Summer 2021

Household Food Security, Lifestyle Factors, and Glycemic Control Among Youth and Young Adults With Diabetes

Lauren A. Reid

HOUSEHOLD FOOD SECURITY, LIFESTYLE FACTORS, AND GLYCEMIC CONTROL AMONG YOUTH AND YOUNG ADULTS WITH DIABETES

by

Lauren A. Reid

Bachelor of Science
Kennesaw State University, 2013

Master of Public Health
University of South Carolina, 2016

Submitted in Partial Fulfillment of the Requirements

For the Degree of Philosophy in

Epidemiology

Arnold School of Public Health

University of South Carolina

2021

Accepted by:

Angela D. Liese, Major Professor

Marco Geraci, Committee Member

Anwar Merchant, Committee Member

Jason Mendoza, Committee Member

Tracey L. Weldon, Interim Vice Provost and Dean of the Graduate School

DEDICATION

My dissertation is dedicated to my dearly departed grandmother, Francine Melissa Edwards Tucker. She was a phenomenal woman, a loved educator, and she always encouraged me to be the best at whatever task I set for myself. I can hear her saying "Be a task great or small, do it well or not at all." I know she would be proud. Grandmama, I studied my lesson.

I would also like to dedicate my dissertation to my son, my legacy, Harvey Gennadi Hills. I want him to know that if you set goals, work hard, and stay committed, you can surpass your wildest dreams. My ultimate goal is to give him a future he deserves and make it possible for him to dream big.

ACKNOWLEDGEMENTS

First, I would like to acknowledge my dissertation committee. I am extremely grateful for the support, expertise, and constructive feedback I received to make this dissertation possible. Thank you to my dissertation chair, Dr. Angela Liese for agreeing to mentor me when I was a novice epidemiology student. The guidance, patience, and grace I received from her during this journey is unmatched.

I would like to acknowledge my mother, Dr. Samela Francine-Tucker Reid, for setting positive examples for me early on and showing me that earning a doctoral degree was possible. On days I struggled, I channeled my determination to keep going from her. Thanks to her sacrifices, I am the person I am today. I would also like to acknowledge my brother Zachary-Eugene Tucker Reid for helping me create tables for chapter 6. He relieved so much stress when I was feeling overwhelmed. He is a great brother!

I must acknowledge my friends and family who helped me with Harvey during my time as a student. To my brother, Alexander Tucker Reid, thank you for keeping Harvey on weekends so that I could research, write, and edit my dissertation. Harvey and I agree that he is the cool uncle. Thank you to Dr. Michele Josey and Amara Marshall, for taking care of Harvey when I did not have a babysitter so that I could go to class. Thank you to Harvey's aunt, Shaquita Lee, for always saying yes to keeping Harvey so that I could work on weekends. To Harvey's grandmother, Jenette Outing, thank you for giving me time to work and time to take a break. Thank you Shawndya Clark for being my go-to

Atlanta babysitter. I would like to especially acknowledge my cousins Charles and Shanda Kearse for allowing me to move in with them for a semester of school. Harvey was only 7 months old, and I was grappling with being a new mother. I would not have made it to this point without their generosity. Thank you to anyone that I may have missed. It takes a village to raise a child and I would be lost without mine.

Finally, I would like to acknowledge Omar Hills for making daycare possible, keeping me company as I worked, staying up late with me while I was writing, tough love, and unconditional support.

ABSTRACT

The purpose of this study was to assess the associations between household food insecurity (HFI) and glycemic control, physical activity, and diet quality in youth and young adults (YYA) with type 1 diabetes (T1D) and type 2 diabetes (T2D). Among older adults, HFI has been shown to complicate diabetes management due to the essential role of diet in diabetes management and the financial stress associated with HFI. Although HFI is more prevalent among YYA with diabetes than the general population, there are only a handful of studies that have focused on this population and, studies that include YYA with T2D are especially rare.

Each study cross-sectionally analyzed the association between HFI and outcomes using data from the SEARCH for Diabetes in Youth Study. HFI was measured with the 18-item US Household Food Security Survey Module. The survey was completed by young adult SEARCH participants or by parents of participants that were less than 18 years old.

The first study focused on the association between HFI and HbA1c, glycemic control, and acute diabetes complications (experiencing either diabetic ketoacidosis or hypoglycemia in the last year) in YYA with T2D. The results suggested that YYA with T2D were more likely to experience diabetic ketoacidosis or hypoglycemia if they lived in a food insecure household than a food secure household. The second study assessed the association between HFI, physical activity and inactivity. It found that YYA with

T1D reported more time walking per week if they had HFI than if they did not. Additionally, YYA with T2D who had HFI spent more time sitting per day than those that did not have HFI. The final study examined the association between HFI and diet quality, measured with the Health Eating Index-2015. There was no statistical difference in diet quality between those who had HFI and those that did not. However, females with T1D and HFI had lower sodium component Health Eating Index-2015 scores than those who were food secure.

Each individual study indicated that HFI impacts diabetes management and/or behaviors which affect diabetes control in YYA with diabetes. Collectively, these studies lay the foundation for future analyses to assess the mediating role of lifestyle factors such as diet quality and physical activity in the relationship between HFI and glycemic control in YYA with diabetes. Ultimately, this research contributes broadly to the food insecurity literature and the body of evidence calling for diabetes healthcare providers to universally screen for HFI and tailor diabetes management plans to overcome obstacles that interfere with diabetes management.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ADA..American Diabetes Association

AOR..Adjusted Odds Ratio

CGM ....Continuous Glucose Monitoring

CI..Confidence Interval

DGA... Dietary Guidelines for Americans

DKA.. Diabetic Ketoacidosis

FFQ ....Food Frequency Questionnaire

HEI-2015..Healthy Eating Index-2015

HFI ....Household Food Insecurity

HFS ....Household Food Security

HFSSM ....Household Food Security Survey Module

IPAQ-SF ....International Physical Activity Questionnaire Short Form

IPS...Initial Patient Survey

MPA...Moderate Physical Activity

MVPA ....Moderate to Vigorous Physical Activity

NIDDK..........................National Institute of Diabetes and Digestive and Kidney Diseases

PA ....Physical Activity

PAGA..Physical Activity Guidelines for Americans

SEARCH...SEARCH for Diabetes in Youth Study

T1D .... Type 1 Diabetes

T2D .... Type 2 Diabetes

VPA..Vigorous Physical Activity

YYA...Youth and Young Adults

CHAPTER 1

INTRODUCTION

Household food insecurity (HFI) is defined as “limited or uncertain availability of nutritionally adequate and safe foods or limited or uncertain ability to acquire acceptable foods in socially acceptable ways.”[1] In 2018, 11% of U.S. households were food insecure at least some time during the year.[2] The prevalence of HFI is even higher among low income households, households with children (13.9%), households with children headed by single caregiver (27.8% if female and 15.9% if male), women and men living alone (14.2% and 12.5%, respectively), and households in principal cities (13.2%).[2,3] HFI tends to vary by race and gender. In 2018, 8.1% of non-Hispanic Whites had HFI, 16.2% of Hispanics had HFI, and 21.2% of non-Hispanic Blacks had HFI.[2] Women consistently have more food insecurity than men in resource-rich and resource limited areas.[3]

HFI is also prevalent among adults with cardiometabolic diseases,[4] specifically diabetes,[5] and families with a child who has diabetes.[6] In studies of youth and young adults with diabetes, the prevalence of HFI is usually around 20%[6–8], with a slightly higher prevalence among youth with T2D (~29%) than type 1 diabetes ([T1D]~16%; $p< 0.010$).[8] Food insecurity is problematic for people with diabetes because food insecurity complicates the goal of normoglycemia[9] by increasing the risk of hyper- and hypoglycemia. There is an increased risk for hyperglycemia because people with diabetes and HFI may frequently eat inexpensive, carbohydrate-rich, processed foods or binge eat. They may also have to choose between filling diabetes medication prescriptions and buying food. There is an increased risk of hypoglycemia due to inadequate or erratic carbohydrate consumption following administration of sulfonylureas or insulin.[10,11]

Because food insecurity complicates diabetes management and providers need to be prepared to guide their patients with food insecurity,[10,11] the American Diabetes Association (ADA) began recommending universal screening for and addressing food insecurity as tailored treatment to help people manage diabetes in 2017.[11,12]

The HFI and diabetes literature currently primarily focuses on HFI and glycemic control of adults with T2D.[13–18] For example, a study of low income adults with T2D found that participants with food insecurity were significantly more likely than food secure participants to have poor glycemic control as defined by $HbA_{1c} \geq 8.5\%$.[13] One small pilot study exists which concluded that HFI is associated with poor glycemic control in youth and young adults (YYA) with T1D.[7] However, there are virtually no studies focusing on youth with T2D.[19] Poor diabetes management is of particular concern for young people with T2D because YYA with T2D have a higher risk of developing chronic complications, including nephropathy and retinopathy.[20] Moreover, YYA with T2D are typically overweight or obese and therefore prone to secondary comorbidities such as cardiovascular disease,[21] and the long-term risk of cardiovascular disease in YYA with T2D is worse than in those who are diagnosed as older adults.[21]

HFI may also negatively impact lifestyle factors such as physical activity (PA), and diet quality which in turn influence glycemic control. The benefits of regular PA for people with diabetes are well established;[22–24] and, PA is usually prescribed as a lifestyle change in addition to prescribed medications.[25] Two studies, among healthy populations, have found that food insecurity was associated with decreased PA – one among children[26] and, one among adolescents and adults.[27] Sedentary behavior research suggests that those who engage in high amounts of sedentary behavior (i.e. sitting) can be at increased risk of morbidity and mortality regardless of their level of PA.[28] Food insecurity may encourage inactivity among YYA with diabetes because they are less energetic.

Poorer dietary intake and higher prevalence of nutrient inadequacy have been observed among seemingly healthy adolescents and adults in food insecure households.[29] Additionally, greater levels of child reported food insecurity have resulted in higher consumption of energy, fat, sugar, and fiber and a diet lower in vegetables.[26] General public health research supports that hunger and undernourishment are often associated with poor meal planning and disordered eating patterns among people with diabetes.

Between 2001 and 2009, the SEARCH for Diabetes in Youth Study documented a 21% increase in type 1 diabetes (T1D) and a 31% increase in type 2 diabetes (T2D) prevalence in U.S. youth and young adults (YYA).[30] Additionally, between 2002 and 2012, the relative annual increase in the incidence of T1D was 1.8% and that of T2D was 4.8%.[31] These trends suggest that an increasing number of youth and young adults, many with food insecurity, will be burdened with diabetes. Therefore, studying the effects of food insecurity in youth and young adults with diabetes is of utmost importance. The overarching goal of this study is to assess the associations between HFI and glycemic control, PA, diet quality.

Aim 1: To examine the association between household food security (HFI), glycemic control, and acute diabetes complications (experiencing diabetic ketoacidosis (DKA) or hypoglycemia) among youth and young adults with type 2 diabetes.

Hypothesis: HFI will be associated with higher HbA_{1c}, worse glycemic control, and a higher odds of experiencing either DKA or hypoglycemia in the last 12 months.

Implications: There is substantial evidence which supports an association between HFI and glycemic control among older adults with T2D[13–18,32,33] and new evidence to support a relationship between HFI among youth and young adults with T1D.[7] T2D in youth and young adults is unique from T2D among older adults and T1D among youth and young adults and therefore requires a unique study. A significant association between HFI and glycemic control found among youth and young adults with T2D will support the growing body of evidence that in the presence of HFI, glycemic control is difficult. As this body of evidence grows, researchers and clinicians can support arguments to improve diabetes education.[15]An observed association could also encourage diabetes educators to consider that their patients may not have access to adequate food for successful diabetes management and work with their patients to manage their diabetes accordingly. It may also encourage diabetes healthcare providers to be aware of foodbanks, food-share programs, and federal assistance programs that may help their patients. In terms of policy, results of this study may bolster the body of evidence aiming to encourage healthcare providers to identify people with HFI and diabetes[7] and at an institutional level support linking people to more reliable food access. Long term, results of this study may influence interventions aiming to stop the cycle of food insecurity and chronic disease. Stopping this cycle will, over time, decrease healthcare expenditures.

Aim 2: To examine the association between HFI and PA in YYA with T1D and T2D.

Hypothesis 1: YYA with HFI will have lower PA levels than YYA who have household food security (HFS).

Hypothesis 2: YYA with HFI will spend more time sitting than YYA who have HFS.

Implications: The results of this aim may help interventions aiming to improve food insecurity also improve PA and reduce sedentary behaviors in YYA with diabetes.[27] Additionally, an observed association between HFI and PA levels will support the body of evidence which encourages health care providers to assess HFI in addition to well-being assessments such as PA level.[26]

Aim 3: To examine the association between HFI and DQ in YYA with T1D and T2D

Hypothesis: YYA with HFI will have poorer DQ scores than YYA who have HFS.

Implications: Studies generally show that there is an association between food insecurity and diet quality among adults.[34] Although a systematic review of food insecurity and diet quality in US children and adults concluded that parents may shield their children from poor diet quality caused by food insecurity, the authors also concluded that this evidence is not consistent.[34] Actually, several studies show that food insecurity negatively impacts diet patterns and diet quality among youth and adolescents.[26,35–37] The results of this aim would support the growing body of evidence supporting a negative impact of food insecurity on diet quality in YYA. Long term, a consistent body of evidence on HFI and diet quality will help research interventions targeting YYA with HFI improve their diet quality. Specific to YYA with diabetes, the results of this study will strengthen the literature arguing that people with diabetes and HFI have increased difficulty following a high-quality diet needed to manage diabetes. This will help diabetes educators and clinicians know how to better serve patients with HFI.

Aim 3a: To assess the association between HFI and component scores of the 2015 Healthy Eating Index (HEI) among YYA with T1D and T2D.

Hypothesis 3a: YYA who have HFI will have poorer scores for HEI adequacy components (e.g., total fruits, whole fruits, total vegetables, green beans, whole grains, dairy, total protein foods, seafood and plant proteins, and fatty acids) and poorer scores for moderation components (e.g., refined grains, sodium, added sugars, and saturated fats) than YYA who have HFS.

Implications: A deeper understanding of specific dietary components negatively impacted by HFI will help diabetes educators, health care providers, and interventionists target and focus on specific problematic food categories when working with YYA that have diabetes and HFI.

1.1 Conceptual Framework

Weiser et al. (2011) proposed a conceptual framework for understanding bidirectional links between food insecurity and HIV/AIDS.[38,39] The authors describe structural drivers (ecological, economic, and social factors), which influence three pathways through which food insecurity ultimately influences the acquisition and/or progression of HIV.[38] The three pathways through which food insecurity influence HIV/AIDS are 1) nutritional pathways, 2) mental health pathways, and 3) behavioral pathways. This conceptual framework can be modified and applied to individuals with diabetes,[39] and will be for the purpose of the present study. Specifically, the proposed studies will focus on nutritional and behavioral pathways between HFI and diabetes management as well as a direct pathway between HFI and diabetes management, measured via glycemic control. A diagram of the proposed framework is depicted in Figure 1.1.

Several studies exist to support a relationship between food insecurity and glycemic control among adults with diabetes and YYA with T1D. [7,13,14,40] There is sparse research on food insecurity and glycemic control among YYA with T2D. Food insecurity in North America is consistently more prevalent among households with a person living with diabetes, and similarly, diabetes is also more prevalent in food-insecure households.[41]

The behavioral pathways between HFI and glycemic control are possibly the more established pathways in the literature. Behaviors such as cost-related poor adherence to prescriptions and missed appointments are frequently found to be associated with food insecurity[39] and negatively impact diabetes management and healthcare utilization. Aim 2 focuses specifically on physical activity and inactivity behaviors of YYA with diabetes. HFI has been found to be associated with less physical activity among children and adults in the U.S. population.[27] There is substantial evidence that physical activity improves glycemic control.[42] Through the nutritional pathway, research consistently finds that food insecurity is associated with poor eating habits. For example, in a study on food insecurity and cardiometabolic risk factors among adolescents, food insecurity was associated with not eating breakfast daily.[35] A systematic review by Hanson et al. (2014) concluded that food insecurity negatively impacts intake of nutrientrich vegetables, fruit, and dairy that promote good health in U.S adults and fruit consumption in U.S. children.[34] There is also evidence that regardless of obesity status, poor diet can lead to general greater morbidity among people with diabetes.[39] A study among outpatients with type 2 diabetes found that lower diet quality, defined by the Healthy Eating Index-2010, was associated with poor glycemic control.[43]

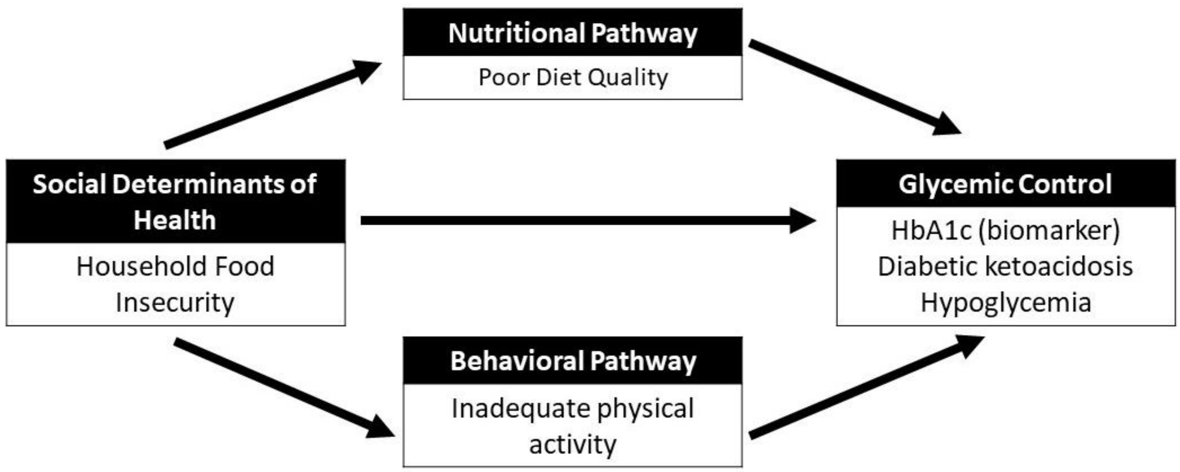

Figure 1.1 Conceptual framework of food insecurity's impact in persons with diabetes, modified from Weiser et al. (2015)

,

CHAPTER 2

LITERATURE REVIEW

2.1 Household Food Insecurity

Household food insecurity (HFI) is defined as “limited or uncertain availability of nutritionally adequate and safe foods or limited or uncertain ability to acquire acceptable foods in socially acceptable ways.”[1] This definition was first developed in 1990 by the Life Science Research Office of the Federation of American Societies for Experimental Biology.[1] HFI is different from hunger in that hunger can result from situations such as dieting or being too busy to eat. Hunger is also an individual experience in that some members of a household may be hungry, while others are not. In contrast, HFI is primarily a result of financial resource constraint and adverse social conditions. It is also a group level phenomenon because it includes all individuals in the household. The Household Food Security Survey Module was developed by the United States Department of Agriculture (USDA) and focuses on households that do not have enough food or money to buy food.[1] The USDA and the U.S. Census Bureau uses the Household Food Security Survey Module to estimate population level HFS and HFI in the U.S.[2]

2.1.1 Epidemiology of HFI in the U.S.

The prevalence of HFI reached a high of 14.9% in 2011.[2] In 2018, the prevalence of HFI in the United States was 11.8% (~14.3 million households), with 4.3% (~5.6 million households) of households experiencing very low food security.[2] Very low food security is categorized as the most severe range of food insecurity and indicates that "food intake of some household members was reduced and normal eating patterns were disrupted at times during the year due to limited resources."[2] The full impact of the COVID-19 pandemic is yet to be understood; however researchers expect HFI to have increased due to pandemic-induced adverse economic and social conditions. Early impact studies have found a 32.3% increase in household food insecurity since COVID-19 ($p < 0.001$), with 35.5% of food insecure households classified as newly food insecure.[44] A Feeding America report indicates that a 1.1% increase in unemployment and a 1.5% increase in poverty due to the coronavirus will result in 3.3 million new food insecure individuals and a 4.5% increase in unemployment coupled with a 2.6% increase in poverty will result in 9.9 million additional individuals who are food insecure.[45] The U.S Bureau of Labor and Statistics released a report on May 13, 2020 that the unemployment rate in April 2020 increased by 10.3 percentage points to 14.7%.[46]

In 2018, 13.9% of United States households with children were food insecure at some point in that year. A little more than half of these households in 2018 (7.1%) included food insecurity for both adults and children, meaning approximately 2.7 million households were at some time during the year not able to provide adequate and nutritious food for children in the home.[2] Overall, HFI decreased in 2018 from 15.7% in 2017.[2]

In comparison to 11.8% of households with HFI in the US, the prevalence of HFI has been found to be higher among low income households (incomes near or below the federal poverty line), households with children (13.9%), households with children headed by a single caregiver (27.8% if head is female and 15.9% if male), women and men living alone (14.2% and 12.5%, respectively), and households in principal cities (13.2%).[2,3] HFI also tends to vary by race and gender. In 2018, 8.1% of non-Hispanic Whites had HFI, 16.2% of Hispanics had HFI, and 21.2% of non-Hispanic Blacks had HFI.[2] Women consistently have more food insecurity than men in resource-rich and resource limited areas.[3]

2.1.2 Consequences of HFI

Food insecurity has been found to be associated with a vast array of adverse consequences beyond hunger and low nutrient intake.[39] In adults, food insecurity has been linked to non-communicable diseases[39] and non-communicable disease risk factors such as obesity[47], high blood pressure[4], abnormal blood lipids[4], poor diabetes management[40], and obstructive health behaviors.[27,34] HFI has also been linked to HIV[48–50], and poor mental health outcomes including stress, anxiety, and depression among females in high income countries.[51]

Experiencing food insecurity early in life can impact the growth and development of children and adolescents.[39,52] For example, food insecurity has been documented as a risk factor for childhood stunting in resource-poor settings.[53] Among children in resource-rich settings, associations have been found between food insecurity and delayed development,[54] decreased health care access,[55] and poor health.[56] Further, food insecurity among children and adolescents has been linked to undesirable academic outcomes, mental health and behavioral problems, fewer friends, substance abuse, chronic illnesses, lower physical activity levels, and poor diet quslity.[27,35,36,57–60] Robson et al (2017) assessed cardiometabolic risk factors among adolescents in Pennsylvania using NHANES 2014-2015 data, and found that after adjusting for sex, race/ethnicity, school grade, and neighborhood safety, food insecure adolescents had an increased odds of not eating breakfast each day (adjusted odds ratio [AOR] = 2.27; 95% confidence interval [CI], 1.61–3.21), reporting less than 8 hours per day of sleep (AOR = 1.60; 95% CI, 1.15–2.23), being a current cigarette smoking (AOR = 1.65; 95% CI, 1.16–2.36), and reporting alcohol consumption (AOR = 1.36; CI, 1.01–1.84), compared with food-secure adolescents.[35]

2.2 Diabetes

Diabetes mellitus is a group of metabolic diseases characterized by hyperglycemia, or chronic elevation of blood glucose (blood sugar).[61,62] Hyperglycemia, is a result of pancreatic β-cell dysfunction leading to impaired insulin secretion (i.e. too little insulin) and/or ineffective insulin action (i.e. the body can not use insulin properly due to insulin resistance).[61,62] The long-term complications linked to hyperglycemia and uncontrolled diabetes include damage to major organs, especially the eyes, kidneys, nerves, heart, and blood vessels.[62] The vast majority of cases of diabetes fall into two broad etiopathogenetic categories: Type 1 Diabetes (T1D) and Type 2 Diabetes (T2D).[62] There are a few caveats regarding diagnosis T1D and T2D. First, at the time of diagnosis, some individuals cannot be clearly diagnosed with T1D or T2D because these diseases are heterogeneous, meaning clinical presentation and disease progression may vary considerably from person to person.[33,62] Additionally, the traditional idea that T1D occurs in children and T2D occurs in adults is not accurate, as both diseases occur in both age-groups.[33]

2.3 Type 1 Diabetes in Youth

2.3.1 Definition and Diagnosis of T1D

T1D can be further categorized into immune-mediated diabetes and idiopathic diabetes.[33,62] Immune-mediated diabetes is the more common of the two, making up 5-

10% of all diabetes cases.[33,62] It results from cellular-mediated autoimmune destruction of the pancreatic β-cells which usually leads to complete insulin deficiency.[33,62] The rate of β-cell destruction is variable; however, it is mainly rapid in infants and children and slower in adults.[62] Immune-mediated T1D progression is recognized in 3 stages. Stage 1 includes warning signs of autoimmunity, however glycemic control is still within a healthy range and the person is asymptomatic.[33] Stage 2 includes dysglycemia (abnormal blood glucose).[33] Clinical symptoms are presented in stage 3 along with hyperglycemia.[33] Children and adolescents typically present with the hallmark symptoms of polydipsia/ polyuria (intense thirst despite taking in fluids/passing abnormally large amounts of urine), and/or ketoacidosis (blood acids or ketones are produced in excess) as the first manifestation of T1D.[33,62] A T1D diagnosis is confirmed with hyperglycemia and a random plasma glucose ≥ 200 mg/d (11.1 mmol/L).[33]

Less is known about idiopathic T1D. Scientists believe that there is no known etiology therefore, research is needed to determine the cause of β-cell destruction.[33,62] Additionally, people with idiopathic T1D are insulin deficient and prone to ketoacidosis but, there is no evidence of β-cell autoimmunity and insulin replacement therapy may be needed intermittentantly.[33,62]

2.3.2 Epidemiology of T1D in Youth

The SEARCH for Diabetes in Youth Study (SEARCH) analyses support that the incidence and prevalence of T1D is increasing in the US.[31,63] In 2002-2003, the incidence of T1D in youth < 20 years old was 19.5 cases per 100,000 youths per year. In 2011-2012, the incidence increased to 21.7 cases per 100,000 youths per year, resulting in an unadjusted annual increase in T1D incidence of 1.4% [CI: 0.1-2.8%, p-value = 0.03. [31]

After adjusting for age, sex, and race/ethnicity, the relative annual increase in T1D incidence was 1.8% (CI: 1.0-2.6%, p-value<0.001).[31] The incidence of T1D in youth in 2014-2015 was 22.3 cases per 100,000 youths per year. The adjusted annual percent change from 2002-2003 to 2014-2015 was 1.9% per year (CI: 1.34 to 2.51).[64] The annual percentage change from 2002-2015 was higher among blacks (2.7% per year), Hispanics (4.0% per year) and Asians and Pacific Islanders (4.4% per year) than among whites (0.7% per year).[64]

The prevalence of T1D in US youth < 20 years increased from 1.48 per 1, 000 in 2001 to approximately 1.93 per 1000 in 2009.[30] Recent SEARCH data indicates that in 2017, the prevalence of T1D in youth had increased to 2.24 per 1000.[65] Between 2001 and 2017, the annual percentage change in prevalence was 2.3% (CI: 2.1- 2.6%).[65] During this time period, T1D prevalence increased among those who are non-Hispanic white (Δ= 0.89, 0.84-0.94; annual percent change=2.5%, 2.2- 2.7%) and non-Hispanic black youth (Δ= 0.86, 0.76-0.95; annual percent change=3.2%, 2.5-4.0%).[65] Assuming constant incidence over time, the number of US youth with T1D is projected to increase from 166,018 in 2010 to 203,382 in 2050.[66]

2.3.3 Treatment and Management of T1D

Treating and managing T1D in youth requires a multidisciplinary team of pediatric specialists in diabetes self-management education and support, medical nutrition therapy, and psychosocial support, to address the unique aspects of care that youth and their families need.[33] The American Diabetes Association Standards of Care in Medicine states that most children with T1D will need to be treated with intensive insulin therapy through multiple daily injections of insulin or continuous insulin infusion.[33] Healthcare providers should be aware of existing racial/ethnic disparities in insulin treatment among children with T1D. Research indicates that Non-Hispanic White children are twice as likely to use an insulin pump than Non-Hispanic Black children and the odds of Hispanic children using insulin pumps are higher than Non-Hispanic Black children. This racial disparity has existed for the last 15 years, adjusted for insurance status.[67] Standardized treatment protocols may reduce unconscious bias in prescribing.[67] It is also recommended that continuous glucose monitoring be considered in all youth with T1D to help manage their glucose and know when insulin is needed.[68]

In addition to insulin therapy, nutrition therapy and physical activity or exercise are needed to help youth with T1D manage their diabetes.[33,68] Nutrition therapy and physical activity recommendations for youth with T1D along with evidence grades assigned by the American Diabetes Association are presented in Tables 1 and 2. It is important for specialists to develop individual approaches when prescribing nutrition therapy and exercise programs for people with T1D.[33,69] Dietary plans should have family habits, food preferences, religious or cultural needs, finances, schedules, physical activity, the youth's diabetes education level and self-management ability taken into consideration.[33]

The physical activity recommendation for youth with T1D is the same recommendation for youth without diabetes: attaining an average of 60 minutes of moderate-to-vigorous intensity aerobic activity per day and muscle-strengthening and bone strengthening activities at least 3 days per week.[33,68,70] In general, the literature supports the importance of physical activity to manage diabetes, improve health indicators, and support the psychological well-being of youth with T1D.[24,69,71,72] In youth with T1D, regular physical activity has been shown to improve lipid levels, improve endothelial function, increase insulin sensitivity (both short and long term), lower blood glucose levels, ameliorate body mass composition, and improve cardiovascular function thereby reducing cardiovascular disease mortality.[69,72] However, due to the loss of the beta-cell pancreatic mass and/or b-cell function, individuals with T1D may face challenges before, during, and after exercise.[69] If insulin levels are too high, hypoglycemia may arise during and after exercise; and if insulin levels are low, exercise may lead to hyperglycemia or DKA.[23,69] Recommendations, benefits, and challenges of physical activity and exercise should all be taken into consideration when individual exercise plans are prescribed to people with diabetes.

2.3.4 Glycemic Control of T1D

The generally accepted HbA_{1c} target for youth with T1D is 7.5%; however, an HbA_{1c} target can be individualized based on the needs and situation of the youth and their family.[68] Glycemic control is of concern for youth and young adults (YYA) with T1D, as 17% have HbA_{1c} levels reflecting poor glycemic control ($HbA_{1c} \geq 9.5\%$);[73] and, more than half (55.6%) do not achieve optimal glycemic control ($HbA_{1c} < 7.5\%$).[73] Racial/ethnic disparities in glycemic control also exist. Approximately 65% of non-Hispanic black and 61% of Hispanic YYA with T1D do not have optimal glycemic control compared to 29% of non-Hispanic whites.[73] A review published in 2016 by Walker et al.[18] found that racial or ethnic differences in glycemic control persist. When glycemia is not properly managed DKA and hypoglycemia are two acute complications that often occur in youth with T1D.[33,68]

Table 2.1. Nutrition Therapy Recommendations by the American Diabetes Association for Youth with Type 1 Diabetes, Standards of Care in Diabetes (2020)

	Grade
• Monitoring carbohydrate intake whether by carbohydrate counting or experience-based estimation, is key to achieving optimal glycemic control.	A
• Comprehensive nutrition education at diagnosis, with annual updates, by an experienced registered dietitian nutritionist is recommended to assess caloric and nutrition intake in relation to weight status and cardiovascular disease risk factors and to inform macronutrient choices.	B
• Comprehensive nutrition education at diagnosis, with annual updates, by an experienced registered dietitian nutritionist is recommended to assess caloric and nutrition intake in relation to weight status and cardiovascular disease risk factors and to inform macronutrient choices.	E

A - Clear evidence from well-conducted, generalizable randomized controlled trials that
are adequately powered; Compelling nonexperimental evidence; Supportive evidence from well-conducted randomized controlled trials that are adequately powered
B - Supportive evidence from well-conducted cohort / case-control studies
C- Supportive evidence from poorly controlled or uncontrolled studies; Conflicting evidence with the weight of evidence supporting the recommendation
E- Expert consensus or clinical experience

Table 2.2 Physical Activity and Exercise Recommendations by the American Diabetes Association for Youth with Type 1 Diabetes, Standards of Care in Diabetes (2020)

	Grade
• Exercise is recommended for all youth with T1D with the goal of 60 min of moderate-to-vigorous intensity aerobic activity daily, with vigorous muscle-strengthening and bone strengthening activities at least 3 days per week.	C
• Education about frequent patterns of glycemia during and after exercise, which may include initial transient hyperglycemia followed by hypoglycemia, is essential. Families should also receive education on prevention and management of hypoglycemia during and after exercise, including ensuring patients have a pre-exercise glucose level of 90–250 mg/dL and accessible carbohydrates before engaging in activity, individualized according to the type/intensity of the planned physical activity.	E
• Patients should be educated on strategies to prevent hypoglycemia during exercise, after exercise, and overnight following exercise, which may include reducing prandial insulin dosing for the meal/ snack preceding (and, if needed, following) exercise, reducing basal insulin doses, increasing carbohydrate intake, eating bedtime snacks, and/or using continuous glucose monitoring.	C
• Frequent glucose monitoring before, during, and after exercise, with or without use of continuous glucose monitoring, is important to prevent, detect, and treat hypoglycemia and hyperglycemia with exercise.	C

A - Clear evidence from well-conducted, generalizable randomized controlled trials that
are adequately powered; Compelling nonexperimental evidence; Supportive evidence from well-conducted randomized controlled trials that are adequately powered
B - Supportive evidence from well-conducted cohort / case-control studies
C- Supportive evidence from poorly controlled or uncontrolled studies; Conflicting evidence with the weight of evidence supporting the recommendation
E- Expert consensus or clinical experience

2.4 Type 2 Diabetes in Youth

2.4.1 Definition and Diagnosis of T2D

T2D ranges from insulin resistance with relative insulin deficiency to an insulin secretory defect with insulin resistance. In contrast to individuals with T1D, individuals with T2D do not always need insulin treatment for survival.[25,33,62] The paths of β-cell dysfunction in T2D are also not as well understood as in T1D. However, a progressive loss of β-cell insulin secretion, frequently in the setting of insulin resistance, appears to be a common denominator in T2D.[33]

A specific etiology of T2D is unknown because there are multiple causes of T2D.[33,62] Diabetes clinicians and researchers have observed that the causes of T2D insulin secretory defects range from inflammation and metabolic stress to genetic factors.[33] Research also supports that the risk of developing T2D is associated with increasing age, female sex, low socioeconomic status, family history of diabetes, lack of physical activity, and obesity.[33,62] It should be noted that obesity alone can cause insulin resistance.[33,62] Individuals with T2D who are not obese according to traditional BMI cut points may have an increased percentage of body fat distributed predominantly in the abdominal region.[33,62]

Obesity may also contribute to development of T1D and more children with T1D are overweight than ever before.[33,74] Also, it was traditionally accepted that T2D did not include autoimmune destruction of b-cells, however, numerous studies have now demonstrated β-cell autoimmunity in children with T2D.[75]

T2D frequently goes undiagnosed for many years because hyperglycemia develops gradually and there are often no symptoms severe enough for the individual to notice.[33,62] YYA with T2D may present as symptomatic or asymptomatic.[25] Asymptomatic children (up to 40% of cases) are typically early in the disease process and are often identified during screening for hyperglycemia because of the presence of diabetes risk factors.[25] DKA is not as prevalent among people with T2D in comparison to T1D; and, spontaneous DKA is rare in people with T2D.[33,62,76,77] Reports suggest that only up to 25% of children and adolescents who present with ketoacidosis have T2D, meaning many more have T1D or another complication.[21] SEARCH found that DKA prevalence at diagnosis in youth ≤19 years of age was significantly lower among those with T2D (9.7%) than in those with T1D (29.4%).[77] In youth 10-19 years old with T2D, DKA prevalence at diagnosis drops to approximately 6%.[76] SEARCH has also found that among youth with T2D, DKA prevalence decreased between 2002 and 2010 from 11.7% to 5.7% (p-value for trend = .005).[76] When DKA does occur in people with T2D, it typically occurs in conjunction with another stressor such as an illness or an infection.[62] DKA at diagnosis is more common among ethnic minorities.[33]

T2D accounts for 90-95% of all diabetes cases; however, it is much more prevalent in adults than in youth.[33,62] Evidence suggests T2D in youth differs from T2D in adults in that youth with T2D experience a more rapidly progressive decline in β-cell function and accelerated development of diabetes related complications.[33] Despite these differences, there are currently no T2D recommendations for diagnosis with laboratory testing specific to children.[25] Diagnostic criteria for T2D includes: a fasting blood glucose level of ≥126 mg/dL (7.0 mmol/L), a two-hour plasma glucose level of ≥200 mg/dL (11.1 mmol/L) during an oral glucose tolerance test, an A1C level of ≥6.5% (48 mmol/mol), or a random plasma glucose level of >200 mg/dL (11.1 mmol/l) plus symptoms of classic hyperglycemia (polyuria, polydipsia, or unintentional weight loss).[25,33,78] When hyperglycemia is absent, the diagnosis should be confirmed with repeat testing.[78]

To diagnose T2D in youth, evidence suggests that oral glucose tolerance tests or testing fasting plasma glucose values are more suitable diagnostic tests than A1C, especially among certain ethnicities.[33] Although A1C validity studies are not currently available among youth with T2D[33], the validity of using this method to diagnose youth has been questioned because of inaccuracies among certain ethnicities and comorbidities (e.g., sickle-cell trait).[74] The American Diabetes Association continues to support the use of A1C levels for diagnosis, while acknowledging a lack of studies supporting its use in children with T2D.[79]

Insulin resistance may improve among people with T2D with weight loss and/or medication for hyperglycemia but insulin levels rarely return to normal.[33,62] The American Diabetes Association recommends screening for T2D beginning at 10 years of age or the onset of puberty, whichever occurs first, in children who are overweight (BMI $\geq 85^{th}$ percentile) or obese (BMI ≥ percentile) and have one or more additional risk factor.[33] If the tests are negative, it is recommended that tests are repeated every 3 years, or more frequently if the child's BMI is increasing.[33]

2.4.2 Epidemiology of T2D in Youth

In the last two decades, the incidence and prevalence of type 2 diabetes in adolescents has increased dramatically, especially in racial and ethnic minority populations.[33] SEARCH has estimated that the incidence of T2D in youth in the U.S. is approximately 12.5 cases per 100,000[31] or 5,000 cases per year.[80] The incidence of T2D is higher in non-Hispanic black youth (32.6 per 100,000) and American Indian youth (46.5 per 100,000).[80]

Between 2002 and 2012, after adjustment for age, sex, and race/ethnicity, the annual percent change in the incidence of T2D in youth was 4.8% (95% CI: 3.2 to 6.4). The annual percent change was higher among American Indians (8.9%; 95% CI: 5.0, 13.1), Asian/Pacific Islanders (8.5%; 95% CI: 2.0, 15.4), and non-Hispanic blacks (6.3%; 95% CI: 4.0, 8.8), in comparison to an increase of 0.6% (95% CI: − 2.0, 3.4) among non-Hispanic whites and 3.1% (95% CI: 0.8, 5.4%) among Hispanics.[31] This same study found the number of T2D cases diagnosed annually increased from 3,800 cases in 2002-2003 to 5,300 in 2011-2012.[31] The adjusted annual percentage change remained 4.8% (95% CI: 3.7 to 5.92) from 2002 to 2015.[64]

In terms of prevalence, T2D in youth increased by 31% between 2001 and 2009.[30] SEARCH data presented at the 2020 American Diabetes Association Scientific Sessions concluded that the prevalence of T2D increased from 0.3 per 1,000 in 2001 to 0.7 per 1,000 in 2017 (annual percent change =4.3%, CI: 3.6-4.9%).[65] The greatest increases in T2D were observed among non-Hispanic black youth (Δ= 0.9, CI: 0.7-1.0; annual percent change =4.1%, CI: 2.9-5.3%), and Hispanic youth (Δ= 0.6, CI: 0.5-0.6; annual percent change =5.2%, CI: 4.0-6.5%).[65] The prevalence of T2D in youth is expected to continue to grow. Assuming a 2.3% annual percentage increase, Imperatore et al. (2012) projected T2D to increase from 22,820 cases (0.27 per 1,000) in 2010 to 84,131 (0.5 per 1,000) in 2050. This is a 178% increase and implies that the number of youth with T2D will quadruple in the next 30 years.[66]

2.4.3 Treatment and Management of T2D

Most of the recommended guidelines for treatment of T2D in youth are extrapolated from research in adults with T2D.[81] However, T2D in youth presents unique challenges and managing it requires a multidisciplinary approach which includes the child's family, school, primary care physicians, specialists trained in the care of children and adolescents with T2D.[25,33,82] Although self-motivation is necessary for management plans to be successful,[81] management plans must also be family-centered because, without the support of family, it is difficult for youth with T2D to sustain healthy lifestyle changes and self-management behaviors.[9,25,33,82] Engaging family members also improves medication adherence.[82] It is well documented that T2D disproportionately affects youth with racial and ethnic minority backgrounds.[30,33]Therefore, clinicians should also ensure that education and management plans are culturally appropriate.[25,81,82]

With the support of family, physicians, and specialists, youth should self-manage their diabetes to the extent appropriate for their age.[25] Both pharmacologic management and lifestyle interventions are recommended to help youth with T2D achieve normoglycemia.[9,25,33,81] Few youth can be treated with diet and exercise alone.[81] More specifically, metformin in combination with healthy eating patterns and exercise is considered first-line therapy for youth 10 years and older. Metformin (taken orally) and insulin are the only medications for T2D that are approved by the U.S. Food and Drug Administration for use in children and adolescents.[9,25,83] Most pediatric diabetologists use oral agents for youth with T2D due to convenience for the child and potentially higher compliance.[81] Daily medications to treat various comorbidities and daily monitoring of blood glucose are also considered for treatment in youth with T2D.[9] Nutrition therapy and physical activity recommendations for youth with T2D along with evidence grades assigned by the American Diabetes Association are presented in Table 3.

2.4.3.1 Pharmacologic Management: Metformin

Metformin is an insulin sensitizer, meaning it works to lower blood glucose by increasing liver and muscle sensitivity to insulin without a direct effect on β-cell function.[9,81] It is typically the starting point for pharmacological treatment in youth with T2D[81] because its effectiveness has been proven for adolescents in a randomized controlled trial,[84] and it has a good safety record.[81] Along with its ability to significantly improve glycemic control in youth with T2D,[9] metformin also enhances weight reduction and causes a decrease in lipids without the risk of hypoglycemia.[81] It is recommended that metformin be initiated at a dosage of 500 mg per day, regardless of the patient's weight, then adjusted in 500 mg intervals over four weeks to the maximum dos- age of 2,000 mg per day.[25] Metformin should not be prescribed if there is any doubt at all about the nature of diagnosis.[81]

2.4.3.2 Pharmacologic Management: Insulin

Insulin therapy is considered for youth with T2D when the child has signs of dehydration, ketosis, or ketoacidosis[25,82] because insulin is the only feasible way of controlling hyperglycemia.[81] Insulin therapy may also be beneficial for youth with no signs of ketoacidosis but who have random plasma glucose levels of 250 mg per dL (13.9 mmol per L) or greater, or whose HbA_{1c} level is greater than 9%.[25,82] Under these circumstances, insulin-therapy can be discontinued after beginning metformin therapy and lifestyle changes.[25] Insulin regimes should be adopted that are carefully tailored to lifestyle (bedtime insulin alone, twice-a-day insulin or multidose insulin regimes).[81]

2.4.3.3. Lifestyle Intervention: Nutrition Therapy

To manage T2D in youth, it is recommended that youth with T2D be referred to a registered dietician with knowledge and expertise in nutritional management of youth with diabetes.[25,81] The dietician should be capable of making dietary recommendations which are culturally appropriate and sensitive to the family resources.[81] Additionally, recommendations must be shared with all caregivers.[81] In summary, general healthy eating habits with an emphasis on consuming nutrient-dense, high-quality foods and reducing calorie-dense, nutrient-poor, and high fat foods, should be encouraged for the entire family.[25,81]

2.4.3.4 Lifestyle Intervention: Physical Activity and Exercise

In regards to exercise to manage T2D in youth, exercise counseling should be addressed at the time T2D is diagnosed and as a part of ongoing management.[25,82] The general recommendation for youth with T2D is 60 minutes per day of moderate-to-vigorous intensity exercise and limit nonacademic screen time to less than two hours per day.[25,33,70,83,85] Exercise can be completed in multiple short sessions.[25,70] Clinicians must be aware of the potential effects of exercise on the need for hypoglycemic medication and adjust the dosage accordingly, especially in youth receiving insulin.[25,82]

2.4.3.4 Lifestyle Intervention: Weight Reduction and Bariatric Surgery

The most common comorbidity of T2D in youth is obesity.[9] Studies indicate that over 85% of youth with T2D are either overweight or obese at diagnosis.[9] In a comparison of youth with T1D and T2D, 96% of those with T2D, versus 24% of children with T1D, were overweight or obese at diagnosis[86] Because most youth with T2DM are overweight or obese, it is essential for them to lose weight by focusing on improving dietary intake, increasing physical activity, and decreasing sedentary behaviors.[9] The American Diabetes Association recommends that youth with overweight/obesity and T2D should utilize lifestyle programs and diabetes management to achieve a 7–10% decrease in excess weight.[33] The target body mass index for youth with T2D is less than the 85th percentile for age and sex.[25,33]

Bariatric surgery can be considered to reverse diabetes or improve cardiovascular risk factors for extremely obese youth with T2D in which lifestyle changes and pharmacotherapy have been unsuccessful.[9,81]

2.4.3.5 Self-monitored Blood Glucose Testing

When youth with T2D utilize insulin therapy, have comorbid illness(es), are not meeting glycemic targets, or are changing their diabetes medication regimen, it is recommended that self-monitored blood glucose testing (finger prick) be performed ≥3 times per day.[25,82] Self-monitored blood glucose testing is also important for youth with T2D when diabetes is newly diagnosed,[83] during an acute illness, or in the presence of hyper- or hypoglycemic symptoms.[81]

2.4.4 Glycemic Control of T2D

The American Academy of Pediatrics recommends that clinicians monitor HbA_{1c} levels in youth with T2D every three months.[25,82] According to the ADA and International Society for Pediatric and Adolescent Diabetes (ISPAD) 2014 Guidelines for HbA_{1c}, for ages <18 years, <7.5% is optimal glycemic control, 7.5-9.0% is suboptimal, and >9.0% is high risk.[73,87] For ≥18 years, <7.0% is optimal, 7.0-9.0% is suboptimal, and >9.0% is high risk.[73,87] In 2018, ISPAD recommended that YYA (≤25 years) who have access to comprehensive care aim for an HbA1c of <7.[88] Only about 35% of YYA with T2D reach the HbA_{1c} goal of 7%.[19] Minority youth and are particularly disadvantaged: 41% of non-Hispanic black and 49% of Hispanic YYA with T2D do not have optimal glycemic control in comparison to 19% of non-Hispanic white youth.[73] The literature supports racial or ethnic differences in glycemic control.[18]

It should be noted that the optimal glycemic control cut points are based only on expert opinions because to date, no randomized controlled trials have established the relationship between glycemic control and the risk of microvascular complications in youth with T2D.[25,82] Individualized goals are acceptable for youth with T2D if the accepted HbA_{1c} targets are unattainable.[25,82] If glycemic control is not achieved, the treatment regimen for YYA should be intensified (e.g., modification or addition of medication, change in lifestyle interventions, and more frequent clinic visits and blood glucose monitoring).[25]

For youth with T2D, glycemic control typically begins to deteriorate within two years after diagnosis.[9,89] Poor glycemic control will eventually result in serious health complications such as retinopathy, neuropathy, nephropathy, and cardiovascular disease.[9] Research has supported that many youth with T2D have signs of microvascular and macrovascular complications, hypertension, dyslipidemia, and fatty liver early on.[9,21] For example, in a SEARCH study comparing the prevalence of early complications and comorbidities in T1D and T2D at age 21, T2D was associated with a significantly higher prevalence of diabetic nephropathy, retinopathy, peripheral neuropathy, arterial stiffness, and hypertension.[20,90] Additionally, in the U.S. multi-site TODAY trial with 704 youth with a diagnosis of T2D of less than two years, at baseline, 80% had low HDL-cholesterol, 26% had systolic hypertension, 13% had microalbuminuria, 10% had high triglycerides, and most were obese (mean zBMI of 2.15).[91] The long-term prognosis of youth with T2D is not currently known, but it is estimated that these youth may have a loss of up to 15 years of life expectancy, and increased risk of serious health complications by the time they reach their 40's, depending on their level of glycemic control.[9,92] Additionally, the long-term risk of cardiovascular disease in youth with type 2 diabetes is worse than in those who are diagnosed as adults.[21]

2.4.4.1 Diabetic ketoacidosis (DKA)

Diabetic ketoacidosis (DKA) due to insulin deficiency can be a life- threatening condition.[76] In SEARCH, DKA is indicated when, in the presence of hyperglycemia, blood bicarbonate levels are < 15 mmol/L, and/or pH is < 7.25 (venous) or < 7.30 (capillary), and/or DKA is indicated in the medical record. The prevalence of DKA among youth with T2D has decreased over time and is much lower in comparison to youth with T1D.[76] SEARCH recently reported that among youth aged 10-19 with T2D, there was a decrease in DKA at diagnosis: 11.7% (95% CI: 8.2, 15.2%) in 2002–2003 to 5.7% (95% CI: 4.1, 7.4%) in 2008– 2010.[33,76,90] DKA at diagnosis of T2D is more prevalent among younger age groups, males, and in minority as race and ethnicity groups.[76] A study among African-American adolescents found that 25% of those with T2D met criteria for diabetic ketoacidosis at diagnosis.[21] Currently, no reports have been published on morbidity or mortality associated specifically with DKA in adolescents with T2D.[21] Youth with prediabetes and type 2 diabetes, like all children and adolescents, should be encouraged to participate in at least 60 min of moderate to vigorous physical activity daily (with muscle and bone strength training at least 3 days/week) B and to decrease sedentary behavior.

Table 2.3. Nutrition and Physical Activity Recommendations by the American Diabetes Association for Youth with Type 2 Diabetes, Standards of Care in Diabetes (2021)

	Grade
Nutrition	
• Nutrition for youth with type 2 diabetes, like for all children, should focus on healthy eating patterns that emphasize consumption of nutrient dense, high-quality foods and decreased consumption of calorie dense, nutrient-poor foods, particularly sugar-added beverages.	C
Physical Activity	
• Youth with T2D diabetes are encouraged to participate in at least 60 min of moderate-to-vigorous physical activity per day (and strength training on at least 3 days/week) and to decrease sedentary behavior.	B/C

A - Clear evidence from well-conducted, generalizable randomized controlled trials that
are adequately powered; Compelling nonexperimental evidence; Supportive evidence from well-conducted randomized controlled trials that are adequately powered
B - Supportive evidence from well-conducted cohort / case-control studies
C- Supportive evidence from poorly controlled or uncontrolled studies; Conflicting evidence with the weight of evidence supporting the recommendation
E- Expert consensus or clinical experience

2.5 HFI and Diabetes

HFI is particularly prevalent among households of people with cardiometabolic diseases[4,5] and among households with children who have diabetes.[6] In studies of YYA with diabetes, the prevalence of HFI is about 20%[6–8], with a slightly higher prevalence among youth with T2D (~29%) than youth with T1D (~16%; $p < 0.01$).[8] This is higher than the prevalence of HFI in U.S. households with children (13.9%).[2]

HFI among youth who have diabetes presents unique challenges because quality balanced diets are necessary for successful management of diabetes and carbohydrate-rich snacks or beverages for the mitigation of hypoglycemia. Current evidence indicates that people who have diabetes and HFI are at an increased risk for poor glycemic control (A1C >7%),[7,13–18,33] hypoglycemia,[40,41,93] hyperglycemia,[94] more frequent hospital visits,[6,7] depression[33], and chronic diseases related to diabetes complications,[16,41] compared to people who are food secure. In children specifically, poor glycemic control can have severe consequences such as hypoglycemia and ketoacidosis, leading to hospital admissions[6], as well as various chronic complications later in life.[21,95] The increased risk for hyperglycemia in people who are living in food insecure households may be due to steady consumption of inexpensive carbohydrate-rich processed foods, binge eating, financial constraints to the filling of diabetes medication prescriptions, and anxiety/depression leading to poor diabetes self-care behaviors. The increased risk of hypoglycemia may be a result of inadequate or erratic carbohydrate consumption following administration of sulfonylureas or insulin.[11,94]

HFI has also been found to indirectly negatively affect behaviors which impact diabetes management such as obtaining adequate physical activity,[26,27,96] adhering to prescription regimens, and attending doctor's appointments.[39] In a review of the intersection between food insecurity and diabetes, Gucciardi et al.[41] found that people who have diabetes and food insecurity struggle to financially balance acquiring food, their day to day expenses, and medicine and supplies for diabetes. These competing priorities contribute to a worse condition and overall health.[41]

For these reasons, since 2017 the American Diabetes Association Standards of Medical Care in Diabetes has recommended assessing HFI for people with diabetes.[11,33] Vitale et al.[97] found that most families that have a child with diabetes appreciated the opportunity to express their concerns and learn about affordable food resources; however, ~20% of families with HFI described stigma and fear of judgment by clinicians if they screened positive for food insecurity.[97] They also found that although diabetes educators felt comfortable with HFI screening questions, they reported lack of time to screen all families and to follow-up with resources after a positive screen.[97] The authors concluded their study by recommending that a standardized self-reported intake form is a respectful method to ensure that everyone is systematically screened and will simultaneously help clinicians better tailor treatment plans and support for families of children with diabetes and HFI.[97]

2.6 HFI and Glycemic Control

The goal of diabetes treatment and management is normoglycemia.[9] Although a relationship between food insecurity and poor glycemic control is consistently documented in the literature,[7,13–18] the vast majority are among adults with T2D and none of these studies have been completed among YYA with T2D. As of now there are at least

5 cross-sectional studies among adults with diabetes which found an association between food insecurity (measured with the USDA HFSSM) and glycemic control.

Seligman et al. (2012)[13] completed a study among 711 adults with T2D and found that, more food-insecure participants than food-secure participants had poor glycemic control, defined as an HbA1c ≥8.5% (41.9 vs 32.8%), with an unadjusted odds ratio of 1.48 (CI: 1.07-2.04). After controlling for age, sex, race/ethnicity, income, education, tobacco use, BMI, insulin use, and medication adherence, the relationship remained (Odds ratio: 1.46; CI: 1.01-2.11). Difficulty following a healthy diet and emotional distress partially mediated this association.[13]

In a sample of 843 adults (ages 22-84) with T2D, Bawadi et al. (2012)[16] found that after adjusting for age, gender, income, education, and duration of diabetes, body mass index, and caloric consumption; moderate and severe food insecurity were associated with poor glycemic control ($p = 0.04$).

Berkowitz et al. (2013)[14] analyzed data on 2,557 adults (mean age: 59.4 year) with T1D or T2D from the 1999-2009 National Health and Nutrition Examination Survey. After adjustment for age, sex, educational attainment, household income, insurance status and type, smoking status, BMI, duration of diabetes, diabetes medication use and type, and presence of a usual source of care, food insecurity remained significantly associated with poor glycemic control (odds ratio 1.53; 95% CI 1.07–2.19).[14]

Heerman et al. (2016)[17] assessed 401 adults (mean age: 52) with T2D and found that HFI was associated with worse glycemic control (adjusted $\beta = 0.1$, $P = 0.03$), as well as several self-care behaviors after adjusting for age, gender, race/ethnicity, BMI, household income, highest education and duration of diabetes.[17]

Holben et al. (2019)[15] studied 155 adults with diabetes (34.2% T1D and 65.8% T2D; mean age: 53 ±16 years) using free and fee-for-service clinics. Regardless of the type of clinic used, A1C values increased as household food security (r = 0.293, P <0.001) and household adult food security (r = 0.288, P = 0.001) worsened.[15] A limitation of this study is that Pearson r correlations were used to examine the relationship of household food security status and household adult food security status to A1C, so no adjustments were made.

In contrast to these studies, in a study of 1, 237 food pantry participants with diabetes and a high prevalence of food insecurity (84%), Ippolito et al. (2017)[98] found that HbA1c (mean: 8.1%) did not vary significantly by food security status; however, after adjustment, very-low-food-secure participants had poorer diabetes self-efficacy, greater diabetes distress, greater medication non-adherence, higher prevalence of severe hypoglycemic episodes, higher prevalence of depressive symptoms, more medication affordability challenges, and more food and medicine or health supply trade-offs, compared with both low-food-secure and food-secure participants.[98] An association between HFI and HbA1c may not have been observed because the sample included people using a food pantry. People who use food pantries but indicate that they do not have HFI are possibly different from the general population that is food secure.

Research specific to effects of food insecurity among youth with diabetes is limited.[6,7] Among a cross-sectional study of 226 YYA (mean age: 15.6 ± 5.4 years) with T1D, Mendoza et al. (2018)[7] found that with HFI had a 2.37 higher odds (95% CI: 1.10-

5.09) of high risk glycemic control (HbA1c >9.0%), compared to YYA from food-secure households. This analysis was adjusted for age, sex, race/ethnicity, SES, SEARCH site, duration of diabetes diagnosis, health insurance type, and insulin regimen.[7] Primarily among youth with T1D, Marjerrison et al. (2011) also found a positive association between food insecurity HbA1c level; however, this association did not remain after adjustment for parental education, household income, child's age, and number of other family members with medical conditions. There was a positive association between food insecurity and rates of hospitalizations.[6]

2.7 Physical Activity and Diabetes

In the general population, physical activity has been found to decline with age.[99] Based on accelerometer data obtained by NHANES, 42% (SE: 1.6) of children ages 6-11 years old obtain the recommended 60 minutes of moderate-to-vigorous activity per day; however, only 8% (SE 1.1) of adolescents 12-15 years and 7.6% (SE:1.2) of adolescents 16-19 years reach this goal.[99]

A review of physical activity in youth with diabetes by Liese et al.[23] found studies which support and refutes that youth with diabetes meet the physical activity recommendation levels, depending on how physical activity was measured.[23] There is also evidence that boys with diabetes tend to be more active than girls with diabetes and, activity levels are higher in youth with T1D than in youth with T2D.[23]

In a study of SEARCH participants in which measured physical activity with a 3 day physical activity recall, Lobelo et al.[100] found compliance with the national aerobic physical activity recommendations was lower among youth with T2D (68.3%), compared to youth with T1D (81.7%; odds ratio: 0.51 [95% confidence interval: 0.26-1.00]; P =

.047).[100] While 82.3% (± 3.5%) of males with T1D met the recommendation, only 64.6% (± 7.8%) of males with T2D met the recommendation. This difference was statistically significant.[100] The proportion of female youth with T1D who meet the physical activity recommendation was about 81.3% (± 3.4%) and the proportion of female youth with T2D was who met the recommendation was 71.3% (±5.3%).[100]

Pedometer based studies, which provide an objective, more accurate measure of physical activity compared to subjective recall methods, do not indicate that youth meet recommended physical activity levels.[23] The recommendation for steps per days in adolescents (12-19 years) is at least 10,000 steps per day. In school age boys (6-11 years) the recommendation is at least 13,000 steps per day and, in school age girls it is at least 11,000 steps per day.[23,101] One study found that on average, girls with T1D achieved ~ 6,773 ± 2,986, boys with T1D achieved ~8,071 ± 3,702, girls with T2D achieved ~8,071 ± 3,702, and boys with T2D achieved ~ 6,175 ±2708.[23,102]

In terms of METS per day, Faulkner et al. reported an average of 34.9 ± 3.5 METs per day for youth with T1D and 33.7 ± 1.6 METs per day for youth with T2D.[103] Nadeau et al. reported that youth with T2D achieve about 64 METs per day.[23,104] The benefits of regular physical activity for people with diabetes are well established.[22–24] Most benefits of aerobic and resistance training physical activity on diabetes management are realized through acute and chronic improvements in insulin action. Physical activity also improves blood glucose control and positively affects lipids, blood pressure, cardiovascular events, mortality, and quality of life.[105] Liese et al[23] (2013) concluded that PA seems to consistently impact glycemic control in intervention and observational studies.[23]

It should be noted that studies use either a subjective or an objective instrument to measure physical activity. Subjective physical activity measures include self-report questionnaires (i.e. short term questionnaires, global questionnaires, and quantitative history recall questionnaires), logs, and diaries. [106,107] Subjective measures are the most common method of physical activity assessment.[107] However, all subjective measures of physical activity are dependent on the participant's ability to recall their activity and are subject to over reporting which typically biases hypotheses toward the null. Objective measures of physical activity include direct observation, accelerometers, pedometers, heart-rate monitors, and armbands.[106,107]

2.8 HFI and Physical Activity

The fatigue and depression associated with inadequate access to nutritious food, may decrease some individuals' motivation for physical activity and/or make physical activity challenging.[41,94,108] There is a dearth of studies exist examining an association between HFI and physical activity[17,26,27,35,96,109] and to my knowledge, only two exists among people with diabetes.[17,109] The majority of studies examining an association between HFI and physical activity are among YYA[26,27,35,96,109] and at least one study includes adolescents with diabetes.[109]

To et al. (2014)[27] posited that people with HFI were less physiologically and psychologically energetic and therefore less likely to do physical activity and more likely to have poorer health. This particular study analyzed data from NHANES 2003-2006 and had two key advantages: 1) Children and adults were included in the sample. 2) Physical activity measured with both a questionnaire and accelerometry. The final physical activity questionnaire sample was 788 children and 4886 adults. The final accelerometry sample was 2261 children and 2712 adults. The authors found that although children with HFI participated in less moderate-to-vigorous physical activity than food-secure children (adjusted coefficient = -5.24, P= 0.02), food insecurity was not associated with adherence to physical-activity guidelines measured with the questionnaire or accelerometry. This may be because continuous variables are more sensitive to detecting changes than dichotomous variables. In adults, food insecurity was significantly associated with adherence to physical-activity guidelines (adjusted OR= 0.72, P= 0.03 for accelerometry; and OR= 0.84, P< 0.01 for the questionnaire) but was not associated with sedentary minutes (P> 0.05).[27] Adjusted models included age, gender, race/ethnicity, education, marital status, household size, and poverty income ratio.[27]

Although Fram et al. (2015)[26] did not find an association between food insecurity and self-reported physical activity among 3,605 children (mean age: 10.1), they did find that each unit increase in child food-insecurity score was associated with 8% lower odds of liking PA (P < 0.001), 20% higher odds of always feeling too tired for PA (P < 0.001), and 25% higher odds of always feeling that weight makes PA hard (P < 0.001).[26] This lack of association between HFI and PA may be due to the use of self-reported physical activity measure, which is known to result in overreporting of PA and would bias results to the null hypothesis.[99]

Among 1,903 16-year-old students, Gulliford et al. (2006)[96] concluded that after adjustment for BMI, age, sex, ethnicity, and socioeconomic variables, adolescents who experienced HFI engage in less physical activity than participants with the same BMI from food secure households.[96]

Heerman et al. (2016)[17] assessed 401 adults (mean age: 52) with T2D and found that after adjustment for age, gender, race/ethnicity, BMI, household income, highest education and duration of diabetes, food insecurity was significantly associated with less physical activity measured with a questionnaire (OR 0.9, P =0.04).[17]

Gucciardi et al. (2009)[109] assessed 6,237 Canadians with diabetes who were 12 years old or older. They found that after adjustment for age, sex, duration of diabetes, insulin status, whether or not an individual had a regular medical doctor, whether or not an individual had the effects of a stroke, adjusted income ratio, household education level, First Nations status, smoking status, and physical activity level, HFI was associated with physical inactivity (odds ratio 1.54 [95% CI 1.10–2.17]).[109] Food-insecure adults are also less likely to engage in physical activity than adults in food- secure households with diabetes.[41,109]

In contrast to these studies, Robson et al. (2017)[35] found no association between HFI and meeting the aerobic physical activity guidelines for children using Youth Risk Behavior Survey data.[35] From a slightly different perspective, Gunter at al. (2017)[110] examined the association between readiness to change family-level physical activity behaviors and family HFI status among 144 families living in rural Oregon. HFI was measured with a 2-item HFI screener and physical activity was measured with a family stage of change survey. After adjusting for education, race, ethnicity, and eligibility for federal meal programs, readiness to provide opportunities for family-level physical activity was lower among families with HFI (p = 0.002).[110] This study important because it is recommended that diabetes management in youth involves the entire family.[33]

2.9 Diet Quality and Diabetes

Diet is a cornerstone of diabetes management. While nutrition therapy among YYA with diabetes focuses on monitoring carbohydrate intake and nutrition education for the entire family,[33] nutrition recommendations include following the dietary guidelines for the general population[111] with high attention to carbohydrate intake.[33] A review by Rovner and Nansel (2009)[112] concluded that children with T1D typically fall short of meeting dietary guidelines and may even consume less healthful diets than children without diabetes.[112] In SEARCH, Youth with T2D have been found to have poorer diets that youth with T1D in that they consumed twice the amount of sugar sweetened beverages, less calcium, magnesium, and vitamin E, and were less likely to meet recommendations of < 10% of their daily intake of calories from saturated fat.[113] Evidence shows that the diet quality among adults with T1D and T2D is improving; however, there are observed disparities of diet quality measured with the Health Eating Index-2010 (HEI-2010) that are not improving between high and low education, high and low income and food secure and food insecure.[114]

A higher quality diet and management of diabetes is well documented in the literature. Cross-sectional research among youth with T1D indicate that diets characterized by higher carbohydrate, lower fat, lower added sugar, higher fiber, and higher fruit and vegetable intake are associated with better glycemic control.[115] Additionally, a longitudinal study among youth with T1D found that glycemic control may be improved by increasing intake of high-fiber, low glycemic–index, carbohydrate-containing foods[115] Among youth with T2D, a very-low-energy diet intervention pilot study concluded that youth who adhered to the diet benefitted from rapid weight loss, dramatic reductions in liver fat, and no longer meeting the American Diabetes Association criteria for T2D.[116] In contrast to these studies, a study, among outpatients with T2D, found that lower diet quality, defined by HEI-2010, was associated with poor glycemic control.[43] There is also evidence that regardless of obesity status, poor diet can lead to general greater morbidity among people with diabetes[39] which in turn will lead to more hospital visits and health care utilization.

2.10 HFI and Diet Quality

Hanson et al. (2014)[34] systematically reviewed evidence of associations between food insecurity and dietary quality in US households and stratified their analysis by associations observed in adults and children. They found that among adults, out of 170 observational studies, 50 suggested an adverse association between HFI and diet quality; and among children, out of 130 observational studies, 21 suggested an adverse association. The authors concluded that the lower percentage of studies supporting an association between HFI and poor diet quality among children supports the idea that parents with HFI shield their children from a poor diet quality. However, there were several studies which indicated that children with HFI have lower fruit intake in comparison to children that are food secure.[34]

More recent studies have supported an association between HFI and diet quality among youth and adults. Fram et al. (2015)[26] found that among 3,605 children (mean age: 10.1), greater levels of child food insecurity were associated with higher consumption of energy ($p=0.02$) , fat, sugar ($p=0.04$), and fiber ($p=0.02$) and a diet lower in vegetables ($p=0.02$). Children at the highest level of child food insecurity, on average, consumed ;494 kJ/d (118 kcal), 8 g/d of sugar, and 4 g/d of fat more than a food-secure child.[26]

Using the Youth Risk Behavior Survey and a weighted sample of 495,509 adolescents, Robson et al. (2017)[35] found that adolescents with HFI had had more than a twofold increased odds of not eating breakfast on all 7 days (adjusted odds ratio [AOR] = 2.27; 95% confidence interval [CI], 1.61–3.21; P < .001).[35]

Jomaa et al. (2020)[37] cross-sectionally analyzed 693 Lebanese adolescents (10-18 years, 55.2% food insecure) to determine dietary patterns in participants and evaluate the association between HFI and the identified dietary patterns. HFI was measured with a survey tool which assesses HFI within the previous 4 weeks. The authors found that higher HFI, measured with the validated Arabic-version of the Household Food Insecurity Access Scale, was associated with lower adherence to a Lebanese-Mediterranean dietary pattern (i.e. higher intakes of fruits, vegetables, dairy products, and whole grains), after adjustment for age, gender, crowding index, father's and mother's education, mother's major in health, and mother and father's employment ($\beta = -0.026$, 95% CI -0.046, -0.006).[37] The U.S. Household Food Insecurity Access Scale measures household food insecurity within the previous 4 weeks.

Larson et al. (2020)[117] used data from the Eating and Activity over Time study to conduct a study on 1,568 emerging adults (mean age = 22.0 ±2.0 years). Food insecurity was defined by eating less than they thought they should and not eating when hungry because of lack of money. It was associated with poorer diet quality (e.g., less vegetables and whole grains, more sugar-sweetened drinks and added sugars), lower home availability of healthy foods, skipping breakfast, frequently eating at fast-food restaurants, binge eating, binge drinking, and substance use (all $P < .01$).[117]

In a study similar to the proposed study, Leung and Tester (2019)[118] examined associations between HFI and diet quality variations by sex and race/ethnicity. The study included 4,393 adults with family incomes ≤300% of the federal poverty level from the 2011-2014 National Health and Nutrition Examination Surveys. HFI was measured with the USDA Household Food Security Survey Module and Diet Quality was assessed with the Healthy Eating Index-2015 (HEI-2015). Both total and component HEI-2015 scores were used. Generalized linear models were adjusted for age, sex, birthplace, educational attainment, marital status, poverty income ratio, and smoking status. Adults with HFI had a 2.22 unit lower HEI-2015 score (95% CI -3.35 to -1.08) than adults who were food-secure. Among non-Hispanic whites, food insecurity was associated with lower scores for total protein foods, seafood and plant proteins, and added sugar. Among Asians, food insecurity was associated with lower scores for whole fruit. However, there were no associations among non-Hispanic black or Hispanic adults. There were also no differences by sex.[118]

2.10.1 HFI, Diet Quality, and Diabetes

A high-quality diet is important for diabetes management. Before taking HFI into consideration, research indicates that youth with diabetes do not typically meet national diet recommendations.[112,113] and, the diet quality of adults with diabetes is improving only in select populations.[114] General public health research supports that hunger and undernourishment are often associated with poor meal planning and disordered eating patterns among people with diabetes. Additionally, maintaining a healthy diet for people with diabetes that have HFI is challenging because they generally consume fewer fruits, vegetables, and protein, and rely more on energy-dense foods than food-secure people with diabetes.[41] Two studies have assessed food insecurity and diet quality among people with diabetes.

Gucciardi et al. (2009)[109] analyzed 6,237 Canadians with diabetes (ages ≥12 years). Not only was HFI more prevalent among individuals with diabetes (9.3% [8.2-10.4]) than among those without diabetes (6.8% [6.5-7.0]), it was also associated with physical inactivity (odds ratio 1.54 [95% CI 1.10-2.17]), lower fruit and vegetable consumption (0.52 [0.33-0.81]), and several physical and mental adverse outcomes.[109]

Orr et al. (2019)[114] included 5,882 adults with T1D or T2D in a repeated cross-sectional analysis of eight National Health and Nutrition Examination Survey cycles. The authors tested whether there were differences in diet quality across food security categories, and whether any differences changed over time. After adjustment for race/ethnicity, year, age and gender, the HEI-2010 score was 2.06 points higher among people with diabetes who were food secure than people with diabetes who were food insecure ($p=0.002$). This disparity did not improve over time.[114]

2.11 Research Gaps

Youth, adolescents, and young adults with HFI are an overlooked segment of the food-insecure population, as many studies focus on adults and younger children. For example, Leung and Tester[118] assessed HFI and diet quality among adults and excluded participant less than 20 years old. Studying YYA is important because this is the time of life when healthy behaviors are formed and continue into adulthood.[35]

There are also only a few studies that have assessed YYA with diabetes and HFI. Studies assessing HFI among people with diabetes have focused on middle-aged or older adults with T2D. Studies that did include youth focused on youth with T1D, leaving literature gaps and opportunities to explore further explore YYA with T1D. Studies on youth with T2D specifically are needed. SEARCH offers the largest cohort of YYA with T2D in the United States. This research will contribute to the body of literature on youth with T2D.

Studies that quantify a relationship between HFI, glycemic control and known behaviors which help manage diabetes will support physicians and diabetes educators in tailoring diabetes treatment plans.

CHAPTER 3

METHODS

3.1 Aims and Hypotheses

The overarching goals of this research are to cross-sectionally assess the associations between household food insecurity (HFI) and physical activity (PA), physical inactivity, diet quality, and glycemic control in youth and young adults (YYA) with diabetes.

The purpose of Aim 1 is to examine the association between HFI and glycemic control among YYA with type 2 diabetes (T2D). It is hypothesized that HFI will be associated with higher HbA_{1c} or worse glycemic control.[7,13–16] Further it is hypothesized that HFI will be associated with more frequent episodes of diabetic ketoacidosis (DKA), a complication of poorly controlled diabetes, in the last 12 months.

Aim 2 will examine the relationship between HFI and PA in YYA with type 1 diabetes (T1D) and T2D. We will assess PA as the following outcomes: total PA, vigorous PA, moderate PA, walking, moderate-to-vigorous physical activity (MVPA), meeting the 2018 Physical Activity Guidelines for Americans (PAGA) or not, and physical inactivity (i.e. sitting). It is hypothesized YYA with HFI will have lower physical activity levels than YYA who have household food security (HFS).[27] Additionally, YYA with HFI will spend more time sitting than YYA who have HFS.

The purpose of Aim 3 is to examine the association between HFI and diet quality in YYA with T1D and T2D. Diet quality will be defined with the Health Eating Index-2015 (HEI-2015). We hypothesize that YYA with HFI will have poorer HEI-2015 scores than YYA who have HFS. The purpose of sub-aim 3a is to assess the association between HFI and component scores of the HEI-2015. It is hypothesized that YYA who have HFI will have poorer scores for HEI adequacy components (e.g. total fruits, whole fruits, total vegetables, green beans, whole grains, dairy, total protein foods, seafood and plant proteins, and fatty acids) and poorer scores for moderation components (e.g. refined grains, sodium, added sugars, and saturated fats) than YYA who have HFS.

3.2 The SEARCH for Diabetes in Youth Study

3.2.1 Design

The SEARCH for Diabetes in Youth Study (SEARCH) comprises a surveillance effort assessing incidence and prevalence of youth-onset diabetes and, built on the surveillance effort, a longitudinal multi-site cohort study.[119,120] The SEARCH Cohort was funded by the National Institute of Diabetes and Digestive and Kidney Diseases. The overarching goals of SEARCH are to advance the understanding of the epidemiology of non-gestational diabetes among YYA who were initially diagnosed with diabetes before 20 years old. SEARCH has already successfully identified incidence and prevalence trends of YYA with T1D and T2D.[30,31] Data collection sites include: California, Colorado, Ohio, South Carolina, and Washington.[120]

SEARCH Phase 1 began in 2001 with prevalent diabetes cases and added incident cases in 2002-2005. SEACH Phase 2 included surveillance efforts for incident diabetes cases in 2006 and 2008; and, participants enrolled in Phase 1 were invited to re-enroll.[120]

SEARCH Phase 3 (funded period 2010-2015) recruited persons with incident cases between 2010 and 2015. It also created the SEARCH cohort by inviting participants from Phases 1 and 2 to another in-person visit if they (1) had a diagnosis date between 2002- and 2005, 2006, or 2008, (2) completed a baseline in-person visit, and (3) had at least 5 years of diabetes duration at the time of the visit. Of the 3,863 people eligible, 2,777 completed the in-person cohort visit.

The SEARCH Phase 4 Cohort study (funding period 2015-2020) includes eligible participants from SEARCH 3. It was divided into 2 groups: 1) those invited to another in-person study visit, and 2) those who were only invited to complete surveys. Participants invited to the in-person visit included all those with T2D, all nonwhites and a random sample of non-Hispanic whites with T1D that were all 10 years or older. Participants (n=806) that participated in the SEARCH 3 registry in-person visit after becoming an incident case in 2012 were also invited to the in-person visit in SEARCH 4. Together, these yielded a cohort of 3,549, of which 2,484 were invited to an in-person visit and 1,065 were invited to answer survey questionnaires. At the end of SEARCH 4, 1,673 individuals had completed the in-person visit, 212 had been invited to the visit but only completed surveys, and 783 participants were invited to complete the surveys only completed them, yielding a total of 2,668 individuals who completed the cohort protocol.

The proposed study will utilize data from the SEARCH 4 to conduct cross-sectional examinations of food insecurity and outcomes. SEARCH 4 includes data on 2,669 individuals [2,274 with T1D (mean age: 20.99; 15% food insecure) and 395 with T2D (mean age: 24.69; 5% food insecure)]. A flowchart of the progression SEARCH 1 to SEARCH 4 is depicted in Figure 3.1.

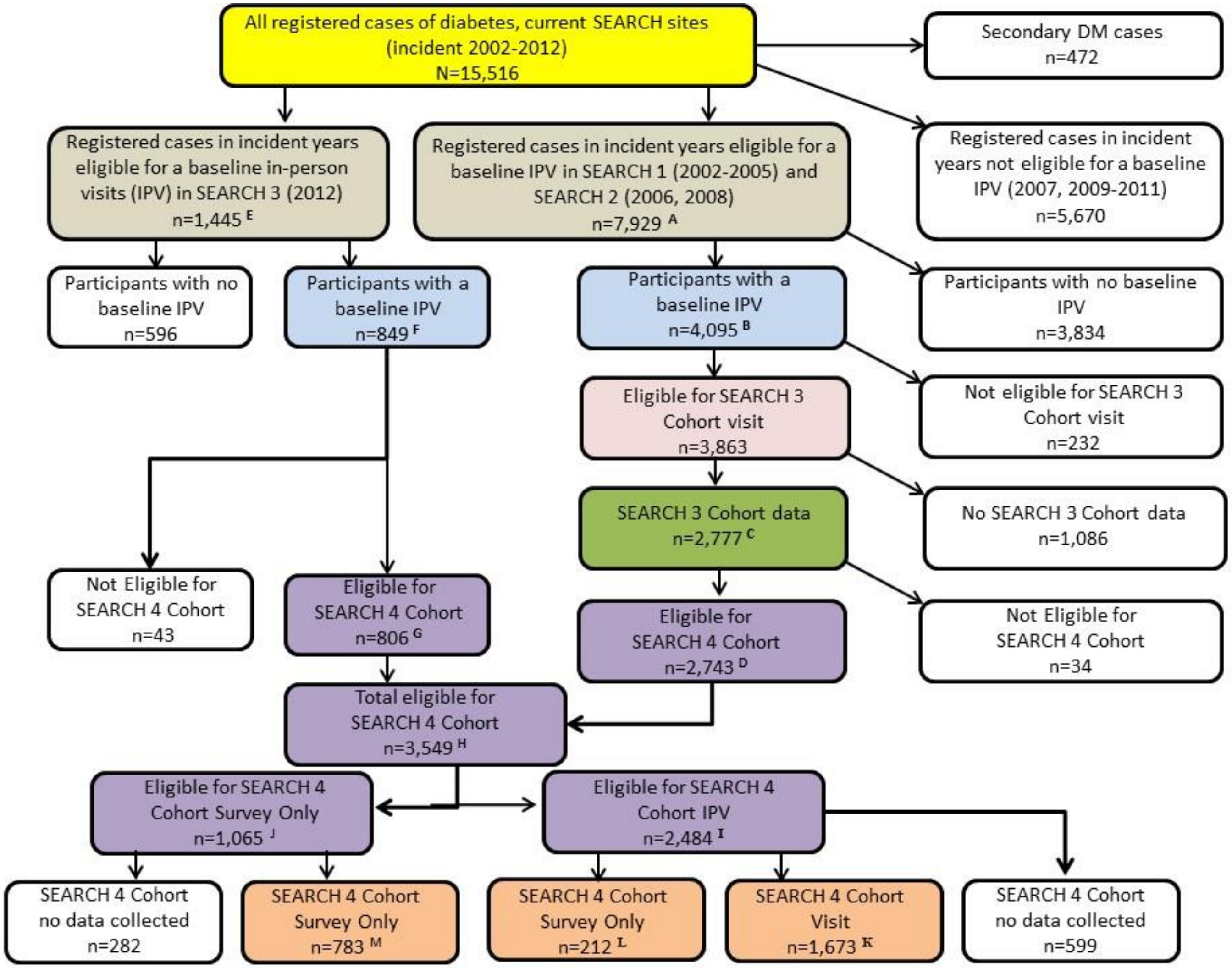

Figure 3.1 CONSORT flow chart: Design of the SEARCH Cohort Study

3.2.2 Data Collection

Institutional Review Board approval to conduct this study was granted at each of the participating funded centers before data collection began. During a SEARCH 4 Cohort Study visit, participants completed questionnaires, physical exams, and laboratory tests.[119] Questionnaires involving demographic information and medical history were filled out by adult participants or the participants' legal guardian. Questionnaires regarding health behaviors (i.e., PA, and diet) were completed by the participant regardless of age. Physical exams and laboratory tests assess chronic complications of diabetes, such as glycemic control. The dataset containing variables for analysis will be provided by the SEARCH coordinating center. Participants will only be identified with a participant ID number and investigators, thus will not have access to identifiable information.[120]

3.3 Measures

3.3.1 Household Food Insecurity

HFI is the main exposure of interest for all aims of the proposal. In SEARCH 4, HFI is evaluated in SEARCH Module 17 using the 18-item United States Household Food Security Survey Module (HFSSM)[1], which measures household food insecurity over the previous 12 months. Parents/guardians of SEARCH participants under age 18 and participants with diabetes ≥18 years of age complete the HFSSM. The first 10 questions pertain to all households (with or without children) and the last 8 questions are specific to households with children ages 0-17.[1] Possible answers to 6 of the 18 questions are "Often," "Sometimes," or "Never" true. Answers to 3 questions include "Every month," "Some months but not every month," or "In only 1 or 2 months." The remaining 9 questions are answered with a "Yes" or "No."

For the analyses, HFS will be dichotomized into food secure households and food insecure households. Households are classified as food insecure if the survey respondent reports ≥3 affirmative food insecure conditions or behaviors whether they answer only the first 10 questions or all 18 questions.[2] A continuous scaled HFS score, developed by Bickel et al. (2000), will also be considered because it may capture an association that a binary HFS variable cannot capture. The continuous scaled score, which ranges from 0 to 9.3, with a high score indicating more food insecurity, allows for a direct comparison between households with children and households without children.[1]

For the purpose of assessing the prevalence of HFI among U.S. households, the HFSSM has been shown to be a stable, robust, valid, and reliable measurement tool.[1] Table 3.1 reflects the values of the continuous, scaled HFSSM scores, the dichotomous levels, and the corresponding number of affirmations.

Table 3.1. Food security scale values and dichotomous levels, per U.S. Department of Agriculture HFSSM[1]

Number of Affirmative Responses			
Households with Children (18-Item)	Households without Children (10-Item)	Food Security Scale Values	Food Security Status Level
0	0	0.0	Food Secure
1		1.0	
	1	1.2	
2		1.8	
	2	2.2	
3		2.4	
4		3.0	Food Insecure
	3	3.0	
5		3.4	
	4	3.7	
6		3.9	
7		4.3	
	5	4.4	
8		4.7	
	6	5.0	
9		5.1	
10		5.5	
	7	5.7	
11		5.9	
12		6.3	
	8	6.4	
13		6.6	
14		7.0	
	9	7.2	
15		7.4	
	10	7.9	
16		8.0	
17		8.7	
18		9.3	

3.3.2 HbA_{1c} and Glycemic Control

HbA_{1c} is the standard measure of glycemic control and a measure of blood sugar levels over the past three months and is the primary outcome for Aim 1. HbA_{1c} is measured in a sample of whole blood taken from participants during an in-person SEARCH 4 visit. A higher HbA_{1c} indicates poorer glycemic control. Glycemic control will be categorized using the American Diabetes Association and International Society for Pediatric and Adolescent Diabetes 2014 Guidelines for HbA_{1c} as follows: for ages <18 years: <7.5% is optimal, 7.5-9.0% is suboptimal, and >9.0% is high risk; for ages ≥18 years: <7.0% is optimal, 7.0-9.0% is suboptimal, and >9.0% is high risk.[87]

3.3.3 Acute Diabetes Complications

"Acute diabetes complications" is a secondary outcome of Aim 1. It includes experiencing either diabetic ketoacidosis (DKA) or severe hypoglycemia. Adult participants (age 18+) and caregivers of participants who are minors (age <18) are prompted in SEARCH Module 6 to report DKA and severe hypoglycemia with yes/no questions. Specifically, the question concerning to DKA states "In the last 12 months, have you (has your child) had diabetic ketoacidosis (often called DKA, frequently with high blood sugar, vomiting and shortness of breath)?" The question concerning severe hypoglycemia states "In the last 12 months, have you had any severe hypoglycemia, that is, very low blood sugar that required you to get help?" The results of questions were combined into one dichotomous variable to indicate experiencing an acute diabetes complication or not.

3.3.4 Physical Activity and Inactivity

PA is the primary continuous outcome for Aim 2. It is assessed in SEARCH Module 19 with the International Physical Activity Questionnaire Short Form (IPAQ-SF).[121] This survey asks participants to recall the last 7 days and report time spent in vigorous and moderate activity and time spent walking. PA time is first reported as number of days per week. Then time is reported as hours per day and minutes per day that you usually spend doing the activity on one of those days. According to the IPAQ Score Guide, PA can then be derived into minutes per week or metabolic equivalent minutes per week of vigorous intensity PA (VPA), moderate intensity (excluding walking) PA (MPA), walking PA, and total PA. MVPA and categorical outcomes, such as meeting the PAGA or not, can also be derived.[122,123] To assess meeting the 2018 PAGA or not, I will need to derive meeting the PAGA or not separately for participants < 18 years and participants ≥ 18 years. According to the 2018 PAGA, "children and adolescents ages 6-17 years should engage in 60 minutes or more of MVPA per day. Additionally, adults should engage in at least 150 minutes- 300 minutes per week of moderate-intensity, or 75 minutes -150 minutes per week of vigorous-intensity aerobic PA, or an equivalent combination of moderate- and vigorous-intensity aerobic activity."[70]

The creators of the IPAQ and IPAQ-SF developed and tested it for use in participants 15-69 years old.[121] This decision is supported by a systematic review of the IPAQ and IPAQ-SF that included validity and reliability studies from 12 different countries and found positive validity and reliability among adults for the IPAQ-SF.[124] In terms of reliability and repeatability for the IPAQ-SF, 75% of the observed correlation coefficients were above 0.65 and the pooled Spearman's correlation was 0.76 (95% CI

0.73–0.77).[124] In terms of criterion validity, 781 adults tested agreement between the IPAQ-SF and the Computer Science Application (CSA) accelerometer. The pooled correlation was 0.30 (95% CI: 0.23-0.36).[124] The authors concluded that the IPAQ-SF is recommended for national survelliance.[124]

A more recent systematic review of the IPAQ-SF which included 23 validation studies found that the correlation between total physical activity measured with the IPAQ-SF and objective measures of activity ranged from 0.09 to 0.39; and, the correlation between sections of the IPAQ-SF and objective measures ranged from -0.18 to 0.76. Although the correlations for total physical activity and objective measures were lower than the acceptable standard (0.50 for objective activity measuring devices, 0.40 for fitness measures), several studies of the sections against an objective measure met the minimum standard.[125]

Surveys are the most feasible method of assessing population level surveillance of physical activity. A recent study reported that the IPAQ-SF was the most suitable survey out of three surveys for determining whether university students, i.e. young adults, meet physical activity guidelines.[123] The other two surveys were a single-item measure and a two-item measure typically used to assess attainment the physical activity guidelines in youth. The agreement (77.4%), sensitivity (78.2%), specificity (50.0%), positive predictive value (96.6%), and negative predictive value (11.1%) between the IPAQ-SF and accelerometer measured physical activity was concluded to be the best of the three surveys.[123]

In the IPAQ-SF, participants are also asked to report time spent sitting at work, at home, while doing course work, and during leisure time during the last 7 days. The provided examples of time which can be spent sitting include: sitting at a desk, visiting friends, reading, or sitting or lying down to watch television. Time is reported as hours per day and minutes per day.[121] In the systematic review that included studies from 12 different countries, criterion validity Spearman's coefficients comparing the IPAQ-SF sitting data with the CSA ranged from 0.07-0.61.[124] In Chinese youth, the IPAQ-SF was found to overestimate sedentary-time;[126] and, in adult South Asian women (mean age 46.3±15) the IPAQ-SF was not associated with accelerometer assessed PA ($r = -.140$, $p = .229$).[127]

3.3.5 Diet Quality

Overall diet quality, defined with the HEI-2015, is the primary outcome for Aim 3. In SEARCH, diet intake is first assessed with a self-administered SEARCH food frequency questionnaire (FFQ) that was modified from the Block Kids Questionnaire.[128] The SEARCH FFQ assesses food eaten over the past week and has proven to be valid and reliable in youth with T1D.[129] In a SEARCH validity and reliability study in youth with T1D, the correlation between the FFQ and true usual intake for food groups and nutrients was 0.41 and 0.38, respectively, after adjustment for measurement error. Specific food groups and nutrient groups had higher and lower correlations.[129] Based on completion of 2 FFQ's, the reliability included 54% of Pearson correlation coefficients ≥ 0.5.[129]

The FFQ is self-reported by all SEARCH participants. It includes 85 questions in which the participant indicates if the food item(s) was (were) consumed in the past week ("yes/no") and if yes, how many days, and the average portion size. Portion size is queried either as a number (e.g. number of slices of bread) or as very small, small, medium, or large relative to pictures of food in bowls or plates provided with the form.

An open-ended question at the end of the SEARCH FFQ asks about other foods that the participant might want to report. The nutrient and portion size databases for this instrument were modified from the respective Diabetes Prevention Program databases, by means of industry sources and the Nutrition Data System for Research (Nutrition Coordinating Center, University of Minnesota, Minneapolis MN, Database version 2.6/8A/23).[129]

The HEI-2015 was designed to align with the 2015-2020 Dietary Guidelines for Americans (DGA).[130–132] The index reflects the DGA through 13 components, each of which measures compliance with a different aspect of the DGA. The components are further divided into 2 groups: adequacy components (n=9) and moderation components (n=4). Adequacy components represent the food groups and dietary elements that are encouraged. These groups include 1) total fruits, 2) whole fruits, 3) total vegetables, 4) greens and beans, 5) whole grains, 6) diary, 7) total protein foods, 8) seafood and plant proteins, and 9) fatty acids. Moderation components represent the food groups and dietary elements for which there are recommended limits to consumption. These groups include 10) refined grains, 11) sodium, 12) added sugars, and 13) saturated fats. For adequacy components, higher scores reflect higher intakes, because higher intakes are desirable. However, for moderation components, higher scores reflect lower intakes, because lower intakes are more desirable.

Each component of the HEI-2015 is weighted equally and receives a maximum of 10 points. Some areas (fruits, vegetables, and proteins) are divided into two components (ex: total fruits and whole fruits) that receive five points each total 10 points.[130] The 13 components can be looked at as a set of scores whose total creates an overall HEI-2015 score, ranging 0-100. A higher score indicates a diet that aligns better with DGA.[130,131] The overall HEI-2015 score and the component scores are continuous outcomes. Figure 3.2 shows the HEI-2015 components and scoring standards.

Because the HEI-2015 estimates intake in terms of per 1,000 kilocalorie (i.e. density) rather than absolute amount it can be used across the entire range of caloric intakes.[130,131] The results of two studies have shown that the HEI-2015, similar to the HEI-2010, aligns well with the DGA and a higher score is associated with lower risk of mortality from all-cause, cardiovascular disease, and cancer.[132–134]

3.3.6 Covariates

Covariate measures will be similar within each Aim. Many demographic and socioeconomic characteristics are captured with the SEARCH initial patient survey (IPS).This survey is completed by adult participants and parents of participants who are less than 18 years old.[119] If any covariate must be calculated or categorized, previous SEARCH publications will inform presentation of the variable to maintain consistency.

HEI-2015[1] Components and Scoring Standards

Component	Maximum points	Standard for maximum score	Standard for minimum score of zero
Adequacy:			
Total Fruits[2]	5	≥0.8 cup equivalent per 1,000 kcal	No Fruit
Whole Fruits[3]	5	≥0.4 cup equivalent per 1,000 kcal	No Whole Fruit
Total Vegetables[4]	5	≥1.1 cup equivalent per 1,000 kcal	No Vegetables
Greens and Beans[4]	5	≥0.2 cup equivalent per 1,000 kcal	No Dark-Green Vegetables or Legumes
Whole Grains	10	≥1.5 ounce equivalent per 1,000 kcal	No Whole Grains
Dairy[5]	10	≥1.3 cup equivalent per 1,000 kcal	No Dairy
Total Protein Foods[4]	5	≥2.5 ounce equivalent per 1,000 kcal	No Protein Foods
Seafood and Plant Proteins[4,6]	5	≥0.8 ounce equivalent per 1,000 kcal	No Seafood or Plant Proteins
Fatty Acids[7]	10	(PUFAs + MUFAs) / SFAs ≥2.5	(PUFAs + MUFAs)/SFAs ≤1.2
Moderation:			
Refined Grains	10	≤1.8 ounce equivalent per 1,000 kcal	≥4.3 ounce equivalent per 1,000 kcal
Sodium	10	≤1.1 grams per 1,000 kcal	≥2.0 grams per 1,000 kcal
Added Sugars	10	≤6.5% of energy	≥26% of energy
Saturated Fats	10	≤8% of energy	≥16% of energy

[1] Intakes between the minimum and maximum standards are scored proportionately.
[2] Includes 100% fruit juice.
[3] Includes all forms except juice.
[4] Includes legumes (beans and peas).
[5] Includes all milk products, such as fluid milk, yogurt, and cheese, and fortified soy beverages.
[6] Includes seafood; nuts, seeds, soy products (other than beverages), and legumes (beans and peas).
[7] Ratio of poly- and mono-unsaturated fatty acids (PUFAs and MUFAs) to saturated fatty acids (SFAs).

Figure 3.2 Healthy Eating Index-2015 Components and Scoring Standards

3.3.6.1 Demographic and Socioeconomic Covariate Measures

- *Age at SEARCH 4 cohort visit* is determined by calculating the difference between the date of birth reported on IPS and the date of cohort visit. Age will be used as a continuous variable and presented in years.
- *Sex* is reported via the IPS. Optional answers include male or female. Female will be the reference group.
- *Race/ethnicity* is reported via the IPS. Race-ethnicity will be categorized into non-Hispanic white, non-Hispanic black, Hispanic, and other. Non-Hispanic white will serve as the reference group.

- *Parent Education* is reported via Module 16 of the questionnaires completed prior to or during the in-person visit. Adult participants are asked "What is the highest degree or level of school your mother (or other parent/guardian) has completed?" and "What is the highest degree or level of school your father (or other parent/guardian) has completed?" Parent's of minors are asked "What is the highest degree or level of school you have COMPLETED?" and "What is the highest degree or level of school your child's other parent/guardian has completed?" Optional answers include: No schooling completed, nursery school to 4th grade, 5th grade or 6th grade, 7th grade or 8th grade, 9th grade, 10th grade, 11th grade, 12th grade no diploma, High school graduate (high school diploma) or equivalent (for example GED), Business/ technical school, some college credit but less than 1 year, 1 or more years of college (no degree), Associate degree, Bachelor's degree, Master's degree, Professional or doctorate degree, and Don't know. For adults and parents of youth, the level of education will be used for analysis. For all analyses, parent education will be further categorized into 4 levels: Less than high school, high school graduate, some college – Associate's degree, and Bachelor's degree or more. "Bachelor's degree or more" will serve as the reference group.
- *Household Income is self-reported* in Module 16. The question states "Which of these categories best describes the total income of all persons living in your primary household, including yourself for the last 12 months? (Income can be from salaries, alimony, child support, or other sources)." It will be categorized as less than $25,000, $25,000-49,999, $50,000- 74,999, and $75,000 and greater.

- *SEARCH clinics* include South Carolina, Colorado, Washington, California, and Ohio. The reference will be Ohio.
- *Health insurance type* is self-reported in Module 9 and will be categorized as private, state/federal, and Other/unknown, none. Private insurance will serve as the reference group.
- *Smoking Status* is self-reported in Module 20 of the SEARCH survey. Participants are asked "“Have you ever tried cigarette smoking, even one or two puffs?” If a participant answers “no” they will be classified as a nonsmoker. Participants who answer “yes” to this question are then asked “During the past 30 days, on how many days did you smoke cigarettes?” Participants that answer “none” will be classified as a “former” smoker; and, participants who answer 1-2 days or more will be classified as a “current” smoker.[135]

3.3.6.2 Clinical Covariate Measures

- *Diabetes type* is self-reported with the IPS and confirmed by the participant’s physician or health care provider through electronic medical records. Options include T1D or T2D. For Aims 2 and 3, T1D will be the reference level.
- *Diabetes Duration* is determined by calculating the difference between the date of birth reported on the initial patient survey and the date of diabetes diagnosis.
- *Continuous Glucose Monitoring (CGM)* is assessed in SEARCH Module 4. This variable will be a dichotomous variable of CGM use or not. CGM use will be the reference group.
- *Diabetes medication regimen* is self-reported in Module 3 of the SEARCH survey packet. It will be categorized into insulin pump use, insulin long acting 3+ rapid

acting injections, any other combination of insulin injections, oral hypoglycemic medication, and no treatment. Insulin pump will serve as the reference category.

- *Daily energy intake is* derived from the SEARCH Food Frequency Questionnaire. It will be used in Aim 3 in kilocalories. Kilocalories is a continuous variable.

3.4 Descriptive Statistics

Descriptive statistics for the entire sample and by food security status will be reported in each Aim. Continuous variables will be summarized with mean and standard deviation while discrete variables will be summarized with percentages of different categories. To test for differences between those with HFS and those with HFI, we will use t-tests for continuous variables and Rao-Scott chi-squared tests for categorical variables. The significance level for tests will be set at 0.05.

3.5 Aim 1 Analysis

The purpose of specific Aim 1 is to examine the association between HFI, glycemic control, and acute diabetes complications (experiencing diabetic ketoacidosis (DKA) or hypoglycemia) among youth and young adults with type 2 diabetes. A DAG to represent this relationship is presented in Figure 3.3 and Table 3.2 includes descriptions of all variables that will be used in the analysis. To assess this association, HFI will be analyzed as either a dichotomous variable (where "0" is food secure and "1" is food insecure) or a continuous variable. Because HbA1c is a continuous measure, linear regression (ordinary least squares) will be used. In the initial regression model (Model 1) we will test the crude association between HFI and HbA1c. Subsequently, we will adjust Model 1 with demographic and socioeconomic characteristics (age, education, household income, health insurance type, race/ethnicity, sex, and SEARCH clinic) to obtain Model

2. Finally, we will further adjust Model 2 with clinical characteristics (diabetes duration, diabetes medication regimen, and continuous glucose monitoring (CGM) use) to obtain Model 3.

The expression of our multiple linear regression model is as follows:

$$Mean(Y) = \beta_0 + \beta_1 X_1 + \cdots + \beta_k X_k$$

where Y is the outcome (HbA1c), the X_j's are covariates, and the β_j's are the associated parameters. If we let X_1 be the exposure (food security), then β_1 is the main parameter of interest as it represents the difference between expected HbA1c in the food insecure and food secure groups, adjusted for the other covariates. A positive β_1 implies a higher mean HbA1c level in the food insecure group.

Based on the publication of Mendoza et al.[7], the relationship between HFI and HbA1c may be not be linear. If the assumptions of the linear model are not met, we will consider parametric nonlinear models as well as nonparametric (e.g., splines) models.

To assess the association between HFI and categorical outcomes, glycemic control (where Optimal is "0", suboptimal is "1", and High risk is "2") and DKA (where having DKA is "0" and not having DKA is "1"), multinomial logistic regression and binomial logistic regression will be used, respectively. These models will be adjusted following the same procedure described above for linear regression models. The multinomial logistic regression involves 3 categories (optimal, suboptimal, and high risk glycemic control) and 2 equations. A proportional-odds cumulative logit model will be considered. The multinomial logistic regression equations are as follows:

$$\text{logit}(\text{Y} = 0) = \log\left(\frac{P(Y = 0)}{P(Y > 0)}\right) = \beta_0 + \beta_1 X_1 + \cdots \beta_k X_k$$

where, $P(Y = 0)$ is the probability that glycemic control is optimal, $P(Y > 0)$ is the probability that glycemic control is suboptimal or high risk. The parameter β_1 is the main parameter of interest as it represents the log odds ratio (OR) of optimal glycemic control in the food insecure and food secure groups, adjusted for the other covariates.

A positive β_1 implies a higher OR in the food insecure group.

$$\text{logit}(\text{Y} = 1) = \log\left(\frac{P(Y \leq 1)}{P(Y > 1)}\right) = \beta_0 + \beta_1 X_1 + \cdots \beta_k X_k$$

where, $P(Y \leq 1)$ is the probability that glycemic control is optimal or suboptimal, $P(Y > 1)$ is the probability that glycemic control is high risk. The parameter β_1 is the main parameter of interest as it represents the log OR of optimal or suboptimal glycemic control in the food insecure and food secure groups, adjusted for the other covariates. A positive β_1 implies a higher OR in the food insecure group.

The binomial logistic regression analysis, which will assess the relationship between HFI and DKA, is represented in the following equation:

$$\log\left(\frac{P\ (Y = 1)}{1 - P(Y = 1)}\right) = \beta_0 + \beta_1 X_1 + \cdots \beta_k X_k$$

where, $P(Y = 1)$ is the probability of having DKA, and $1 - P(Y = 1)$is the probability of not having DKA. The parameter β_1 is the main parameter of interest as it represents the log of OR of having DKA in the food insecure and food secure groups, adjusted for the other covariates. A positive β_1 implies a higher OR in the food insecure group.

3.5.1 Inclusion/ Exclusion

The analysis for Aim 1 will be restricted to individuals with T2D and those that have all variables of interest (exposure, outcome, and covariates) in the dataset. List wise deletion will be used to determine the final sample size.

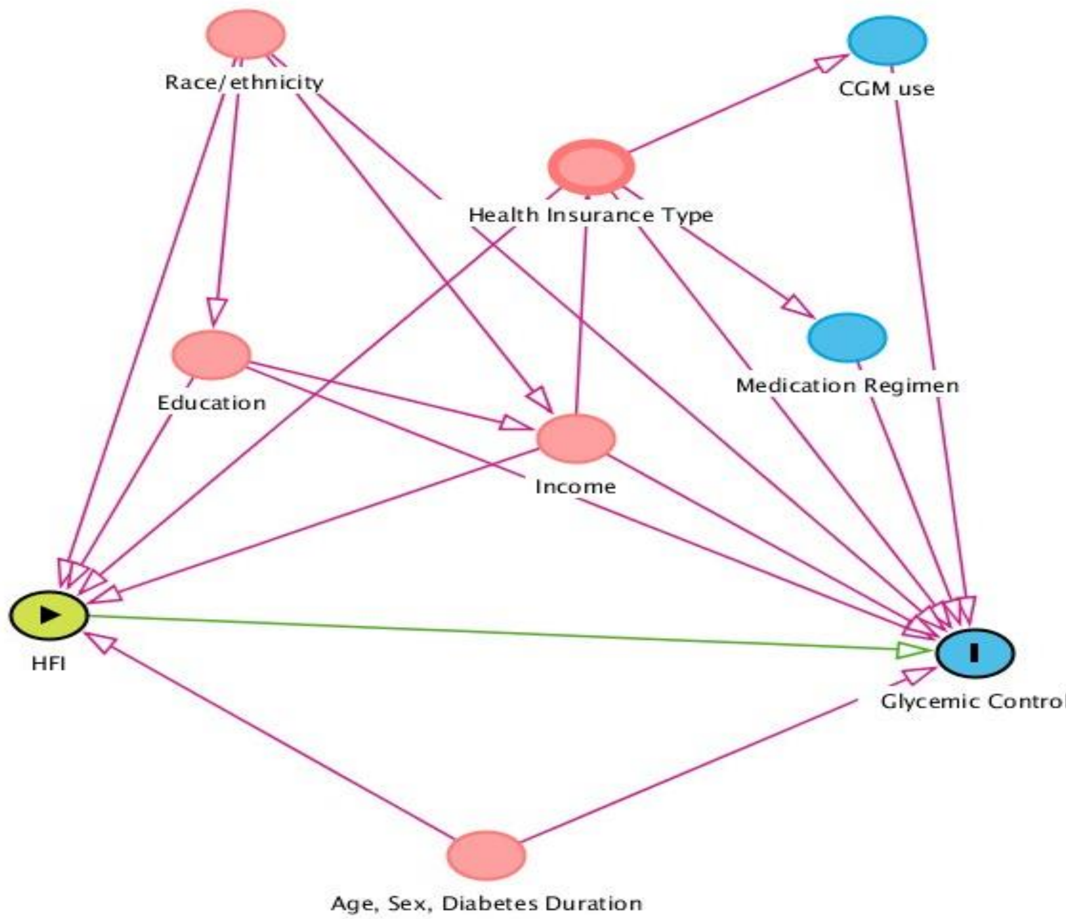

Figure 3.3. Aim 1 DAG depicting the association between HFI and glycemic control among YYA with T2D

Table 3.2. Relevant Variables for Analysis of Specific Aim 1 (N=395)

Type for Analysis	Variable	Aim	Measure	Type	Units / Categories
Outcomes	HbA1c	1	Whole blood sample	Continuous	%
	Glycemic Control	1	ADA Guidelines**	Ordinal	Optimal, suboptimal, high risk
	Acute diabetes complications	1	Module 6	Dichotomous	Yes / No
	Hypoglycemia	1	Module 6	Dichotomous	Yes / No
	Diabetic Ketoacidosis	1	Module 6	Dichotomous	Yes / No
Exposure	Food Security	1,2,3	18-item HFSSM	Dichotomous	HFI / HFS
	Food Security	1	18-item HFSSN	Continuous	
Covariates	Age	1,2 ,3	IPS	Continuous	Years
	Sex	1, 2, 3	IPS	Nominal	Female / Male
	Race/ethnicity	1, 2, 3	IPS	Nominal	NHW / NHB / Other
	Education	1, 2, 3	Module 16	Ordinal	Less than HS, HS graduate, Some college – assoc degree, Bachelor's degree or more
	Income	1, 2, 3	Module 16	Dichotomous	<25k, $25+
	Insurance Type	1, 2, 3	Module 9	Nominal	State / Federal, Private/Exchanges, None, Other/Unknown
	SEARCH clinic	1, 2, 3	IPS	Nominal	South Carolina, Colorado, Ohio, Washington/California
	Diabetes Duration	1, 2, 3	IPS	Continuous	Months
	Diabetes medication regimen	1,2,3	Module 3	Dichotomous	Medication, No Medication
	CGM use	1, 2, 3	Module 4	Dichotomous	Use / No use

3.6 Aim 2

The purpose of Aim 2 is to examine the relationship between HFI and PA in YYA with T1D and T2D. To assess this association, a series of median regression models will be conducted, where the exposure of interest is HFI (a dichotomous variable where "0" is food secure and "1" is food insecure) and the PA outcomes of interest are VPA, MPA, MVPA, walking, total activity, meeting the PAGA, and sitting.

Continuous outcomes (VPA, MPA, MVPA, walking, and total activity) will be assessed in minutes per week. The primary outcome of interest is MVPA. Sitting will be assessed as minutes per day. A preliminary analysis determined that the continuous PA outcomes violate linearity assumptions because they are not normally distributed. Therefore, a median regression will be used to assess the association between HFI and continuous PA outcomes. Median regression is a nonparametric test, and therefore, has fewer conditions for validity than a parametric test. The preliminary analysis also found that participants tend to bin PA time in hour increments (e.g., 30 minutes, 60 minutes, etc.). To make the outcomes pseudo-continuous, jittering will be applied. Jittering adds random, uniform noise to the discretized values. We will then apply median regression to jittered PA outcomes. The equation to represent the relationship of interest is as follows:

$$Median(Y) = \beta_0 + \beta_1 X_1 + \cdots \beta_k X_k$$

where Y is the outcome (PA). The parameter β_1 is the main parameter of interest as it represents the difference of median PA in the food insecure and food secure groups, adjusted for the other covariates. A positive β_1 implies a higher median PA in the food insecure group.

To assess the relationship between HFI and meeting the PAGA indicator (binary), a logistic regression analysis will be completed, where "1" is meeting the PAGA and "0" is not.

The equation to represent this relationship is as follows:

$$\log\left(\frac{P\ (Y=1)}{1-P(Y=1)}\right)=\beta_0+\beta_1X_1+\cdots\beta_kX_k$$

where $P(Y=1)$ is the probability of meeting the PAGA. The parameter β_1 is the main parameter of interest as it represents the log OR of meeting the PAGA in the food insecure and food secure groups, adjusted for the other covariates. A positive β_1 implies higher odds of meeting the PAGA in the food insecure group.

A DAG reflecting the association between HFI and PA in those with T1D is depicted in Figure 3.4 and a DAG for T2D is presented in Figure 3.5. Three sets of models will be used to evaluate the association between HFI and each outcome. Model 1 will test the crude association between HFI and the outcome variables. Model 2 will include Model 1 in addition to demographic and socioeconomic characteristics: age, sex, race/ethnicity, education, household income, insurance type, SEARCH clinic, and smoking status. Model 3 will include Model 2 in addition to clinical characteristics: diabetes duration. The rational for this adjustment sequence is previous studies have assessed this relationship in healthy samples using only demographic and socioeconomic characteristics.[26,27] Model 3 includes characteristics specific to people with diabetes. Table 3.3 reflects all variables that will be used in Aim 2.

The analysis will be completed in the full sample and stratified by diabetes type due to the unique clinical and demographic characteristics of T1D vs. T2D. During the transition to adolescence, sex differences in physical activity behavior appear. The amount of physical activity done by girls tends to decrease dramatically compared to that of boys, and the disparity persists into adulthood.[70] Therefore, an interaction between HFI and sex will be tested to determine if a relationship between HFI and PA is different for males and females. It is hypothesized that any observed relationships will be stronger for females because food-insecure females may have to spend more time with housework and have extra jobs. An interaction between HFI and being an adult will also be tested because physical activity patterns and guidelines for adults and children are different. It is predicted that the relationship between HFI and PA will be stronger for adults.

3.6.1 Inclusion/ Exclusion Criteria

All analyses for Aim 2 will be restricted to participants 15 and older per recommendation by the creators of the IPAQ-SF.[121] The final sample of participants will be restricted to those that have all variables of interest (exposure, outcome, and covariates) in the dataset. List-wise deletion will be used to determine the final sample size.

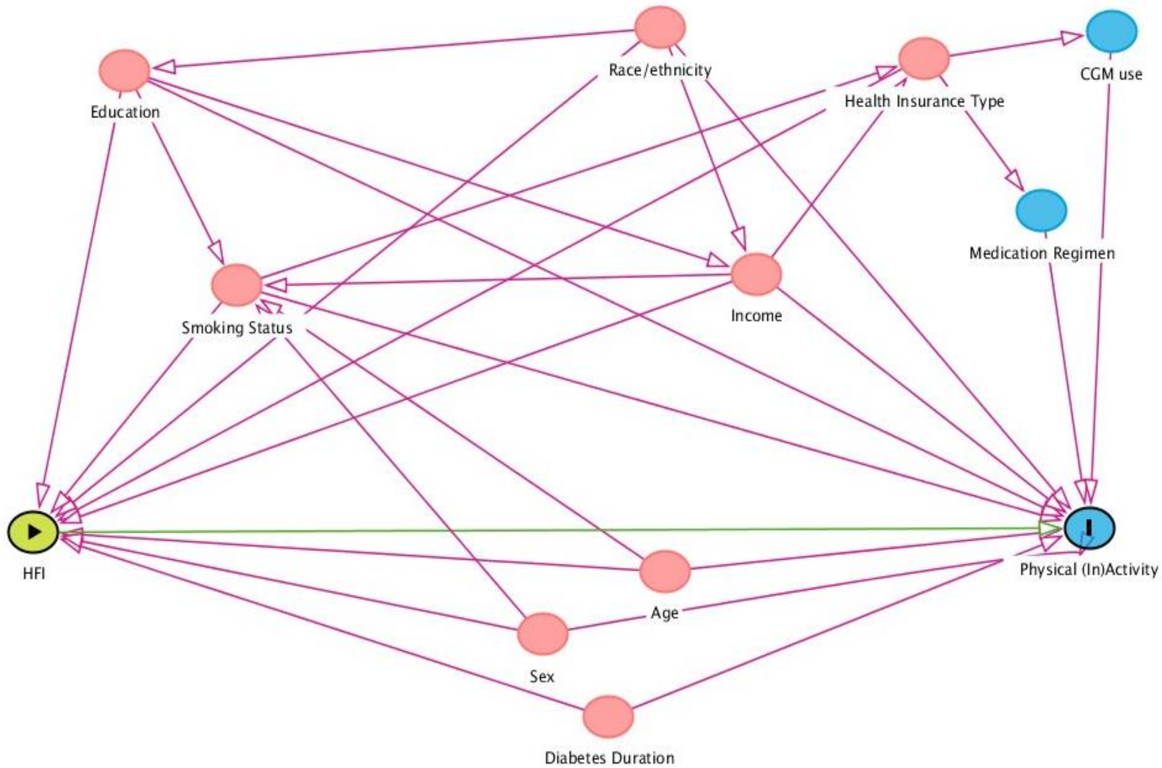

Figure 3.4. Aim 2 DAG depicting the association between HFI and Physical Activity / Inactivity among YYA with T1D

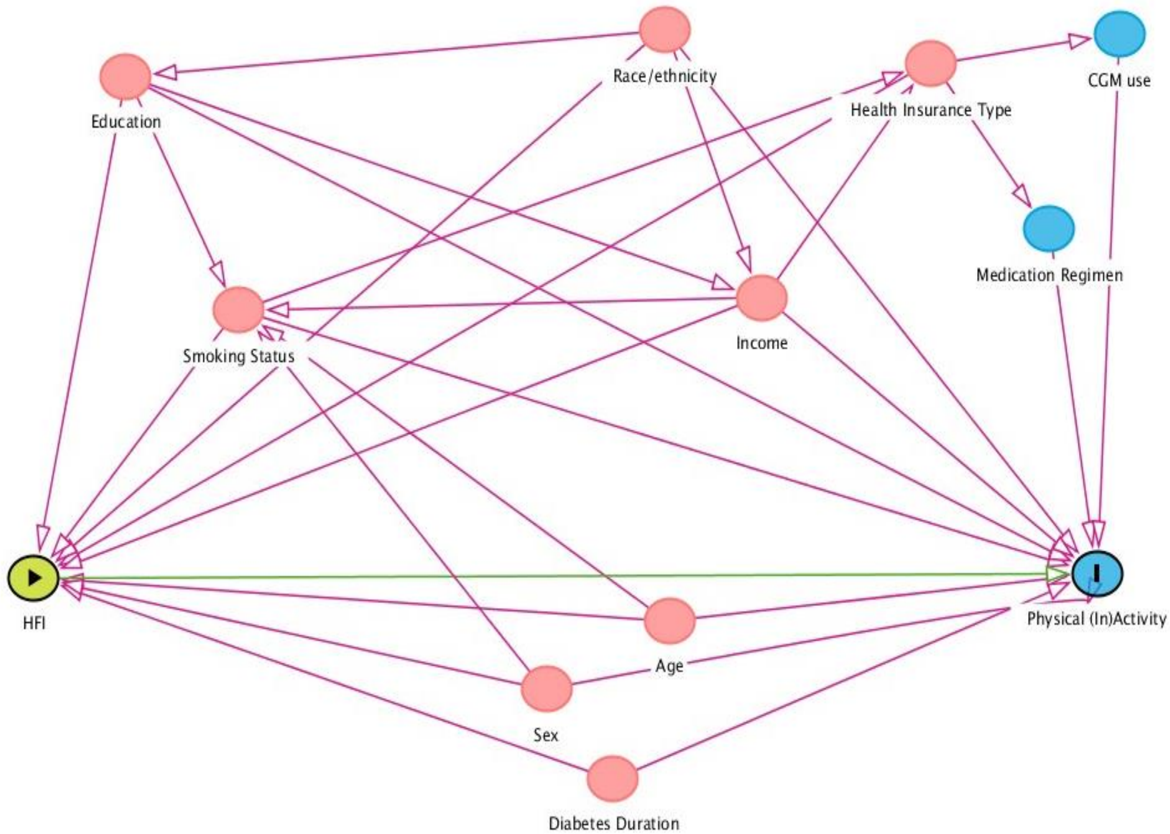

Figure 3.5. Aim 2 DAG depicting the association between HFI and Physical Activity / Inactivity among YYA with T2D

Table 3.3. Relevant Variables for Analysis of Specific Aim 2 (N=2,669)

	Variable	Aim	Measure	Type	Units / Categories
Outcomes	VPA	2	IPAQ-SF	Continuous	min/wk
	MPA	2	IPAQ-SF	Continuous	min/wk
	Walking	2	IPAQ-SF	Continuous	min/wk
	Total	2	IPAQ-SF	Continuous	min/wk
	MVPA	2	IPAQ-SF	Continuous	min/wk
	Met PAGA	2	IPAQ-SF	Dichotomous	Meets / Not
	Sitting	2	IPAQ-SF	Continuous	Min/day
Exposure	Food Security	1,2,3	18-item HFSSM	Dichotomous	HFI / HFS
Covariates	Age	1,2,3	IPS	Continuous	Years
	Sex	1, 2, 3	IPS	Nominal	Female / Male
	Race/ethnicity	1, 2, 3	IPS	Nominal	NHW / NHB / H / Other
	Education	1, 2, 3	Module 16	Ordinal	Less than HS, HS graduate, Some college – associate degree, Bachelor's degree or more
	Income	1, 2, 3	Module 16	Ordinal	<25k, $25-49K, $50-74K, $75K
	Insurance Type	1, 2, 3	Module 9	Nominal	State / Federal, Private/Exchanges, None, Other/Unknown
	SEARCH clinic	1, 2, 3	IPS	Nominal	South Carolina, Colorado, Washington, California, Ohio
	Smoking Status	2,3	Module 20	Ordinal	Nonsmoker, former, current
	Diabetes Duration	1, 2, 3	IPS	Continuous	Months
	Diabetes Type	1, 2, 3	Physician Diagnosis	Categorical	T1D / T2D

3.7 Aim 3

The purpose of Aim 3 is to examine the relationship between HFI and diet quality, characterized with the HEI-2015, in YYA with T1D and T2D. To assess this association, HFI will be assessed as a dichotomous variable (where “0” is food secure and “1” is food insecure). The HEI-2015 score is a continuous outcome. To evaluate this aim, linear regression (Ordinary Least Squares) will be used. DAGs for T1D and T2D reflecting the association between HFS and diet quality are depicted in Figure 3.6 and Figure 3.7.

Three sets of models will be used to assess the association between HFI and diet quality, measured with the HEI-2015. Model 1 will test the crude association between HFI and diet quality. Model 2 will include Model 1 in addition to demographic and socioeconomic characteristics: age, sex, race/ethnicity, education, household income, health insurance type, SEARCH clinic, daily energy intake (in kilocalories), and smoking status. Model 3 will include Model 2 in addition to clinical characteristics: diabetes type, diabetes duration, diabetes medication regimen, and continuous glucose monitoring. Table 3.4 reflects all variables that will be used in Aim 3. Regression coefficients and 95% confidence intervals will be reported for this analysis. The expression of the multiple linear regression model is as follows:

$$Mean(Y) = \beta_0 + \beta_1 X_1 + \cdots + \beta_k X_k$$

where Y is the outcome (HEI-2015 score), the X_j's are covariates, and the β_j's are the associated parameters. If we let X_1 be the exposure (food security), then β_1 is the main parameter of interest as it represents the difference between expected HbA1c in the food insecure and food secure groups, adjusted for the other covariates. A positive β_1 implies a higher mean HEI-2015 level in the food insecure group.

The purpose of Aim 3a is to assess the association between HFI and component scores of HEI-2015 among YYA with T1D and T2D. This may capture associations between HFI and specific dietary components (for example total fruit, whole fruit, total vegetables, greens & beans etc.) that may be obscured by focusing exclusively on the overall score. All component scores will be assessed as a continuous outcome, and linear regression (Ordinary Least Squares) will be utilized. Regression coefficients and p-values will be reported for this analysis.

Aims 3 and 3a will be assessed in the full sample and stratified by diabetes type due to the unique clinical and demographic characteristics of T1D vs. T2D. Previous research has found differences in diet quality by age, sex, race/ethnicity, income, and education level in healthy populations[136] and in income, and education level in people with diabetes.[114]

3.7.1 Inclusion/ Exclusion

The analysis for Aim 3 will be restricted to those that have all variables of interest (exposure, outcome, and covariates) in the dataset. List wise deletion will be used to determine the final sample size.

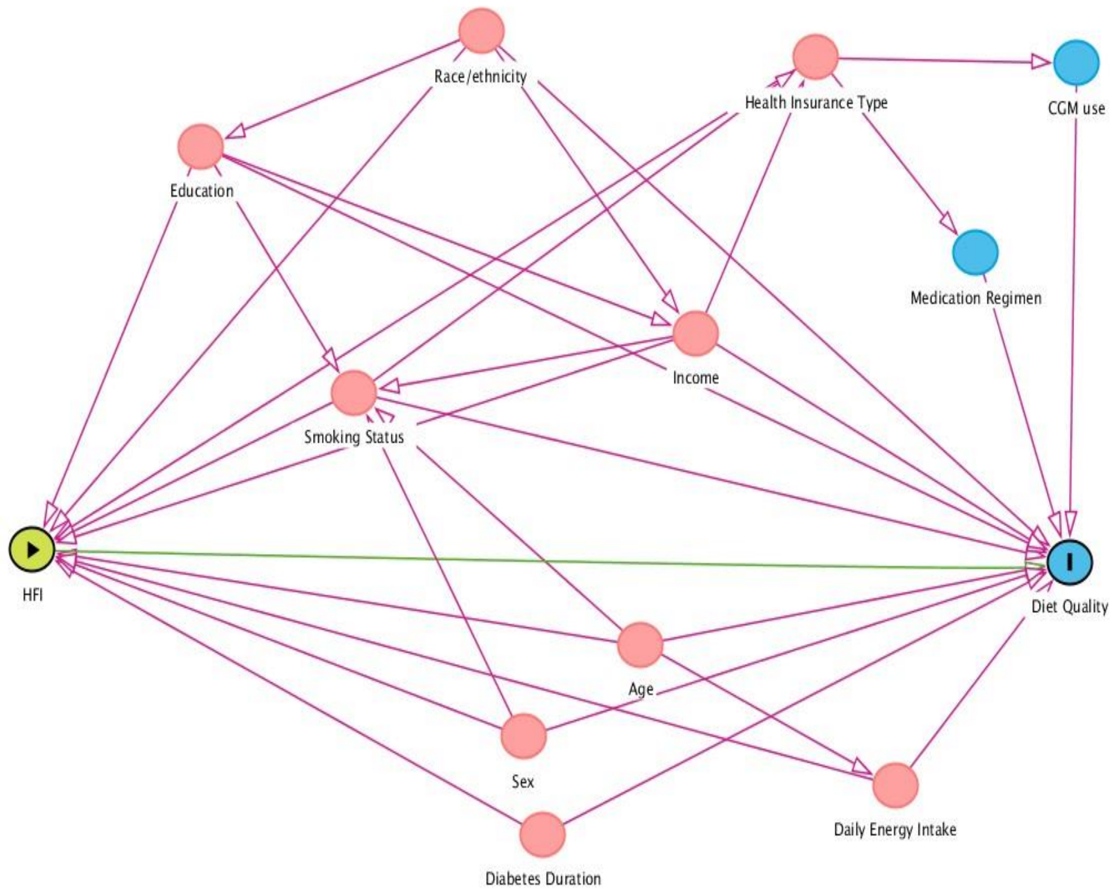

Figure 3.6. Aim 3 DAG depicting the association between HFI and diet quality among YYA with T1D

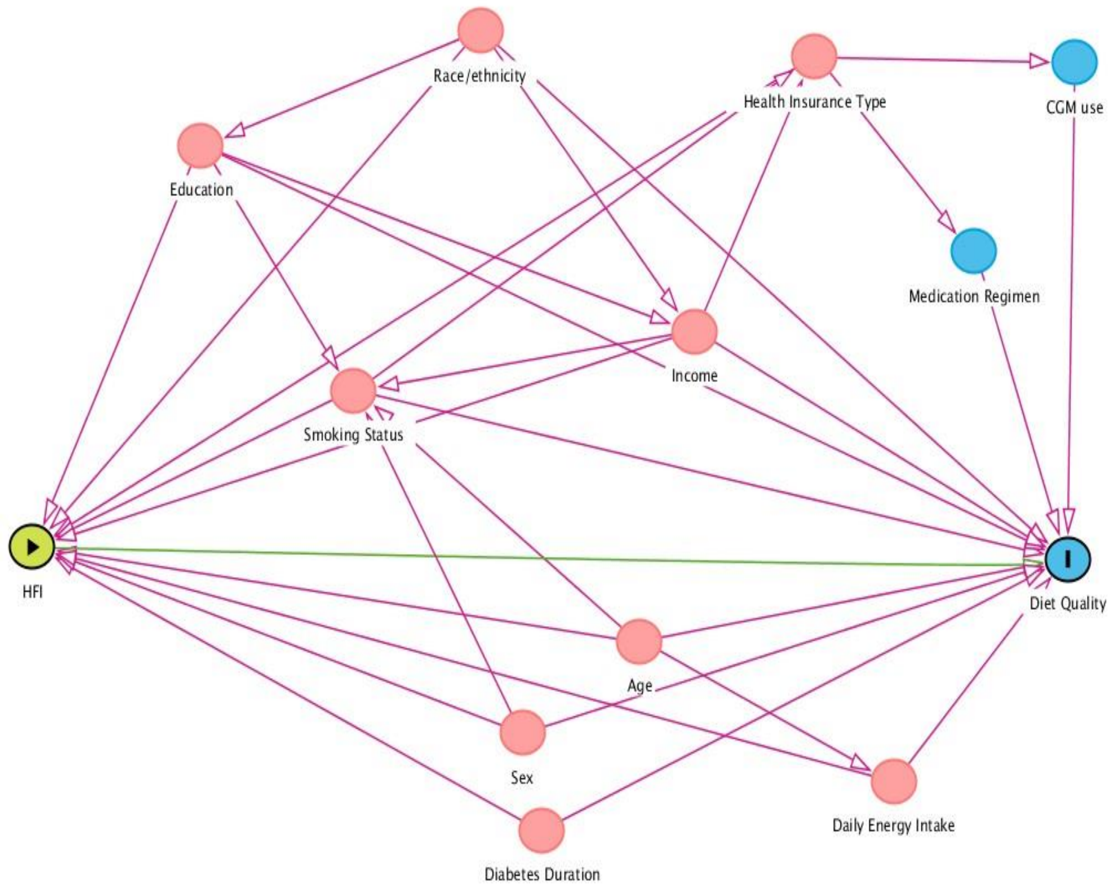

Figure 3.7. Aim 3 DAG depicting the association between HFI and diet quality among YYA with T2D

Table 3.4. Relevant Variables for Analysis of Specific Aim 3 (N=2,669)

	Variable	Aim	Measure	Type	Units / Categories
Outcomes	Diet Quality	3	HEI-2015	Continuous	Units
	Component Scores	3	HEI-2015	Continuous	Units
Exposure	Food Security	1,2,3	18-item HFSSM	Dichotomous	HFI / HFS
Covariates	Age	1,2 ,3	IPS	Continuous	Years
	Sex	1, 2, 3	IPS	Nominal	Female / Male
	Race/ethnicity	1, 2, 3	IPS	Nominal	NHW / NHB / H / Other
	Education	1, 2, 3	Module 16	Ordinal	Less than HS, HS graduate, Some college – associate degree, Bachelor's degree or more
	Income	1, 2, 3	Module 16	Ordinal	<25k, $25-49K, $50-74K, $75K
	Insurance Type	1, 2, 3	Module 9	Nominal	State / Federal, Private/Exchanges, None, Other/Unknown
	SEARCH Clinic	1, 2, 3	IPS	Nominal	South Carolina, Colorado, Washington, California, Ohio
	Smoking Status	2,3	Module 20	Ordinal	Nonsmoker, former, current
	Diabetes Type	1, 2, 3	Physician Diagnosis	Categorical	T1D / T2D
	Diabetes Duration	1, 2, 3	IPS	Continuous	Months
	Diabetes medication regimen	1,2,3	SEARCH survey	Nominal	Insulin pump, Insulin long acting 3+ rapid acting injections, Any other combination of insulin injections, Oral hypoglycemic medication, No treatment
	CGM use	1, 2, 3	Module 4	Dichotomous	Use / No use
	Daily energy intake	3	FFQ	Continuous	Kilocalories

3.8 Model Fit

3.8.1 Linear Regression

The assumptions of linear regression include 1) a linear relationship between Y and the regression coefficients, 2) independent observations 3) the errors are normally distributed 4) the errors have equal variance (homoscedasticity). To check for linearity and homoscedasticity, scatter plots of Studentized residuals will be assessed.[137], The independence assumption is considered to be met based on the study design. Q-Q plots of the residuals will be used to assess normality. For multiple linear regression, there is also a non-collinearity requirement. Collinearity will be checked with the variance inflation factor (VIF). If the VIF is large (VIF > 10), then collinearity is considered to be present.[137] If the assumptions of the linear model are not met, we will consider parametric nonlinear models as well as nonparametric (e.g., splines) models.

3.8.2 Logistic Regression

In binomial logistic regression we assume, 1) the logistic transformation is the true model, 2) the log-odds are linear in the parameters, 3) the observations are independent.[137] Assumptions will be tested with the Hosmer-Lemeshow Goodness of Fit test, where a p-value < 0.05 will indicate the model is not a good fit.

In multinomial logistic regression we assume independence and non-perfect separation of the categories. If the groups of the outcome variable are perfectly separated by the predictor or predictors, then the estimated coefficients will be unrealistic, and the effect sizes will be overestimated.

For a proportional-odds cumulative logit model to be valid, the assumption that all the logit surfaces are parallel (i.e., logit equations differ by intercept only) must be tested using, e.g., a score or a Wald test. A nonsignificant test is taken as evidence that the logit surfaces are parallel and that the slopes are constant across all logit equations.[138][139] If the test rejects the proportional-odds assumption, then one can use the baseline category logit model instead.[140]

3.8.3 Median Regression

Median regression does not make assumptions about the shape of the error distribution. Therefore, inference is valid regardless of whether the error is symmetric or skewed, unimodal or bimodal, normal or heavy-tailed, etc.

3.9 Strengths and Limitations

There are several strengths of the studies presented. All aims will use the HFSSM to measure HFS. This is a strength because it is the United States' reference measure for food insecurity. Because glycemic control is based on criteria established by the American Diabetes Association and International Society for Pediatric and Adolescent Diabetes 2014 Guidelines for long term glycemic control, our results will be comparable to studies using the same glycemic control criteria. Finally, the large sample size of Aims 2 and 3 is a strength. Aim 1 involves one of the largest samples of YYA with T2D to date.

As with every study there are limitations to consider. This is a cross-sectional study, therefore temporality is not guaranteed and temporal bias may exist. Additionally, we are not able to calculate risks. Although use of the HFSSM is a strength, there is one limitation. The HFSSM measures HFS at the household level rather than measuring HFS of individuals. All outcomes are in regard to individual characteristics. Although this may introduce some error, HFS is the standard measure of food security status.

The IPAQ-SF, like other physical activity survey measures, has been found to overestimate physical activity.[125] The IPAQ-SF also does not separate different types of walking; therefore, we cannot interpret walking for transportation (i.e. work vs. leisure). The SEARCH FFQ assesses food eaten during the last 7 days. In order to capture seasonal variation in diet, the diet assessment would need to span an entire year or be repeated during different seasons.[141] A large number of participants are missing data on income (Aim 1: 37% [n=146]; Aim 2 and 3: 27% [n=729]) necessitating some type of imputation to overcome this issue.

3.10 Missing Data

There is also a considerable proportion of missing for physical activity outcomes, the outcome that will be analyzed in Aim 2. To characterize patterns of missing values, a comparison of demographic and HFI statistics will be made for those with and those without missing values.

It will be important to assume a missing data mechanism for each of these variables with missing values. Possible mechanisms[142] are: missing completely at random (MCAR); missing at random (MAR); and missing not at random (MNAR). MCAR implies that the probability of missingness is independent of any variable, whether observed or not. Data that is MAR means that the probability of being missing may depend on observed variables, but not on the missing values themselves. Finally, MNAR implies informative missing, since the probability of missingness depends on unobserved values, even conditional on observed ones. The MCAR hypothesis will be tested for. If rejected, we will apply appropriate methods (e.g., multiple imputation) for assessing the sensitivity of the results to MAR or MNAR assumptions.

3.11 Alternative approaches

A three category (food secure, low food security, very low food security) and a four category (high food security, marginal food security, low food security, very low food security) approach to measure HFS are described by Coleman-Jensen et al. (2019).[2,15,16] These variables will also be considered for analysis.

SEARCH also collects data on child food security for participants who are less than 18 years old. This will not be considered for analysis for continuity. SEARCH 4 has HFS data for all participants from an adult perspective, whether participant or parent/guardian. Participants who were not adults at the SEARCH 4 visit will not have child-reported HFS.

SEARCH uses multiple diet indices to capture diet quality of participants. However, the HEI-2015 has the greatest potential to capture diet quality of US participants. The Mediterranean Diet Quality Index actually evaluates the degree to which dietary intake resembles a Mediterranean diet. The Dietary Approaches to Stop Hypertension index has been found to have a very high correlation with the HEI (r = 0.67).[143]

Previous studies assessing the association between HFS and glycemic control have used body mass index as a co-variate in the analyses.[13,14] Body mass index will not be used for analysis in Aim 1 because it could also be considered a mediator, rather than a confounder, on the path between HFS and glycemic control.

3.12 Public Health Implications

There are several ways that this study will contribute to the body of literature surrounding food security and diabetes. To date, several studies have assessed the association between HFI and PA or HFI and diet quality. However, no studies have examined these relationships in a sample of YYA with diabetes. There may be unique and important consequences of these relationships for YYA with diabetes. Additionally, clinical care may be improved by identifying the mechanisms by which HFI impacts behaviors which contribute to glycemic control, the primary goal of managing diabetes.

There have been a number of studies examining HFS and glycemic control among adults with T2D;[13,14] however, limited studies have examined this relationship in YYA[6] and none are specific to youth with T2D. YYA have unique characteristics which make generalizing findings from adults inadequate. Long term, initiatives targeting HFI or behaviors and outcomes affected by HFI, among YYA with diabetes may help improve their glycemic control and could potentially reduce hospitalizations and/or trips to the emergency rooms.

CHAPTER 4

HOUSEHOLD FOOD INSECURITY, GLYCEMIC CONTROL, AND ACUTE COMPLICATIONS, IN YOUTH AND YOUNG ADULTS WITH TYPE 2 DIABETES

4.1 Abstract

Household food insecurity (HFI) is a modifiable risk factor of glycemic control among people with type 2 diabetes (T2D). Although the prevalence of HFI is extremely high among youth and young adults (YYA) with T2D, studies examining the association between HFI and glycemic control is lacking. The purpose of this study is to examine the association between HFI, glycemic control, and acute complications of diabetes among YYA with youth-onset T2D.

This cross-sectional study included 395 YYA with T2D from the SEARH for Diabetes in Youth Study (2016-2020). HFI was measured with the US Household Food Security Survey Module and completed by young adult participants or parents of participants that were minors. HFI was assessed as a continuous variable and a binary variable, where affirming ≥3 food insecure conditions classified a household as food insecure. HbA_{1c} values were available for 326 participants (82.5%). It was measured in a sample of whole blood and analyzed as a continuous variable. Glycemic control was categorized as optimal, suboptimal, or high risk based on HbA1c and cut points were based on international guidelines. Acute complications of diabetes included self-

reporting severe hypoglycemia or diabetic ketoacidosis (DKA) in the last 12 months. Acute complications data was available for 351 participants (88.9%). Logistic and linear regression were used for modeling the association of HFI with binary and continuous outcomes, respectively. All models were adjusted for the participant's age, gender, race, parent education, insurance type, clinic, diabetes duration, continuous glucose monitoring use, and medication regimen.

This sample included YYA with T2D ages 14-35 years (median age 24.7 years). Approximately 34% reported experiencing HFI in the past 12 months. The mean HbA_{1c} of those with HFI was 9.2%, 56% had an HbA_{1c} >9.0%, and 17% reported experiencing DKA or severe hypoglycemia. YYA without HFI had a mean HbA_{1c} of 9.4%, 55% had HbA_{1c} >9.0%, and 8% reported acute complications. No associations were observed between HFI and HbA_{1c} or glycemic control. An association between HFI and acute complications was observed in crude and adjusted models. In the fully adjusted model, YYA with HFI had 2.2 (CI: 1.02-4.56; p-value: 0.0448) times the odds of experiencing DKA or hypoglycemia as those without HFI.

HFI affected more than a third of our sample and was associated with acute diabetes-related complications. Future research among YYA with T2D should involve longitudinal studies which examine whether alleviating HFI reduces DKA and severe hypoglycemic occurrences.

4.2 Introduction

The SEARCH for Diabetes in Youth Study has recently reported rising incidence and prevalence of type 2 diabetes (T2D) in youth (< 20 years) and young adults (YYA), particularly in racial and ethnic minorities. Between 2002 and 2015, the incidence of T2D increased at a constant rate of 4.8% (95% CI: 3.7 to 5.92) per year and, increased in all race-ethnic groups except whites.[64] From 2001-2017, the prevalence of T2D increased from 0.3 per 1,000 to 0.7 per 1,000, indicating a 95% increase.[144] The highest absolute increases in prevalence over 16 years were observed among non-Hispanic black adolescents (0.85 per 1,000), and Hispanic adolescents (0.57/1,000).[144]

Moreover, glycemic control levels in YYA with T2D leave significant room for improvement, with only 35% reaching the HbA_{1c} goal of 7%[19] and approximately 27% with poor glycemic control (HbA1c $\geq$ 9.5%).[73] Minority YYA are even worse off, as 41% of non-Hispanic black and 49% of Hispanic YYA with T2D do not have optimal glycemic control in relation to 19% of non-Hispanic white YYA.[3] When glycemia is not properly managed diabetic ketoacidosis (DKA) and severe hypoglycemia are two acute complications that often occur in people with diabetes.[33] In 2008-2010, DKA at diagnosis occurred in 5.7% of T2D cases.[76] Poor diabetes management is of particular concern for YYA with T2D because young people with T2D have a higher risk of developing chronic complications, including nephropathy, retinopathy and peripheral neuropathy than YYA with T1D.[20] Moreover, YYA with T2D are typically overweight or obese and therefore prone to secondary comorbidities including hypertension, hyperlipidemia, non-alcoholic fatty liver disease, and cardiovascular disease.[21]

Among the little that is known about the etiology of T2D in YYA, social determinants of health seem to play an important role[145], with a common demographic of YYA with T2D being low socioeconomic status (SES).[145,146] One potentially modifiable attribute associated with being in a low SES household is household food insecurity (HFI). Household food insecurity (HFI) is the limited or uncertain availability of nutritionally adequate and safe foods or limited or uncertain ability to acquire acceptable foods in socially acceptable ways."[1] Substantial evidence supports an association between HFI, poor glycemic control,[13–18,32] and hypoglycemia[40,41,93] among older adults with T2D. Additionally, a recent study has reported a similar relationship between HFI and glycemic control among YYA with T1D.[7] Even though more than 30% of YYA with T2D experience HFI;[147] a prevalence much higher than YYA with T1D and higher than the national average in 2019 of 10.5% (6.5% of households with children),[148] to the best of our knowledge no studies to date have focused on YYA with T2D with respect to HFI. Few to no studies have examined a relationship between HFI and DKA. Many young adults experience a transition period of living at home to a more independent phase of life that affects diabetes self-management.[149] The purpose of this study is to examine the association between HFI, glycemic control, and acute complications of diabetes among YYA with youth-onset T2D. We hypothesize that HFI will be associated with higher $HbA_{1c,}$ worse glycemic control, and higher odds of experiencing DKA or severe hypoglycemia in the last 12 months.

4.3 Methods

We utilized data from the SEARCH for Diabetes in Youth Study (SEARCH) to conduct a cross-sectional analysis. SEARCH is a longitudinal multi-site cohort study that aims to advance the understanding of the epidemiology of non-gestational diabetes among YYA who were diagnosed with diabetes before 20 years old.[120,150] Institutional Review Board approval to conduct this study was granted at each of the five participating funded centers before data collection began. An in-depth synopsis of the methods used in SEARCH have been published elsewhere.[26] The current study focused on YYA from SEARCH with provider diagnosed type 2 diabetes (n =395) with data collected between 2015 and 2020.

4.3.1 Household Food Insecurity

HFI was measured with the18-item United States Household Food Security Survey Module.[148] This instrument measures HFI over the previous 12 months and has been shown to be a robust, valid, and reliable measurement tool.[1] Parents/guardians of SEARCH youth participants (<18 years of age) and participants 18 years of age or older completed the survey. Households were classified as food insecure if the respondent affirmed ≥3 food insecure conditions or behaviors.[148] A continuous scaled score,[1] which ranges from 0 to 9.3, with a higher score indicating more HFI was also used in the analysis.

4.3.2 HbA_{1c} and Glycemic Control

HbA_{1c} was measured in a sample of whole blood taken from participants during an in-person clinic visit. A higher HbA_{1c} indicated poorer glycemic control. Glycemic control was categorized using the American Diabetes Association and the International Society for Pediatric and Adolescent Diabetes 2014 Guidelines for HbA_{1c} as follows: for ages <18 years: HbA_{1c} <7.5% is optimal, 7.5-9.0% is suboptimal, and >9.0% is high risk; for ages ≥18 years: <7.0% is optimal, 7.0-9.0% is suboptimal, and >9.0% is high risk.[87]

4.3.3 Acute Complications of Diabetes

DKA and severe hypoglycemia were reported via a survey and completed by parents/guardians of participants under age 18 and young adult participants (age ≥18). The question pertaining to DKA states "In the last 12 months, have you (has your child) had diabetic ketoacidosis (often called DKA, frequently with high blood sugar, vomiting and shortness of breath)?" The question pertaining to hypoglycemia states "In the last 12 months, have you (has your child) had any severe hypoglycemia, that is, very low blood sugar that required you to get help?" Optional answers to each question include yes, no, or don't know. Don't know answers were set to missing. A binary variable was created that dichotomized people into having DKA, sever hypoglycemia, or both in the last 12 months or not. Binary variables considering DKA or not and severe hypoglycemia or not in the last 12 months were also considered.

4.4.4 Covariates

All data for covariates used in the adjusted analyses were collected via questionnaires. The participant's age and diabetes duration were analyzed as continuous variables. Categorical variables included sex (female, male), race/ethnicity (Non-Hispanic White, Non-Hispanic black, other), SEARCH clinic site (South Carolina, Colorado, Ohio, California/Washington), highest parental education (Less than high school graduate, High school graduate, Some college / Associate degree, Bachelor's degree or more), household income (Less than $25,000, ≥$25,000), insurance type (Private/Exchanges, State/Federal, Other/Unknown, None), diabetes medication regimen (Medication, No treatment) and continuous glucose monitoring use (yes/no).

4.4.5 Statistical Analysis

The SEARCH study included 395 youth and young adults with T2D. To assess HbA1c and glycemic control, if people missing HbA1c (n=36), food security status (n=6), and any covariates (n=149) were removed from the analysis, this would result in a sample size of 204. For acute complications, if people missing both DKA and severe hypoglycemia (n=8), food security status (n=9), and any covariates (n=161), were excluded, this would result in 217 for the analysis. Thus, we explored methods to minimize missing data by leveraging the longitudinal, repeated measures in SEARCH.

The covariates household income, parent education, and insurance status were missing data for 146 participants, 35 participants, and 15 participants, respectively. SEARCH is a longitudinal study spanning 20 years and includes 3 to 6 prior data collection points. Therefore, for our cross-sectional study, if household income, parent education, or insurance status were missing, we retained data from the most recently available data collection time point and used it the analysis. After retaining household income, 62 income values were still missing from the assessment of HFI and HbA1c models and 65 values were missing from the assessment of HFI and acute complications' models. We conducted a sensitivity analysis to compare including household income in the adjusted models vs. not including household income in the adjusted models. Removing household income as a covariate from the analysis did not change the results of the study; so, we did not include income in the final analysis to preserve the sample size. Without restricting the dataset to those that had income, the analysis for the association between HFI, HbA1c and glycemic control yielded 326 participants and the analysis for the association between HFI and acute complications of diabetes yielded 351 participants. Appendix A provides further details of missing data and analyses based on multiple imputation.

All analyses were completed in SAS 9.4. The relationship between HFI and HbA1c was assessed with linear regression (ordinary least squares). To evaluate the association between HFI and glycemic control, multinomial logistic regression via a proportional-odds cumulative logit model was used. Finally, logistic regression was used to assess the association between HFI and experiencing acute complications of diabetes (severe hypoglycemia or DKA), DKA, or sever hypoglycemia. All models were adjusted for the participant's age, diabetes duration, sex, race/ethnicity, SEARCH clinic site, parent education, insurance type, medication regimen, and continuous glucose monitoring use.

4.6 Results

Descriptive characteristics of the sample of YYA with T2D can be found in Table 4.1. Most (95% were 18 or older) were young adults (mean age: 24.7, SD: 4.3, range 11.0 - 35.6) female (67.5%), and minority (80.7%). Almost 38% reported the highest parent education to be some college- associate degree and 43.6% utilized private insurance. Although 73% had some diabetes medication regimen, 27% reported no current medication regimen. Half of the sample reported a household income less than $25,000 per year.

The mean HbA1c was 9.4 (SD: 2.9) which placed 55.2% of the sample in the high-risk glycemic control category and 8.2% reported experiencing DKA, 3.9% severe hypoglycemia or both (10.8%) in the past year. HbA1c levels were lower among YYA with HFI compared to those that were in a food secure home, but this difference was not statistically significant in crude (Estimate: -0.34; p-value=0.3603) or adjusted models (Estimate: -0.46; p-value=0.2135). As shown in Tables 4.2 and 4.3, no statistically significant associations were observed between HFI status and HbA1c in crude or multivariate adjusted models, and this was true both for comparing food insecure with food secure households with respect to mean HbA1c or studying the association of the continuous HFI and HbA1c. Likewise, there was no indication of an association between HFI and glycemic control in the crude nor in adjusted models.

HFI was associated with acute complications (DKA or severe hypoglycemia) in crude and adjusted models. YYA with T2D who had HFI had a 2-fold higher odds of experiencing an acute complication (OR: 2.16; CI: 1.02-4.56; p=0.0448), controlling for covariates. This relationship was also reflected in the associations between the continuous HFI score and acute complications of diabetes (adjusted OR:1.23; CI: 1.04-1.45; p=0.0160).

The odds of experiencing DKA for those that had HFI was 2.42 (CI:1.02-5.72; p=0.0450) times the odds of experiencing DKA for those who were food secure after adjusting for all covariates (data not shown). The odds ratio of the relationship between HFI and severe hypoglycemia indicated no statistical association (OR: 1.043; CI: 0.31-3.49, p-value: 0.9453, data not shown).

4.7 Discussion

This is the first study to assess the association between HFI and glycemic control in YYA with youth-onset T2D and the first to assess the association between HFI and acute complications of diabetes, including severe hypoglycemia or DKA, in YYA with T2D. Our demographics of YYA with T2D were reflective of other studies of YYA with

T2D.[145,146] More than three-fourths identified with a minority race or ethnicity, half had a household income less than $25,000 per year, and only 16% had a parent with an education level of bachelor's degree or higher. These characteristics are associated with higher frequencies of DKA and severe hypoglycemia in YYA with T1D.[151]

The prevalence of HFI was triple the national average in 2019 (31% vs. 10.5%).[148] It is supported in the literature that HFI among people with T2D, more specifically YYA with T2D is high.[13,147]

Although studies have shown an association between HFI and glycemic control in older adults with T2D;[13–18] and in YYA with T1D[6,7], we did not observe a statistical association between HFI and HbA1c or glycemic control in YYA with T2D. One possible explanation is that variability of HbA1c was extremely constrained at very high levels among those with HFI (mean 9.5, SD 3.0) and those without HFI (mean 9.2, SD 2.8). High HbA1c levels were reflected in that more than half (55%) of our sample had high risk glycemic control and 17.8% had suboptimal glycemic control. Poor glycemic control in YYA with T2D is reported in many studies.[19,152] No observed association between HFI and HbA1c is consistent with a study by Ippolito et al. (2017), which found that older adults with T2D utilizing food pantries had a high mean HbA1c of 8.1%; and, HbA1c was not different by food security status.[98]

Our hypothesis regarding food insecurity and diabetes complications was supported by our data in that YYA with T2D and HFI were more likely to experience an acute diabetes complication (DKA or severe hypoglycemia). Several studies have found an association between HFI and hypoglycemia in adults.[40,93,98] For example, Ippolito et al. (2017) also found that very-low-food-secure participants had a higher prevalence of severe hypoglycemic episodes than food-secure participants.[98] Although in this study the association between HFI and severe hypoglycemia was not statistically significant, this result should be interpreted with caution because the prevalence of hypoglycemia in our sample was less than 5% (n=14). Seligiman et al. suggests that people with HFI cycle through food adequacy and food scarcity within a given year.[13,40,93,153] During times of scarcity, the risk of hypoglycemia is increased if medication is taken rather than food or, in the presence of continued medication adherence, meals are skipped and caloric intake is reduced.[40] In a qualitative study, Liese et al. (2020)[154] found that many adults with T2D and HFI feared hypoglycemia which may have driven them to over-compensate by drinking sugary beverages and foods in excess.[154] Education and training in managing diabetes in a food insecure household, screening for HFI, and medication modifications may help reduce the likelihood of a hypoglycemic episode among YYA with T2D who have HFI.[41,94]

The odds of experiencing DKA was significantly higher among those with HFI compared to those who were food secure. Although DKA is uncommon in people with T2D, when it does occur, it is likely sparked by being newly diagnosed with diabetes, not adhering to medication regimens, an acute illness, or a significant infection.[155–157] It is quite possible that illnesses and infections act as a mediator between HFI and DKA. Research supports an association between HFI and illnesses and infections. In HIV patients, HFI has been found to act as a mediator between HIV-related sigma and opportunistic infections and infections of the skin.[158] A Canadian population based cohort study recently concluded that HFI was associated with higher mortality, and the association was especially pronounced for infectious-parasitic diseases.[159] Finally, among adults, HFI has been found to be associated with poorer self-reported physical health.[160] Future research should establish a relationship between HFI and infections in YYA with T2D and, explore infections as a mediator between HFI and DKA. Further, diabetes education programs for YYA with T2D and HFI may decease episodes of DKA by focusing on medication adherence and self-management of diabetes during illness.

Because DKA was self-reported, it is also possible that DKA was mistaken for hyperglycemic hyperosmolar state (HHS), a more common acute complication of T2D than DKA that has overlapping symptoms with DKA.[156] If DKA was mistaken for HHS, it does not change that, in our study, acute complications of diabetes were more likely to occur in YYA with T2D that had HFI than those who did not.

This study is not without limitations. The measurement of HbA1c, which assessed glycemic control in the last 3 months, could have been measured during a time when food was adequate, and may not be concurrent with HFI experienced during a 12-month period. This could have contributed to a type II error and there is in actuality an association between HFI and HbA1c in YYA with T2D. Both HFI and experiencing severe hypoglycemia or DKA were reflective of an entire year, making these variables more comparable. Additionally, the cross-sectional study design introduces the possibility of reverse causality. We cannot truly know whether HFI or acute diabetes complications occurred first. Future research among YYA with T2D should consider longitudinal studies to establish if alleviating HFI reduces frequency of DKA and hypoglycemia episodes.

There are also several advantages of our study. This is the largest study to date to assess HFI among YYA with T2D and the first to examine a relationship between HFI and diabetes complications. Additionally, we were able to adjust for a number of confounders that previous literature was not able to include their study.

In conclusion, HFI was much more prevalent in our sample of YYA with T2D than the general population, indicating research to understand how it affects YYA with T2D is of high importance. Acute diabetes complications were more likely to occur among those with HFI; however, there were no observed differences in HbA1c or glycemic control by food insecurity status. This study supports the American Diabetes Association recommendation to universally screen for and address food insecurity as tailored treatment to help people manage diabetes.[11,33] Universally screening may improve clinical care of people with diabetes and increase awareness of providers who can help guide those with HFI to better manage their diabetes.[10,33]

Table 4.1. Demographic characteristics of youth and young adults with type 2 diabetes from the SEARCH for Diabetes in Youth Study (n=326)[1]

Characteristic	**Total**	**Food Secure (n=224)**	**Food Insecure (n=102)**
Continuous HFI Score	1.7 (2.1)	0.4 (0.7)	4.4 (1.5)
Age in yrs, mean (sd)	24.7 (4.3)	24.5 (4.4)	25.2 (4.1)
Sex, %			
Female	67.5	65.2	72.6
Male	32.5	34.8	27.5
Race/Ethnicity, %			
NH White	19.3	16.1	26.5
NH Black	44.2	45.5	41.2
Other[3]	36.5	38.4	32.4
Clinic, %			
Carolinas	33.4	32.1	36.3
Ohio	17.8	18.3	16.7
Colorado	22.1	21.0	24.5
California/Washington	26.7	28.6	22.6
Parent Education, %			
<HS graduate	12.0	12.1	11.8
HS graduate	34.4	35.7	31.4
Some College – Asso.	37.7	36.2	41.2
Bachelors degree +	16.0	16.1	15.7
Insurance Status			
State / Federal	37.7	35.7	42.2
Private/Exchanges	43.6	46.0	38.2
None	14.4	13.8	15.7
Other/Unknown	4.3	4.5	3.9
Diabetes duration in months, mean (sd)	124.0 (42.9)	124.2 (42.0)	123.6 (45.0)
Diabetes regimen, %			
Medication	73.0	72.3	74.5
No Medication	27.0	27.7	25.5
CGM use, %	18.4	17.0	21.6
Household Income,[2] %			
<$25,000	49.5	46.4	58.7
$25,000+	50.6	53.6	41.3
HbA1c, mean (sd)	9.4 (2.9)	9.5 (3.0)	9.2 (2.8)
Glycemic Control, %			
Optimal	27.0	25.9	29.4
Suboptimal	17.8	19.2	14.7
High Risk	55.2	54.9	55.9
Acute Complications, %[4]	10.8	7.9	17.4
DKA, %[4]	8.2	5.5	14.4
Hypoglycemia, %	4.1	3.4	4.7

[1] NH, Non-Hispanic; HS, High School; Asso, Associate’s degree; CGM, Continuous glucose monitoring; DKA, Diabetic Ketoacidosis
[2] n of household income = 271
[3] Other race includes Hispanic, Native American, Asian-Pacific Islander, and Other
[4] n of DKA only= 351

Table 4.2. Association between food security and Hba1c in SEARCH YYA with T2D (n=326)

	Crude		Model 1	
Variable	**Estimate**	**P-value**	**Estimate**	**P-value**
HFI (dichotomous)	-0.27	0.4357	-0.26	0.4629
HFI (continuous)	-0.01	0.9206	-0.00	0.9734
	Model 2		**Model 3**	
	Estimate	**P-value**	**Estimate**	**P-value**
HFI (dichotomous)	0.36	0.4628	-0.33	0.3512
HFI (continuous)	-0.01	0.8788	-0.01	0.9405

Model 1 adjusted for: age, gender, race
Model 2 adjusted for: age, gender, race, parent education, insurance level, clinic
Model 3 adjusted for: age, gender, race, parent education, insurance level, clinic, diabetes duration, CGM use, medication regimen

Table 4.3. Association between food security and high-risk glycemic control in SEARCH YYA with T2D (n=326)

	Crude			Model 1		
Variable	**Odds Ratio**	**CI**	**P-value**	**Odds Ratio**	**CI**	**P-value**
HFI (dichotomous)	0.90	0.57-1.42	0.6545	1.11	0.70-1.76	0.6608
HFI (continuous)	0.97	0.87-1.07	0.5216	1.03	0.93-1.14	0.5460
	Model 2			**Model 3**		
	Odds Ratio	**CI**	**P-value**	**Odds Ratio**	**CI**	**P-value**
HFI (dichotomous)	1.09	0.68-1.75	0.7134	1.04	0.64-1.69	0.8686
HFI (continuous)	1.04	0.94-1.16	0.4699	1.03	0.92-1.14	0.6467

Model 1 adjusted for: age, gender, race
Model 2 adjusted for: age, gender, race, parent education, insurance level, clinic
Model 3 adjusted for: age, gender, race, parent education, insurance level, clinic, diabetes duration, CGM use, medication regimen

Table 4.4. Association between food security and acute complications of diabetes in SEARCH YYA with T2D (n=351)

	Crude			Model 1		
Variable	**Odds Ratio**	**CI**	**P-value**	**Odds Ratio**	**CI**	**P-value**
HFI (dichotomous)	2.48	1.25-4.90	0.0091	2.32	1.16-4.65	0.0175
HFI (continuous)	1.25	1.08-1.44	0.0023	1.23	1.06-1.42	0.0053
	Model 2			**Model 3**		
	Odds Ratio	**CI**	**P-value**	**Odds Ratio**	**CI**	**P-value**
HFI (dichotomous)	2.30	1.13-4.69	0.0223	2.16	1.02-4.56	0.0448
HFI (continuous)	1.23	1.06-1.43	0.0076	1.23	1.04-1.45	0.0160

Model 1 adjusted for: age, gender, race
Model 2 adjusted for: age, gender, race, parent education, insurance level, clinic
Model 3 adjusted for: age, gender, race, parent education, insurance level, clinic, diabetes duration, CGM use, medication regimen

CHAPTER 5

HOUSEHOLD FOOD INSECURITY AND PHYSICAL ACTIVITY IN YOUTH AND YOUNG ADULTS WITH DIABETES

5.1 Abstract

Household food insecurity (HFI) may discourage physical activity among youth and young adults (YYA) with diabetes because they have less energy for physical activity. Low physical activity levels are problematic for people with diabetes because physical activity is essential to diabetes management, and it is usually prescribed as a lifestyle change in addition to a medication regimen. The purpose of this study is to examine the association between HFI and physical activity in YYA with type 1 diabetes (T1D) and type 2 diabetes (T2D).

Data from 1,998 YYA with T1D and 391 YYA with T2D were cross-sectionally analyzed from the SEARCH for Diabetes in Youth Study. HFI status was measured with the 18-item U.S. Household Food Security Survey Module. The survey was completed by adult participants or parents of participants that were minors. Households that affirmed ≥3 food-insecure conditions or behaviors were considered food-insecure. Physical activity and inactivity were measured with the International Physical Activity Questionnaire Short Form. This survey measures time spent per week walking at work and at home, for travel, or for recreation, sport, exercise, or leisure, time in moderate (excluding walking) intensity physical activity (MPA) that resulted in 10 minutes of

activity or more, and time in vigorous intensity physical activity (VPA) that resulted in 10 minutes of activity or more. MPA and VPA were summed to calculate moderate-to-vigorous physical activity per week; and, walking, MPA and VPA were summed to calculate total physical activity per week. Meeting the Physical Activity Guidelines for Americans or not was analyzed as a dichotomous variable. Time spent sitting was assessed in minutes per day. Multiple imputation was used to impute missing values. Median regression was utilized for continuous physical activity outcomes and logistic regression was used for the outcome meeting the physical activity guidelines or not. All analyses were stratified by diabetes type.

Approximately 18% of YYA with T1D and 34% of YYA with T2D experienced HFI. For YYA with T1D, those who experienced HFI obtained less VPA (β: -70.2; p-value=0.0069) and more walking (β: 103.5; p-value=0.0179) per week than those who had food security in crude models. The association for walking persisted after covariate adjustment (β: 85.7; p=0.0241). A significant association between HFI and total physical activity per week was also observed (β: 182.1; p=0.0095). YYA with T2D experiencing HFI obtained more minutes per day sitting than food-secure YYA with T2D in adjusted models (β: 60.6; p=0.0434).

YYA with T1D experiencing HFI reported more walking and total physical activity minutes per week than those who were food-secure. YYA with T2D experiencing HFI spent more time sitting per day than YYA with T2D who did not have HFI. YYA with T2D and HFI may spend more time sitting because they are more fatigued. Future research should consider different domains of walking (e.g., leisure, travel, work) among YYA with T1D who have HFI.

5.2 Introduction

The SEARCH for Diabetes in Youth Study (SEARCH) supports that the incidence and prevalence of type 1 (T1D) and type 2 diabetes (T2D) among youth (<20 years) and young adults (YYA) is increasing in the US.[31,63] The adjusted annual percent change in incidence from 2002-2003 to 2014-2015 was 1.9% for YYA with T1D and 4.8% for YYA with T2D.[64] Furthermore, between 2001 and 2017, the prevalence of T1D among youth increased by 45%, and the prevalence of T2D among youth increased by 95%.[144] Due to the expected increases in diabetes among YYA, methods to help manage diabetes are a public health concern.

Household food insecurity (HFI) has been identified as a modifiable risk factor for poor diabetes management.[85] HFI is "limited or uncertain availability of nutritionally adequate and safe foods or limited or uncertain ability to acquire acceptable foods in socially acceptable ways."[1,148] Approximately 18% of YYA with T1D and 31% of YYA with T2D experience HFI sometime during a given year.[147] HFI has also been found to negatively affect health behaviors which impact diabetes management.[17,26,27,96] For example, the fatigue and depression associated with inadequate intake of nutritious food, may decrease some individuals' motivation for physical activity and/or make physical activity challenging.[41,94,108] It may also increase time spent in inactivity.

The benefits of regular physical activity for people with diabetes are well established,[22–24,105] and include acute and chronic improvements in insulin action.[23] Physical activity is so essential for diabetes management that it is usually prescribed as a lifestyle change in addition to prescribed medications.[25] The American Diabetes Association recommends youth with T1D and T2D engage in 60 minutes of moderate-to-vigorous intensity aerobic physical activity (MVPA) per day and muscle and bone strengthening activities a minimum of 3 days per week.[85] This recommendation is in accordance with the 2018 physical activity guidelines for children.[70] Further, the 2018 Physical Activity Guidelines for Americans (PAGA) state that adults with chronic health conditions should engage in at least 150 minutes of moderate physical activity (MPA) per week, 75 minutes of vigorous physical activity (VPA) per week, or an equivalent of MVPA. The American Diabetes Association also recommends youth with diabetes decrease sedentary behavior. decreasing sedentary behavior.[85] Research suggests that those who engage in high amounts of sedentary behavior can be at increased risk of morbidity and mortality regardless of their level of MVPA.[28] Based on national accelerometer data, 42% of children ages 6-11 years old obtain the recommended 60 minutes of MVPA per day; however, only 8% adolescents reach this goal. Additionally, less than 5% of adults achieve 30 minutes of physical activity per day.[99] Youth-onset T1D and T2D typically occurs during adolescence at mid puberty[31,78] when physical activity has been shown to decline. Studies have concluded that physical activity levels of youth with diabetes are either comparable to or lower than physical activity of youth without diabetes.[23,161]

Few studies exist examining an association between HFI and physical activity or inactivity in people with diabetes.[17,109] Therefore, the purpose of this study is to examine the association between HFI and physical activity in YYA with T1D and T2D. We hypothesize that 1) YYA with HFI will have lower physical activity levels than YYA who have household food security; 2) YYA with HFI will spend more time sitting than YYA who have household food security.

5.3 Methods

SEARCH is a multi-site cohort study and a surveillance effort spanning 20 years which assess incidence and prevalence of youth-onset T1D and T2D.[119,120] The SEARCH cohort study was funded by the National Institute of Diabetes and Digestive and Kidney Diseases. The proposed study utilized data from the SEARCH 4 Cohort Study (years 2015-2020) to conduct a cross-sectional examination the association between HFI and physical activity. The methods of SEARCH 4 have been described elsewhere.[120] Data collection sites include: California, Colorado, Ohio, South Carolina, and Washington.[120] Each SEARCH cite obtained approval from their respective Institutional Review Board and obtained informed consent from adult participants or assent from participants less than 18 years old.

5.3.1 Household Food Insecurity

HFI was evaluated with the 18-item United States Household Food Security Survey Module (HFSSM).[1] The HFFSM measures HFI over the previous 12 month has been shown to be a stable, robust, valid, and reliable measurement tool.[1] The first 10 questions pertain to all households (with or without children) and the last 8 questions are specific to households with children ages 0-17.[1] Parents/guardians of SEARCH participants under age 18 and participants with diabetes ≥18 years of age complete the HFSSM. Affirming ≥3 food-insecure conditions or behaviors resulted in a respondent being classified as food-insecure, whether they answer only the first 10 questions or all 18 questions.[2].

5.3.2 Physical Activity and Inactivity

Physical activity was assessed with the International Physical Activity Questionnaire Short Form (IPAQ-SF).[121] This survey requests that participants recall the last 7 days and report time spent walking at work and at home, for travel, or for recreation, sport, exercise, or leisure, total time in moderate (excluding walking) intensity physical activity (MPA) that resulted in 10 minutes of activity or more, and total time in vigorous intensity physical activity (VPA) that resulted in 10 minutes of activity or more. Physical activity is first reported as number of days per week. Then time is reported as hours per day and minutes per day that you usually spend doing the activity on one of those days. Physical activity was assessed as minutes per week of walking physical activity, moderate intensity (excluding walking) physical activity (MPA), and vigorous intensity physical activity (VPA). Moderate-to-vigorous physical activity (MVPA) and total physical activity (walking + MPA + VPA) were calculated from the three original physical activity variables.[122,123]

The IPAQ-SF also queried participants on time spent sitting at work, at home, while doing course work, and during leisure time during the last 7 days. Time was reported as hours and minutes per day.[121] For our analysis, time spent sitting was analyzed as minutes per day.

A dichotomous variable to indicate adherence to the 2018 PAGA was derived separately for participants < 18 years and participants ≥ 18 years because the guidelines for adults and children are different. Children (ages 6-17 years) meeting the guidelines engage in ≥60 minutes of MVPA per day. Adults meeting the guidelines engage in at least 150 - 300 minutes per week of moderate-intensity, or 75-150 minutes per week of vigorous-intensity aerobic physical activity, or an equivalent combination of moderate- and vigorous-intensity aerobic activity."[70]

The IPAQ-SF was developed and tested for use in people 15-69 years old.[121] Therefore, our study was restricted to SEARCH participants who were 15 years or older.[121] This decision is supported by a systematic review of the IPAQ and IPAQ-SF that included validity and reliability studies from 12 different countries and found positive validity and reliability among adults for the IPAQ-SF.[124] In terms of reliability and repeatability for the IPAQ-SF, 75% of the observed correlation coefficients were above 0.65 and the pooled Spearman's correlation was 0.76 (95% CI 0.73–0.77).[124] The sitting time data had higher reliability, with 67% of all repeatability coefficients above 0.70.[124] In terms of criterion validity, 781 adults tested agreement between the IPAQ-SF and the Computer Science Application (CSA) accelerometer. The pooled correlation was 0.30 (95% CI: 0.23-0.36).[124]

5.3.3 Covariates

Questionnaires were used to collect information on all covariates. The participant's age and diabetes duration were analyzed as continuous variables. Categorical variables included sex (female, male), race/ethnicity (Non-Hispanic White, Non-Hispanic black, Hispanic, other), SEARCH clinic site (South Carolina, Colorado, Ohio, California/Washington), highest parental education (Less than high school graduate, High school graduate, Some college / Associate degree, Bachelor's degree or more), household income (< $25,000, $25,00-$49,999, $50,000-$74,999, $75,000+), insurance type (Private/Exchanges, State/Federal, Other/Unknown, None), and smoking status (None-smoker, Current smoker, Former smoker).

5.3.4 Analysis

Participants tended to round physical activity time in hour increments (e.g., 0 minutes, 30 minutes, 60 minutes, etc.). Therefore, random, uniform noise (jittering) was applied to the physical activity outcomes to discretize the values and make the physical activity values pseudo-continuous. A summary of physical activity outcomes with random noise added can be found in the Appendix B.

Detailed information on missing data can be found in Table 5.1. To characterize patterns of missing values, a comparison of demographic and HFI statistics was made for those with and those without missing demographic and outcome values. Under the assumption of missing at random, we imputed missing values with multiple imputation and followed the fully conditional specification method.[162] All variables used in the adjusted models were included in the imputation model. A total of 20 imputed datasets based on 200 iterations were created.

A crude and fully adjusted model were used to evaluate the association between HFI and each outcome. Fully adjusted models included the participant's age, diabetes duration, sex, race/ethnicity, SEARCH clinic site, parent education, insurance type, and smoking status. Median regression was used for continuous physical activity outcomes. Logistic regression was utilized to assess the relationship between HFI and adherence to the PAGA. All analyses were stratified by diabetes type. Significance was accepted at 5%. All analyses were completed with SAS 9.4.

5.4 Results

Table 5.1 reflects the descriptive characteristics of the sample by diabetes type and food security status. The sample of YYA with T1D (n=1,998) was 73% Non-

Hispanic white, 53% female, on average 22.1 years old (SD:4.3; range 15-36) and had been living with diabetes for 140.9 (SD: 37.7) months (almost 12 years). They were of high socioeconomic status, as over half (55%) of their parents earned a bachelor's degree or higher, 78% had private insurance, and 41% had an annual household income of $75,000 or greater. Approximately 18% experienced HFI.

The mean age of YYA with T2D (n=391) was 24.8 years (SD: 4.2; range: 15 - 35.6) with a diabetes duration averaging 124.4 (SD: 42.2) months (approximately 10 years). Additionally, 67% were female, 46% were Non-Hispanic black, 24% were Hispanic. Half of YYA with T2D had an annual household income less than $25,000, 40% of parent education was some college – Associate's degree, and 34% experienced HFI.

YYA with T1D spent a median of 120 minutes per week in VPA (IQR: 360), 120 minutes per week in MPA (IQR: 420), 315 minutes per week walking (IQR: 740), and 325 minutes per day (IQR: 240) sitting. Approximately 64% of YYA with T1D reported enough physical activity to meet the PAGA. YYA with T2D spent a median of 0 minutes per week in VPA (IQR: 360), 60 minutes per week in MPA (IQR: 360), 240 minutes per week walking (IQR: 210), and 180 minutes per day (IQR: 720) sitting. Half (54%) of the YYA with T2D reported enough physical activity to meet the PAGA. YYA with T2D obtained a median of 270 (IQR: 240) minutes per day sitting.

The results of the analyses for YYA with T1D are reflected in Table 5.2a. In crude analyses, YYA with T1D who experienced HFI obtained 70.2 (SD: 25.9) less minutes of VPA per week (p=0.0069) and 103.5 (SD: 43.4) more minutes of walking per week (p= 0.0179) than YYA with T1D who did not experience HFI. Whereas the association between HFI and VPA was completely attenuated after adjustment for covariates, the association with time spent walking remained statistically significant: YYA with T1D who experienced HFI obtained 85.7 (SD: 38.0) more minutes of walking per week than YYA with T1D who were food-secure (p=0.0241). In the fully adjusted models, we also observed a statistical association between HFI and total physical activity minutes per week. Those who experienced HFI obtained 182.1 (SD: 70.2) more minutes of total physical activity per week than those who had household food security (p = 0.0095). There were no observed relationships between HFI and MPA, MVPA, or sitting time per week.

Among YYA with T2D, although there were no statistically significant associations between HFI and continuous physical activity outcomes in unadjusted models, YYA with T2D experiencing HFI obtained 60.6 (SD: 29.7) more minutes of sitting per day than those who lived in a food-secure household (p=0.0434) after adjusting for covariates. No other statistical associations were observed between HFI and physical activity outcomes for YYA with T2D. These results are reflected in Table 5.2b.

There were no statistically significant differences by food security status in adherence/meeting the PAGA in crude or adjusted models. This was true for YYA with T1D and YYA with T2D. The results are reflected in Table 5.3.

5.5 Discussion

In our study, 18% of YYA with T1D and 34% of YYA with T2D experienced HFI. The high prevalence of HFI among YYA with diabetes in our study and other studies[147] indicates HFI is a common phenomenon. YYA with T1D experiencing HFI had only a slightly lower percentage of meeting the PAGA (65% vs 61%). Approximately

54% of YYA with T2D, regardless of food security status, reported enough physical activity to meet the PAGA. High activity levels among YYA with T1D and T2D is consistent with the literature.[23] For example, an earlier SEARCH study measured physical activity with a 3-day physical activity recall and found compliance with the national aerobic physical activity recommendations was 82% for YYA with T1D and 68% for YYA with T2D.[100] A more recent SEARCH study reported that youth with T1D averaged 3.5 days per week of ≥20 minutes of VPA and 2.8 days per week of ≥30 minutes of MPA.[163]

YYA with T1D obtained a median of 325 minutes per day sitting and YYA with T2D obtained a median of 270 minutes per day sitting. This is respectively equivalent to 5.4 and 4.5 hours of sitting per day. Our results are consistent with other studies which have utilized the IPAQ-SF. In one study, African American adults obtained approximately 4.5 hours of sitting per weekday.[164] In a second study of healthy young adults (mean age 21 year), the average time spent sitting at baseline of a prospective study on personality traits was 331 minutes per day.[165]

Contrary to our hypothesis, YYA with T1D who had HFI engaged in more walking and total physical activity per week than YYA with T1D who were food-secure. Total physical activity is likely explained through walking time per week. Specifically, YYA with T1D who experienced HFI obtained almost 86 more minutes of walking per week than YYA with T1D who were food-secure. This equates to an hour and 26 minutes per week or approximately 12 minutes per day. The 2018 PAGA state that reducing inactivity and increasing MVPA in any duration is valuable for health.[70] It is possible the association between HFI and time spent walking is at least partially a reflection of the well documented association between HFI and low socioeconomic status (SES). Although we adjusted for SES variables (household income, parent education, and insurance type), occupation and transportation are key SES variables not captured through our covariates. Education and physical activity, income and physical activity, and occupation and physical activity each have different associations with different domains of walking.[166] YYA with T1D and HFI may spend more time walking for transportation or doing jobs that require more walking. One study confirmed that HFI is associated with lower white-collar and blue collar jobs.[167] Additionally, a report on traveling to work, featuring data from the American Community Survey, stated that households in the lowest income category (<$10,000 per year) had the highest walking rate at 8.2 percent.[168] A limitation of the IPAQ-SF is it does not separate different domains of walking. Future research should explore walking for transportation vs. work vs. leisure among YYA with T1D experiencing HFI.

YYA with T2D who were food-insecure spent an additional hour sitting per day compared to YYA with T2D who lived in a food-secure household. IPAQ-SF validity and reliability studies indicate there is strong reliability and moderate validity for the sitting assessment.[124] This finding is consistent with previous studies of people with diabetes, concluding HFI is associated with inactivity or activity that requires little physical effort.[96,109] YYA with T2D experiencing HFI may spend more time sitting per day because they are more fatigued than those who are food-secure and have less energy that is provided through diet. Interventions focused on HFI among YYA with T2D may also help decrease inactivity in this group.

There were no associations between HFI and VPA, MPA, MVPA or meeting the PAGA for those with T1D or T2D. Meeting the PAGA indicates achieving 75 minutes of VPA, 150 minutes of MPA, or a combination of both (i.e. MVPA). These results are inconsistent with To et al. (2014) who found a relationship between HFI and meeting the PAGA in adults.[27] It is possible we saw no associations because YYA with and without HFI were highly active.

The lack of association between HFI and VPA, MPA, or MVPA may also be due to the use of a self-reported physical activity measure. The IPAQ-SF, like other self-reported physical activity measures, are known to result in overreporting of physical activity and would bias results.[125] Furthermore, the physical activity questions tend to have a low correlation with comparison methods in validation studies, giving way to possible measurement error.[124] However, surveys are the most feasible method of assessing population level surveillance of physical activity and a recent study reported that the IPAQ-SF was the most suitable survey out of three surveys for determining whether university students, i.e. young adults, meet physical activity guidelines.[123] Furthermore, a review of physical activity in youth with diabetes by Liese et al.[23] found studies which support and refute that youth with diabetes meet physical activity recommendation levels, depending on how physical activity is measured.[23] A SEARCH pedometer based study, which provided an objective measure of physical activity, did not indicate that youth with diabetes meet recommended physical activity levels.[23,102] Future studies assessing HFI and physical activity should consider use of an objective measure of physical activity to advance the research in this field.

There are additional limitations of this study. Because it is a cross-sectional study, temporality is not known. The Household Food Security Survey Module measures food insecurity at the household level rather than at an individual level and physical activity is an individual characteristic. Although this may introduce some error, household food security is the standard measure of food security status. An additional limitation is that HFI is reflective of 12 months; however, the IPAQ-SF measures physical activity over the last 7 days. Therefore, the experience of HFI may not be concurrent with reported physical activity. Finally, a limitation of the IPAQ-SF is that many types of walking could meet the requirements of moderate intensity physical activity, and so measuring walking and MPA separately reduces the actual amount of MPA. The large sample size of YYA with T1D and T2D is an advantage of the study.

In conclusion, physical activity is a behavior with many health benefits that should not be inhibited by HFI. YYA with T1D experiencing HFI reported more walking and total physical activity time per week than those who were food secure. In contrast YYA with T2D who were food-insecure reported more time sitting per day than those who were food-secure. These findings have the potential to inform the planning of intervention programs in YYA with diabetes focused on food security, diabetes management or lifestyle behaviors. Given the interrelated nature of these factors, there may be unintended consequences to ameliorating food insecurity just as there may be unanticipated challenges to increasing physical activity levels among persons who are food insecure. Future research should explore walking for leisure vs. other domains of walking among YYA with T1D who have HFI and additionally use objective physical activity measures to confirm associations between HFI and physical activity in YYA with diabetes.

Table 5.1a. Demographic and Clinical Characteristics of Youth and Young Adults with Type 1 Diabetes Participating in the SEARCH for Diabetes in Youth Cohort Study (2015-2020), According to Household Food Security Status,[1,2] n=1,998

	Total	Food Secure	Food Insecure
Age, mean (sd)	22.1 (4.3)	22.0 (4.3)	22.6 (4.3)
Missing data, n (%)	0		
Sex, %			
Female	52.7	52.0	57.3
Male	47.3	48.0	42.7
Missing data, n (%)	0		
Race/Ethnicity, %			
NH-white	72.6	74.1	64.6
NH-black	11.6	10.0	19.6
Hispanic	13.1	13.2	12.3
Other	2.8	2.7	3.5
Missing data, n (%)	0		
Household Income, %			
<$25,000	20.0	15.2	41.1
$25-49,999	22.7	20.4	33.1
$50-74,999	16.5	16.2	17.9
$75,000+	40.9	48.2	8.0
Missing data, n (%)	539 (27.0)		
Clinic, %			
Carolinas	20.3	19.0	26.0
Ohio	18.3	19.8	14.2
Colorado	33.1	33.3	33.6
California	12.2	12.7	9.9
Washington	16.1	15.2	16.1
Missing data, n (%)	0		
Parent Education, %			
<HS graduate	4.3	4.0	5.8
HS graduate	14.6	12.6	23.6
Some Col. - Asso.	26.7	24.5	37.1
Bachelors degree +	54.5	59.0	33.4
Missing data, n (%)	129 (6.5)		
Insurance Status, %			
State/Federal	14.8	11.7	29.7
Private	78.2	81.8	61.2
Other/Unknown	3.2	3.4	2.7
None	3.8	3.1	6.5
Missing data, n (%)	56 (2.8)		
Diabetes duration, months, mean (sd)	140.9 (37.7)	140.6 (37.6)	142.1 (37.9)
Missing data, n (%)	0		

Smoking Status, %			
Never smoker	71.3	74.0	57.7
Former smoker	17.3	17.2	18.7
Current smoker	11.5	8.8	23.6
Missing data, n (%)	102 (5.1)		
VPA, min/week, median (Q1, Q3)	120 (0, 360)	120 (0, 360)	60 (0, 360)
Missing data, n (%)	203 (10.2)		
MPA, min/week, median (Q1, Q3)	120 (0, 420)	120 (0, 360)	150 (0, 360)
Missing data, n (%)	316 (15.8)		
Walking, min/week, median (Q1, Q3)	315 (100, 840)	300 (90, 840)	420 (144, 900)
Missing data, n (%)	417 (20.9)		
Sitting, min/day, median (Q1, Q3)	325 (240, 480)	300 (240, 480)	360 (240, 480)
Missing data, n (%)	522 (26.1)		
MVPA, min/week, median (Q1, Q3)	300 (60, 732)	300 (60, 720)	360 (0, 860)
Missing data, n (%)	172 (8.6)		
Total PA, min/week, median (Q1, Q3)	675 (255, 1335)	660 (270, 1260)	780 (205, 1560)
Missing data, n (%)	157 (7.9)		
Meets PA Guidelines, %	63.9	64.6	60.9
Missing data, n (%)	172 (8.6)		

[1]Activity reported before adding random noise to make variable truly continuous.
[2]VPA, Vigorous Physical Activity; MPA, Moderate Physical Activity; PA, Physical Activity; MVPA, Moderate-to-vigorous physical activity.

Table 5.1b Demographic and Clinical Characteristics of Youth and Young Adults with Type 2 Diabetes Participating in the SEARCH for Diabetes in Youth Cohort Study (2015-2020), According to Household Food Security Status,[1,2] n=391

	Total	**Food Secure**	**Food Insecure**
Age, mean (sd)	24.8 (4.2))	24.6 (4.2)	25.3 (4.3)
Missing data, n (%)	0		
Sex, %			
Female	67.0	65.0	71.2
Male	33.0	35.0	28.8
Missing data, n (%)	0		
Race/Ethnicity, %			
NH-white	18.7	15.6	25.4
NH-black	45.5	47.5	42.4
Hispanic	24.3	25.9	19.5
Other	11.5	11.0	12.7
Missing data, n (%)	0		
Household Income, %			
<$25,000	50.2	44.4	59.3
$25-49,999	34.8	33.3	38.5
$50-74,999	6.9	10.5	1.1
$75,000+	8.1	11.8	1.1
Missing data, n (%)	144 (36.8)		
Clinic, %			
Carolinas	36.1	35.7	38.1
Ohio	16.4	17.1	16.1
Colorado	21.0	20.2	28.9
California	20.7	23.6	12.7
Washington	5.9	3.4	10.2
Missing data, n (%)	0		
Parent Education, %			
<HS graduate	10.9	10.4	11.6
HS graduate	32.2	34.0	29.5
Some Col. - Asso.	39.2	37.8	42.0
Bachelors degree +	17.7	17.8	17.0
Missing data, n (%)	34 (8.7)		
Insurance Status, %			
State/Federal	33.4	31.4	38.9
Private	45.6	47.8	39.8
Other/Unknown	6.4	7.5	3.5
None	14.6	13.3	17.7
Missing data, n (%)	14 (3.5)		
Diabetes duration, months, mean (sd)	124.4 (42.2)	124.2 (41.2)	124.8 (44.2)
Missing data, n (%)	0		

Smoking Status, %			
Never smoker	65.2	67.6	60.0
Former smoker	17.0	15.2	21.7
Current smoker	17.8	17.2	18.3
Missing data, n (%)	15 (3.8)		
VPA, min/week, median (Q1, Q3)	0 (0, 360)	0 (0, 360)	0 (0, 360)
Missing data, n (%)	49 (12.5)		
MPA, min/week, median (Q1, Q3)	60 (0, 360)	60 (0, 360)	60 (0, 360)
Missing data, n (%)	67 (17.1)		
Walking, min/week, median (Q1, Q3)	240 (60, 833)	210 (50, 720)	330 (100, 840)
Missing data, n (%)	106 (27.1)		
Sitting, min/day, median (Q1, Q3)	270 (180, 420)	240 (180, 390)	300 (210, 480)
Missing data, n (%)	150 (38.4)		
MVPA, min/week, median (Q1, Q3)	180 (0, 720)	180 (0, 720)	165 (0, 652)
Missing data, n (%)	38 (9.7)		
Total PA, min/week, median (Q1, Q3)	535 (90, 1260)	510 (90, 1230)	540 (90, 1350)
Missing data, n (%)	34 (8.7)		
Meets PA Guidelines, %	53.8	53.8	54.6
Missing data, n (%)	38 (9.7)		

[1]Activity reported before adding random noise to make variable truly continuous.
[2]VPA, Vigorous Physical Activity; MPA, Moderate Physical Activity; PA, Physical Activity; MVPA, Moderate-to-vigorous physical activity.

Table 5.2a. Association between Household Food Insecurity and Physical Activity in Youth and Young Adults with Type 1 Diabetes, the SEARCH for Diabetes in Youth Study,[3] n=1,998

	Model 1[1,3]		Model 2[2,3]	
	Estimate (SE)	**P-value**	**Estimate (SE)**	**P-value**
Outcomes				
VPA (min/week)	**-70.2 (25.9)**	**0.0069**	0.8 (14.3)	0.9580
MPA (min/week)	0.4 (22.4)	0.9852	24.5 (18.0)	0.1748
Walking (min/week)	**103.5 (43.4)**	**0.0179**	**85.7 (38.0)**	**0.0241**
Sitting (min/day)	37.6 (19.5)	0.0600	30.2 (16.1)	0.0625
MVPA (min/week)	55.0 (49.3)	0.2648	36.9 (34.6)	0.2868
Total PA (min/week)	112.2 (74.0)	0.1480	**182.1 (70.2)**	**0.0095**

[1]Crude Model

[2]Adjusted for participant's age, diabetes duration, sex, race/ethnicity, SEARCH clinic site, parent education, insurance type, and smoking status, household income

[3]Analysis based on multiple imputation.

VPA, Vigorous Physical Activity; MPA, Moderate Physical Activity; PA, Physical Activity; MVPA, Moderate-to-vigorous physical activity.

Table 5.2b. Association between Household Food Insecurity and Physical Activity in Youth and Young Adults with Type 2 Diabetes, the SEARCH for Diabetes in Youth Study[3], n=391

	Model 1[1,3]		**Model 2[2,3]**	
	Estimate (SE)	**P-value**	**Estimate (SE)**	**P-value**
Outcomes				
VPA (min/week)	18.0 (45.6)	0.6940	17.5 (19.5)	0.3692
MPA (min/week)	-9.3 (40.2)	0.8184	-6.2 (20.0)	0.7586
Walking (min/week)	81.1 (61.8)	0.1900	66.9 (48.6)	0.1692
Sitting (min/day)	46.8 (33.2)	0.1631	**60.6 (29.7)**	**0.0434**
MVPA (min/week)	-8.5 (70.2)	0.9031	5.0 (45.7)	0.9133
Total PA (min/week)	79.7 (143.0)	0.5779	81.1 (116.4)	0.4861

[1]Crude Model
[2]Adjusted for participant's age, diabetes duration, sex, race/ethnicity, SEARCH clinic site, parent education, insurance type, and smoking status, household income
[3]Analysis based on multiple imputation.
VPA, Vigorous Physical Activity; MPA, Moderate Physical Activity; PA, Physical Activity; MVPA, Moderate-to-vigorous physical activity.

Table 5.3. Association between Household Food Insecurity and Meeting the Physical Activity Guidelines for Americans in Youth and Young Adults with Type 1 Diabetes and Type 2 Diabetes, the SEARCH for Diabetes in Youth Study

	Model 1[1,3]			**Model 2[2.3]**		
	Odds Ratio	**CI**	**P-value**	**Odds Ratio**	**CI**	**P-value**
Outcomes						
T1D Meets PA Guidelines	1.2	0.9-1.5	0.1742	1.0	0.7-1.3	0.8911
T2D Meets PA Guidelines	0.9	0.6-1.3	0.7935	0.9	0.5-1.5	0.6905

[1]Crude Model
[2]Adjusted for participant's age, diabetes duration, sex, race/ethnicity, SEARCH clinic site, parent education, insurance type, and smoking status, household income
[3]Analysis based on multiple imputation.
[4]T1D, type 1 diabetes; T2D, type 2 diabetes.

CHAPTER 6

HOUSEHOLD FOOD INSECURITY AND DIET QUALITY IN YOUTH AND YOUNG ADULTS WITH DIABETES

6.1 Abstract

A proper diet is crucial for diabetes management. Youth and young adults with diabetes experiencing food insecurity may have a poorer diet quality, making diabetes management more difficult. Utilizing data from the 2016- 2020 SEARCH for Diabetes in Youth Study, this study examined the cross-sectional association between household food insecurity (HFI) and diet quality among youth and young adults with type 1 diabetes (T1D, n=1,059) and type 2 diabetes (T2D, n=245). Household food insecurity (HFI) was measured with the 18-item US Household Food Security Survey Module and completed by adult participants or parents of participants that were minors. Those who confirmed 3 or more food insecure conditions were considered food insecure. Diet intake was measured with a food frequency questionnaire that was modified from the Block Kids Questionnaire. Results from the questionnaire were applied to the Healthy Eating Index-2015 (HEI-2015) to obtain overall diet quality and component scores. All diet scores were assessed as continuous outcomes. To assess the associations, linear regression (Ordinary Least Squares) adjusting for daily energy intake in kilocalories, age, sex, race/ethnicity, parent education, household income, insurance type, clinic, diabetes duration, diabetes medication regimen, and continuous glucose monitoring was utilized.

All models were stratified by sex and diabetes type. The mean HEI-2015 scores were as follows: 56.1 (females with T1D), 52.4 (males with T1D), 54.2 (females with T2D) and 51.2 (males with T2D). There was no association between HFI and the HEI-2015 score for YYA with T1D or T2D. Female YYA with T1D and HFI had poorer sodium component scores than female YYA with T1D who were food secure. Females with T1D and HFI consumed more sodium than those who were food secure. Future research should consider a diet assessment that assesses diet over an entire year or conducts repeated measures of diet during different seasons and time periods. Future research should more deeply explore specific dietary components that may be negatively impacted by HFI.

6.2 Introduction

The incidence and prevalence of type 1 (T1D) and type 2 diabetes (T2D) among youth and young adults (YYA) is on the rise in the United States.[64,144] Between 2002 and 2015, the adjusted annual incidence increased at a constant rate of 1.9% per year for YYA with T1D and 4.8% per year for YYA with T2D.[64] From 2001 to 2017, the prevalence of T1D increased from 1.48 to 2.15; and the prevalence of T2D increased from 0.34 to 0.67.[144] Identifying intervenable mechanisms to help this growing population manage diabetes in is highly important.

A high-quality diet is one modifiable factor that is essential for diabetes management. While nutrition therapy for YYA with diabetes focuses on monitoring carbohydrate intake and nutrition education for the entire family,[85] nutrition recommendations include following the dietary guidelines for the general population, consuming nutrient dense, high-quality foods, and decreasing intake of nutrient-poor foods[85,111] with high attention to carbohydrate intake.[33]

Household food insecurity (HFI), by definition, implies barriers to a high-quality diet and dietary inadequacies. HFI is defined as "limited or uncertain availability of nutritionally adequate and safe foods or limited or uncertain ability to acquire acceptable foods in socially acceptable ways."[1] In studies of YYA with diabetes, the prevalence of HFI is about 20%;[6,7,147] with 18% of YYA with T1D and 31% of YYA with T2D experiencing HFI during the year.[147] The impact of HFI on diet quality among YYA with diabetes is of particular concern because, youth with T1D typically fall short of meeting national diet reccomendations[112] and in the SEARCH for Diabetes in Youth study, youth with T2D have been found to have poorer diets that youth with T1D.[113] Evidence shows that the diet quality among adults with T1D or T2D improved between 1999-2000 and 2013-2014.[114] However, in 1999-2000, there were observed diet quality disparities between high and low education, high and low income, and food secure and food insecure that did not improve by 2013-2014.[114] These disparities were measured with the Healthy Eating Index-2010.[114]

Although it seems intuitive that HFI would be associated with diet, research findings have been inconsistent.[34] Many studies of HFI and diet quality have also focused on younger children and older adults, leaving gaps in knowledge for an association among YYA.[37] Leung and Tester (2019)[118] recently used data from the 2011-2014 National Health and Nutrition Examination Surveys to examine the association between HFI and diet quality, measured with HEI-2015 in the general population. They concluded that food insecure adults had lower HEI-2015 scores;[118] however, the results of this study may not be generalizable to youth and young adults with diabetes. Because diet plays an intricate role in diabetes management, YYA with diabetes may have a unique association between HFI and diet quality, characterized by a diet that would result in negative health outcomes such as high blood pressure, high cholesterol levels. A poor diet might include consuming more refined grains, saturated fat, sodium, and less fruits and vegetables, whole grains, and proteins.

The purpose of this study was to 1) assess the association between HFI and diet quality, measured with the Healthy Eating Index-2015 (HEI-2015) in YYA with T1D and T2D and 2) assess the association between HFI and component scores of the HEI-2015 among YYA with T1D and T2D. We hypothesize that YYA with HFI will have poorer diet quality scores than YYA who have household food security. We further hypothesize that YYA who have HFI will have poorer scores for HEI adequacy components (e.g., total fruits, whole fruits, total vegetables, green beans, whole grains, dairy, total protein foods, seafood and plant proteins, and fatty acids) and poorer scores for moderation components (e.g., refined grains, sodium, added sugars, and saturated fats) than YYA who have household food insecurity. Each analysis will be stratified by diabetes type as well as sex because previous research found higher prevalence of HFI among women than men.[169]

6.3 Methods

The SEARCH for Diabetes in Youth Study (SEARCH) is a multi-site, longitudinal cohort study with the goal of understanding youth-onset T1D and T2D. Participants are recruited into the study if they are diagnosed with T1D or T2D before 20 years old.[119,120] SEARCH was funded by the National Institute of Diabetes and Digestive and Kidney Diseases. The present study utilized data from SEARCH Phase 4 (2015 - 2020). Methods of the full SEARCH study and SEARCH Phase 4 have been described elsewhere. Data collection sites for SEARCH included: California, Colorado, Ohio, South Carolina, and Washington.[120] Each SEARCH site obtained approval from their respective Institutional Review Board and obtained informed consent from adult participants or assent from participants less than 18 years old.

6.3.1 Household Food Insecurity

Parents/guardians of SEARCH participants under age 18 and participants ≥18 years of age completed the 18-item United States Household Food Security Survey Module (HFSSM). The HFSSM evaluates the prevalence of HFI over the previous year.[1] The first 10 questions pertain to all households (with or without children) and the last 8 questions are specific to households with children ages 0-17.[1] If the survey respondent reported ≥3 affirmative food insecure conditions or behaviors whether they answered only the first 10 questions or all 18 questions,[2] the household was considered food insecure.

6.3.2 Diet Quality

Diet intake was assessed with a self-administered SEARCH food frequency questionnaire that was modified from the Block Kids Questionnaire.[128] The SEARCH food frequency questionnaire includes 85 questions in which the participant indicates if the food item(s) was (were) consumed in the past week ("yes/no") and if yes, how many days, and the average portion size. Portion size was queried either as a number (e.g., number of slices of bread) or as very small, small, medium, or large relative to pictures of food in bowls or plates provided with the form. An open-ended question at the end of the SEARCH food frequency questionnaire asks about other foods that the participant might want to report. The nutrient and portion size databases for this instrument were modified from the respective Diabetes Prevention Program databases, by means of industry sources and the Nutrition Data System for Research (Nutrition Coordinating Center, University of Minnesota, Minneapolis MN, Database version 2.6/8A/23).[129] The SEARCH food frequency questionnaire has proven to be valid and reliable in youth with T1D.[129]

The cup equivalent scores obtained by the SEARCH food frequency questionnaire were then applied to the HEI-2015. The HEI-2015 was designed to align with the 2015-2020 Dietary Guidelines for Americans.[130–132] It includes nine adequacy components, each assigned either five or ten points [total fruits (5), whole fruits (5), total vegetables (5), greens and beans (5), whole grains (10), dairy (10), total protein foods (5), seafood and plant proteins (5), fatty acids (10)] and four moderation components, each assigned 10 points (refined grains, sodium, added sugars, saturated fats). For adequacy components, higher scores reflect higher intakes, because higher intakes are desirable. However, for moderation components, higher scores reflect lower intakes, because lower intakes are more desirable.[130] The 13 components can be looked at as a set of scores whose total creates an overall HEI-2015 score, ranging 0-100. A higher score indicates a diet that aligns better with the Dietary Guidelines for Americans.[130–133]

6.3.3 Covariates

Questionnaires were used to collect information on all covariates. The participant's age (in years), diabetes duration (in months), and daily energy intake (in kilocalories) were analyzed as continuous variables. Categorical variables included sex (female, male), race/ethnicity (Non-Hispanic White, Non-Hispanic black, Hispanic, other), SEARCH clinic site (South Carolina, Colorado, Ohio, California/Washington), highest parental education (less than high school graduate, high school graduate, some college / associate degree, bachelor's degree or more), household income (< $25,000, $25,00-$49,999, $50,000-$74,999, $75,000+), health insurance type (private/exchanges, state/federal, other/unknown, none), and smoking status (non-smoker, current smoker, former smoker). Covariates related to diabetes included diabetes regimen (insulin pump, insulin long-acting 3+ rapid acting injections, any other combination of insulin injections, oral hypoglycemic medication, no treatment) and use of continuous glucose monitoring (yes/no).

6.3.4 Analysis

The original sample size included 1,540 YYA (81% T1D and 19% T2D). Because this sample has been part of a longitudinal study with 3 to 6 prior data collection points, missing demographic characteristics (household income, parent education, and insurance type) were obtained from the most recent data collection time point for 296 participants. The analysis was restricted to those that had data for all outcomes, HFI, and all covariates. Out of the 1,540 participants, 24 did not have a measure for HFI. Other missing variables included parent education (n=2), household income (n=141), insurance (n=1), smoking status (n=29), medication regimen (n=17), and continuous glucose monitoring use (n=25). This left a final sample of 1,304. All analyses were stratified by diabetes type and sex (596 females with T1D, 463 males with T1D, 166 females with T2D, and 79 males with T2D). Appendix C provides further details of missing data and analyses based on multiple imputation.

The association between HFI and diet quality was examined with a linear regression (ordinary least squares) analysis using four sets of models. Model 1 included the unadjusted association between HFI and diet quality. Model 2 included diet quality and daily energy intake as covariates. Model 3 included Model 2's covariates and age, race, diabetes duration, site, parent education, household income, and health insurance type. The last model, Model 4, added medication regimen, use of continuous glucose monitoring, and smoking status to Model 3's covariates. All analyses were completed with SAS 9.4.

6.5 Results

Demographic results are reflected in Table 6.1. YYA with T1D were on average 21 (±5.1) years old, mostly female, (56%) non-Hispanic white (59%), and of a high socioeconomic status as 42% had a household income of $75,000 or greater and 51% had a parent education of a bachelor's degree or higher. YYA with T1D consumed an average of 1,642.3 (±765.2) kilocalories per day. YYA with T2D were slightly older, averaging 25 years. They were also mostly female (68%), mostly minority (78%), and 50% had a household income less than $25,000. YYA with T2D consumed an average of 1684.7 (±842.1) kilocalories per day.

Tables 6.2a and 6.2b present the HEI component scores and overall scores. Females with T1D obtained an average HEI-2015 score of 56.1 (±10.5); and males with T1D obtained and average score of 52.4 (±10.9). Females with T2D obtained an average HEI-2015 score of 54.2 (±10.7); and males with T2D obtained an average score of 51.2 (±10.8). Tables 3a and 3b present the dietary intake in terms of the mean cup equivalents. Although we did not test for statistical significance, the scores for YYA with T1D and T2D do not appear to differ by food security status.

Tables 6.4a, 6.4b, 6.4c, and 6.4d present the association between HFI and diet quality in our sample. Table 6.4a focuses on female YYA with T1D. Female YYA with T1D who were food insecure had lower HEI-2015 scores than those who were food secure. In the unadjusted model, this relationship was statistically significant (β = -2.62, p=0.0189); however, in the fully adjust model, the relationship was not statistically significant (β = -1.16, p=0.3349). In unadjusted models, the association between HFI, total fruits (β = -0.47, p=0.0093), and whole fruits (β = -0.39, p=0.0390), was statistically significant and in the direction of our hypothesis. These associations did not remain in the final adjusted models. In the final model, the sodium HEI-2015 score was 0.63 units lower for female YYA with T1D who were food insecure than those who were food secure (p=0.0446). This indicates female YYA with T1D who were food insecure consumed more sodium than those who were food secure.

Table 6.4b focuses on male YYA with T1D. Male YYA with T1D and HFI had lower total HEI-2015 scores than those who were food secure; however, there was no statistical association between HFI and the total HEI-2015 score. In the unadjusted model, male YYA with T1D who were food insecure had a 0.83 lower added sugars component HEI-2015 score than those who were food secure (p=0.0074). There were no observed associations between HFI and component HEI-2015 scores in the final adjusted models.

Tables 6.4c and 6.4d focus on YYA with T2D. There were no associations observed between HFI and diet quality as measured by HEI-2015 or its components for males with T2D or females with T2D.

6.6. Discussion

In our sample of YYA with diabetes, the total mean HEI-2015 scores ranged from 51.2 (±10.8) (males with T2D) to 56.1 (±10.5) (females with T1D). Thus, the diet intake quality of YYA with diabetes leave significant room for improvement, as the mean score was just over 50 on a scale of 0 to 100. The highest individual HEI-2015 scores were 89.4 (females with T1D), 85.1 (males with T1D), 80.4 (females with T1D) and 78.5 (males with T2D). This is consistent with previous literature, in that YYA with diabetes do not typically meet national dietary guidelines.[112,113]

Our mean scores are comparable to other studies in youth and adults that have utilized the HEI-2015 to examine diet quality, in which scores range from 45.7 to 69.0.[118,170–174] For example, in a population sample of adults aged 20 to 65 years, Leung and Tester (2019) found an average HEI-2015 score of 54.6 among food secure adults and 52.4 among food insecure adults.[118] Using NHANES data from 2009-2014, Thomson et al. (2019) found a mean HEI-2015 score of 54.9 among youth, ages 2-18.[171] In general, diet quality among Americans is poor and needs improvement. Our study builds on previous research by assessing YYA with diabetes.

The results of our study did not support our hypothesis. There was no statistical association between HFI and the total HEI-2015 score in females or males with T1D or T2D. Our finding may in part be due to the different time frames in which diet and HFI are assessed in our study. While the SEARCH food frequency questionnaire assesses food eaten in the last seven days, HFI is reflective of a year. For some participants, the questionnaire may not have been completed during a time of food insecurity. In order to capture seasonal variation in diet and diet during times of food insecurity, the diet assessment would need to span an entire year or be repeated during different seasons and time periods.[141] It is also possible there was less variation in diet because the overall diet of YYA with diabetes in this study was poor.

While this particular study focused on youth who were adolescents and young adults, there are studies which postulated that parents/caregivers shield their children from the burden of HFI by taking on more of the burden themselves.[34] Similar to this, It is also possible that other household members shield YYA with diabetes from the effects of HFI given their higher needs for reliable dietary intake.

An association may not have been observed among YYA with T2D because half of our sample of YYA with T2D (46% food secure, 58% food insecure) had a household income less than $25,000. There is evidence that low-income adults under-report their dietary intake.[34] Although we do not have evidence that diet was under-reported, it is possible. Detecting differences in diet quality may be difficult if diet is truly under-reported.

Although our study is not consistent with the majority of published literature on HFI and diet quality, our study is not the first to find no evidence of an association.[34] Moreover, it is well known that null findings are harder to publish due to publication bias.[34]

Female YYA with T1D had a sodium HEI-2015 score 0.63 units lower than those who were food secure. Processed foods that are high in salt are usually easily accessible, inexpensive and satiating,[175,176] making these foods more appealing to people who may be on a tight food budget. Additionally, Leung et al. (2014) hypothesized that people experiencing food insecurity are chronically stressed and may consume foods that taste good, but are energy-dense, as a coping mechanism.[176] An association among females but not among males is also consistent with research which has observed that the risks of HFI are higher and consequences are stronger for females than males.[169]

There are several strengths of this study. It is the first to assess diet quality among YYA with diabetes using the HEI-2015. Our sample of YYA with diabetes is also a strength because YYA are often forgotten in HFI research and research specific to this population is needed. Additionally, our study included YYA with T1D and T2D.

In conclusion, contrary to our hypothesis, YYA with diabetes who were food insecure did not exhibit a poorer diet quality, measured with the HEI-2015 but the overall diet quality was quite poor. Future research should consider assessing diet over an entire year, conducting repeated measures of diet during different seasons and time periods, or statistically estimating long term intake from repeated diet measures. Future research should more deeply explore specific dietary components that may be negatively impacted by HFI. This research will help diabetes educators, health care providers, and interventionists target and focus on specific problematic food categories when working with YYA that have diabetes and HFI.

Table 6.1a. Demographic and Clinical Characteristics of Female Youth and Young Adults with Type 1 Diabetes Participating in the SEARCH for Diabetes in Youth Cohort Study (2015-2020), by Household Food Security Status, n=1,059

	Total	**Food Secure N=876**	**Food Insecure n=183**
Age, mean (SD)	21.1 (5.1)	21.1 (5.0)	21.1 (5.3)
Sex, %			
Female	56.3	55.7	59.0
Male	43.7	44.3	41.0
Race/Ethnicity, %			
NH-white	59.0	61.6	46.5
NH-black	16.6	13.6	31.2
Hispanic	20.1	20.7	17.5
Other	4.3	4.1	4.9
Household Income, %			
<$25,000	18.6	14.8	36.6
$25-49,999	22.1	19.6	33.9
$50-74,999	17.0	16.2	20.8
$75,000+	42.3	49.3	8.7
Clinic, %			
Carolina	19.2	17.6	26.8
Ohio	16.2	16.6	14.2
Colorado	32.4	33.0	29.5
California	18.5	19.9	12.0
Washington	13.8	13.0	17.5
Parent Education, %			
<HS graduate	5.0	4.8	6.0
HS graduate	14.1	12.8	20.2
Some Col. - Asso.	29.9	27.6	41.0
Bachelor's degree +	51.0	54.8	32.8
Insurance Status, %			
State/Federal	17.3	14.3	31.7
Private	77.8	80.8	63.4
Other/Unknown	1.9	2.2	0.6
None	3.0	2.7	4.4
Diabetes duration in months, mean (SD)	138.0 (38.9)	137.8 (38.9)	139.3 (38.8)
Smoking Status, %			
Nonsmoker	73.6	75.9	67.2
Former smoker	16.1	16.7	13.1
Current smoker	10.4	8.5	19.7
Medication Regimen, %			
Insulin pump	56.5	58.6	46.5
Insulin, long-acting 3+ rapid acting injections	37.2	35.5	45.4

Any other combo of insulin injections	5.3	5.1	6.0
Oral hypoglycemic medication	0.6	0.3	1.6
No treatment	0.5	0.5	0.6
CGM use, %	37.9	41.1	22.4
Daily energy intake, kcal/day, mean (SD)	1642.3 (765.2)	1598.7 (731.2)	1851.1 (883.2)

[1]NH, Non-Hispanic; HS, High School; Asso, Associate's degree; SD, Standard Deviation; CGM, Continuous Glucose Monitoring; Kcal, kilocalories

Table 6.1b. Demographic and Clinical Characteristics of Female Youth and Young Adults with Type 2 Diabetes Participating in the SEARCH for Diabetes in Youth Cohort Study (2015-2020), by Household Food Security Status, n=245

	Total	**Food Secure N=158**	**Food Insecure n=87**
Age, mean (SD)	25.3 (4.3)	25.6 (4.3)	25.6 (4.3)
Sex, %			
Female	67.8	65.8	71.3
Male	32.2	34.2	28.7
Race/Ethnicity, %			
NH-white	22.5	20.3	26.4
NH-black	43.7	43.7	43.7
Hispanic	24.5	27.9	18.4
Other	9.4	8.2	11.5
Household Income, %			
<$25,000	49.8	45.6	57.5
$25-49,999	32.7	29.1	39.1
$50-74,999	7.8	10.8	2.3
$75,000+	9.8	14.6	1.2
Clinic, %			
Carolina	35.5	34.2	37.9
Ohio	19.2	20.3	17.2
Colorado	18.4	16.5	21.8
California	20.4	24.7	12.6
Washington	6.5	4.4	10.3
Parent Education, %			
<HS graduate	11.8	11.4	12.6
HS graduate	33.1	34.2	31.0
Some Col. - Asso.	39.2	37.3	42.5
Bachelor's degree +	15.9	17.1	13.8
Insurance Status, %			
State/Federal	39.2	37.3	42.5
Private	45.3	47.5	41.4
Other/Unknown	2.5	2.5	2.3
None	13.1	12.7	13.8
Diabetes duration in months, mean (SD)	131.5 (42.2)	133.5 (40.5)	128.0 (45.1)
Smoking Status, %			
Nonsmoker	64.9	67.1	60.9
Former smoker	17.1	15.2	20.7
Current smoker	18.0	17.7	18.4
Medication Regimen, %			
Insulin pump	3.7	3.8	3.5
Insulin, long-acting 3+ rapid acting injections	18.4	15.8	23.0

Any other combo of insulin injections	35.5	37.3	32.2
Oral hypoglycemic medication	16.7	15.2	19.5
No treatment	25.7	27.9	21.8
CGM use, %	18.0	15.8	21.8
Daily energy intake, kcal/day, mean (SD)	1684.7 (842.1)	1623.2 (749.4)	1796.4 (983.5)

[1]NH, Non-Hispanic; HS, High School; Asso, Associate’s degree; SD, Standard Deviation; CGM, Continuous Glucose Monitoring; Kcal, kilocalories

Table 6.2a. Mean Healthy Eating Index-2015 Scores of Youth and Young Adults with Type 1 Diabetes, Stratified by Sex and Household Food Security Status

Females n=596				
	Maximum Score	**Total Mean (SD)**	**Food Secure n=488**	**Food Insecure N=108**
		Mean (SD)	**Mean (SD)**	**Mean (SD)**
Total HEI-2015 Score		56.1 (10.5)	56.6 (10.5)	53.9 (10.4)
Adequacy Components				
Total Fruits	5	2.9 (1.7)	3.0 (1.7)	2.5 (1.6)
Whole Fruits	5	3.2 (1.8)	3.3 (1.8)	2.9 (1.8)
Total Vegetables	5	3.6 (1.3)	3.6 (1.3)	3.6 (1.4)
Greens and Beans	5	3.3 (1.9)	3.3 (1.9)	3.3 (1.9)
Whole Grains	10	2.1 (1.9)	2.2 (1.9)	1.8 (1.6)
Dairy	10	6.1 (2.8)	6.0 (2.7)	6.3 (2.9)
Total Protein Foods	5	4.7 (0.7)	4.7 (0.7)	4.8 (0.6)
Seafood and Plant Proteins	5	3.3 (1.9)	3.3 (1.9)	3.1 (2.0)
Fatty Acids	10	5.0 (2.8)	5.0 (2.8)	4.7 (2.7)
Moderation Components				
Refined Grains	10	6.2 (3.1)	6.2 (3.1)	6.4 (2.9)
Sodium	10	3.2 (2.7)	3.3 (2.7)	2.8 (2.7)
Added Sugars	10	7.6 (2.6)	7.6 (2.6)	7.2 (2.8)
Saturated Fats	10	4.9 (2.7)	5.0 (2.8)	4.6 (2.3)
Males n=463				
	Maximum Score	**Total**	**Food Secure n=**	**Food Insecure N=**
		Mean (SD)	**Mean (SD)**	**Mean (SD)**
Total HEI-2015 Score		52.4 (10.9)	52.4 (10.9)	52.4 (10.9)
Adequacy Components				
Total Fruits	5	2.3 (1.7)	2.3 (1.7)	2.3 (1.7)
Whole Fruits	5	2.7 (1.8)	2.7 (1.8)	2.7 (1.8)
Total Vegetables	5	3.0 (1.4)	3.0 (1.4)	3.0 (1.4)
Greens and Beans	5	2.7 (2.0)	2.7 (2.0)	2.7 (2.0)
Whole Grains	10	1.9 (1.7)	1.9 (1.7)	1.9 (1.7)
Dairy	10	6.5 (2.6)	6.5 (2.6)	6.5 (2.6)
Total Protein Foods	5	4.8 (0.5)	4.8 (0.5)	4.8 (0.5)
Seafood and Plant Proteins	5	3.2 (2.0)	3.2 (2.0)	3.2 (2.0)
Fatty Acids	10	4.4 (2.6)	4.4 (2.6)	4.4 (2.6)
Moderation Components				
Refined Grains	10	5.8 (3.1)	5.8 (3.1)	5.8 (3.1)
Sodium	10	3.2 (2.8)	3.2 (2.8)	3.2 (2.8)
Added Sugars	10	7.8 (2.5)	7.8 (2.5)	7.8 (2.5)
Saturated Fats	10	4.0 (2.6)	4.0 (2.6)	4.0 (2.6)

Table 6.2b. Mean Healthy Eating Index Scores of Youth and Young Adults with Type 2 Diabetes, Stratified by Sex and Household Food Security Status

	Maximum Score	Total	Food Secure n=104	Food Insecure n=62
Females n=166				
		Mean (SD)	**Mean (SD)**	**Mean (SD)**
Total HEI-2015 Score		54.2 (10.7)	53.5 (10.9)	55.4 (10.5)
Adequacy Components				
Total Fruits	5	2.7 (1.9)	2.5 (1.9)	2.9 (1.8)
Whole Fruits	5	2.9 (1.9)	2.8 (2.0)	3.1 (1.8)
Total Vegetables	5	3.5 (1.3)	3.5 (1.2)	3.5 (1.4)
Greens and Beans	5	3.0 (2.0)	3.0 (2.1)	3.0 (2.0)
Whole Grains	10	1.7 (1.8)	1.6 (1.6)	1.9 (2.0)
Dairy	10	5.3 (2.7)	5.5 (2.7)	4.9 (2.7)
Total Protein Foods	5	4.8 (0.5)	4.8 (0.6)	4.9 (0.4)
Seafood and Plant Proteins	5	3.2 (1.9)	3.2 (1.9)	3.3 (1.9)
Fatty Acids	10	5.2 (2.6)	5.2 (2.5)	5.2 (2.9)
Moderation Components				
Refined Grains	10	6.9 (3.1)	6.6 (3.1)	7.3 (3.1)
Sodium	10	3.2 (3.0)	2.9 (2.9)	3.6 (3.2)
Added Sugars	10	6.7 (3.3)	6.5 (3.4)	6.9 (3.1)
Saturated Fats	10	5.1 (2.5)	5.2 (2.6)	5.0 (2.4)
Males n=79				
	Maximum Score	**Total**	**Food Secure n=104**	**Food Insecure n=62**
		Mean (SD)	**Mean (SD)**	**Mean (SD)**
Total HEI-2015 Score		51.2 (10.8)	51.2 (10.8)	51.2 (10.8)
Adequacy Components				
Total Fruits	5	2.0 (1.8)	2.0 (1.8)	2.0 (1.8)
Whole Fruits	5	2.3 (1.9)	2.3 (1.9)	2.3 (1.9)
Total Vegetables	5	3.2 (1.3)	3.2 (1.3)	3.2 (1.3)
Greens and Beans	5	2.7 (2.1)	2.7 (2.1)	2.7 (2.1)
Whole Grains	10	1.8 (1.9)	1.8 (1.9)	1.8 (1.9)
Dairy	10	5.2 (2.6)	5.2 (2.6)	5.2 (2.6)
Total Protein Foods	5	4.9 (0.5)	4.9 (0.5)	4.9 (0.5)
Seafood and Plant Proteins	5	3.2 (2.0)	3.2 (2.0)	3.2 (2.0)
Fatty Acids	10	5.0 (2.8)	5.0 (2.8)	5.0 (2.8)
Moderation Components				
Refined Grains	10	5.9 (3.3)	5.9 (3.3)	5.9 (3.3)
Sodium	10	2.9 (2.9)	2.9 (2.9)	2.9 (2.9)
Added Sugars	10	7.8 (2.6)	7.8 (2.6)	7.8 (2.6)
Saturated Fats	10	4.3 (2.8)	4.3 (2.8)	4.3 (2.8)

Table 6.3a. Dietary intake in Cup Equivalents of Youth and Young Adults with Type 1 Diabetes, Stratified by Sex and Household Food Security Status

	Females n=596			Males n=463		
	Total	**Food Secure n=488**	**Food Insecure N=108**	**Total**	**Food Secure n=388**	**Food Insecure N=75**
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
Adequacy Components						
Total Fruits, cups[1]	0.6 (0.5)	0.6 (0.5)	0.5 (0.4)	0.4 (0.4)	0.4 (0.4)	0.4 (0.4)
Whole Fruits, cups[1]	0.4 (0.3)	0.4 (0.3)	0.3 (0.3)	0.3 (0.3)	0.3 (0.3)	0.3 (0.2)
Total Vegetables, cups[1]	1.0 (0.6)	1.0 (0.5)	1.0 (0.7)	0.8 (0.5)	0.8 (0.5)	0.7 (0.3)
Greens and Beans, cups[1]	0.3 (0.4)	0.3 (0.4)	0.4 (0.6)	0.2 (0.4)	0.3 (0.4)	0.2 (0.2)
Whole Grains, ounces[1]	0.3 (0.3)	0.3 (0.3)	0.3 (0.3)	0.3 (0.3)	0.3 (0.3)	0.3 (0.3)
Dairy, cups[1]	0.9 (0.5)	1.0 (0.5)	0.9 (0.5)	0.9 (0.5)	0.9 (0.5)	0.8 (0.4)
Total Protein Foods, ounces[1]	3.5 (1.3)	3.4 (1.3)	3.6 (1.3)	3.8 (1.2)	3.8 (1.3)	3.7 (1.2)
Seafood and Plant Proteins, ounces[1]	1.0 (1.1)	1.0 (1.1)	1.0 (1.2)	1.0 (1.0)	1.0 (1.0)	0.8 (1.0)
Fatty Acids, (PUFAs + MUFAs)/SFAs	1.9 (0.5)	1.9 (0.5)	1.9 (0.5)	1.8 (0.4)	1.8 (0.4)	1.8 (0.4)
Moderation Components						
Refined Grains, ounces[1]	2.7 (1.0)	2.7 (1.0)	2.6 (0.9)	2.8 (0.9)	2.8 (1.0)	2.9 (1.0)
Sodium, grams[1]	1.7 (0.3)	1.7 (0.3)	1.8 (0.4)	1.8 (0.3)	1.8 (0.3)	1.7 (0.3)
Added Sugars, % of energy	11.0 (6.2)	10.8 (5.9)	11.9 (6.4)	10.4 (5.6)	10.1 (5.4)	11.9 (6.5)
Saturated Fats, % of energy	12.1 (2.5)	12.1 (2.5)	12.4 (2.0)	12.93 (2.4)	13.0 (2.4)	12.6 (2.6)

[1]Density per 1000 kcal

[2]Fatty Acid Ratio

[3]Percent of calories

Table 6.3b. Dietary intake in Cup Equivalents of Youth and Young Adults with Type 2 Diabetes, Stratified by Sex and Household Food Security Status

	Females n=166			**Males n=79**		
	Total	**FS N=104**	**FI N=62**	**Total**	**FS N=54**	**FI N=25**
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
Adequacy Components						
Total Fruits, cups[1]	0.5 (0.4)	0.5 (0.4)	0.6 (0.5)	0.4 (0.6)	0.5 (0.7)	0.4 (0.4)
Whole Fruits, cups[1]	0.3 (0.3)	0.3 (0.3)	0.3 (0.3)	0.3 (0.4)	0.3 (0.4)	0.2 (0.2)
Total Vegetables, cups[1]	0.9 (0.5)	0.9 (0.5)	0.8 (0.8)	0.8 (0.5)	0.8 (0.5)	0.8 (0.5)
Greens and Beans, cups[1]	0.3 (0.4)	0.3 (0.4)	0.3 (0.3)	0.3 (0.5)	0.3 (0.6)	0.2 (0.3)
Whole Grains, ounces[1]	0.3 (0.3)	0.2 (0.3)	0.3 (0.3)	0.3 (0.3)	0.3 (0.3)	0.3 (0.2)
Dairy, cups[1]	0.7 (0.5)	0.8 (0.5)	0.7 (0.5)	0.7 (0.4)	0.7 (0.4)	0.8 (0.5)
Total Protein Foods, ounces[1]	3.9 (1.4)	3.8 (1.4)	4.1 (1.3)	4.2 (1.5)	4.3 (1.4)	4.0 (1.5)
Seafood and Plant Proteins, ounces[1]	1.00 (1.2)	0.9 (1.1)	1.1 (1.2)	1.1 (1.2)	1.1 (1.2)	1.0 (1.3)
Fatty Acids, (PUFAs + MUFAs)/SFAs	1.9 (0.5)	1.9 (0.5)	1.9 (0.5)	1.9 (0.5)	1.88 (0.42)	1.90 (0.50)
Moderation Components						
Refined Grains, ounces[1]	2.5 (1.0)	2.5 (1.1)	2.4 (0.9)	2.8 (1.1)	2.8 (1.0)	2.9 (1.1)
Sodium, grams[1]	1.8 (0.3)	1.8 (0.3)	1.7 (0.3)	1.8 (0.4)	1.8 (0.4)	1.7 (0.3)
Added Sugars, % of energy	13.1 (8.0)	136 (8.4)	12.4 (7.3)	10.1 (6.3)	9.7 (6.1)	10.8 (6.7)
Saturated Fats, % of energy	12.0 (2.2)	11.9 (2.3)	12.0 (2.0)	12.6 (2.9)	12.6 (3.1)	12.5 (2.3)

[1]Density per 1000 kcal
[2]Fatty Acid Ratio
[3]Percent of calories

Table 6.4a. Association between Household Food Insecurity and Diet Quality among Youth and Young Adult Females with Type 1 Diabetes, N=596

	Model 1		Model 2	
	Estimate (SE)	**P-value**	**Estimate (SE)**	**P-value**
Outcomes				
Total Score	-2.62 (1.11)	0.0189	-2.37 (1.12)	0.0351
Total Fruits	**-0.47 (0.18)**	**0.0093**	**-0.42 (0.18)**	**0.0193**
Whole Fruits	**-0.39 (0.19)**	**0.0390**	-0.33 (0.19)	0.0856
Total Vegetables	0.03 (0.14)	0.7986	0.18 (0.14)	0.5704
Greens and Beans	-0.05 (0.20)	0.8039	-0.003 (0.20)	0.9900
Whole Grains	-0.31 (0.20)	0.1220	-0.24 (0.20)	0.2295
Dairy	0.26 (0.30)	0.3782	0.30 (0.30)	0.3109
Total Protein Foods	0.11 (0.10)	0.1739	0.19 (1.8)	0.2629
Seafood and Plant Proteins	-0.20 (0.20)	0.3339	-0.26(0.20)	0.2094
Fatty Acids	-0.36 (0.30)	0.2316	-0.35 (0.30)	0.2410
Refined Grains	0.21 (0.33)	0.5235	0.09 (0.33)	0.7901
Sodium	-0.56 (0.29)	0.0507	**-0.63 (0.29)**	**0.0296**
Added Sugars	-0.45 (0.28)	0.1092	-0.34 (0.28)	0.2277
Saturated Fats	-0.45 (0.29)	0.1184	-0.35 (0.29)	0.2234
	Model 3		**Model 4**	
Outcomes	**Estimate (SE)**	**P-value**	**Estimate (SE)**	**P-value**
Total Score	-1.47 (1.2)	0.2156	-1.16 (1.2)	0.3349
Adequacy Components				
Total Fruits	-0.32 (0.19)	0.0962	-0.29(0.19)	0.1402
Whole Fruits	-0.19 (1.00)	0.3474	-0.13 (0.20)	0.5216
Total Vegetables	0.17 (0.14)	0.2288	0.17 (0.15)	0.2431
Greens and Beans	0.01 (0.21)	0.9511	0.02 (0.22)	0.9387
Whole Grains	-0.22 (0.22)	0.3102	-0.22 (0.22)	0.3022
Dairy	0.62 (0.31)	0.0447	0.56 (0.31)	0.0740
Total Protein Foods	0.11 (0.08)	0.1923	0.11 (0.08)	0.1837
Seafood and Plant Proteins	-0.10 (0.22)	0.6355	-0.07 (0.22)	0.7540
Fatty Acids	-0.41 (0.32)	0.1976	-0.33 (0.32)	0.3094
Moderation Components				
Refined Grains	0.06 (0.35)	0.9411	0.08 (0.35)	0.8299
Sodium	**-0.66 (0.31)**	**0.0325**	**-0.63 (0.31)**	**0.0446**
Added Sugars	0.003(0.29)	0.9909	0.07 (0.30)	0.8152
Saturated Fats	-0.52 (0.31)	0.0934	-0.50 (0.31)	0.1095

Model 1: Food security status
Model 2: Food security status, kcal
Model 3: Food security status, kcals, age, race, diabetes duration, clinic, parent education, income, insurance type
Model 4: Food security status, kcals, age, race, diabetes duration, clinic, parent education, income, insurance type, medication regimen, cgm use, smoking status

Table 6.4b. Association Between Household Food Insecurity and Diet Quality among Youth and Young Adult Males with Type 1 Diabetes N=463

	Model 1		**Model 2**	
	Estimate (SE)	**P-value**	**Estimate (SE)**	**P-value**
Outcomes				
Total Score	-2.10 (1.38)	0.1279	-2.26(1.39)	0.1048
Adequacy Components				
Total Fruits	0.13 (0.21)	0.5240	0.14 (0.21)	0.5035
Whole Fruits	0.03 (0.23)	0.8880	0.06 (0.23	0.8056
Total Vegetables	-0.28 (0.17)	0.1074	-0.26 (0.17)	0.1337
Greens and Beans	-0.38 (0.25)	0.1305	-0.37 (0.25)	0.1402
Whole Grains	-0.13 (0.22)	0.5626	-0.10 (0.22)	0.6649
Dairy	-0.52 (0.33)	0.1110	-0.46 (0.33)	0.1667
Total Protein Foods	0.02 (0.06)	0.6854	0.01 (0.06)	0.8928
Seafood and Plant Proteins	-0.42 (0.25)	0.0922	**-0.52 (0.25)**	**0.0382**
Fatty Acids	0.11 (0.33)	0.7509	0.01 (0.34)	0.9853
Moderation Components				
Refined Grains	-0.43 (0.40)	0.2740	-0.50 (0.40)	0.2126
Sodium	0.03 (0.36)	0.9248	-0.09 (0.36)	0.8015
Added Sugars	**-0.83 (0.31)**	**0.0074**	**-0.74 (0.31)**	**0.0184**
Saturated Fats	0.55 (0.33)	0.0926	0.55 (0.33)	0.0975
	Model 3		**Model 4**	
Outcomes	**Estimate (SE)**	**P-value**	**Estimate (SE)**	**P-value**
Total Score	-0.91 (1.50)	0.5443	-0.58 (1.52)	0.7024
Adequacy Components				
Total Fruits	0.26 (0.23)	0.2600	0.32 (0.23)	0.1635
Whole Fruits	0.25 (0.25)	0.3154	0.29 (0.25)	0.2563
Total Vegetables	-0.18 (0.18)	0.3337	-0.14 (0.19)	0.4395
Greens and Beans	-0.20 (0.27)	0.4474	-0.19 (0.27)	0.4710
Whole Grains	-0.26 (0.24)	0.2730	-0.27 (0.24)	0.2714
Dairy	-0.39 (0.35)	0.2624	-0.37 (0.35)	0.2921
Total Protein Foods	-0.04 (0.07)	0.5640	-0.04 (0.06)	0.5779
Seafood and Plant Proteins	-0.27 (0.27)	0.3167	-0.25 (0.27)	0.3509
Fatty Acids	0.07 (0.36)	0.8434	0.09 (0.36)	0.8091
Moderation Components				
Refined Grains	-0.33(0.43)	0.4436	-0.30 (0.44)	0.5010
Sodium	0.14 (0.39	0.7123	0.19 (0.40)	0.6316
Added Sugars	-0.39 (0.34)	0.2450	-0.31 (0.34)	0.3663
Saturated Fats	0.44 (0.36)	0.2253	0.41 (0.36)	0.2586

Model 1: Food security status
Model 2: Food security status, kcal
Model 3: Food security status, kcals, age, race, diabetes duration, clinic, parent education, income, insurance type
Model 4: Food security status, kcals, age, race, diabetes duration, clinic, parent education, income, insurance type, medication regimen, cgm use, smoking status

Table 6.4c. Association between Household Food Insecurity and Diet Quality among Youth and Young Adult Females with Type 2 Diabetes N=166

	Model 1		**Model 2**	
	Estimate (SE)	**P-value**	**Estimate (SE)**	**P-value**
Outcomes				
Total Score	1.91 (1.72)	0.2668	1.89 (1.73)	0.2758
Adequacy Components				
Total Fruits	0.40 (0.30)	0.1822	0.39 (0.30)	0.1932
Whole Fruits	0.26 (0.31)	0.4024	0.25 (0.31)	0.4146
Total Vegetables	-0.01(0.21)	0.9689	0.02 (0.20)	0.9206
Greens and Beans	-0.00 (0.33)	0.9935	0.01 (0.33)	0.9656
Whole Grains	0.27 (0.29)	0.3568	0.27 (0.29)	0.3496
Dairy	-0.58 (0.43)	0.1825	-0.54 (0.43)	0.2078
Total Protein Foods	0.11 (0.08)	0.1824	0.11 (0.08)	0.1980
Seafood and Plant Proteins	0.11 (0.31)	0.7332	0.09 (0.31)	0.7670
Fatty Acids	-0.08 (0.43)	0.8457	-0.11 (0.42)	0.7895
Moderation Components				
Refined Grains	0.62 (0.50)	0.2151	0.62 (0.50)	0.2171
Sodium	0.68 (0.48)	0.1605	0.61 (0.47)	0.1981
Added Sugars	0.35 (0.53)	0.5108	0.40 (0.52)	0.4496
Saturated Fats	-0.20 (0.41)	0.6221	-0.23 (0.41)	0.5747
	Model 3		**Model 4**	
Outcomes	**Estimate (SE)**	**P-value**	**Estimate (SE)**	**P-value**
Total Score	1.84 (1.83)	0.3149	1.22 (1.83)	0.5074
Adequacy Components				
Total Fruits	0.40 (0.32)	0.2216	0.42 (0.33)	0.2054
Whole Fruits	0.40 (0.34)	0.2331	0.34 (0.33)	0.3068
Total Vegetables	-0.13 (0.22)	0.5616	-0.15 (0.22)	0.4891
Greens and Beans	-0.00 (0.35)	0.9971	-0.06 (0.36)	0.8592
Whole Grains	0.39 (0.32)	0.2223	0.40 (0.32)	0.2128
Dairy	-0.63 (0.46)	0.1779	-0.77 (0.47)	0.1026
Total Protein Foods	0.07(0.10)	0.4452	0.07 (0.10)	0.4920
Seafood and Plant Proteins	-0.01 (0.33)	0.9845	-0.09 (0.34)	0.7816
Fatty Acids	0.23 (0.46)	0.6190	0.14 (0.48)	0.7763
Moderation Components				
Refined Grains	0.32 (0.49)	0.5148	0.22 (0.49)	0.6557
Sodium	0.50 (0.52)	0.3318	0.45 (0.53)	0.3919
Added Sugars	-0.012 (0.55)	0.9852	-0.06 (0.55)	0.9137
Saturated Fats	0.30 (0.44)	0.5073	0.32 (0.46)	0.4917

Model 1: Food security status
Model 2: Food security status, kcal
Model 3: Food security status, kcals, age, race, diabetes duration, clinic, parent education, income, insurance type
Model 4: Food security status, kcals, age, race, diabetes duration, clinic, parent education, income, insurance type, medication regimen, cgm use, smoking status

Table 6.4d. Association between Household Food Insecurity and Diet Quality among Youth and Young Adult Males with Type 2 Diabetes N=79

	Model 1		Model 2	
	Estimate (SE)	**P-value**	**Estimate (SE)**	**P-value**
Outcomes				
Total Score	-0.66 (2.62)	0.8013	-0.98 (2.71)	0.7190
Adequacy Components				
Total Fruits	0.01 (0.43)	0.9787	0.04 (0.44)	0.9300
Whole Fruits	-0.07 (0.45)	0.8717	0.00 (0.47)	0.9993
Total Vegetables	-0.05 (0.31)	0.8833	0.05 (0.31)	0.8722
Greens and Beans	-0.07 (0.51)	0.8918	-0.04 (0.53)	0.9367
Whole Grains	0.02 (0.45)	0.9704	-0.02 (0.47)	0.9718
Dairy	0.33 (0.63)	0.6021	0.22 (0.65)	0.7334
Total Protein Foods	0.04 (0.11)	0.7175	0.04 (0.12)	0.7498
Seafood and Plant Proteins	-0.15 (0.49)	0.7585	-0.34 (0.50)	0.5057
Fatty Acids	-0.13 (0.68)	0.8462	-0.00 (0.70)	0.9982
Moderation Components				
Refined Grains	-0.57 (0.81)	0.4778	-1.03 (0.80)	0.2053
Sodium	0.24 (0.70)	0.7335	-0.20 (0.70)	0.7756
Added Sugars	-0.40 (0.64)	0.5324	-0.07 (0.64)	0.9165
Saturated Fats	0.15 (0.68)	0.8318	0.36 (0.70)	0.6067
	Model 3		**Model 4**	
Outcomes	**Estimate (SE)**	**P-value**	**Estimate (SE)**	**P-value**
Total Score	2.23 (3.45)	0.5203	3.49 (3.98)	0.3841
Adequacy Components				
Total Fruits	0.20 (0.57)	0.7312	0.33 (0.66)	0.6186
Whole Fruits	0.21 (0.60)	0.7224	0.53 (0.70)	0.4523
Total Vegetables	0.25 (0.40)	0.5325	0.21(0.41)	0.6119
Greens and Beans	0.68 (0.65)	0.2932	0.92 (0.71)	0.2054
Whole Grains	-0.06 (0.61)	0.9217	-0.01 (0.69)	0.9860
Dairy	0.40 (0.84)	0.6326	0.47 (0.98)	0.6323
Total Protein Foods	0.07 (0.14)	0.6137	0.00 (0.17)	0.9995
Seafood and Plant Proteins	0.32 (0.66)	0.6294	0.60 (0.74)	0.4221
Fatty Acids	0.58 (0.93)	0.5348	0.48 (1.08)	0.6579
Moderation Components				
Refined Grains	-1.16 (1.02)	0.2609	-0.90 (1.20)	0.4578
Sodium	-0.18 (0.90)	0.8410	0.16 (1.05)	0.8796
Added Sugars	0.74 (0.78)	0.3454	0.85 (0.86)	0.3275
Saturated Fats	0.17 (0.93)	0.8539	-0.14 (1.03)	0.8931

Model 1: Food security status
Model 2: Food security status, kcal
Model 3: Food security status, kcals, age, race, diabetes duration, clinic, parent education, income, insurance type
Model 4: Food security status, kcals, age, race, diabetes duration, clinic, parent education, income, insurance type, medication regimen, cgm use, smoking status

CHAPTER 7

SUMMARY AND CONCLUSIONS

The overarching goal of this study was to assess the associations between household food insecurity (HFI) and glycemic control, physical activity, and diet quality among youth and young adults (YYA) with type 1 diabetes (T1D) and type 2 diabetes (T2D). Aim 1 explored the association between HFI, HbA_{1c}, glycemic control, and acute complications of diabetes (diabetic ketoacidosis (DKA) or severe hypoglycemia) among YYA with T2D. Although HbA1c and glycemic control did not significantly differ by food security status, YYA with T2D and who had HFI were more likely to experience an acute diabetes complication than those who were from food secure households. The observed association was likely driven by the significant relationship between HFI and DKA. It is possible that YYA with T2D have a higher risk for infections and morbidity which place them at a higher risk for DKA. Future research should target longitudinal studies to determine if alleviating HFI reduces the frequency of acute complications of diabetes, specifically DKA.

The purpose of Aim 2 was to examine the association between HFI and physical activity in YYA with T1D and T2D. It was hypothesized that YYA with HFI would spend less time per week walking, in moderate intensity physical activity that excludes walking, in vigorous intensity physical activity, in moderate-to-vigorous intensity physical activity, and in total physical activity than YYA with diabetes who were food secure. Additionally, it was hypothesized that YYA with diabetes experiencing HFI would be less likely to meet the 2018 Physical Activity Guidelines for Americans and spend more time sitting per day than those who were food secure. Contrary to our hypothesis, YYA with T1D who were food insecure spent more time walking and achieved more total physical activity per week. Future research should examine different domains of walking (leisure vs. work vs. transportation) among YYA with diabetes because YYA who are food insecure may spend more time walking for work or transportation rather than leisure due to potential physical demands being of a low socioeconomic status. These demands may include lower paying jobs or not having a car.

In Aim 2, YYA with T2D who were food insecure spent more time sitting per day than those who were food secure, supporting our hypothesis. YYA with T2D who are food insecure may have less energy and therefore spend more time in sedentary behaviors. There was no relationship between HFI and physical activity among YYA with T2D.

The purpose of Aim 3 was to examine the association between HFI and diet quality, measured with the Health Eating Index-2015 (HEI-2015) in YYA with T1D and T2D stratified by sex. Overall, there was no statistical association between HFI and the HEI-2015. It is possible no association was observed because HFI is reflective of the experience of the past year; however, the SEARCH food frequency questionnaire assesses food consumed in the last 7 days. Future studies addressing this research aim should assess food consumed over a given year or conduct multiple diet assessments throughout a given year. Female YYA with T1D who experienced HFI did have lower sodium HEI-2015 component scores than those who were food secure. This means that females with T1D consumed more sodium if they were food insecure. Further research is needed to help diabetes educators, providers, and interventionists determine specific diet challenges and problematic food categories when working with YYA that have diabetes and HFI.

A major strength of this study was the assessment of YYA with diabetes and the inclusion of YYA with T2D. The relationships of HFI among YYA is unique from older adults and small children because YYA are in a transitional stage of life. Unfortunately, this group is often overlooked in HFI research. Additionally, studies among YYA with T2D are limited because the prevalence is smaller in comparison to YYA with T1D. However, research specific to YYA with T2D is needed because the incidence and prevalence of YYA with T2D is exponentially growing.

Each study indicated that HFI may impact diabetes management in YYA with diabetes and reinforces that ameliorating HFI can improve health across many different domains. In reference to the conceptual framework of this study, the results contribute to the literature supporting a nutritional pathway, and a behavioral pathway between HFI and diabetes management. However further assessment of these pathways is needed to help YYA manage their diabetes. Future research should consider physical activity and diet quality as mediators between HFI and diabetes management.

These results also support the important American Diabetes Association recommendation to universally screen for food insecurity as a tailored treatment to help people manage their diabetes. In each study, the prevalence of HFI among YYA with diabetes was much higher than the general population. By screening for HFI and identifying ways in which HFI may affect diabetes management, clinical care of YYA with diabetes will be improved.

REFERENCES

1. Bickel G, Nord M, Price C, Hamilton W, Cook J. *Guide to Measuring Household Food Security, Revised 2000*.; 2000. Accessed April 11, 2017. http://www.fns.usda.gov/oane

2. Coleman-Jensen A, Rabbitt MP, Gregory CA, Singh A. *Household Food Security in the United States in 2018*.; 2019. Accessed October 4, 2019. https://www.ers.usda.gov/webdocs/publications/94849/err-270.pdf?v=963.1

3. Weiser, S. D., Leiter K, Bangsberg DR, et al. Food insufficiency is associated with high-risk sexual behavior among women in Botswana and Swaziland. *PLOS Med*. 2007;4(10):1589-1597. doi:doi: 10.1371/journal.pmed.0040260

4. Seligman HK, Laraia BA, Kushel MB. Food insecurity is associated with chronic disease among low-income NHANES participants. *J Nutr*. 2010;140(2):304-310. doi:10.3945/jn.109.112573

5. Seligman HK, Bindman AB, Vittinghoff E, Kanaya AM, Kushel MB. Food insecurity is associated with diabetes mellitus: results from the National Health Examination and Nutrition Examination Survey (NHANES) 1999-2002. *J Gen Intern Med*. 2007;22(7):1018-1023. doi:10.1007/s11606-007-0192-6

6. Marjerrison S, Cummings EA, Glanville NT, Kirk SFL, Ledwell M. Prevalance and Associations of Food Insecurity in Children with Diabetes Mellitus. *J Pediatr*. 2011;158:607-611. doi:10.1016/j.jpeds.2010.10.003

7. Mendoza J., Haaland W, D'Agostino RB, et al. Food insecurity is associated with high risk glycemic control and higher health care utilization among youth and young adults with type 1 diabetes. *Diabetes Res Clin Pract*. 2018;138(5):128-137. doi:10.1016/j.physbeh.2017.03.040

8. Malik F, Liese A, Reboussin B, et al. Oral Session I - Epidemiology, Genetics, Immunology and the Environment: T1D and T2D - Prevalence and sociodemographic correlates of household food insecurity in youth and young adults with diabetes: the SEARCH for diabetes in youth study. *Pediatr Diabetes*. 2019;20(S28):34. doi:10.1111/pedi.12923

9. Pulgaron E, Delamater A. Obesity and Type 2 Diabetes in Children: Epidemiology and Treatment. *Curr Diab Rep*. 2014;14(8):1-21. doi:10.1007/s11892-014-0508-y.Obesity

10. Seligman HK, Schillinger D. Hunger and Socioeconomic Disparities in Chronic Disease. *N Engl J Med*. 2010;363(1). doi:10.1056/NEJMp1003173

11. American Diabetes Association. Standards of Medical Care in Diabetes - 2017. *Diabetes Care*. 2017;40 (sup 1)(January). doi:10.2337/dc17-S001

12. American Diabetes Association. Standards of Medical Care in Diabetes - 2019. *Diabetes Care*. 2019;42(1).

13. Seligman HK, Jacobs EA, Lopez A, Tschann J, Fernandez A. Food Insecurity and Glycemic Control Among Low-Income Patients With Type 2 Diabetes. *Diabetes Care*. 2012;35(2):233-238. doi:10.2337/dc11-1627

14. Berkowitz SA, Baggett TP, Wexler DJ, Huskey KW, Wee CC. Food Insecurity and Metabolic Control Among U.S. Adults with Diabetes. *Diabetes Care*. 2013;36(10):3093-3099. doi:10.2337/dc13-0570

15. Holben DH, Brown KA, Shubrook JH. Food insecurity is associated with poorer glycemic control in patients receiving free versus fee-based care. *Clin Diabetes*. 2019;37(1):44-48. doi:10.2337/cd17-0133

16. Bawadi HA, Ammari F, Abu-Jamous D, Khader YS, Bataineh S, Tayyem RF. Food insecurity is related to glycemic control deterioration in patients with type 2 diabetes. *Clin Nutr*. 2012;31(2):250-254. doi:10.1016/j.clnu.2011.09.014

17. Heerman W, Wallston KA, Osborn CY, et al. Research: Educational and psychological aspects Food insecurity is associated with diabetes self-care behaviours and glycaemic control. *Diabet Med*. 2016;33(6):844-850. doi:10.1111/dme.12896

18. Walker RJ, Strom Williams J, Egede LE. Impact of Race, Ethnicity and Social Determinants of Health on Diabetes Outcomes. *Am J Med Sci*. 2016;351(4):366-373. doi:10.1016/j.amjms.2016.01.008

19. Pinto CA, Stafford JM, Wang T, et al. Changes in diabetes medication regimens and glycemic control in adolescents and young adults with youth-onset type 2 diabetes: The SEARCH for diabetes in youth study. *Pediatr Diabetes*. 2018;19(6):1065-1072. doi:10.1111/pedi.12691

20. Dabelea D, Stafford JM, Mayer-Davis EJ, et al. Association of Type 1 Diabetes vs Type 2 Diabetes Diagnosed During Childhood and Adolescence With Complications During Teenage Years and Young Adulthood. *JAMA*. 2017;317(8):825-835. doi:10.1001/jama.2017.0686

21. Pinhas-hamiel O, Zeitler P. Acute and chronic complications of type 2 diabetes mellitus in children and adolescents. 2007;369:1823-1831.

22. Nadella S, Indyk JA, Kamboj MK. Management of diabetes mellitus in children and adolescents: engaging in physical activity. *Transl Pediatr*. 2017;6(3):215-224. doi:10.21037/tp.2017.05.01

23. Liese AD, Ma X, Maahs DM, Trilk JL. Physical activity, sedentary behaviors, physical fitness, and their relation to health outcomes in youth with type 1 and type 2 diabetes: A review of the epidemiologic literature. *J Sport Heal Sci*. 2013;2(1):21-38. doi:10.1016/j.jshs.2012.10.005

24. Tully C, Aronow L, Mackey E, Streisand R. Physical Activity in Youth With Type 1 Diabetes: a Review. *Curr Diab Rep*. 2016;16(9). doi:10.1007/s11892-016-0779-6

25. Xu H, Verre MC. Type 2 Diabetes Mellitus in Children. *Am Fam Physician*. 2018;98(9):590-594.

26. Fram MS, Ritchie LD, Rosen N, Frongillo EA. Child Experience of Food Insecurity Is Associated with Child Diet and Physical Activity. *J Nutr*. 2015;145(3):499-504. doi:10.3945/jn.114.194365

27. To QG, Frongillo EA, Gallegos D, Moore JBM. Household Food Insecurity Is Associated with Less Physical Activity among Children and Adults in the U.S. Population. *J Nutr*. 2014;144:1797-1802. doi:10.3945/jn.114.198184.Investigating

28. Sedentary Behaviour Research Network. Letter to the Editor: Standardized use of the terms "sedentary" and "sedentary behaviours." *Appl Physiol Nutr Metab*. 2012;37(3):540-542. doi:10.1139/h2012-024

29. Kirkpatrick SI, Tarasuk V. Food Insecurity Is Associated with Nutrient Inadequacies among Canadian Adults and Adolescents. *J Nutr*. 2008;138(3):604-612. doi:10.1093/jn/138.3.604

30. Dabelea D, Mayer-Davis E, Saydah S, et al. Prevalence of Type 1 and Type 2 Diabetes among children and adolescents from 2001 to 2009. *JAMA*. 2014;311(17):1778-1786. doi:10.1001/jama.2014.3201.Prevalence

31. Mayer-Davis EJ, Lawrence JM, Dabelea D, et al. Incidence Trends of Type 1 and Type 2 Diabetes among Youths, 2002–2012. *N Engl J Med*. 2017;376(15):1419-1429. doi:10.1056/nejmoa1610187

32. Silverman J, Krieger J, Kiefer M, Hebert P, Robinson J, Nelson K. The Relationship Between Food Insecurity and Depression, Diabetes Distress and Medication Adherence Among Low-Income Patients with Poorly-Controlled Diabetes. *J Gen Intern Med*. 2015;30(10):1476-1480. doi:10.1007/s11606-015-3351-1

33. American Diabetes Association. Standards of Medical Care in Diabetes - 2020. *Diabetes Care J Clin Appl Res Educ*. 2020;42(Supplement 1):960-1010. doi:10.1192/bjp.111.479.1009-a

34. Hanson K, Connor L. Food insecurity and dietary quality in US adults and children: a systematic review. *Am J Clin Nutr*. 2014;100(2):684-692.

35. Robson SM, Lozano AJ, Papas M, Patterson F. Food Insecurity and Cardiometabolic Risk Factors in Adolescents. *Prev Chronic Dis*. 2017;14:170222. doi:10.5888/pcd14.170222

36. Landry MJ, van den Berg AE, Asigbee FM, Vandyousefi S, Ghaddar R, Davis JN. Child-Report of Food Insecurity Is Associated with Diet Quality in Children. *Nutrients*. 2019;11(7). doi:10.3390/nu11071574

37. Jomaa L, Naja F, Itani L, Kharroubi S, Diab El Harake M, Hwalla N. Food insecurity is associated with lower adherence to the Mediterranean dietary pattern among Lebanese adolescents: a cross-sectional national study. *Eur J Nutr*. Published online 2020. doi:10.1007/s00394-019-02166-3

38. Weiser SD, Young SL, Cohen CR, et al. Conceptual framework for understanding the bidirectional links between food insecurity and HIV/AIDS. In: *American Journal of Clinical Nutrition*. Vol 94. ; 2011. doi:10.3945/ajcn.111.012070

39. Weiser S, Palar K, Hatcher A, Young S, Frongillo E, Laraia B. Food insecurity and health: A conceptual framework. In: In Ivers, L E, ed. *Food Insecurity and Public Health*. Vol 144. Food Insec. CRC Press; 2015:23-50. doi:10.1542/peds.2019-0347

40. Seligman HK, Davis TC, Schillinger D, Wolf MS. Food insecurity is associated with Hypoglycemia and poor diabetes self-management in a low-income sample with diabetes. *J Health Care Poor Underserved*. 2010;21(4):1227-1233. doi:10.1353/hpu.2010.0921

41. Gucciardi E, Vahabi M, Norris N, Del Monte JP, Farnum C. The Intersection between Food Insecurity and Diabetes: A Review. *Curr Nutr Rep*. 2014;3(4):324-332. doi:10.1007/s13668-014-0104-4

42. Colberg SR, Sigal RJ, Yardley JE, et al. Physical Activity/Exercise and Diabetes: A Position Statement of the American Diabetes Association. *Diabetes Care*. 2016;39:2065-2079. doi:10.2337/dc16-1728

43. Antonio JP, Sarmento RA, de Almeida JC. Diet Quality and Glycemic Control in Patients with Type 2 Diabetes. *J Acad Nutr Diet*. 2019;119(4):652-658. doi:10.1016/j.jand.2018.11.006

44. Niles MT, Bertmann F, Belarmino EH, Wentworth T, Biehl E, Neff R. The Early Food Insecurity Impacts of Covid-19. *Nutrients*. 2020;12(7):1-23. doi:10.3390/nu12072096

45. Feeding America. *The Impact of the Coronavirus on Food Insecurity*.; 2020. https://www.feedingamerica.org/sites/default/files/2020-04/Brief_Impact of Covid on Food Insecurity 4.22 %28002%29.pdf

46. U.S. Bureau of Labor and Statistics. TED: The Economics Daily, Unemployment rate rises to record high 14.7 percent in April 2020. Accessed September 28, 2020. https://www.bls.gov/opub/ted/2020/unemployment-rate-rises-to-record-high-14-point-7-percent-in-april-2020.htm

47. Dinour LM, Bergen D, Yeh M-C, et al. The Food Insecurity–Obesity Paradox: A Review of the Literature and the Role Food Stamps May Play. *J Am Diet Assoc*. 2007;107(11):1952-1961. doi:10.1016/j.jada.2007.08.006

48. Miller CL, Bangsberg DR, Tuller DM, et al. Food insecurity and sexual risk in an HIV endemic community in uganda. *AIDS Behav*. 2011;15(7):1512-1519. doi:10.1007/s10461-010-9693-0

49. Mendoza JA, Paul ME, Schwarzwald H, et al. Food insecurity, CD4 counts, and incomplete viral suppression among HIV+ patients from Texas Children's Hospital: A pilot study. *AIDS Behav*. 2013;17(5):1683-1687. doi:10.1007/s10461-013-0419-y

50. Mendoza JA, Matshaba M, Makhanda J, Liu Y, Boitshwarelo M, Anabwani GM. Food insecurity and CD4% among HIV+ children in gaborone, botswana. *J Acquir Immune Defic Syndr*. 2014;66(4):414-418. doi:10.1097/QAI.0000000000000190

51. Maynard M, Andrade L, Packull-McCormick S, Perlman CM, Leos-Toro C, Kirkpatrick SI. Food insecurity and mental health among females in high-income countries. *Int J Environ Res Public Health*. 2018;15(7). doi:10.3390/ijerph15071424

52. Slopen N, Fitzmaurice G, Williams DR, Gilman SE. *NEW RESEARCH Poverty, Food Insecurity, and the Behavior for Childhood Internalizing and Externalizing Disorders*. Vol 49.; 2010. doi:10.1016/j.jaac.2010.01.018

53. Baig-Ansari, N., M. H. Rahbar, Z. A. Bhutta and SHB. Child's gender and household food insecurity are associated with stunting among young Pakistani children residing in urban squatter settlements. *Food Nutr Bull*. Published online 2006:114-127.

54. Rose-Jacobs R, Black MM, Casey PH, et al. Household food insecurity: Associations with at-risk infant and toddler development. *Pediatrics*. 2008;121(1):65-72. doi:doi: 10.1542/peds.2006-3717

55. Ma CT, Gee L, Kushel MB. Associations between housing instability and food insecurity with health care access in low-income children. *Ambul Pediatr*. 2008;8(1):50-57. doi:doi: 10.1016/j.ambp.2007.08.004

56. Gundersen C, Kreider B. Bounding the effects of food insecurity on children's health outcomes. *J Health Econ*. 2009;28(5):971-983. doi:10.1016/j.jhealeco.2009.06.012

57. Shankar P, Chung R, Frank DA. Association of Food Insecurity with Children's Behavioral, Emotional, and Academic Outcomes: A Systematic Review. *J Dev Behav Pediatr*. 2017;38(2):135-150. doi:10.1097/DBP.0000000000000383

58. Alaimo K, Olson CM, Frongillo EA. Food insufficiency and American school-aged children's cognitive, academic, and psychosocial development. *Pediatrics*. 2001;108(1):44-53.

59. Ke J, Ford-Jones EL. Food insecurity and hunger: A review of the effects on children's health and behaviour. *Paediatr Child Health*. 2015;20(2):89-91. doi:10.1093/pch/20.2.89

60. Whitaker RC, Phillips SM, Orzol SM. Food insecurity and the risks of depression and anxiety in mothers and behavior problems in their preschool-aged children. *Pediatrics*. 2006;118(3). doi:10.1542/peds.2006-0239

61. American Diabetes Association (ADA). Hyperglycemia (High Blood Glucose). Accessed July 3, 2020. https://www.diabetes.org/diabetes/medication-management/blood-glucose-testing-and-control/hyperglycemia

62. American Diabetes Association. Diagnosis and classification of diabetes mellitus. *Diabetes Care*. 2014;37(SUPPL.1):S81-S90. doi:10.2337/dc14-S081

63. Dabelea D, Mayer-Davis EJ, Saydah S, et al. Prevalence of type 1 and type 2 diabetes among children and adolescents from 2001 to 2009. *JAMA - J Am Med Assoc*. 2014;311(17):1778-1786. doi:10.1001/jama.2014.3201

64. Divers J, Mayer-Davis EJ, Lawrence JM, et al. Trends in Incidence of Type 1 and Type 2 Diabetes Among Youths — Selected Counties and Indian Reservations, United States, 2002–2015. *MMWR Morb Mortal Wkly Rep*. 2020;69(6):161-165. doi:10.15585/mmwr.mm6906a3

65. Lawrence JM, Liese AD, Saydah SH, et al. Trends in Prevalence of Youth-Onset Type 1 and Type 2 Diabetes, 2001-2017: The SEARCH for Diabetes in Youth Study. *Diabetes*. 2020;69(Supplement 1).

66. Imperatore G, Boyle JP, Thompson TJ, et al. Projections of type 1 and type 2 diabetes burden in the U.S. population aged. *Diabetes Care*. 2012;35(12):2515-2520. doi:10.2337/dc12-0669

67. Lipman TH, Willi SM, Lai CW, Smith JA, Patil O, Hawkes CP. Insulin pump use in children with type 1 diabetes: Over a decade of disparities. *J Pediatr Nurs*. 2020;55:110-115. doi:10.1016/j.pedn.2020.08.007

68. Chiang JL, Maahs DM, Garvey KC, et al. Type 1 diabetes in children and adolescents: A position statement by the American Diabetes Association. *Diabetes Care*. 2018;41(9):2026-2044. doi:10.2337/dci18-0023

69. Codella R, Terruzzi I, Luzi L. Why should people with type 1 diabetes exercise regularly? *Acta Diabetol*. 2017;54(7):615-630. doi:10.1007/s00592-017-0978-x

70. Piercy KL, Troiano RP, Ballard RM, et al. The Physical Activity Guidelines for Americans. *JAMA*. 2018;320(19):2020. doi:10.1001/jama.2018.14854

71. Pivovarov JA, Taplin CE, Riddell MC. Current perspectives on physical activity and exercise for youth with diabetes. *Pediatr Diabetes*. 2015;16(4):242-255. doi:10.1111/pedi.12272

72. Chimen M, Kennedy A, Nirantharakumar K, Pang TT, Andrews R, Narendran P. What are the health benefits of physical activity in type 1 diabetes mellitus? A literature review. *Diabetologia*. 2012;55(3):542-551. doi:10.1007/s00125-011-2403-2

73. Petitti DB, Klingensmith GJ, Bell RA, et al. Glycemic Control in Youth with Diabetes: the SEARCH for Diabetes in Youth Study. *J Pediatr*. 2009;155(5):668-72.e1-3. doi:10.1016/j.jpeds.2009.05.025

74. Dileepan K, Max Feldt M. Type 2 diabetes mellitus in children and adolescents. *Pediatr Rev*. 2013;34(12):541-548. doi:10.1542/pir.34-12-541

75. Badaru A, Pihoker C. Type 2 Diabetes in Childhood : Clinical Characteristics and Role of β -Cell Autoimmunity. Published online 2012:75-81. doi:10.1007/s11892-011-0247-2

76. Dabelea D, Rewers A, Stafford JM, et al. Trends in the Prevalence of Ketoacidosis at Diabetes Diagnosis: The SEARCH for Diabetes in Youth Study. *Pediatrics*. 2014;133(4). doi:10.1542/peds.2013-2795

77. Rewers A, Klingensmith G, Davis C, et al. Presence of Diabetic Ketoacidosis at Diagnosis of Miabetes Mellitus in Youth: The SEARCH for Diabetes in Youth Study. *Pediatrics*. 2008;121(5):e1258-e1266. doi:10.1542/peds.2007-1105

78. Arslanian S, Bacha F, Grey M, Marcus MD, White NH, Zeitler P. Evaluation and Management of Youth-Onset Type 2 Diabetes: A Position Statement by the American Diabetes Association. *Diabetes Care*. 2018;41(12):2648-2668. doi:10.2337/dci18-0052

79. Dabelea D, Pihoker C, Talton JW, et al. Etiological Approach to Characterization of Diabetes Type The SEARCH for Diabetes in Youth Study. *Diabetes Care*. 2011;34(7):1628-1633.

80. Lawrence JM, Imperatore G, Pettitt DJ, et al. Incidence of diabetes in U.S. youth by type, race/ethnicity and age, 2008 - 2009. *Diabetes*. 2014;63(Suppl. 1):A407.

81. Reinehr T. Type 2 diabetes mellitus in children and adolescents. *World J Diabetes*. 2013;4(6):270-281. doi:10.4239/wjd.v4.i6.270

82. Copeland KC, Silverstein J, Moore KR, et al. Management of Newly Diagnosed Type 2 Diabetes Mellitus (T2DM) in Children and Adolescents. *Pediatrics*. 2013;131(2):364-382. doi:10.1542/PEDS.2012-3494

83. Nadeau KJ, Anderson BJ, Berg EG, et al. Youth-Onset Type 2 Diabetes Consensus Report: Current Status, Challenges, and Priorities. *Diabetes Care*. 2016;39(9):1635-1642. doi:10.2337/dc16-1066

84. Jones KL, Arslanian S, Peterokova VA, Park JS, Tomlinson MJ. Effect of metformin in pediatric patients with type 2 diabetes: A randomized controlled trial. *Diabetes Care*. 2002;25(1):89-94. doi:10.2337/diacare.25.1.89

85. American Diabetes Association. Standards of Medical Care in Diabetes - 2021. *Diabetes Care*. 2021;Supplement.

86. Scott CR, Smith JM, Cradock MM, Pihoker C. Characteristics of youth-onset noninsulin-dependent diabetes mellitus and insulin-dependent diabetes mellitus at diagnosis. *Pediatrics*. 1997;100(1):84-91. doi:10.1542/peds.100.1.84

87. Rewers MJ, Pillay K, de Beaufort C, et al. Assessment and monitoring of glycemic control in children and adolescents with diabetes. *Pediatr Diabetes*. 2014;15(S20):102-114. doi:10.1111/pedi.12190

88. DiMeglio LA, Acerini CL, Codner E, et al. ISPAD Clinical Practice Consensus Guidelines 2018: Glycemic control targets and glucose monitoring for children, adolescents, and young adults with diabetes. Published online 2018. doi:10.1111/pedi.12737

89. Levitt Katz LE, Magge SN, Hernandez ML, Murphy KM, McKnight HM, Lipman T. Glycemic control in youth with type 2 diabetes declines as early as two years after diagnosis. *J Pediatr*. 2011;158(1):106-111. doi:10.1016/j.jpeds.2010.07.011

90. Jensen ET, Dabelea D. Type 2 Diabetes in Youth: New Lessons from the SEARCH Study. *Curr Diab Rep*. 2018;18(6). doi:10.1007/s11892-018-0997-1

91. Copeland KC, Zeitler P, Geffner M, et al. Characteristics of adolescents and youth with recent-onset type 2 diabetes: The TODAY cohort at baseline. *J Clin Endocrinol Metab*. 2011;96(1):159-167. doi:10.1210/jc.2010-1642

92. Rhodes ET, Prosser LA, Hoerger TJ, Lieu T, Ludwig DS, Laffel LM. Estimated morbidity and mortality in adolescents and young adults diagnosed with Type 2 diabetes mellitus. *Diabet Med*. 2012;29(4):453-463. doi:10.1111/j.1464-5491.2011.03542.x

93. Seligman HK, Jacobs EA, Lopez A, Sarkar U, Tschann J, Fernandez A. Food insecurity and hypoglycemia among safety net patients with diabetes. *Arch Intern Med*. 2011;171(13):1204-1206. doi:10.1001/archinternmed.2011.287

94. López A, Seligman HK. Clinical Management of Food-Insecure Individuals With Diabetes. *Diabetes Spectr*. 2012;25(1). Accessed August 3, 2020. http://www.snap-step1.usda.gov/fns

95. Daneman D. Type 1 diabetes. In: *Lancet*. Vol 367. Elsevier; 2006:847-858. doi:10.1016/S0140-6736(06)68341-4

96. Gulliford MC, Nunes C, Rocke B. Food insecurity, weight control practices and body mass index in adolescents. *Public Health Nutr*. 2006;9(5):570-574. doi:10.1079/PHN2005886

97. Vitale M, Dorado L, Pais V, Sidani S, Gucciardi E. Food Insecurity Screening Among Families of Children With Diabetes. *Diabetes Spectr*. 2019;32(4):338-348. doi:10.2337/ds18-0083

98. Ippolito MM, Lyles CR, Prendergast K, Marshall MB, Waxman E, Seligman HK. Food insecurity and diabetes self-management among food pantry clients. *Public Health Nutr*. 2017;20(1):183-189. doi:10.1017/S1368980016001786

99. Troiano RP, Berrigan D, Dodd KW, et al. Physical Activity in the United States Measured by Accelerometer. *Med Sci Sport Exerc*. 2008;40(1):181-188. doi:10.1249/mss.0b013e31815a51b3

100. Lobelo F, Liese AD, Liu J, et al. Physical activity and electronic media use in the search for diabetes in youth case-control study. *Pediatrics*. 2010;125(6). doi:10.1542/peds.2009-1598

101. Tudor-Locke C, Craig CL, Beets MW, et al. How many steps/day are enough? For children and adolescents. *Int J Behav Nutr Phys Act*. 2011;8(1):78. doi:10.1186/1479-5868-8-78

102. O'Neill JR, Liese AD, McKeown RE, et al. Physical activity and self-concept: The SEARCH for diabetes in youth case control study. *Pediatr Exerc Sci*. 2012;24(4):577-588. doi:10.1123/pes.24.4.577

103. Faulkner MS. Cardiovascular Fitness and Quality of Life in Adolescents with Type 1 or Type 2 Diabetes. *J Spec Pediatr Nurs*. 2010;15(4):307-316. doi:10.1111/j.1744-6155.2010.00254.x

104. Nadeau KJ, Zeitler PS, Bauer TA, et al. Insulin resistance in adolescents with type 2 diabetes is associated with impaired exercise capacity. *J Clin Endocrinol Metab*. 2009;94(10):3687-3695. doi:10.1210/jc.2008-2844

105. Colberg SR, Sigal RJ, Fernhall B, et al. Exercise and Type 2 Diabetes The American College of Sports Medicine and the American Diabetes Association: joint position statement. *Diabetes Care*. 2010;33:e147-167. doi:10.2337/dc10-9990

106. Ainsworth BE, Cahalin L, Buman M, Robert R. The Current State of Physical Activity Assessment Tools. *Prog Cardiovasc Dis*. 2015;57(4):387-395.

107. Sylvia LG, Bernstein EE, Hubbard JL, Keating L, Anderson EJ. Practical guide to measuring physical activity. *J Acad Nutr Diet*. 2014;114(2):199-208. doi:10.1016/j.jand.2013.09.018

108. Hamelin A-M, Habicht J-P, Beaudry M. Food Insecurity: Consequences for the Household and Broader Social Implications. *J Nutr*. 1999;129:525S-528S. Accessed July 31, 2020. https://academic.oup.com/jn/article-abstract/129/2/525S/4731686

109. Gucciardi E, Vogt JA, DeMelo M, Stewart DE. Exploration of the relationship between household food insecurity and diabetes in Canada. *Diabetes Care*. 2009;32(12):2218-2224. doi:10.2337/dc09-0823

110. Gunter KB, Jackson J, Tomayko EJ, John DH. Food insecurity and physical activity insecurity among rural Oregon families. *Prev Med Reports*. 2017;8:38-41. doi:10.1016/j.pmedr.2017.07.006

111. U.S. Department of Health and Human Services and U.S. Department of Agriculture. *2015-2020 Dietary Guidelines for Americans, 8th Edition*.; 2015. doi:10.1097/NT.0b013e31826c50af

112. Rovner AJ, Nansel TR. Are children with type 1 diabetes consuming a healthful diet?: A review of the current evidence and strategies for dietary change. *Diabetes Educ*. 2009;35(1):97-107. doi:10.1177/0145721708326699

113. Mayer-Davis EJ, Nichols M, Liese AD, et al. Dietary Intake among Youth with Diabetes: The SEARCH for Diabetes in Youth Study. *J Am Diet Assoc*. 2006;106(5):689-697. doi:10.1016/j.jada.2006.02.002

114. Orr CJ, Keyserling TC, Ammerman AS, Berkowitz SA. Diet quality trends among adults with diabetes by socioeconomic status in the U.S.: 1999-2014. *BMC Endocr Disord*. 2019;19(1):1-9. doi:10.1186/s12902-019-0382-3

115. Nansel TR, Lipsky LM, Liu A. Greater diet quality is associated with more optimal glycemic control in a longitudinal study of youth with type 1 diabetes. *Am J Clin Nutr*. 2016;104(1):81-87. doi:10.3945/ajcn.115.126136

116. Gow ML, Baur LA, Johnson NA, Cowell CT, Garnett SP. Reversal of type 2 diabetes in youth who adhere to a very-low-energy diet: a pilot study. *Diabetologia*. 2017;60(3):406-415. doi:10.1007/s00125-016-4163-5

117. Larson N, Laska MN, Neumark-sztainer D. Food Insecurity , Diet Quality , Home Food Availability , and Health Risk Behaviors Among Emerging Adults : Findings From the EAT 2010 – 2018 Study. *Am J Public Health*. 2020;110(9):1422-1429. doi:10.2105/AJPH.2020.305783

118. Leung CW, Tester JM. The Association between Food Insecurity and Diet Quality Varies by Race/Ethnicity: An Analysis of National Health and Nutrition Examination Survey 2011-2014 Results. *J Acad Nutr Diet*. 2019;119(10):1676-1686. doi:10.1016/j.jand.2018.10.011

119. Bell Wake R, Lawrence JM, Permanente Southern California K, et al. SEARCH for Diabetes in Youth: a multicenter study of the prevalence, incidence and classification of diabetes mellitus in youth. *Pacific Heal Res Control Clin Trials*. 2004;25:458-471. doi:10.1016/j.cct.2004.08.002

120. Hamman R, Bell R, Dabelea D, et al. The SEARCH for Diabetes in Youth Study: rationale, findings, and future directions. *Diabetes Care*. 2014;37(12):3336-3344.

121. Ipaq. Guidelines for Data Processing and Analysis of the International Physical Activity Questionnaire (IPAQ) – Short and Long Forms. *Ipaq*. 2005;(November):1-15.

122. Tran VD, Do VV, Pham NM, et al. Validity of the International Physical Activity Questionnaire–Short Form for Application in Asian Countries: A Study in Vietnam. *Eval Heal Prof*. Published online 2018. doi:10.1177/0163278718819708

123. Murphy JJ, Murphy MH, MacDonncha C, Murphy N, Nevill AM, Woods CB. Validity and Reliability of Three Self-Report Instruments for Assessing Attainment of Physical Activity Guidelines in University Students. *Meas Phys Educ Exerc Sci*. 2017;21(3):134-141. doi:10.1080/1091367X.2017.1297711

124. Craig CL, Marshall AL, Sjöström M, et al. International physical activity questionnaire: 12-Country reliability and validity. *Med Sci Sports Exerc*. 2003;35(8):1381-1395. doi:10.1249/01.MSS.0000078924.61453.FB

125. Lee PH, Macfarlane DJ, Lam TH, Stewart SM. Validity of the international physical activity questionnaire short form (IPAQ-SF): A systematic review. *Int J Behav Nutr Phys Act*. 2011;8(115). doi:10.1186/1479-5868-8-115

126. Wang C, Chen P, Zhuang J. Validity and reliability of international physical activity questionnaire-short form in chinese youth. *Res Q Exerc Sport*. 2013;84(SUPPL. 2):80-87. doi:10.1080/02701367.2013.850991

127. Curry WB, Thompson JL. Comparability of accelerometer- and IPAQ-derived physical activity and sedentary time in South Asian women: A cross-sectional study. *Eur J Sport Sci*. 2015;15(7):655-662. doi:10.1080/17461391.2014.957728

128. Questionnaires and Screeners – Assessment & Analysis Services – NutritionQuest. Accessed January 30, 2020. https://nutritionquest.com/assessment/list-of-questionnaires-and-screeners/

129. Liese AD, Crandell JL, Tooze JA, et al. Relative validity and reliability of a food frequency questionnaire in youth with type 1 diabetes. *Public Heal Nutr*. 2015;18(3):428-437. doi:10.1017/S1368980014000408

130. Krebs-Smith SM, Pannucci TE, Subar AF, et al. Update of the Healthy Eating Index: HEI-2015. *J Acad Nutr Diet*. 2018;118(9):1591-1602. doi:10.1016/j.jand.2018.05.021

131. How the HEI Is Scored | USDA-FNS. Published 2018. Accessed September 30, 2019. https://www.fns.usda.gov/how-hei-scored

132. Panizza CE, Shvetsov YB, Harmon BE, et al. Testing the Predictive Validity of the Healthy Eating Index-2015 in the Multiethnic Cohort: Is the Score Associated with a Reduced Risk of All-Cause and Cause-Specific Mortality? *Nutrients*. 2018;10(4):452-undefined. doi:10.3390/nu10040452

133. Reedy J, Lerman JL, Krebs-Smith SM, et al. Evaluation of the Healthy Eating Index-2015. *J Acad Nutr Diet*. 2018;118(9):1622-1633. doi:10.1016/j.jand.2018.05.019

134. Liese AD, Krebs-Smith SM, Subar AF, et al. The Dietary Patterns Methods Project: Synthesis of Findings across Cohorts and Relevance to Dietary Guidance. *J Nutr*. 2015;145(3):393-402. doi:10.3945/jn.114.205336

135. Shah AS, Dabelea D, Talton JW, et al. Smoking and arterial stiffness in youth with type 1 diabetes: The SEARCH cardiovascular disease study. *J Pediatr*. 2014;165(1):110-116. doi:10.1016/j.jpeds.2014.02.024

136. Hiza HAB, Casavale KO, Guenther PM, Davis CA. Diet Quality of Americans Differs by Age, Sex, Race/Ethnicity, Income, and Education Level. *J Acad Nutr Diet*. 2013;113(2):297-306. doi:10.1016/j.jand.2012.08.011

137. Schreiber-Gregory D, Jackson Foundation HM. *Logistic and Linear Regression Assumptions: Violation Recognition and Control*.

138. Gameroff MJ. *Using the Proportional Odds Model for Health-Related Outcomes: Why, When, and How with Various SAS® Procedures*.; 2005. Accessed February 6, 2020. https://pdfs.semanticscholar.org/f88d/0a046727f8dc2661dce54d561843ebc0dd0c.pdf?_ga=2.173184931.1019768711.1583958212-289980559.1583958212

139. Fullerton AS, Xu J. Constrained and Unconstrained Partial Adjacent Category Logit Models for Ordinal Response Variables. *Sociol Methods Res*. 2018;47(2):169-206. doi:10.1177/0049124115613781

140. Agresti A. *An Introduction to Categorical Data Analysis*. 2nd ed. John Wiley & Sons, Inc.; 2007.

141. INDDEX Project. *Data4Diets: Building Blocks for Diet-Related Food Security Analysis*.; 2018. Accessed January 30, 2020. https://inddex.nutrition.tufts.edu/data4diets.

142. Little RJ., Rubin DB. *Statistical Analysis with Missing Data*. 2nd ed. John Wiley & Sons; 2002.

143. Costacou T, Crandell J, Kahkoska AR, et al. Dietary Patterns Over Time and Microalbuminuria in Youth and Young Adults With Type 1 Diabetes: The SEARCH Nutrition Ancillary Study. *Diabetes Care*. 2018;41(8):1615-1622. doi:10.2337/dc18-0319

144. Lawrence JM, Divers J, Isom S, et al. Trends in Prevalence of Type 1 and Type 2 Diabetes in Children and Adolescents in the United States, 2001-2017. *JAMA*.

145. Butler AM. Social Determinants of Health and Racial/Ethnic Disparities in Type 2 Diabetes in Youth. *Curr Diab Rep*. 2017;17(8):60. doi:10.1007/s11892-017-0885-0

146. Klingensmith G, Connor C, Ruedy KJ, et al. Presentation of youth with type 2 diabetes in the Pediatric Diabetes Consortium. *Pediatr Diabetes*. 2016;17:266-273. doi:10.1111/pedi.12281

147. Malik FS, Liese AD, Reboussin BA, et al. Prevalence and sociodemographic correlates of household food insecurity in youth and young adults with diabetes: the SEARCH for Diabetes in Youth Study. In: *Pediatric Diabetes*. Vol 20. ; 2019:34.

148. Coleman-Jensen A, Rabbitt MP, Gregory C, Singh A. Household food security in the United States in 2019. *US Dep Agric Econ Res Serv*. 2020;ERR-275:1-56.

149. Garvey K, Laffel L. Transitions in Care from Pediatric to Adult Health Care Providers: Ongoing Challenges and Opportunities for Young Persons with Diabetes. *Endocr Dev*. 2018;33. doi:10.1159/000487866

150. SEARCH Study Group. SEARCH for Diabetes in Yonth: a multicenter study of the prevalence, incidence and classification of diabetes mellitus in youth. *Control Clin Trials*. 2004;25:458-471.

151. Cengiz E, Xing D, Wong JC, et al. Severe Hypoglycemia and Diabetic Ketoacidosis among Youth with Type 1 Diabetes in the T1D Exchange Clinic Registry. *Pediatr Diabetes*. 2013;14(6):447-454. doi:10.1111/pedi.12030.Severe

152. Mayer-Davis EJ, Ma B, Lawson A, et al. Cardiovascular Disease Risk Factors in Youth With Type 1 and Type 2 Diabetes: Implications of a Factor Analysis of Clustering. *Metab Syndr Relat Disord*. 2009;7(2):89-95. doi:10.1089/met.2008.0046

153. Wilde PE, Ranney CK. The monthly food stamp cycle: Shopping frequency and food intake decisions in an endogenous switching regression framework. *Am J Agric Econ*. 2000;82(1):200-213. doi:10.1111/0002-9092.00016

154. Liese AD, Davis RE, Diaz D, et al. Experiences of Food Insecurity and Type 2 Diabetes Management in Adults. *J Hunger Environ Nutr*. Published online 2020. https://doi.org/10.1080/19320248.2020.1826380

155. Eledrisi M, Elzouki A-N. Management of diabetic ketoacidosis in adults: A narrative review. *Saudi J Med Med Sci*. 2020;8(3):165. doi:10.4103/sjmms.sjmms_478_19

156. Rewers A. Chapter 17: Acute Metabolic Complications in Diabetes. In: *Diabetes in America*. 3rd ed. National Institute of Diabetes and Digestive and Kidney Diseases (US); 2018. Accessed May 31, 2021. http://www.ncbi.nlm.nih.gov/pubmed/33651551

157. Welch BJ, Zib I. Case Study: Diabetic Ketoacidosis in Type 2 Diabetes: "Look Under the Sheets." *Clin Diabetes*. 2004;22(4):198-200. doi:10.2337/diaclin.22.4.198

158. Shin SS, Carpenter CL, Ekstrand ML, et al. Household Food Insecurity as Mediator of the Association Between Internalized Stigma and Opportunistic Infections. *AIDS Behav*. 2018;22(12):3897-3904. doi:10.1007/s10461-018-2193-3

159. Men F, Gundersen C, Urquia ML, Tarasuk V. Association between household food insecurity and mortality in Canada: A population-based retrospective cohort study. *CMAJ*. 2020;192(3):E53-E60. doi:10.1503/cmaj.190385

160. Stuff JE, Casey PH, Szeto KL, et al. Household food insecurity is associated with adult health status. In: *Journal of Nutrition*. Vol 134. ; 2004:2330-2335. doi:10.1093/jn/134.9.2330

161. Shaibi GQ, Faulkner MS, Weigensberg MJ, Fritschi C, Goran MI. Cardiorespiratory Fitness and Physical Activity in Youth with Type 2 Diabetes. *Pediatr Diabetes*. 2008;9(5):460-463. doi:10.1111/j.1399-5448.2008.00407.x.Cardiorespiratory

162. van Buuren S. Multiple imputation of discrete and continuous data by fully conditional specification. *Stat Methods Med Res*. 2007;16(3):219-242. doi:10.1177/0962280206074463

163. Roberts AJ, Taplin CE, Isom S, et al. Association between fear of hypoglycemia and physical activity in youth with type 1 diabetes : The SEARCH for diabetes in youth study. *Pediatr Diabetes*. 2020;21(7):1277-1284. doi:10.1111/pedi.13092

164. Leach HJ, Mama SK, Soltero EG, Lee RE. The influence of sitting time and physical activity on health outcomes in public housing residents. *Ethn Dis*. 2014;24(3):370-375. Accessed June 7, 2021. https://pubmed-ncbi-nlm-nih-gov.pallas2.tcl.sc.edu/25065081/

165. Joyner C, Biddle SJH, Loprinzi PD. Association of Personality on Changes in Weekday Sitting Time: Cross-Sectional and Prospective Evaluation. *J Lifestyle Med*. 2019;9(1):60-66. doi:10.15280/jlm.2019.9.1.60

166. Cusatis R, Garbarski D. Different domains of physical activity: The role of leisure, housework/care work, and paid work in socioeconomic differences in reported physical activity. *SSM - Popul Heal*. 2019;7. doi:10.1016/j.ssmph.2019.100387

167. Maia I, Monjardino T, Lucas R, Ramos E, Santos AC, Maia I. Household food insecurity and socio-demographic determinants in young adults: findings from a Portuguese population-based sample. *Int J Public Health*. 2019;64(6):887-895. doi:10.1007/s00038-019-01243-y

168. Mckenzie B. *Modes Less Traveled-Bicycling and Walking to Work in the United States: 2008-2012 American Community Survey Reports*.; 2014. Accessed May 29, 2021. www.census.gov/acs/www

169. Martin MA, Lippert AM. Feeding her children, but risking her health: the intersection of gender, household food insecurity and obesity. *Soc Sci Med*. 2012;74(11):1754-1764. doi:10.1016/j.socscimed.2011.11.013

170. Harrison S, Brassard D, Lemieux S, Lamarche B. Dietary Saturated Fats from Different Food Sources Show Variable Associations with the 2015 Healthy Eating Index in the Canadian Population. *J Nutr*. 2020;150(12):3288-3295.

171. Thomson JL, Tussing-Humphreys LM, Goodman MH, Landry AS. Diet quality in a nationally representative sample of American children by sociodemographic characteristics. *Am J Clin Nutr*. 2019;109(1):127-138. doi:10.1093/ajcn/nqy284

172. de Paula Matos Souza J, Magela de Lima M, Martins Horta P. Diet Quality among the Brazilian Population and Associated Socioeconomic and Demographic Factors: Analysis from the National Dietary Survey 2008-2009. *J Acad Nutr Diet*. 2019;119(11):1866-1874. doi:10.1016/j.jand.2019.04.014

173. Juul F, Simões S, Litvak J, et al. Processing level and diet quality of the US grocery cart: is there an association? *Public Health Nutr*. 2019;22(13):2357-2366. doi:10.1017/S1368980019001344

174. Lamarche B, Brassard D, Lapointe A, et al. Changes in diet quality and food security among adults during the COVID-19–related early lockdown: results from NutriQuébec. *Am J Clin Nutr*. Published online 2021:1-9. doi:10.1093/ajcn/nqaa363

175. Gearhardt A, Davis C, Kuschner R, Brownell K. The addiction potential of hyperpalatable foods. *Curr Drug Abuse Rev*. 2011;4(3):140-145.

176. Leung CW, Epel ES, Ritchie LD, Crawford PB, Laraia BA. Food Insecurity Is Inversely Associated with Diet Quality of Lower-Income Adults. *J Acad Nutr Diet*. 2014;114(12):1943-1953.e2. doi:10.1016/j.jand.2014.06.353

APPENDIX A

CHAPTER 4 USING MULTIPLE IMPUTATION

Under the assumption of missing at random, values were imputed with multiple imputation following the fully conditional specification method. All variables used in the adjusted models were included in the imputation model. A total of 20 imputed datasets based on 200 iterations were created.

Table A.1. Demographic characteristics of youth and young adults with type 2 diabetes from the SEARCH for Diabetes in Youth Study (n=395)[1]

Characteristic	Total	Food Secure (n=224)	Food Insecure (n=102)
Continuous HFI Score	1.7 (2.1)	0.4 (0.7)	4.4 (1.5)
Missing, n (%)	11 (2.8)		
Age in yrs, mean (sd)	24.7 (4.3)	24.5 (4.4)	25.2 (4.1)
Missing, n (%)	1 (0.0)		
Sex, %			
Female	67.5	65.2	72.6
Male	32.5	34.8	27.5
Missing, n (%)	0		
Race/Ethnicity, %			
NH White	19.3	16.1	26.5
NH Black	44.2	45.5	41.2
Other[3]	36.5	38.4	32.4
Missing, n (%)	0		
Clinic, %			
Carolinas	33.4	32.1	36.3
Ohio	17.8	18.3	16.7
Colorado	22.1	21.0	24.5
California/Washington	26.7	28.6	22.6
Missing, n (%)	0		
Parent Education, %			
<HS graduate	12.0	12.1	11.8
HS graduate	34.4	35.7	31.4
Some College – Asso.	37.7	36.2	41.2
Bachelors degree +	16.0	16.1	15.7
Missing, n (%)	35 (8.9)		
Insurance Status			
State / Federal	37.7	35.7	42.2
Private/Exchanges	43.6	46.0	38.2
None	14.4	13.8	15.7
Other/Unknown	4.3	4.5	3.9
Missing, n (%)	15 (3.8)		
Diabetes duration in months, mean (sd)	124.0 (42.9)	124.2 (42.0)	123.6 (45.0)
Missing, n (%)	1 (0.0)		
Diabetes regimen, %			
Medication	73.0	72.3	74.5
No Medication	27.0	27.7	25.5
Missing, n (%)	13		
CGM use, %	18.4	17.0	21.6
Missing, n (%)	21 (5.3)		
Household Income,[2] %			

<$25,000	49.5	46.4	58.7
$25,000+	50.6	53.6	41.3
Missing, n (%)	146 (37.0)		
HbA1c, mean (sd)	9.4 (2.9)	9.5 (3.0)	9.2 (2.8)
Missing, n (%)	36 (9.1)		
Glycemic Control, %			
Optimal	27.0	25.9	29.4
Suboptimal	17.8	19.2	14.7
High Risk	55.2	54.9	55.9
Missing, n (%)	36 (9.1)		
Acute Complications, %[4]	10.8	7.9	17.4
Missing, n (%)	8 (2.0)		
DKA, %[4]	8.2	5.5	14.4
Missing, n (%)	20 (5.1)		
Hypoglycemia, %	3.9		
Missing, n (%)	13 (3.3)		

[1] NH, Non-Hispanic; HS, High School; Asso, Associate's degree; CGM, Continuous glucose monitoring; DKA, Diabetic Ketoacidosis
[2]n of household income = 271
[3]Other race includes Hispanic, Native American, Asian-Pacific Islander, and Other
[4]n of DKA only= 351

Table A.2. Association between food security and hba1c in SEARCH YYA with T2D (n=395)[1]

	Model 3	
Variable	**Estimate (SE)**	**P-value**
HFI (dichotomous)	-0.37 (0.32)	0.2423
HFI (continuous)	-0.01 (0.07)	0.8369

Model 3 adjusted for: age, gender, race, parent education, insurance level, clinic, diabetes duration, CGM use, medication regimen
[1]Analysis based on multiple imputation.

Table A.3. Association between food security and glycemic control in SEARCH YYA with T2D (n=395)[1]

	Model 3		
Variable	**Odds**	**CI**	**P-value**
HFI (dichotomous)	1.01	0.64 - 1.60	0.9594
HFI (continuous)	1.02	0.91 – 1.13	0.7714

Model 3 adjusted for: age, gender, race, parent education, insurance level, clinic, diabetes duration, CGM use, medication regimen
[1]Analysis based on multiple imputation.

Table A.4. Association between food security and acute complications of diabetes in SEARCH YYA with T2D (n=395)[1]

	Model 3		
Variable	**Odds**	**CI**	**P-value**
HFI (dichotomous)	1.99	0.96 – 4.10	0.0626
HFI (continuous)	1.18	1.01-1.38	0.0404

Model 3 adjusted for: age, gender, race, parent education, insurance level, clinic, diabetes duration, CGM use, medication regimen
[1]Analysis based on multiple imputation.

APPENDIX B

SUMMARY OF PHYSICAL ACTIVITY OUTCOMES

This table reflects descriptive values of the physical activity outcomes before random noise was added to the data.

Table B.1. Physical Activity of Youth and Young Adults Participating in the SEARCH for Diabetes in Youth Cohort Study (2015-2020), According to Household Food Security Status, After Adding Random Noise to the Data,[1,2] n=2,389

	Type 1 Diabetes (n=1,998)			**Type 2 Diabetes (n=391)**		
	Total	**Food Secure**	**Food Insecure**	**Total**	**Food Secure**	**Food Insecure**
VPA, min/week, median (Q1, Q3)	120.3 (0.6, 360.4)	120.6 (0.7, 360.4)	60.2 (0.4, 360.4)	1.0 (0.5, 360.3)	1.0 (0.5, 360.4)	1.0 (0.5, 300.3)
Missing data, n (%)	203 (10.2)			49 (12.5)		
MPA, min/week, median (Q1, Q3)	120.9 (0.9, 420.1)	120.9 (0.9. 360.8)	150.6 (0.7, 600.7)	60.6 (0.6, 360.2)	60.7 (0.6, 360.5)	60.1 (0.5, 360.2)
Missing data, n (%)	316 (15.8)			67 (17.1)		
Walking, min/week, median (Q1, Q3)	315.1 (101. 840.6)	300.5 (91.0, 840.4)	420.5 (144.7, 900.8)	240.0 (60.9, 833.7)	210.7 (50.9, 720.5)	330.5 (100.9, 840.1)
Missing data, n (%)	417 (20.9)			106 (27.1)		
Sitting, min/day, median (Q1, Q3)	325.3 (240, 480.3)	301.0 (240.1, 480.3)	360.1 (240.1, 480.7)	271.0 (180.4, 420.5)	240.8 (180.2, 390.3)	300.5 (210.0, 480.6)
Missing data, n (%)	522 (26.1)			150 (38.4)		
MVPA, min/week, median (Q1, Q3)	300.7 (60.1, 732.4)	300.4 (60.7, 720.7)	360.1 (0.9, 860.8)	180.4 (0.7, 720.0)	180.7 (0.7, 720.5)	165.4 (0.7, 652.8)
Missing data, n (%)	172 (8.6)			38 (9.7)		
Total PA, min/week, median (Q1, Q3)	675.0 (255.6, 1335.8)	660.3 (270.0, 1261.0)	780.6 (205.3, 1560.9)	535.8 (90.1, 1260.3)	510.1 (90.1, 1230.3)	540.1 (90.2, 1350.7)
Missing data, n (%)	157 (7.9)			34 (8.7)		

[1]Physical activity reported after adding random noise to make variable truly continuous.
[2]VPA, Vigorous Physical Activity; MPA, Moderate Physical Activity; PA, Physical Activity; MVPA, Moderate-to-vigorous physical activity.

APPENDIX C

CHAPTER 6 USING MULTIPLE IMPUTATION

Under the assumption of missing at random, values were imputed with multiple imputation following the fully conditional specification method. All variables used in the adjusted models were included in the imputation model. A total of 20 imputed datasets based on 200 iterations were created. No outcome variables were missing from this dataset.

Table C.1. Demographic and Clinical Characteristics of Female Youth and Young Adults Participating in the SEARCH for Diabetes in Youth Cohort Study (2015-2020), by Household Food Security Status, n=1,540

	Type 1 Diabetes (n= 1216)			**Type 2 Diabetes (n=324)**		
	Total	**Food Secure N=987**	**Food Insecure n=210**	**Total**	**Food Secure N=221**	**Food Insecure n=98**
Household food insecurity, %	17.5			30.7		
Missing, n (%)	19 (1.6)			5 (1.5)		
Age, mean (SD)	20.9 (5.0)	20.9 (5.0)	21.0 (5.2)	24.8 (4.2)	24.6 (4.2)	25.3 (4.3)
Missing, n (%)	0			0		
Sex, %						
Female	54.4	53.9	58.1	67.6	65.2	72.5
Male	45.6	46.1	41.9	32.4	34.8	27.6
Missing, n (%)	0			0		
Race/Ethnicity, %						
NH-white	56.7	59.6	44.3	20.1	16.7	26.5
NH-black	17.5	14.5	31.9	44.8	45.7	42.9
Hispanic	21.0	21.3	19.1	24.4	27.6	18.4
Other	4.8	4.7	4.8	10.8	10.0	12.2
Missing, n (%)	0			0		
Household Income, %						
<$25,000	20.0	15.7	38.9	48.8	44.7	55.7
$25-49,999	21.8	18.9	35.2	34.3	30.3	41.8
$50-74,999	16.4	15.8	19.1	6.6	9.9	1.3
$75,000+	41.8	49.6	6.8	10.3	15.2	1.3
Missing, n (%)	309 (25.4)			111 (34.3)		
Clinic, %						
Carolina	19.6	18.0	26.7	35.5	33.9	38.8
Ohio	15.6	16.2	13.8	17.3	18.1	16.3
Colorado	31.7	32.1	30.0	20.4	19.9	22.5
California	19.0	20.2	12.4	20.7	24.4	12.2

Washington	14.1	13.5	17.1	6.2	3.6	10.2
Missing, n (%)	0			0		
Parent Education, %						
<HS graduate	5.5	5.2	7.0	11.1	10.4	12.9
HS graduate	13.9	12.2	20.9	32.9	34.2	31.2
Some Col. - Asso.	30.2	28.2	40.8	38.6	36.6	41.9
Bachelor's degree +	50.4	54.5	31.3	17.5	18.8	14.0
Missing, n (%)	42 (3.5)			26 (8.0)		
Insurance Status, %						
State/Federal	18.0	15.0	32.7	34.4	32.7	38.7
Private	75.4	78.5	60.1	46.3	48.1	40.9
Other/Unknown	3.2	3.6	1.4	5.5	6.1	4.3
None	3.4	3.0	5.8	13.8	13.1	16.1
Missing, n (%)	20 (1.6)			13 (4.0)		
Diabetes duration in months, mean (SD)	134.4 (40.3)	134.1 (40.3)	1595.4 (727.3)	124.7 (42.7)	124.7 (41.5)	125.8 (45.5)
Missing, n (%)	0			0		
Smoking Status, %						
Nonsmoker	74.7	75.9	68.5	66.5	69.6	60.4
Former smoker	15.6	16.2	13.5	16.6	14.5	21.9
Current smoker	9.7	8.0	18.0	16.9	15,9	17.7
Missing, n (%)	35 (2.9)			11 (3.4)		
Medication Regimen, %						
Insulin pump	54.4	57.0	43.3	3.8	4.2	3.2
Insulin, long-acting 3+ rapid acting injections	38.1	36.3	46.2	17.8	15.3	24.2
Any other combo of insulin injections	6.3	5.8	8.2	34.3	35.7	30.5
Oral hypoglycemic medication	0.6	0.3	1.9	17.8	17.1	20.0
No treatment	0.7	0.5	0.5	26.4	27.8	22.1
Missing, n (%)	16 (1.3)			9 (2.8)		
CGM use, %	37.2	40.4	23.0	81.1	15.6	24.7

Missing, n (%)	24 (2.0)			12 (3.7)		
Daily energy intake, kcal/day, mean (SD)	1639.97 (765.3)	1595.4 (727.3)	1830.5 (883.9)	1698.0 (860.5)	1645.8 (799.0)	1825.1 (988.9)
Missing, n (%)	0			0		

[1]NH, Non-Hispanic; HS, High School; Asso, Associate’s degree; SD, Standard Deviation; CGM, Continuous Glucose Monitoring; Kcal, kilocalories

Table C.2a. Association between Household Food Insecurity and Diet Quality among Youth and Young Adult Females with Type 1 Diabetes, N=662[1]

	Model 4[2]	
	Estimate (SE)	**P-value**
Outcomes		
Total Score	-1.63 (1.11)	0.1411
Adequacy Components		
Total Fruits	-0.29 (0.18)	0.1104
Whole Fruits	-0.15 (0.19)	0.4095
Total Vegetables	0.03 (0.14)	0.8538
Greens and Beans	-0.05 (0.20)	0.7998
Whole Grains	-0.12 (0.20)	0.5453
Dairy	0.43 (0.30)	0.1384
Total Protein Foods	0.09 (0.08)	0.2700
Seafood and Plant Proteins	-0.10 (0.21)	0.6411
Fatty Acids	-0.34 (0.30)	0.2640
Moderation Components		
Refined Grains	-0.03 (0.33)	0.9387
Sodium	-0.66 (0.29)	0.0238
Added Sugars	0.13 (0.28)	0.6460
Saturated Fats	-0.58 (0.30)	0.0540

[1]Analysis based on multiple imputation.
[2]Model 4: Food security status, kcals, age, race, diabetes duration, clinic, parent education, income, insurance type, medication regimen, cgm use, smoking status

Table C.2b. Association between Household Food Insecurity and Diet Quality among Youth and Young Adult Males with Type 1 Diabetes, N=554[1]

	Model 4	
	Estimate (SE)	**P-value**
Outcomes		
Total Score	-0.24 (1.35)	0.8576
Adequacy Components		
Total Fruits	0.27 (0.20)	0.1952
Whole Fruits	0.25 (0.22)	0.2577
Total Vegetables	0.03 (0.17)	0.8666
Greens and Beans	-0.14 (0.25)	0.5740
Whole Grains	-0.04 (0.22)	0.8606
Dairy	-0.39 (0.32)	0.2192
Total Protein Foods	-0.01 (0.06)	0.8464
Seafood and Plant Proteins	-0.23 (0.25)	0.3555
Fatty Acids	0.02 (0.32)	0.9500
Moderation Components		
Refined Grains	-0.20 (0.39)	0.5981
Sodium	0.09 (0.35)	0.8049
Added Sugars	-0.10 (0.32)	0.7495
Saturated Fats	0.22 (0.33)	0.4951

[1]Analysis based on multiple imputation.
[2]Model 4: Food security status, kcals, age, race, diabetes duration, clinic, parent education, income, insurance type, medication regimen, cgm use, smoking status

Table C.2c. Association between Household Food Insecurity and Diet Quality among Youth and Young Adult Females with Type 2 Diabetes, N=219[1]

	Model 4[2]	
	Estimate (SE)	**P-value**
Outcomes		
Total Score	0.91 (1.50)	0.5435
Adequacy Components		
Total Fruits	0.33 (0.27)	0.2274
Whole Fruits	0.04 (0.28)	0.8937
Total Vegetables	-0.07 (0.18)	0.7087
Greens and Beans	0.12 (0.28)	0.6735
Whole Grains	0.30 (0.25)	0.2306
Dairy	-0.68 (0.39)	0.0831
Total Protein Foods	0.03 (0.07)	0.6721
Seafood and Plant Proteins	0.02 (0.28)	0.9422
Fatty Acids	0.01 (0.40)	0.9883
Moderation Components		
Refined Grains	0.32 (0.41)	0.4338
Sodium	0.43 (0.43)	0.3254
Added Sugars	-0.18 (0.45)	0.6951
Saturated Fats	0.26 (0.38)	0.5034

[1]Analysis based on multiple imputation.
[2]Model 4: Food security status, kcals, age, race, diabetes duration, clinic, parent education, income, insurance type, medication regimen, cgm use, smoking status

Table C.2d. Association between Household Food Insecurity and Diet Quality among Youth and Young Adult Females with Type 2 Diabetes, N=105[1]

	Model 4[2]	
	Estimate (SE)	**P-value**
Outcomes		
Total Score	3.72 (3.01)	0.2155
Adequacy Components		
Total Fruits	0.03 (0.48)	0.9534
Whole Fruits	0.28 (0.51)	0.5888
Total Vegetables	0.41 (0.33)	0.2085
Greens and Beans	1.09 (0.56)	0.0547
Whole Grains	0.20 (0.51)	0.7000
Dairy	0.64 (0.71)	0.3684
Total Protein Foods	0.11 (0.12)	0.3449
Seafood and Plant Proteins	0.58 (0.52)	0.2706
Fatty Acids	0.42 (0.79)	0.5966
Moderation Components		
Refined Grains	-0.49 (0.91)	0.5907
Sodium	-0.14 (0.75)	0.8553
Added Sugars	1.22 (0.81)	0.1302
Saturated Fats	-0.61 (0.76)	0.4190

[1]Analysis based on multiple imputation.
[2]Model 4: Food security status, kcals, age, race, diabetes duration, clinic, parent education, income, insurance type, medication regimen, cgm use, smoking status