, 1.56	0.54	0.29, 1.01	0.39	0.18, 0.85
	Model 6	0.65	0.36, 1.16	0.75	0.39, 1.42	0.48	0.24, 0.96	0.48	0.20, 1.17

Values presented are prevalence ratios and 95% confidence intervals [1]Obesity by BMI defined as BMI ≥30 kg/m^2. [2]Abdominal obesity defined as waist circumference ≥88 for women and ≥102 cm for men. [3]Obesity by body fat% defined as body fat ≥32% for women and ≥25% for men. [4]Elevated triglycerides defined as ≥150 mg/dL or medication.

[5]Low HDL-c defined as HDL-c <50 mg/dL for women and <40 mg/dL for men.[6]Metabolic syndrome defined according to 2005 NCEP ATP III diagnostic criteria based on presence ≥3 of the following: abdominal obesity (waist circumference ≥102 cm); fasting plasma glucose ≥100 mg/dL or medication; triglycerides ≥150 mg/dL or medication; HDL-c <50 mg/dL for women and <40 mg/dL for men); and blood pressure >130 mmHg systolic, >85 mmHg diastolic and/or medication use. ǂ Modeled without smoking status due to non-convergence.Abbreviations: BMI, body mass index; HDL-c, high density lipoprotein cholesterol; INCAP, Institute of Nutrition for Central America and Panama; NCEP ATP III, National Cholesterol Education Program Adult Treatment Panel III; SES, socioeconomic status.

Model 1 = BMI trajectory latent class + age

Model 2 = Model 1 + SES in 2015

Model 3 = Model 2 + physical inactivity in 2004 + smoking status in 2015

Model 4 = Model 1 + BMI in 2015

Model 5 = Model 4 + SES in 2015

Model 6 = Model 5 + physical inactivity in 2004 + smoking status in 2015

Table 9.5. Ordinal logistic regression models to predict cardiometabolic risk factors based on body mass index latent class trajectory (high vs. low and missing vs. low in women; high/medium vs. low and missing vs. low in men) in the INCAP Nutrition Supplementation Trial Longitudinal Cohort (n=536 women, n=355 men).

	Women				Men			
	High vs. Low		Missing vs. Low		High/medium vs. Low		Missing vs. Low	
CMD risk factor	Proportional Odds	95% CI	Proportional Odds	95% CI	Proportional Odds	95% CI	Proportional Odds	95% CI
Elevated blood pressure (pre-hypertension[1] and hypertension[2])								
Model 1	0.91	0.60, 1.38	0.79	0.60, 1.38	1.40	0.82, 2.39	1.08	0.57, 2.03
Model 2	0.91	0.60, 1.39	0.77	0.50, 1.18	1.42	0.83, 2.43	1.02	0.54, 1.93
Model 3	0.91	0.59, 1.40	0.90	0.57, 1.42	1.42	0.80, 2.51	0.98	0.72, 2.89
Model 4	0.79	0.51, 1.22	0.76	0.49, 1.18	0.99	0.56, 1.74	0.93	0.48, 1.79
Model 5	0.79	0.51, 1.22	0.74	0.48, 1.15	0.98	0.56 1.73	0.81	0.41, 1.58
Model 6	0.78	0.50, 1.21	0.85	0.53, 1.36	0.90	0.49, 1.64	0.69	0.32, 1.51
Dysglycemia (pre-diabetes[3] and diabetes[4])								
Model 1	1.03	0.69, 1.54	1.27	0.84, 1.91	0.75	0.45, 1.24	0.38	0.19, 0.72
Model 2	1.04	0.70, 1.55	1.30	0.86, 1.96	0.74	0.45, 1.23	0.38	0.20, 0.73
Model 3	1.04	0.69, 1.56	1.34	0.86, 2.08	0.72	0.42, 1.23	0.42	0.20, 0.88
Model 4	0.94	0.63, 1.41	1.26	0.84, 1.90	0.58	0.34, 0.98	0.34	0.17, 0.67
Model 5	0.95	0.63, 1.42	1.29	0.86, 1.95	0.57	0.34, 0.97	0.34	0.17, 0.66
Model 6	0.92	0.60, 1.40	1.33	0.85, 2.07	0.53	0.30, 0.94	0.36	0.17, 0.76
Number of MetS risk factors[5]								
Model 1	1.04	0.71, 1.51	1.01	0.68, 1.49	1.48	0.92, 2.24	0.75	0.44, 1.26
Model 2	0.86	0.59, 1.26	0.88	0.56, 1.38	0.77	0.48, 1.23	0.58	0.33, 1.00
Model 3	0.86	0.59, 1.27	0.97	0.65, 1.44	0.78	0.48, 1.25	0.56	0.32, 0.97
Model 4	0.84	0.56, 1.24	1.02	0.67, 1.57	0.71	0.42, 1.18	0.59	0.31, 1.10
Model 5	1.05	0.72, 1.53	0.99	0.67, 1.47	1.43	0.91, 2.23	0.78	0.46, 1.31
Model 6	1.04	0.71, 1.53	1.05	0.69, 1.60	1.45	0.90, 2.34	0.95	0.53, 1.72
Model 1	1.04	0.71, 1.51	1.01	0.68, 1.49	1.48	0.92, 2.24	0.75	0.44, 1.26
Model 2	1.05	0.72, 1.53	0.99	0.67, 1.47	1.43	0.91, 2.23	0.78	0.46, 1.31

Model 3	1.04	0.71, 1.53	1.05	0.69, 1.60	1.45	0.90, 2.34	0.95	0.53, 1.72
Model 4	0.86	0.59, 1.26	0.88	0.56, 1.38	0.77	0.48, 1.23	0.58	0.33, 1.00
Model 5	0.86	0.59, 1.27	0.97	0.65, 1.44	0.78	0.48, 1.25	0.56	0.32, 0.97
Model 6	0.84	0.56, 1.24	1.02	0.67, 1.57	0.71	0.42, 1.18	0.59	0.31, 1.10

Values presented are proportional odds ratios and 95% confidence intervals. [1]Pre-hypertension is defined as systolic blood pressure 120-129 mmHg and/or diastolic blood pressure 80-89 mmHg among participants without self-reported hypertension and/or anti-hypertensive medication use. [2]Hypertension is defined as systolic blood pressure >130 mmHg and/or diastolic blood pressure >90 mmHg and/or self-reported hypertension and/or anti-hypertensive medication use. [3]Pre-diabetes is defined according to the ADA diagnostic criteria: impaired fasting glucose (fasting plasma glucose 100-125 mg/dL) and/or impaired glucose tolerance (post challenge glucose 140-199 mg/dL) among participants without self-reported diabetes. [4]Diabetes is defined according to the ADA diagnostic criteria: fasting plasma glucose ≥126 mg/dL, and/or post-challenge glucose ≥200 mg/dL, and/or self-reported diabetes. [5]Metabolic syndrome risk factors were defined according to 2005 NCEP ATP III diagnostic criteria: abdominal obesity (waist circumference ≥102 cm); fasting plasma glucose ≥100 mg/dL or medication; triglycerides ≥150 mg/dL or medication; HDL-c <40 mg/dL); and blood pressure >130 mmHg systolic, >85 mmHg diastolic and/or medication use. Women with 0 or 1 metabolic syndrome risk factor(s) have been combined into a single group. Men with 4 or 5 metabolic syndrome risk factors have been combined into a single group. Abbreviations: ADA, American Diabetes Association; BMI, body mass index; CMD, cardiometabolic disease INCAP, Institute of Nutrition for Central America and Panama; MetS, metabolic syndrome; NCEP ATP III, National Cholesterol Education Program Adult Treatment Panel III; SES, socioeconomic status.

Model 1 = BMI trajectory latent class + age

Model 2 = Model 1 + SES in 2015

Model 3 = Model 2 + physical inactivity in 2004 + smoking status in 2015

Model 4 = Model 1 + BMI in 2015

Model 5 = Model 4 + SES in 2015

Model 6 = Model 5 + physical inactivity in 2004 + smoking status in 2015

Table 9.6. Classifications of obesity by body fat percentage, waist circumference, and waist-height ratio by obesity by BMI and gender in the INCAP Nutrition Supplementation Trial Longitudinal Cohort (n=408 women, n=281 men).

Classification of Obesity	Women		Men	
	Not Obese (BMI <30 kg/m^2) % (n)	Obese (BMI ≥30 kg/m^2) % (n)	Not Obese (BMI <30 kg/m^2) % (n)	Obese (BMI ≥30 kg/m^2) % (n)
Obese by body fat %[1]				
No	8.3 (20)	1.2 (2)	33.0 (80)	7.6 (3)
Yes	91.7 (221)	98.8 (165)	66.9 (162)	92.3 (26)
Abdominal obesity by WC[2]				
No	15.7 (38)	0.0 (0)	94.2 (228)	10.2 (4)
Yes	84.2 (203)	100.0 (167)	5.7 (14)	89.7 (35)
Abdominal obesity by WHtR[3]				
No	0.8 (2)	0.0 (0)	15.7 (38)	0.0 (0)
Yes	99.1 (239)	100.0 (167)	84.3 (204)	100.0 (39)

Values presented are proportions. [1]Obesity by body fat % defined as body fat % ≥32% for women and ≥25% for men.

[2]Abdominal obesity defined as WC ≥88 cm for women and ≥102 cm for men. [3]Abdominal obesity by WHtR defined as WHtR >0.50. Abbreviations: BMI, body mass index; INCAP, Institute of Nutrition for Central America and Panama; WC, waist circumference; WHtR, waist-height ratio.

Table 9.7. Food groups and food items from the food frequency questionnaire. INCAP Nutrition Supplementation Trial Longitudinal Cohort.

Main group	Food groups	Food items
Grains	Corn tortilla	Corn tortilla
	Whole grains	Oatmeal, whole wheat tortilla
	Refined grains	White bread, rice (cooked, fried), corn flakes, noodles, sweet bread, pastries
Vegetables	Fresh vegetables	Avocado, beet, broccoli, cabbage, cactus (nopal), carrot, cauliflower, celery, chayote, chayote root, corn, cucumber, eggplant, greens, green beans, guicoy (sazon and tierno), herbs, lettuce, loroco flower, okra, onion, pacaya palm, peas, plantain (boiled), potato (boiled), radish, soy, sweet pepper, squash, tomato, turnip yucca flower
	Fried starches	French fries, fried plantains
Fruits	Fresh fruits	Apple, banana (various types), blackberry, cashew fruit, chicozapote, coconut, grapes, green mango, grapefruit, guanabana, guava, jocote (yellow/red, green), leechee, mandarin orange, mamey, mango, melon, nance, orange, papaya, passion fruit, paterna, peach, pear, pineapple, plum, strawberry, sweet lime, sugar apple, sunza, watermelon, zapote
Meats	Baked/roasted meat and fish	Poultry (breast, leg, thigh, wing), beef, pork, giblets (chicken liver, gizzard, feet; beef brain, kidney, liver, other), fish
	Processed and fried meats	Fried chicken (wing, thigh, leg, breast), pork skin, pork sausage, hot dog, ham
Eggs	Eggs	Eggs
Dairy	Dairy	Milk, cheese
Beans	Beans	Beans (boiled, smashed, refried)
Fats	Nuts	Peanuts
	Oils/fats	Cream or butter, mayonnaise
Sugar	Sugar	Sugar added to coffee
Beverages	Coffee	Coffee
	Alcohol	Beer, rum, whisky, other liquor
	Sugar-sweetened beverages	Soft drinks, lemonade, sweetened juice-flavored drinks
Other	Traditional Guatemalan foods	Tamale, taco
	Transitional foods	Hamburgers, pizza, chips (papalinas/tortrix/ricitos), processed soup, candies/caramels/chocolates, ice cream, jelly

Abbreviations: INCAP, Institute of Nutrition for Central America and Panama.

Table 9.8. Food group factor loadings and mean intake (g) by PCA-derived dietary pattern tertile for rural Guatemalan adults. INCAP Nutrition Supplementation Trial Longitudinal Cohort, 2002-04 (n=479 women, n=303 men).

	Western 2002-04				Traditional 2002-04			
Food Groups	Factor loading	T1[1] (g)	T2 (g)	T3 (g)	Factor loading	T1 (g)	T2 (g)	T3 (g)
				WOMEN				
Corn tortilla	9	410.7	382.2	372.4	79	269.6	383.4	512.3
Refined grains	48	81.7	121	154	23	106.3	117.7	132.9
Vegetables	50	14.4	28.8	65.7	-17	54.8	28.6	25.8
Fried starches	60	14.1	28.7	80.2	-9	51.1	40.4	31.7
Fruits	33	147.7	183.8	283.6	22	205.3	183.0	227.5
Baked/roasted meat, fish	57	32.0	49.7	91.2	-2	61.6	59.8	51.6
Processed and fried meats	58	11.9	27.1	43.4	-3	29.7	27.2	25.6
Eggs	38	17.6	28.1	39.7	29	21.6	27.5	36.4
Dairy	37	28.5	70.2	130	-14	110.4	63.5	55.4
Beans	-11	152.4	118.6	95.4	73	57.1	90.9	218.6
Oils/fats	36	4.6	9.9	14.7	12	9.4	9.2	10.6
Sugar added to coffee	-11	14.9	12.6	11.0	46	6.3	11.8	20.5
SSB	56	214	411	575	10	415.3	401.1	385.0
Tamales and tacos	40	30.2	48.5	69.8	-10	57.9	46.2	44.6
Transitional foods[2]	51	8.9	22.5	42.9	-5	32.5	21.3	20.8
				MEN				
Corn tortilla	9	555.0	562.5	588.7	79	414.9	558.9	732.5
Refined grains	48	106.4	154.5	198.5	23	135.3	148.0	175.7
Vegetables	50	21.6	36.7	64.5	-17	44.0	40.4	38.3
Fried starches	60	24.1	38.2	87.9	-9	55.3	48.3	46.1
Fruits	33	195.0	267.7	370.2	22	208.5	257.3	366.7
Baked/roasted meats, fish	57	37.8	60.5	104.0	-2	71.2	61.7	69.2
Processed and fried meats	58	18.1	35.1	61.1	-3	41.8	37.8	34.5
Eggs	38	31.8	44.5	56.5	29	32.1	47.4	53.1
Dairy	37	27.5	67.1	97.5	-14	65.2	58.7	68.1
Beans	-11	166.6	161.7	134.5	73	78.1	126.2	259.5
Oils/fats	36	6.6	14.4	19.4	12	10.8	13.8	15.7

Sugar added to coffee	-11	13.4	12.3	10.6	46	7.2	11.7	17.5
SSB	56	357.9	638.2	795.5	10	545.4	624.1	619.7
Tamales and tacos	40	31.2	52.6	76.3	-10	58.0	56.5	45.2
Transitional foods	51	19.6	36.1	63.1	-5	42.3	40.2	35.9

[1]Mean intake of food groups (g) across tertiles. Tertiles are sex-specific. [2]Soft drinks, lemonade, sweetened juice-flavored drinks. [2]Tamales and tacos. [3]Pizza, hamburgers, salty snacks, processed soup, candy, jelly. Whole grains and nuts were excluded from analyses due to low (<10%) consumption. Alcohol was excluded from analyses due to low frequency of consumption (<0.5g/day). Abbreviations: INCAP, Institute of Nutrition for Central America and Panama; SSB, sugar-sweetened beverages; T, tertile.

Total variance explained in 2004: 28.6%

Table 9.9. Food group factor loadings and mean intake (g) by PCA-derived dietary pattern tertile for rural Guatemalan adults. INCAP Nutrition Supplementation Trial Longitudinal Cohort, 2015-16 (n=479 women, n=303 men).

	Western 2015-16				Traditional 2015-16			
Food Groups	Factor loading	T1[1] (g)	T2 (g)	T3 (g)	Factor loading	T1 (g)	T2 (g)	T3 (g)
			WOMEN					
Corn tortilla	11	346.2	336.6	327.0	69	237.9	333.7	437.5
Refined grains	50	80.7	107.8	152.6	35	95.2	114.2	131.6
Vegetables	47	25.0	47.6	85.2	-19	72.5	47.5	38.1
Fried starches	50	13.9	31.1	63.4	-1	45.7	33.3	29.6
Fruits	46	112.9	216.2	325.9	-24	319.7	192.5	143.6
Baked/roasted meat, fish	58	40.8	72.0	105.5	2	79.8	70.7	67.8
Processed and fried meats	46	21.6	30.0	49.8	27	30.6	34.5	36.4
Eggs	33	20.8	28.2	38.1	44	19.1	26.9	41.0
Dairy	40	28.6	62.9	138.2	-32	123.6	63.7	42.7
Beans	-3	127.6	92.6	96.4	72	49.9	84.7	181.8
Oils/fats	45	4.8	9.1	15.6	20	7.1	10.6	11.7
Sugar added to coffee	-2	13.6	11.7	12.8	35	7.5	11.0	19.6
SSB	48	293.8	430.2	631.8	19	425.3	445.5	485.1
Tamales and tacos	42	24.0	37.0	63.8	4	38.6	42.8	43.4
Transitional foods[2]	45	17.2	25.0	48.3	7	32.2	33.5	24.9
			M					
Corn tortilla	11	524.5	553.0	550.7	69	410.9	507.9	710.6
Refined grains	50	115.5	143.9	213.9	34	121.1	166.4	185.9
Vegetables	47	23.2	43.1	77.4	-19	50.7	49.2	43.9
Fried starches	50	14.7	38.8	80.6	-1	47.6	41.5	45.3
Fruits	46	125.9	216.7	316.7	-24	256.6	188.0	216.5
Baked/roasted meat, fish	58	52.4	77.4	126.2	2	85.5	81.1	89.8
Processed and fried meats	46	34.4	53.3	87.0	27	42.2	56.9	75.7
Eggs	33	33.1	51.0	74.1	44	33.6	53.0	71.7
Dairy	40	31.2	76.0	102.3	-32	98.6	66.4	45.1
Beans	-3	177.9	174.1	160.2	72	85.5	139.5	288.2
Oils/fats	45	6.8	12.3	20.7	20	11.5	12.7	15.8

Sugar added to coffee	-2	12.7	13.5	12.3	35	5.6	14.3	18.6
SSB	48	357.5	638.9	882.5	19	515.8	656.0	709.0
Tamales and tacos	42	26.8	37.7	67.7	4	43.0	43.5	45.9
Transitional foods	45	24.7	41.2	65.4	7	39.7	42.8	49.0

[1]Mean intake of food groups (g) across tertiles. Tertiles are sex-specific. [2]Soft drinks, lemonade, sweetened juice-flavored drinks. [2]Tamales and tacos. [3]Pizza, hamburgers, salty snacks, processed soup, candy, jelly. Whole grains and nuts were excluded from analyses due to low (<10%) consumption. Alcohol was excluded from analyses due to low frequency of consumption (<0.5g/day). Abbreviations: INCAP, Institute of Nutrition for Central America and Panama; SSB, sugar-sweetened beverages; T, tertile.

Total variance explained in 2004: 28.6%

Total variance explained in 2015: 29.0%

Table 9.10. Food groups and food items from the food frequency questionnaire. INCAP Nutrition Supplementation Trial Longitudinal Cohort, 2002-2004.

Main group	Food groups	Food items
Grains	Corn tortilla	Corn tortilla
	Whole grains	Oatmeal
	Refined grains	White bread, wheat tortilla, rice (cooked, fried), corn flakes, noodles
	Pastry	Sweet bread, pastries
	Salty snacks	Chips (Papalinas/tortrix/ricitos)
Vegetables	Non-starchy vegetables	Avocado, beet, broccoli, cabbage, cactus (nopal), carrot, cauliflower, celery, chayote, cucumber, eggplant, greens, green beans, guicoy (sazon and tierno), herbs, lettuce, loroco flower, okra, onion, pacaya palm, radish, soy, sweet pepper, squash, tomato, yucca flower
	Tubers/starchy vegetables	Peas, corn, chayote root, turnip, potato (boiled), plantain (boiled)
	Fried starches	French fries, fried plantains
Fruits	Fresh fruits	Apple, banana (various types), blackberry, cashew fruit, chicozapote, coconut, grapes, green mango, grapefruit, guanabana, guava, jocote (yellow/red, green), leechee, mandarin orange, mamey, mango, melon, nance, orange, papaya, passion fruit, paterna, peach, pear, pineapple, plum, strawberry, sweet lime, sugar apple, sunza, watermelon, zapote
Meats	Poultry	Breast, leg, thigh, wing
	Red meat and pork	Beef or pork
	Processed meat	Pork sausage, hot dog, ham
	Giblets	Chicken (liver, gizzard, feet), beef (brain, kidney, liver, other)
	Fish	Fish
	Fried meat	Chicken (wing, thigh, leg, breast), pork skin
Eggs	Eggs	Eggs
Dairy	Dairy	Milk, cheese
Beans	Beans	Beans (boiled, smashed, refried)
Fats	Nuts	Peanuts
	Oils/fats	Cream or butter, mayonnaise
Sugar	Sugar	Sugar added to coffee
	Sweets	Candies, caramels, chocolates, ice cream, jelly
Beverages	Coffee	Coffee
	Alcohol	Beer, rum, whisky, other liquor
	Juice	Juice, lemonade
	Soda	Soda
Other	Processed soup	Dried/packaged soup
	Traditional Guatemalan foods	Tamale, taco
	Transitional foods	Hamburger, pizza

Abbreviations: INCAP, Institute of Nutrition for Central America and Panama.

Table 9.11. Food group factor loadings and mean intake (g) by PCA-derived dietary pattern tertile for Guatemalan women. INCAP Nutrition Supplementation Trial Longitudinal Cohort, 2002-2004 (n=742).

Food Groups	Meat-based Modern				Starch-based Modern				Traditional			
	Factor loading	T1[1] (g)	T2 (g)	T3 (g)	Factor loading	T1 (g)	T2 (g)	T3 (g)	Factor loading	T1 (g)	T2 (g)	T3 (g)
Corn tortilla	23	343.9	397.7	390.4	3	389.2	382.6	359.3	70	252.4	369.0	510.2
Refined grains	19	64.6	70.4	81.0	39	46.2	73.3	96.8	1	70.2	70.4	75.3
Pastry	25	32.5	52.7	66.7	12	42.3	52.2	57.3	6	46.4	51.1	54.2
Salty snacks	49	1.0	3.9	11.3	2	4.7	4.8	6.7	11	5.4	4.5	6.3
Non-starchy vegetables	8	90.0	77.9	93.0	52	34.7	73.1	154.0	-14	116.6	78.8	65.3
Starchy vegetables	3	37.0	36.2	41.2	56	12.5	29.1	73.3	-13	53.3	33.8	27.2
Fried starches	30	26.5	42.4	58.7	44	18.4	35.6	73.7	-10	49.7	44.6	33.0
Fruits	7	225.6	196.0	231.4	39	126.2	202.6	325.9	2	251.7	186.2	214.6
Eggs	35	19.4	29.8	37.6	21	22.3	29.5	34.9	31	20.1	30.9	35.8
Poultry	5	19.7	21.2	22.9	34	14.2	18.4	31.3	4	21.2	20.5	22.2
Red meat and pork	25	9.1	12.2	19.7	30	8.1	13.6	19.3	-24	18.7	13.0	9.3
Processed meats	39	4.7	8.1	15.2	26	5.8	8.5	13.7	-5	10.8	8.8	8.3
Giblets	8	14.7	13.5	17.0	47	5.3	10.4	29.7	7	12.4	15.8	17.1
Fish	23	5.6	9.6	13.0	21	4.3	6.7	17.3	14	9.1	7.7	11.3
Fried meats	51	8.7	17.2	30.8	19	13.0	20.2	23.4	-9	22.5	17.6	16.5
Dairy	14	64.6	80.9	103.1	34	32.4	83.5	133.1	-36	141.3	65.4	41.0
Beans	3	119.0	117.2	96.1	3	117.1	117.5	97.6	63	53.3	85.7	193.3
Oils/fats	24	6.6	9.8	13.7	37	5.2	9.1	15.9	0	11.1	9.5	9.4
Sugar added to coffee	-6	12.3	13.6	12.6	-2	12.8	13.4	12.3	36	7.5	11.6	19.4
Sweets	48	1.2	3.1	8.6	13	3.5	3.4	5.9	-16	6.7	3.5	2.6
Alcohol	39	0.1	0.3	5.7	-14	4.5	0.6	1.0	17	0.9	1.7	3.5
Juice	1	307.4	297.6	300.7	45	153.4	316.5	438.4	15	288.1	290.8	326.8
Soda	70	24.1	70.1	206.3	-9	105.3	93.8	100.1	-6	113.0	100.7	85.6
Packaged soup	-6	17.3	12.9	12.3	37	3.5	12.1	27.1	-8	18.7	11.1	12.7

Traditional Guatemalan foods[2]	36	25.9	39.7	69.2	17	36.2	42.0	56.4	9	42.4	45.4	46.7
Transitional foods[3]	55	1.0	1.4	8.4	7	3.2	2.5	5.2	-36	8.0	1.9	0.8

[1]Mean intake of food groups (g) across tertiles. [2]Tamales and tacos. [3]Pizza and hamburgers. Whole grains and nuts were excluded from analyses due to low (<10%) consumption. Abbreviations: INCAP, Institute of Nutrition for Central America and Panama; PCA, principal component analysis; T, tertile.

Table 9.12. Food group factor loadings and mean intake (g) by PCA-derived dietary pattern tertile for Guatemalan men. INCAP Nutrition Supplementation Trial Longitudinal Cohort, 2002-2004 (n=681).

Food Groups	Meat-based Modern				Starch-based Modern				Traditional			
	Factor loading	T1[1] (g)	T2 (g)	T3 (g)	Factor loading	T1 (g)	T2 (g)	T3 (g)	Factor loading	T1 (g)	T2 (g)	T3 (g)
Corn tortilla	23	543.3	561.9	576.7	3	527.6	570.9	583.1	70	406.3	547.0	728.5
Refined grains	19	81.0	89.9	104.8	39	61.7	88.4	125.4	1	97.4	88.7	89.6
Pastry	25	55.5	59.7	69.6	12	54.7	65.1	64.9	6	60.6	59.3	64.8
Salty snacks	49	3.0	9.4	19.2	2	11.8	9.8	9.9	11	8.7	10.9	11.9
Non-starchy vegetables	8	100.3	110.0	125.0	52	56.4	92.0	186.7	-14	134.5	103.0	97.8
Starchy vegetables	3	40.0	41.3	44.0	56	22.1	36.1	67.1	-13	46.1	43.3	36.0
Fried starches	30	34.6	50.7	71.9	44	30.0	50.7	76.3	-10	62.3	50.4	44.4
Fruits	7	268.3	262.0	281.0	39	146.9	267.4	396.4	2	264.7	239.8	306.7
Eggs	35	33.5	47.0	55.8	21	37.7	45.7	52.7	31	38.0	42.0	56.2
Poultry	5	19.4	19.9	22.3	34	12.7	19.7	29.3	4	19.0	19.3	23.4
Red meat and pork	25	11.0	16.2	21.4	30	11.3	13.3	23.9	-24	22.3	14.1	12.1
Processed meats	39	7.0	15.0	25.5	26	9.9	15.7	21.9	-5	19.5	14.0	14.1
Giblets	8	12.6	15.2	19.7	47	6.5	13.6	27.3	7	14.5	13.9	19.1
Fish	23	12.4	19.6		21	11.7	16.3	32.2	14	12.6	21.3	26.4
Fried meats	51	12.8	24.8	40.5	19	21.3	24.8	31.9	-9	32.7	23.5	21.8
Dairy	14	49.2	66.3	91.3	34	35.2	64.2	107.0	-36	99.6	56.2	50.8
Beans	3	137.0	154.3	139.0	3	134.6	143.9	151.8	63	78.7	111.4	240.3
Oils/fats	24	10.3	15.0	17.4	37	8.3	13.3	21.1	0	14.7	14.3	13.8
Sugar added to coffee	-6	12.3	11.8	11.4	-2	11.9	11.7	11.8	36	7.5	11.4	16.5
Sweets	48	2.7	6.5	12.7	13	5.3	6.8	9.8	-16	9.9	6.0	5.9
Alcohol	39	12.5	55.1	124.1	-14	100.1	45.4	46.1	17	42.9	61.5	87.0
Juice	1	389.6	395.0	351.8	45	194.8	377.5	563.4	15	329.5	368.8	438.3
Soda	70	79.3	206.5	404.7	-9	283.8	218.1	187.9	-6	280.3	205.4	203.9
Packaged soup	-6	15.7	12.3	12.2	37	6.8	9.9	23.6	-8	17.4	11.8	11.0

Traditional Guatemalan foods[2]	36	29.2	48.1	79.6	17	41.9	53.7	61.2	9	44.0	56.3	56.4
Transitional foods[3]	55	2.3	5.3	20.8	7	8.4	9.4	10.5	-36	20.0	4.8	3.5

[1]Mean intake of food groups (g) across tertiles. [2]Tamales and tacos. [3]Pizza and hamburgers. Whole grains and nuts were excluded from analyses due to low (<10%) consumption. Abbreviations: INCAP, Institute of Nutrition for Central America and Panama; PCA, principal component analysis; T, tertile.

Table 9.13. Food group factor loadings and mean intake (g) by PCA-derived dietary pattern tertile for a randomly split study sample of Guatemalan adults to assess internal validity of dietary patterns. INCAP Nutrition Supplementation Trial Longitudinal Cohort, 2002-2004 (n=373 women, n=344 men).

Food Groups	Meat-based Modern				Starch-based Modern				Traditional			
	Factor loading	T1[1] (g)	T2 (g)	T3 (g)	Factor loading	T1 (g)	T2 (g)	T3 (g)	Factor loading	T1 (g)	T2 (g)	T3 (g)
Women												
Corn tortilla									65	260.2	383.0	502.9
Refined grains					40	47.9	73.4	99.2				
Salty snacks	57	0.7	2.1	13.8								
Non-starchy vegetables					48	39.5	74.7	142.1				
Starchy vegetables					48	13.7	28.7	80.4				
Fried starches					48	20.1	32.0	74.8				
Fruits					44	110.3	206.9	326.5				
Poultry					38	14.2	17.0	30.4				
Processed meats					42	4.3	8.4	15.4				
Giblets					37	6.4	12.0	27.1				
Fried meats	49	9.3	16.6	28.3								
Eggs									38	16.7	30.9	33.1
Dairy					39	27.0	84.9	126.7				
Beans									65	50.6	85.9	196.9
Oils/fats					43	4.8	8.6	16.1				
Sugar added to coffee									39	7.1	10.4	21.0
Sweets	51	1.2	3.1	10.2								
Alcohol	45	0.1	0.1	10.1								
Juice					40	178.8	314.6	395.1				
Soda	68	273.0	279.8	335.5								
Packaged soup					39	2.7	12.1	28.1				

Traditional Guatemalan foods[2]	37	26.2	36.4	73.8								
Transitional foods[3]	39	1.3	2.7	8.1								
Men												
Corn tortilla									65	421.0	532.1	710.4
Refined grains					40	57.5	86.8	131.8				
Salty snacks	57	2.0	7.2	21.3								
Non-starchy vegetables					48	58.2	112.1	183.9				
Starchy vegetables					48	22.9	42.7	67.3				
Fried starches					48	30.0	45.8	86.3				
Fruits					44	113.3	273.5	408.0				
Poultry					38	12.8	19.0	30.1				
Processed meats					42	6.3	15.8	27.1				
Giblets					37	7.4	14.8	25.3				
Fried meats	49	13.4	24.8	38.1								
Eggs									38	31.5	42.3	62.5
Dairy					39	34.5	62.8	118.2				
Beans									65	75.2	109.7	216.0
Oils/fats					43	7.1	14.2	23.6				
Sugar added to coffee									39	7.4	12.1	15.2
Sweets	51	2.5	5.0	14.4								
Alcohol	45	9.5	50.8	150.0								
Juice					40	227.5	425.3	579.8				
Soda	68	366.4	449.4	416.3								
Packaged soup					39	4.3	10.8	27.2				

Traditional Guatemalan foods[2]	37	27.7	49.7	77.4
Transitional foods[3]	39	3.5	8.4	16.1

[1]Mean intake of food groups (g) across tertiles. [2]Tamales and tacos. [3]Pizza and hamburgers. Whole grains and nuts were excluded from analyses due to low (<10%) consumption. Abbreviations: T, tertile.

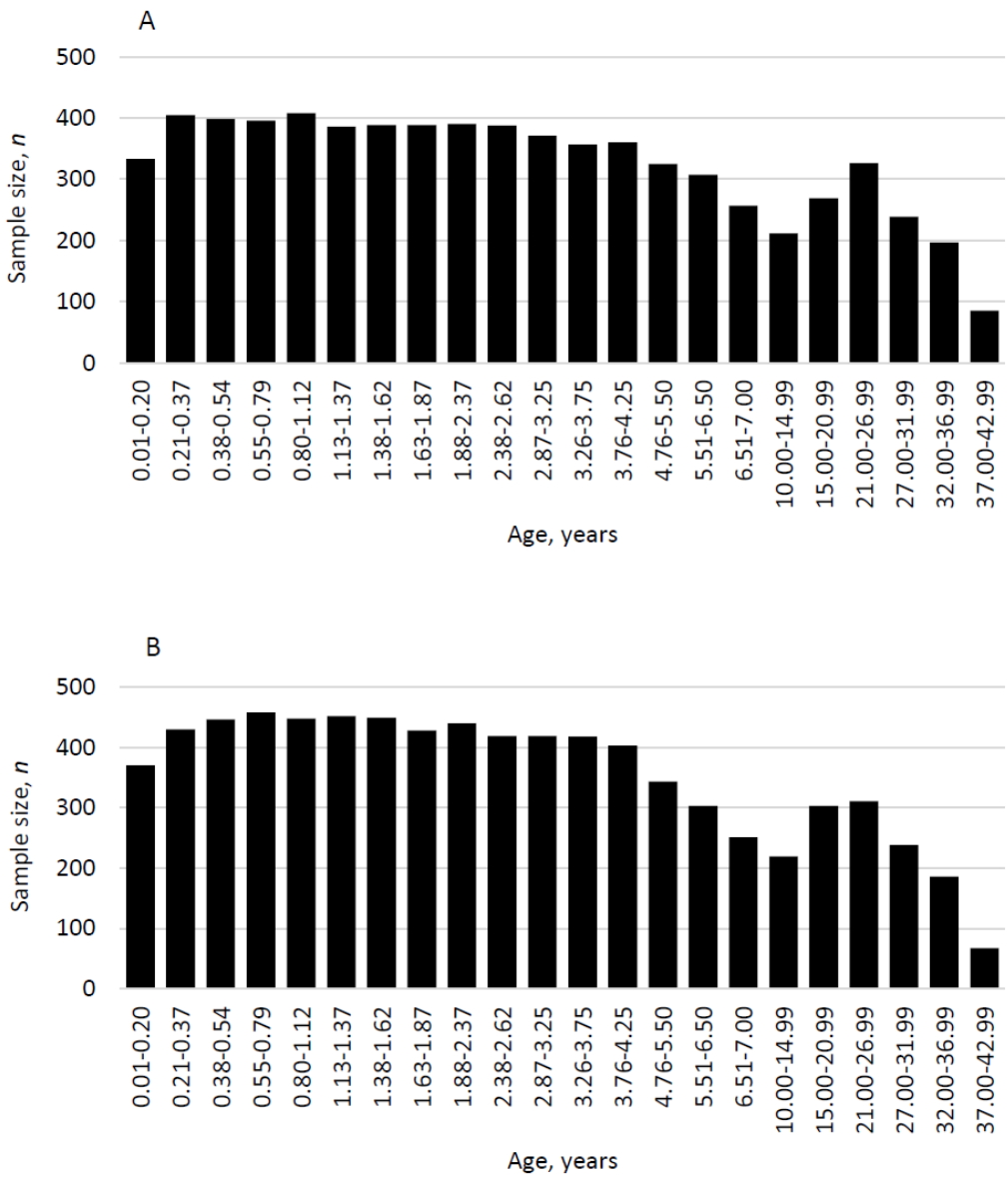

Figure 9.1. Sample size of body mass index by age for females (A) and males (B) in the INCAP Nutrition Supplementation Trial Longitudinal Cohort