# ASSOCIATIONS AMONG ADDED SUGAR CONSUMPTION, GLYCEMIA AND INSULIN RESISTANCE IN OBESE ADOLESCENTS

by

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*To my loving family that has encouraged me every step of the way. To my new and old friends that have encouraged me and pushed me to reach my potential. I would not be here without you all. I am eternally grateful for your love and support.*

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| Abbreviations | Term |
|---|---|
| BMI | Body Mass Index |
| DI | Disposition Index |
| DIG IT Study | Dietary Intervention for Glucose Tolerance in Teens |
| HbA1c | Glycated Hemoglobin |
| HEI | Healthy Eating Index |
| HOMA-IR | Homeostatic Model Assessment of Insulin Resistance |
| IGI | Insulinogenic Index |
| MVPA | Moderate to Vigorous Physical Activity |
| OGTT | Oral Glucose Tolerance Test |
| T2D | Type 2 Diabetes |
| TADA | Technology Assisted Dietary Assessment |
| WBISI | Whole Body Insulin Sensitivity Index |

# ABSTRACT

Incidence rates of adolescents with type 2 diabetes are increasing rapidly; there was an increase of 30% between 2019 and 2009. Even more alarming is that studies show that the most effective treatment, metformin monotherapy, is only effective at maintaining glycemic control in approximately 50% of individuals. Additionally, adolescents with diabetes may experience serious microvascular and macrovascular complications sooner than adults, which can impact the quality of life of young adults across the globe. Therefore, diabetes in adolescents is a public health concern, and there is very little research to guide treatment and prevention. It is widely known that adolescents have a very poor dietary pattern, characterized by increased intakes of added sugars from refined grains, and minimal amounts of fruits, vegetables, and fiber. There is conflicting evidence in the literature connecting increased added sugar intake to insulin resistance and diabetes development. Considering the very poor diets consumed by adolescents, and that nutrition is a modifiable risk factor for diabetes, we aimed to examine the associations between added sugar consumption, glycemic values, and measures of insulin resistance and beta-cell function. This pilot study analyzed dietary and glycemic data from participants that were screened for an ongoing randomized control trial which is an adolescent diabetes prevention program that uses health coaching to improve diet and physical activity behaviors called the Dietary Intervention for Glucose Tolerance in Teens (Dig It) Study. Fasting blood glucose, glycated hemoglobin (HbA1c), and 2-hour glucose concentrations were collected during an oral glucose tolerance test that was used to screen adolescents with obesity for diabetes. Consumption of added sugar and other dietary intake data were collected from food records created by the Technology Assisted Dietary Assessment (TADA) application. The homeostasis model assessment of insulin resistance (HOMA-IR) was calculated from glucose and insulin concentrations in the fasting state (1) obtained from an oral glucose tolerance test (OGTT). Whole-body insulin sensitivity index (WBISI), and the oral disposition index (DI) were calculated from measures obtained during oral glucose tolerance testing(2, 3)

Statistical analysis was performed using SPSS software and included independent t-tests and Pearson correlations. Of the 48 participants included in this analysis, 59.2% were female, 32% were African American, 57% were white, and 8.2% were more than one race. The mean age was 16.20 ± 2.7 years, and 42% had prediabetes. Those with normoglycemia consumed 11.0 ± 5.1%

of energy from added sugars, compared to 9.4±5.1% energy from added sugars for individuals with prediabetes. There was no significant correlation between HbA1c and percent calories coming from added sugar (R= -0.237, P=0.063), percent calories coming from added sugar and fasting blood glucose (R= 0.208, P= 0.090), or percent calories from added sugar and 2-hour glucose (R= 0.017, P= 0.457). There were no significant correlations found between percent calories from added sugar and HOMA-IR (R= 0.129, P= 0.234), percent calories from added sugar and WBISI (R= -0.069, P= 0.350), or percent calories from added sugar and DI (R= -0.118, P= 0.253). There were also no significant differences between the mean values of HbA1c, fasting glucose, or 2-hour glucose between individuals that consumed high vs. low amounts of added sugar, as measured by an independent t-test. The p-values were 0.634, 0.434, and 0.234 respectively. To examine the extent to which % calories from added sugar predicted variances in glycemic values, hierarchical multiple regression analyses were performed. Once energy, physical activity, BMI Z-Score, and age were entered into the model, % energy from added sugar accounted for an additional 9.6% variance in HbA1c. In conclusion, we did not find significant associations between consumption of added sugar and glycemic and insulin resistance or beta-cell function outcomes in adolescents who are obese, however our study lacked sufficient power. While our findings were not definitive, studies to identify dietary factors that promote or prevent hyperglycemia and insulin resistance are needed to inform dietary intervention strategies that may be effective at decreasing T2D in adolescents.

# CHAPTER 1. REVIEW OF LITERATURE

## 1.1. Type 2 Diabetes Overview and Prevalence

Type 2 diabetes (T2D) is a disorder comprised of a combination of insulin resistance and relative insulin deficiency in the absence of autoimmune-mediated beta cell destruction.(4) There is an intermediate phase between normoglycemia and T2D known as prediabetes. Prediabetes refers to patients who have glucose values that are too high to be deemed normal but do not meet the classifications for a diabetes diagnosis. (2) In the 1990's and early 2000's, cases of obese adolescents diagnosed with T2D increased significantly, even though the disease was thought to be a disease exclusively of adulthood. (5) From 2001-2009 the incidence of T2D in adolescents increased by 30.5% (6). Diabetes represents a public health crisis for our youth especially given its unique challenges in diagnosis, management, and potential complications. There is very little research on treatment and intervention methods for T2D in adolescents. This is especially true for minority youth given excess obesity and decreased access to healthcare that has been observed in these populations. (6)

## 1.2. Pathophysiology of Youth Type 2 Diabetes

### *1.2.1. Glucose Homeostasis*

Glucose, an essential energy source for our brain and muscles, plays an essential role in diabetes pathophysiology. The maintenance of glucose homeostasis is dependent upon the coupling of insulin secretion from the β-cells of the pancreas and the insulin sensitivity of the tissues involved with glucose uptake such as the skeletal muscle, adipose tissue, and hepatic tissue. (7) The reduction in insulin action on target tissues is known as insulin resistance or reduced insulin sensitivity. As insulin sensitivity declines, e.g. in the obese state, insulin secretion must increase to maintain glucose homeostasis. (8). Although all individuals with obesity are not insulin resistant, a large majority of insulin resistant individuals are obese. (8) And thus, obesity is seen as an important risk factor in the development of insulin resistance. (8) But as long as pancreatic β-cells can compensate for decreased insulin sensitivity, glucose homeostasis remains within a normal range. When β-cells are no longer able to compensate for decreased insulin sensitivity, impaired glucose tolerance takes place, progressing toward T2D.

### *1.2.2. Prediabetes*

In the late 1990's, the Expert Committee on Diagnosis and Classification of Diabetes Mellitus recognized an intermediate class of individuals with glycemic values that were too high to be deemed normal but did not meet the criteria for T2D. (9) This class was defined as having impaired fasting glucose or impaired glucose tolerance, now known as prediabetes. The transition from impaired fasting glucose or impaired glucose tolerance to diabetes occurs more quickly in adolescents, up to 3 or 4 times as fast as is seen in adults, presenting as a more aggressive disease. (4, 7) Additionally, prediabetes is associated with a high risk of progression to T2D. (10) Cross sectional and longitudinal studies by pediatric researchers in youth have demonstrated that it is β-cell failure that results in prediabetes and that a decrease in insulin secretion relative to insulin sensitivity is the primary pathophysiologic mechanism associated with the development of impaired glucose homeostasis in adolescents (7). This is not surprising, since it has been shown that deficiencies in the β-cell's ability to produce and secrete insulin are also the cause for the progression from impaired fasting glucose or impaired glucose tolerance to prediabetes, and from prediabetes to T2D. (11) Taking into account that glycemic failure rates for individuals on metformin are 51.7% in adolescents and 21% in adults, and that glycemic failure rates for individuals on metformin and rosiglitazone are 38.6% in adolescents and 14% in adults, T2D that presents in adolescence seems to be a more aggressive disease. In addition, adolescence is a vulnerable period for dysglycemia due to transient insulin resistance during puberty. (7) All things considered, it is important to intervene in the earliest stages of the disease to maintain glucose homeostasis (7).

## 1.3. Diabetes Diagnostic Criteria

### *1.3.1. Diabetes and Prediabetes Diagnosis*

Type 2 diabetes mellitus diagnosis from the 1990's and early 2000's has been based on fasting plasma glucose and 2-hour glucose glycemic values obtained during the 75g oral glucose tolerance test (OGTT). This was because of the association between fasting plasma glucose concentrations and the exhibition of retinopathies. (9) More recently, these two measures in addition to glycated hemoglobin (HbA1c) are used to diagnose type 2 diabetes mellitus. (10) Although HbA1c has been widely known as a marker of chronic hyperglycemia, it had not been recommended as a diagnostic

marker of T2D because of the lack of standardization of the assay. As of 2010, HbA1c assays are more standardized, hence its use as a diagnostic measure is now endorsed. (9) Currently, fasting plasma glucose, 2-hour glucose concentrations obtained during the OGTT, and HbA1c are all equally appropriate measures for diabetes diagnosis. (4) For diagnosing type 2 diabetes mellitus the following criteria are used: fasting plasma glucose ≥ 126 mg/dL , where fasting is defined as no caloric intake for a minimum of 8 hours; 2-hour plasma glucose ≥ 200 mg/dL during an OGTT performed using a 75g glucose load with anhydrous glucose dissolved in water; HbA1c concentration ≥ 6.5%, performed using a standardized assay; the presence of any of the three criteria can yield a diabetes diagnosis. Patients presenting with classic symptoms of hyperglycemia or a hyperglycemic crisis can be diagnosed with diabetes if they have a random plasma glucose of ≥ 200 mg/dL. (4) Individuals with prediabetes present with impaired fasting glucose or impaired glucose tolerance and/or HbA1c between 5.7 and 6.4%. (10) Despite the improvements in clinical assays and diagnostic criteria, T2D can remain undiagnosed for years while patients advance through prediabetes (1).

### *1.3.2. Homeostatic Model Assesment of Insulin Resistance*

The Homeostatic Model Assessment of Insulin Resistance (HOMA-IR) is a method used for the assessment of insulin resistance using fasting blood glucose and insulin concentrations. (12) The HOMA-IR index was first proposed by Matthews and colleagues (1) and is a fast, inexpensive, and noninvasive technique for measuring insulin resistance that is highly correlated with the values obtained from the euglycemic clamp method. (13) Although the euglycemic clamp method is considered the gold standard, it is highly invasive and expensive. The HOMA is a "paradigm model", meaning it is based on physiological structures and has theoretical solutions adjusted to the population norms so that HOMA values from individuals can represent estimates of insulin sensitivity without needing more computation. (12) The model of glucose and insulin interactions is used to plot the expected varying degrees of insulin resistance that are possible. The relationship between basal insulin and glucose concentrations is reflective of hepatic glucose output during fasting conditions, identified by Matthews et al as the simplest aspect of the glucose and insulin feedback loop.(1) The HOMA-IR output is calibrated so that a normal insulin resistance value is 1. (12)

### *1.3.3. Matsuda Index (Whole Body Insulin Sensitivity Index (WBISI))*

One method of estimating whole body insulin sensitivity is the Matsuda Insulin Sensitivity Index, or Whole-Body Insulin Sensitivity Index (WBISI), which shows the peripheral insulin sensitivity. The Matsuda Index is calculated using fasting insulin, fasting blood glucose, plus mean insulin, and mean glucose values obtained from the oral glucose tolerance test. (2) The index is able to capture insulin resistance at the level of the pancreas and target tissues in response to a glucose stimulus during the oral glucose tolerance test.(14) Previous studies have shown that the insulin sensitivity index calculated by the Matsuda index is a significant indicator of future diabetes risk, (15) and is closely correlated to whole body insulin sensitivity values obtained from the euglycemic clamp method (2), making it a valuable measure when assessing the degree of pathophysiology in participants with prediabetes.

### *1.3.4. Insulinogenic Index (IGI)*

The insulinogenic index (IGI) measures β-cell function at the level of the pancreas.The IGI is the change in insulin and glucose over the first 30 minutes after the glucose load in an oral glucose tolerance test. (16) The IGI differs from other simpler methods of assessing insulin secretion because it provides information on the secretory response of β-cells to increasing glucose concentrations. (16) Reduction of first phase insulin secretion is widely thought of as the first indication of β-cell dysfunction (17), which makes the IGI a valuable measure in assessing a complete picture of glucose and insulin homeostasis in individuals with prediabetes.

### *1.3.5. Disposition Index (DI)*

The disposition index (DI) represents the hyperbolic relationship between the acute insulin response and insulin sensitivity and is the product of these two values. (18) The DI, measured with values from the oral glucose tolerance test, should give a constant value for a given degree of glucose tolerance and consequently, provide insight into β-cell function. (19) The DI reflects the physiological feedback regulation of glucose homeostasis where pancreatic β-cells compensate for fluctuations in whole body insulin sensitivity. (19) Lower DI values are seen in those with prediabetes.(19) The DI is also highly heritable, and is potentially useful in identifying genetic predisposition to T2D. (19)

## 1.4. Overview of Relevant Studies in Youth

### *1.4.1. SEARCH for Diabetes in Youth Study*

The SEARCH for Diabetes in Youth Study is a registry and cohort study that began in 2000, and collected data from 2001-2009. (6) The study aimed to address the current knowledge gaps in understanding diabetes in children. (6) The SEARCH study is a multi-site study and is the largest, most diverse study of diabetes in American youth thus far. (6) One major study finding is that the prevalence of T2D per 100,000 youths increased annually each year over the study period. The overall increase from 2001-2009 was 21.1%(6) Additionally, the study found that many children with diabetes are at risk for complications, both acute and chronic. These complications include kidney disease, neuropathy, retinopathy, and arterial stiffness. (6) The SEARCH study also found that minority youth and those in older adolescence are not receiving quality or adequate diabetes care according to the American Diabetes Association (ADA) recommended guidelines.(6)

### *1.4.2. The HEALTHY Study*

The HEALTHY Study is a primary prevention trial that was created by the National Institute of Diabetes and Digestive and Kidney Disease (NIDDK) in response to the growing number of children being diagnosed with T2D. The study followed rural youth from sixth grade to eighth grade in 42 schools across Texas, Oregon, California, North Carolina, Maryland, and Pennsylvania. (20) The objective of the study was to moderate the risk factors for T2D through a school-based intervention focusing on nutrition, physical education, and behavior change. The modifiable risk factors examined were indicators of adiposity and glycemic dysregulation. (20) The intervention consisted of improving the nutritional quality of food provided at the school, increasing attendance in physical education classes and time spent in moderate to vigorous physical activity (MVPA), education of family through outreach, and social marketing strategies to urge healthy eating. (20) Although the intervention did not decrease the overall number of students with obesity, it resulted in significant reductions in adiposity among obese participants and helped to clarify the prevalence and complexity of T2D risk factors. (7)

### *1.4.3. TODAY Study*

A Clinical Trial to Maintain Glycemic Control in Youth with Type 2 Diabetes, using the TODAY study group, compared the efficacy of three treatments to achieve durable glycemic control in children with recently diagnosed T2D: metformin alone, metformin and rosiglitazone, and a lifestyle intervention focusing on nutrition and physical activity behaviors. (21) Durable glycemic control was defined as glycated hemoglobin of at least 8% for a minimum of 6 months. (21) The study found that the combination of metformin and rosiglitazone was most effective in maintaining glycemic control, although the individuals in that treatment arm also had the greatest increase in BMI over the study period.(21) Monotherapy with metformin was effective at maintaining glycemic control in only 50% of individuals. (21) Metformin was the least effective in Hispanic and Black populations, and most effective in girls. (21) While these studies added valuable knowledge about the prevalence of T2D in adolescents, they still highlight that there is very little research to guide treatment or interventions in obese adolescents.

## 1.5. Complications of Diabetes in Youth

### *1.5.1. Macrovascular and Microvascular Complications*

It has been established that the length of diabetes duration and level of glycemic control are tightly related to the development of microvascular complications including retinopathy, nephropathy, and neuropathy, which are major disabilities. In fact, the most common cause of blindness in developed countries is diabetic neuropathy. (22) In addition, neuropathic pain can be quite severe, limit mobility and autonomy, and contribute to depressive symptoms. (23) Evidence of microvascular and macrovascular complications have been demonstrated in youth within the first five years of diagnosis and the complications appear to progress rapidly (24). The SEARCH study reported a 42% prevalence of diabetic retinopathy in youth with T2D. The prevalence of retinopathy in the TODAY study increased with increasing HbA1c blood concentration. Additionally, over 50% of youth are hospitalized at diabetes onset and about 30% present with diabetic ketoacidosis. (6) Bearing in mind the toll that these complications could have on the quality of life of adolescents, research investigating specific areas of intervention that could mediate the number of adolescents with diabetes is critical.

### *1.5.2. Psychological Distress*

In addition to microvascular and macrovascular complications, psychological comorbidity is prevalent in adults with T2D, with more than 30% experiencing depressive affect (25). There have been studies in adults on a diabetes specific emotional distress disorder, termed diabetes distress, which captures a wider experience than depressive affect and includes the spectrum of patient experience for those living with a chronic and progressive disorder. Diabetes distress refers to feeling overwhelmed by the demands of self-management that patients are required to have in order to adhere to diet, exercise, and medication prescriptions. Feelings of worry about future complications, concerns about existing comorbidities, and feelings of guilt and shame in relation to lifestyle are all common. Considering that feelings of hopelessness and angst peak during adolescence, feelings of diabetes distress, being overwhelmed by the demands of management and worry about future complications could have a greater impact on youth who are managing diabetes treatment (25).

## 1.6. Modifiable and Nonmodifiable Risk Factors for Type 2 Diabetes

Nonmodifiable risk factors for T2D include genetics, family history, and puberty. Genetic heritability of T2D has been seen to manifest as impaired insulin sensitivity and reduced β-cell function relative to insulin sensitivity in healthy individuals with a family history of T2D.(7) Although it is widely known that T2D has high heritability, the genetic variants that have currently been identified have not produced any clinically relevant tools for prediction of T2D risk. (7) Taking this into account, modifiable risk factors such as diet and physical activity level become the more feasible option for possible intervention.(7) Modifiable risk factors for T2D include environmental and lifestyle habits such as excessive energy consumption, poor dietary quality, and decreased physical activity.

## 1.7. Adolescents Poor Diet Quality

### *1.7.1. Poor Adherence to the Dietary Guidelines for Americans*

The United States Departments of Agriculture and Health and Human Services come together with top scientists in the field of nutrition and form the Dietary Guidelines Advisory Committee, which releases the Dietary Guidelines for Americans every 5 years to guide Americans to consume a

balanced nutritious diet (26). The 2015 Dietary Guidelines for Americans emphasizes the widespread underconsumption of fruits, vegetables, whole grains, low-fat dairy, fish, and unsaturated fatty acids. Other topics addressed in the most recent dietary guidelines were overconsumption of sodium, saturated fat, and added sugar. Adherence to the Dietary Guidelines for Americans is measured with the Healthy Eating Index (HEI), which is released in correspondence with the dietary guidelines(27) . The most recent HEI-15 scores are based on 9 adequacy components (i.e., nutrients to increase to reach adequacy) and 4 moderation components (i.e., nutrients to consume in moderation) (27) . The adequacy components include total fruits, whole fruits, total vegetables, greens and beans, whole grains, dairy, total protein foods, seafood and plant proteins, and fatty acids (excluding saturated and trans fats). The moderation components are refined grains, sodium, added sugars, and saturated fats. The inclusion of separate components for saturated fats and added sugar is new to this version of the dietary guidelines and reflects specific recommendations. For example, it is recommended that added sugar should comprise <10% of energy intake. The scores of each component are summed, the highest possible score being 100. The higher the score indicates higher adherence to the Dietary Guidelines for Americans. The minimum HEI score for disease prevention is 80 (27). Studies determining individual dietary components in United States adolescents have shown that they are not consuming enough dairy, whole grains, fruits, and vegetables(28). Globally, however, adolescents are consuming excess amounts of nutrient poor and calorie dense food in the form of sugar sweetened beverages and grain desserts. A cross sectional study of adolescents in Brazil found that HEI scores were lower between ages 12-20 years as opposed to ages 5-12 years. But the researchers did not report which components contributed to this change. National Health and Nutrition Examination Survey (NHANES) data on United States children and adolescents shows that HEI scores were lower, on average, for older age groups compared to children due to the total fruit, whole fruit, dairy, and whole grains components (29). A significant trend was observed for total fruit and total vegetable components, whereas the age group became older, consumption of fruits and vegetables decreased. The 14-18 group had the highest consumption of moderation components (sodium, empty calories, refined grains) and the lowest overall HEI score (43.5) compared to the 5-9 (52.1) and 10-13 (46.8) age groups. These results highlight the need for research studying the impacts of poor diet on the health outcomes of adolescents such as increased risk of diabetes and other chronic disease.

### *1.7.2. Adolescent Added Sugar Intake*

The Dietary Guidelines for Americans recommends that no more that 10% of dietary energy should come from added sugars. Added sugars are defined as "sugars that are added to foods such as an ingredient during preparation, processing, or at the table and does not include lactose present in milk and fructose present in whole or cut fruit, and from 100% fruit juice"(30). Consumption of excess added sugar is associated with excess energy intake and poor diet quality. Mean energy intakes from added sugars are highest in adolescents compared with children and adults, although all exceed the 10% of energy recommendation set by the Dietary Guidelines for Americans. (30) Consumption levels are 16% and 13% of energy coming from added sugars for adolescents and adults respectively (30) . Poor dietary quality in childhood and especially adolescence is associated with poor health outcomes and increased risk for chronic disease in adulthood (29).

### *1.7.3. Added Sugar Intake and Disease Risk*

Although adolescents' poor dietary quality is established in the literature, research linking adolescents' poor diet to specific health outcomes is generally lacking or contradictory. Overconsumption of sugar sweetened beverages, which we know is a characteristic of adolescents' diet, is amongst the leading dietary factors found to be associated with type 2 diabetes in large epidemiological studies (31). National surveys of food consumption show that sugar sweetened beverage consumption is skyrocketing, similar to diabetes and obesity rates. (31) In addition, added sugar is one of the factors found to be associated with obesity (31).

In fact, the strength of evidence that the dietary guidelines added sugar recommendations are based on is mostly based on the link between consumption of energy dense nutrient poor food, foods that contain high amounts of calories but very little vitamins or minerals, and obesity.(32) The dietary guidelines recommendation of less than 10% of energy coming from added sugar is based on a combination of food pattern modeling and current national intake levels of added sugar, which illuminate the need to decrease added sugar intake to adequately meet food group and nutrient needs within recommended calorie limits.

## 1.8. Rationale and Research Questions

The current literature shows that there have been increases in incidence rates of diabetes development in adolescents since the 1990's. Diabetes in adolescents is more aggressive, and adolescents are at risk for developing serious complications sooner than individuals who are diagnosed with T2D in adulthood. Additionally, there is little research to guide prevention, treatment, and management. Adolescents also have a very poor diet quality, which represents an important modifiable risk factor for diabetes development in obese adolescents. Research is needed to directly link added sugar consumption to health outcomes associated with T2D, and not just to obesity. We aimed to examine the associations between added sugar consumption, glycemia, and insulin resistance to justify a rationale for a lifestyle intervention that targets added sugar consumption to reduce diabetes risk in obese adolescents.

# CHAPTER 2. ASSOCIATIONS AMONG ADDED SUGAR CONSUMPTION, GLYCEMIA, DIET QUALITY, AND INSULIN RESISTANCE IN OBESE ADOLESCENTS

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## 2.1. Abstract

**Background:** The frequency of adolescents being diagnosed with type 2 diabetes has increased since the 1990's. In fact, **t**here have been annual positive increases since 2000, with increases of up to 30% between 2001 and 2009. Even more alarming is that studies show that the most effective treatment, metformin monotherapy, is only effective at maintaining glycemic control in approximately 50% of individuals. Additionally, adolescents with diabetes may experience serious microvascular and macrovascular complications sooner than adults, which can impact the quality of life of young adults across the globe. It is widely known that adolescents have a very poor dietary pattern, characterized by increased intakes of added sugars from refined grains, and minimal amounts of fruits, vegetables, and fiber. There is conflicting evidence in the literature on connecting increased added sugar intake to insulin resistance, glycemic control, and diabetes development. Diabetes in adolescents is a public health concern, and there is very little research to guide treatment and prevention.

**Objective:** Adolescents have a very poor dietary pattern, with high amounts of added sugar. Nutrition represents a feasible modifiable risk factor for diabetes development. We aimed to examine the associations between added sugar consumption, glycemic values, and measures of insulin resistance and beta-cell function to support the rationale of limiting added sugar consumption in a future dietary intervention to decrease diabetes risk.

**Hypothesis:** Individuals consuming lower amounts of added sugars will have better glycemic control, and insulin sensitivity than those who consume higher amounts of added sugars.

**Research Design and Methods:** This pilot study analyzed dietary and glycemic data from the screening visit of an ongoing randomized control trial adolescent diabetes prevention program that uses health coaching to promote healthy diet and physical activity behaviors. Fasting blood glucose, glycated hemoglobin, and 2-hour glucose concentrations were collected during an oral glucose tolerance test that was used to screen obese adolescents for diabetes. Added sugar consumption and other dietary data were collected from food records created by the Technology Assisted Dietary Assessment (TADA) application. Statistical analysis was performed using SPSS software and included students t tests and Pearson correlations. The homeostasis model assessment of insulin resistance (HOMA-IR) was calculated from glucose and insulin concentrations in the fasting state (1). Whole-body insulin sensitivity index (WBISI), and the oral disposition index (DI) were calculated from measures obtained during oral glucose tolerance testing(2, 3)

**Results:** Of the 48 participants included in this analysis, 59.2% were female, 32% were African American, 57% were white, and 8.2% were more than one race. The mean age was 16.2± 2.7 years, and 42% have prediabetes. The mean BMI Z-Score for individuals with prediabetes was 2.3 ± 0.4 compared to 2.1 ± 0.5 of those with normoglycemia (p-value = 0.778). The mean fasting blood glucose of those with prediabetes was 95.5± 6.9 mg/dL, compared to 89.8 ± 6.7 mg/dL in individuals with normoglycemia (p-value = 0.453). The mean 2-hour glucose of those with prediabetes was 131.2 ± 27.7 mg/dL, compared to 105.6 ± 16.6 in those with normoglycemia (p-value = 0.003). Reported energy intakes for individuals with prediabetes and normoglycemia were similar, being 1637.1 ± 526.2 and 1775.3 ± 457.3 kcals respectively (p-value = 0.317). Those with normoglycemia consumed 11.0 ± 5.1% of energy from added sugars, compared to 9.48±5.09% energy from added sugars for individuals with prediabetes. There was no significant association between glycemic values and percent energy from added sugar. (HbA1c R= -0.237, P=0.063, fasting blood glucose R= 0.208, P= 0.090, 2-hour glucose R= 0.017, P= 0.457). Similarly, there were no significant associations between percent calories from added sugar and insulin resistance or beta-cell function measures (HOMA-IR, R= 0.129; P= 0.234; WBISI R= -0.069, P= 0.350; DI R= -0.118, P= 0.253). There were also no significant differences between the mean values of

HbA1c, fasting glucose, or 2-hour glucose between individuals that consumed high vs. low amounts of added sugar, as measured by an independent t-test. The p-values were 0.634, 0.434, and 0.234 respectively. To examine the extent to which % calories from added sugar predicted variances in glycemic values, hierarchical multiple regression analyses were performed. Once energy, physical activity, BMI Z-Score, and age were entered into the model, % energy from added sugar accounted for an additional 9.6% variance in HbA1c

**Conclusions:** We did not find associations between percent energy from added sugar and glycemic and insulin resistance measures in this sample of adolescents who are obese, but this may be because our study lacked sufficient power. Further studies to determine dietary factors that contribute or protect against hyperglycemia and insulin resistance are needed to guide the development of effective intervention methods to decrease T2D risk in adolescents.

## 2.2. Introduction

The number of adolescents being diagnosed with type 2 diabetes are increasing steadily, and has been since the year 2000. (6) Surprisingly, studies show that the most effective treatment, metformin monotherapy, is only effective at maintaining glycemic control in approximately 50% of individuals. (21) Additionally, adolescents with diabetes may experience serious microvascular and macrovascular complications sooner than adults, (22) which can impact the quality of life of young adults across the globe. Diabetes in adolescents is a public health concern, and there is very little research to guide treatment and prevention. It is widely known that adolescents have a very poor dietary pattern, characterized by increased intakes of added sugars and fats from refined grains, and minimal amounts of fruits, vegetables, and fiber. (29) The current evidence in the literature relating added sugar intake to insulin resistance and diabetes development in adolescents is limited and conflicting. For example, one study in approximately 150 adults found that consumption of added sugar in the typical American (between 12-15% of energy), did not increase diabetes risk factors including fasting glucose, fasting insulin, and HOMA-IR values.(33) However, a study in Latino adolescents found that total sugar intake was inversely correlated with disposition index and insulin sensitivity, independent of sex, Tanner stage, energy intake, and fat-free mass. Considering adolescents' very poor dietary patterns, and also that lifestyle and nutrition represents a modifiable risk factor for diabetes, we aimed to examine the associations between added sugar consumption, glycemic values, and measures of insulin resistance and beta-cell

function. To obtain a complete picture of glucose homeostasis we evaluated possible associations between added sugar consumption and fasting blood glucose concentrations, which would reflect glucose homeostasis during a fast, and 2-hour glucose, which would reflect glucose homeostasis in response to a glucose stimulus, as well as HbA1c, which would reflect blood glucose over the preceding 3 months. In addition, we analyzed the possible associations between added sugar consumption and insulin resistance and beta-cell function measures HOMA-IR, WBISI, and DI to gain insight into hepatic and peripheral insulin sensitivity. This pilot study analyzed dietary and glycemic data from individuals screened for an ongoing randomized control trial adolescent diabetes prevention program using health coaching. We hypothesize that individuals with lower consumption of added sugars will have better glycemic outcomes and be more insulin sensitive than individuals that consume higher amounts of added sugar.

## 2.3. Methods

### *2.3.1. Participants*

This study includes data obtained from participants undergoing screening for an ongoing randomized control trial with the aim of using a health coaching intervention to promote healthy dietary and physical activity behaviors in adolescents who are obese and at risk for developing type 2 diabetes. Participants are recruited from Indianapolis, Lafayette, and West Lafayette, IN through fliers posted at public libraries and through physician referral at the Youth Diabetes Prevention Clinic at Riley Children's Health Hospital, Indianapolis. The inclusion criteria included individuals between the ages of 10-21 years old who are overweight and obese according to the Centers for Disease Control (CDC) Guidelines (34) i.e., with a body mass index (BMI) of $\geq 85^{th}$ percentile for age and sex, or $\geq 95^{th}$ percentile for age and sex. Exclusion criteria include the self-reported use of medications that effect glucose metabolism, pregnancy, and syndromic obesity. This study has been approved by the Purdue University and Indiana University Institutional Review Boards (IRB Study#: 1403986016).

### *2.3.2. Demographic Measures*

Written assent from participant and consent from parent or legal guardian was obtained for all minors prior to all study activities. Written consent was obtained from participants 18 or older

prior to any study activities. All participant characteristics including age, sex, and race/ethnicity were self-reported at the screening visit at the Clinical Research Center at the Indiana University Health Hospital in Indianapolis, IN. Participants under the age of 18 years were required to have a parent or guardian present during their study visit.

### *2.3.3. Anthropometric Assessment*

All anthropometric measurements were taken during the screening visit at the Clinical Research Center at the Indiana University Health Hospital in Indianapolis, IN. Height was measured to the nearest 0.1 cm using a stadiometer (Seca Model, Hamburg, Germany) and weight was measured using an electronic scale (35). Additionally, BMI percentiles and Z-scores were calculated using age and sex specific values from the CDC Growth Charts (34). Hip and waist circumference, in addition to sagittal abdominal diameter measurements were taken according to the National Health and Nutrition Examination Survey NHANES Anthropometry Manual. (35)

### *2.3.4. Dietary Assessment*

Dietary information was collected from food diaries created by the Technology Assisted Dietary Assessment (TADA) Application. (36) Food records included three days, including two meals each day. The TADA iPhone® application enables participants to take "before" and "after" images of their meals. (36) In a validation study, adolescents readily adopted the TADA app and 79% said it was easy to use and understand. (36) Registered dietitians at the Purdue Dietary Assessment Center analyzed the images to determine food type and portion size, using a colored fiduciary marker as an aid. Foods and beverages consumed were analyzed using the Nutrition Data System for Research (NDSR, University of Minnesota, Minneapolis, MN). Reported daily intake was calculated as a mean of the three days.

### *2.3.5. Glycemic and Insulin Values*

Glycemic and insulin values were obtained via oral glucose tolerance test (OGTT) at the screening visit, and glycemic status was classified as either normal glucose tolerance, prediabetes, or T2D according to the American Diabetes Association criteria. (9). Blood samples were obtained at -15, 0, 15, 30, 60,90, and 120 minutes from ingestion of a glucose beverage (containing 75g glucose).

For obtaining the diagnostic criteria we used point of care testing for concentrations of blood glucose and glycated hemoglobin (HbA1c) via STAT System (Abbott Point of Care, Princeton, NJ) and DCA Vantage Analyzer (Siemens Medical Solutions USA, Inc., Malvern, PA) instrumentation respectively. For measures of insulin action, serum fractions from the OGTT were frozen at −80 °C until analysis. Concentrations of glucose were determined using an automated chemistry analyzer (COBAS Integra 800, Roche Diagnostics, Indianapolis, IN); concentrations of insulin were assessed using an Elecsys Systems immunoassay analyzer (Roche Diagnostics). The homeostasis model assessment of insulin resistance (HOMA-IR) was calculated from glucose and insulin concentrations in the fasting state (1). Whole-body insulin sensitivity index (WBISI), and the oral disposition index (DI) were calculated from glucose and insulin concentrations obtained during the oral glucose tolerance test. (2, 3)

### 2.4. Power Calculation

A statistical power analysis was performed for sample size estimation, based on data from a previous study (37), relating total sugars consumed to DI values. The effect size in this study was R = -0.29 which is considered to be small using Cohen's (1988) criteria(38). With an alpha = 0.05 and power = 0.80, the projected sample size needed with this effect size, calculated using G*Power 3.1 Software (Heinrich Heine University, Dusseldorf, Germany) (39) is approximately N = 91. Thus, our proposed sample size of N=48 will be underpowered, however, this analysis was considered as a pilot study.

### 2.5. Statistical Analysis

Participant data from this study were securely stored using REDCap (40, 41) electronic data capture tools hosted at Indiana University. REDCap (Research Electronic Capture Tools) which is a secure web-based software platform designed to support data capture for research studies. All statistical analysis was performed using the IBM SPSS Statistics Version 26 Software (IBM Corp. Armonk, NY: IBM Corp.). Examination of the distribution of the data was performed using frequency tables to assess skewness and kurtosis, as well as QQPlots and histograms as a visual representation. Pearson correlation and independent t-tests were used because all data met criteria for normal distribution. Pearson correlations were performed to assess associations among added

sugar consumption and insulin dynamics and glycemic values. Individuals consuming 10% or more of energy from added sugars were considered high consumers and individuals that consumed less than 10% of energy from added sugars were considered low consumers. Independent t-tests were used to assess the differences between high and low added sugar consumption groups. Hierarchical multiple regression analyses were performed to examine the extent to which percent energy from added sugar predicted variances in glycemic and insulin resistance values.

## 2.6. Participant Exclusion

A total of 72 participants were consented and screened for the Dig It Study. In all, 24 participants were excluded from this analysis. Participants from this study were excluded from analysis if: nurses were unable to place IV and glycemic measures were not observed (N=2), or if dietary records were incomplete or deemed invalid (N=22). Valid dietary records were those that had three days of entries with at least two meals photographed each day.

## 2.7. Results

### *2.7.1. Participant Characteristics*

Of the 48 participants included in this analysis, 59.2% were female, 32% were African American, 57% were white, and 8.2% were more than one race. The mean age was 16.2 ± 2.7 years, and 42% had prediabetes. The mean BMI Z-Score for individuals with prediabetes is 2.3 ± 0.4 compared to 2.1 ± 0.5 of those with normoglycemia (p-value = 0.778). The mean fasting blood glucose of those with prediabetes is 95.5± 6.9 mg/dL, compared to 89.8 ± 6.7 mg/dL in individuals with normoglycemia (p-value = 0.453). The mean 2-hour glucose of those with prediabetes is 131.2 ± 27.7 mg/dL, compared to 105.6 ± 16.6 in those with normoglycemia (p-value = 0.003). There were only significant differences in insulin resistance measures between normoglycemic and prediabetes groups for their DI values. Those with normoglycemia had a mean DI of 9.1 ± 6.8 and those with prediabetes had a mean DI of 4.4 ± 4.9 (p-value = 0.016).Those with normoglycemia had mean HOMA-IR values of 5.1 ± 2.8, mean WBISI of 2.5 ± 1.1. Individuals with prediabetes had mean HOMA-IR values of 5.3 ± 2.7, and mean WBISI of 2.3 ± 1.6. The p-values are 0.944 and 0.746, respectively, as measures by independent t-tests. Demographics for this population are presented in **TABLE 2.1 and Table 2.2.**

### *2.7.2. Dietary Data*

Reported energy intakes for individuals with prediabetes and normoglycemia were similar, being 16.37.1 ± 526.2 and 1775.3 ± 457.3 kcals respectively (p-value = 0.317). Those with normoglycemia also consumed 11.0 ± 5.1% of energy from added sugars, 1.2 ± 0.9 servings of fruit, 2.1 ± 1.4 servings of vegetables, 13.0 ± 3.2 grams of fiber, 3075.5 ± 936.7 mg of sodium, and 11.5 ± 2.8 % of energy from saturated fats. Individuals with prediabetes consumed 9.4 ± 5.0% energy from added sugars, 0.8 ± 0.9 servings of fruit, 1.7 ± 0.9 servings of vegetables, 11.4 ± 5.2 grams of fiber, 3137.3 ± 946.2 mg of sodium, and 11.8 ± 2.7 % of energy from saturated fats. The highest sources of added sugars were from refined grains and sweetened dairy products. We found that individuals that were referred to the study from a physician consumed higher amounts of added sugar than those in the self-referral group (11% and 8% respectively). There were no significant differences between the dietary intake of participants with prediabetes and those with normoglycemia. Participant dietary intake is presented in **TABLE 2.3.**

### *2.7.3. Associations Among Added Sugar Consumption and Glycemic Values*

To examine the association between percent of calories from added sugar and measures of glycemia, a Pearson correlation was performed (**TABLE 2.4**.) Overall, there were no associations found between added sugar consumption and measures of glycemia. Specifically, there was no significant correlation between HbA1c and percent calories coming from added sugar (R= -0.237, P=0.063). There was no significant correlation between percent calories coming from added sugar and fasting blood glucose (R= 0.208, P= 0.090). The correlation between percent calories from added sugar and 2-hour glucose did not reach statistical significance (R= 0.017, P= 0.457). There were also no statistically significant differences between the mean values of HbA1c, fasting glucose, or 2-hour glucose between individuals that consumed high vs. low amounts of added sugar, as measured by an independent t-test. The p-values were 0.634, 0.434, and 0.234 respectively. To examine the extent to which percent calories from added sugar predicted variances in glycemic values, hierarchical multiple regression analyses were performed. Once energy, physical activity, BMI Z-Score, and age were entered into the model, percent energy from added sugar accounted for an additional 9.6% variance in HbA1c, although this was not a statistically significant value (Data not shown).

### *2.7.4. Associations Among Added Sugar Consumption and Insulin Resistance or Beta-cell Function Measures*

To examine the association between percent of calories from added sugar and measures of insulin dynamics, a Pearson correlation was performed. Overall, there were no associations between percent calories from added sugar and insulin resistance and beta-cell function measures. Specifically, there was no significant correlation found between percent calories from added sugar and any of the insulin resistance measures: HOMA-IR (R= 0.129, P= 0.234), WBISI (R= -0.069, P= 0.350), or DI (R= -0.118, P= 0.253). In addition, there were no differences between the mean values of HOMA-IR, WBISI, or DI between high and low added sugar consumption groups, as measured by independent t-tests. The p-values were 0.379, 0.314, and 0.196, respectively. Associations among added sugar consumption and insulin resistance measures are presented in **TABLE 2.5.** To examine the extent to which percent calories from added sugar predicted variances in insulin resistance values, hierarchical multiple regression analyses were performed. Once energy, physical activity, BMI Z-Score, and age were entered into the model, percent energy from added sugar accounted for an additional 4.4% variance in HOMA-IR, but this was not a statistically significant value. (Data not shown).

## 2.8. Discussion

The purpose of this study was to examine the relationship between added sugar consumption and measures of glycemia and insulin resistance or beta-cell function in adolescents who are obese. We hypothesized that individuals consuming lower amounts of added sugars will have better glycemic control and insulin sensitivity than those who consume higher amounts of added sugars. There were no significant correlations between percent energy from added sugar and concentrations of HbA1c, fasting blood glucose, or 2-hour glucose. There were also no significant correlations between percent energy from added sugar and HOMA-IR, DI, or WBISI values. There were no significant differences between the glycemia or insulin resistance values of the high versus low added sugar consuming groups. This current pilot study was underpowered and was therefore unable to truly determine if there is an association between higher added sugar consumption and poor glycemia and insulin resistance in our study population.

Participant dietary quality indicated low intakes of fruits, vegetables, and fiber, which is consistent with NHANES analysis of adolescent diets (29), as well as other studies of fruit and vegetable consumption in adolescents. (29, 42-44) The Dietary Guidelines for Americans recommends 2.5 cup equivalents of vegetables each day, 2 cup equivalents of fruit each day, and 6 ounce equivalents of grains each day, half of which should be whole grains.(45) Most servings of fruit in our study population came from fruit juices and vegetable servings came from potatoes, which is consistent with adolescent consumption documented in the literature. (42) The amount and highest source of added sugar consumed were not consistent with those found in the literature, (30, 46) though this may be due to energy underreporting (30). The top sources of added sugar consumed by adolescents in our study were refined grains and sweetened dairy products, compared to sugar sweetened beverages, grain desserts, and sweetened dairy products, which are found to be the top sources of added sugar in adolescents nationally. (30, 47)

Previous studies in adults found no correlation between added sugar consumed at median levels (between 12-15% of energy) and insulin resistance(33). The same study found that median intake levels of consumption of added sugar at had no effect on fasting glucose levels. (33) Since we know that adolescents consume higher amounts of added sugars than adults(46), these findings may not translate to the adolescent population. However, we found no association among added sugar intake and insulin resistance or beta-cell function measures. Previous studies have examined associations between added sugar consumption and increased adiposity in adolescents (46, 48), but few have tried to connect added sugar consumption directly to measures of insulin resistance. One study in Latino youth found that total sugar intake was significantly inversely correlated with beta-cell function and insulin sensitivity, independent of sex, Tanner stage, energy intake, and fat-free mass. (37) The same study in adolescents found that each increase of 10 g/d of added sugars or more was associated with increased HOMA-IR values, lower WBISI values, and higher fasting blood glucose values (49). Additionally, a cross sectional study in adolescents found a positive correlation between HOMA-IR values and added sugar intakes. (50) Wang et al found that consumption of added sugars (measured by two 24-hour dietary recalls at baseline), from liquid sources specifically was associated with higher fasting glucose, higher fasting insulin, and higher HOMA-IR values in obese adolescents (51), suggesting that sugar sweetened beverages may be of

particular importance in this diet-disease relationship. By failing to fully capture beverage consumption, we may have missed this important aspect of the relationship.

One limitation of this study is the small sample size. Because there were only 48 participants, we were underpowered to detect a significant correlation between percent energy from added sugar and measures of glycemia and insulin resistance. Considering the controversy of current evidence tying added sugar to glycemic and insulin resistance outcomes, finding a relationship between added sugar intake and insulin resistance outcomes would have been an important contribution to the literature.

Another limitation of this study is our failure to measure underreporting of dietary data, specifically sugar sweetened beverages. Some methods, such as the Goldberg method have been used to weed out implausible energy reporting. The Goldberg method has high predictive value for implausible energy reporting from food frequency questionnaires and 24-hour dietary recalls (52), but also causes a reduction in power and it has been concluded by some studies that it is not a reliable method for eliminating bias in energy reporting. (53) Additionally, the use of the Technology Assisted Dietary Analysis (TADA) may not be the most appropriate tool for measuring beverage consumption in this population because it relies on images, and it may be difficult to identify beverages in opaque cups or packaging. All in all, being able to measure energy underreporting would have improved the validity of the dietary data.

Despite our limitations our study also had it's strengths. Given the racial differences in T2D development (21), and sugar sweetened beverage consumption (37, 54) it is important to have a racially diverse study population to be able to have more generalizable data. Having successfully recruited a racially diverse population in a rural midwestern area is notable.

In summary, we were unable to find associations between added sugar consumption and glycemia and insulin resistance or beta-cell function in this sample of adolescents who are obese. Additionally, there were no significant differences found between the dietary intake of individuals with prediabetes and individuals with normoglycemia. All participants consumption of fruit, vegetables, and fiber were below the dietary guidelines' recommendations. There were also no

significant differences between the diets, glycemic values, or insulin resistance values between high and low added sugar consuming groups. More research is needed to determine if an association exists between these variables and to determine the specific role that sugar sweetened beverages play in the relationship between added sugar and diabetes risk.

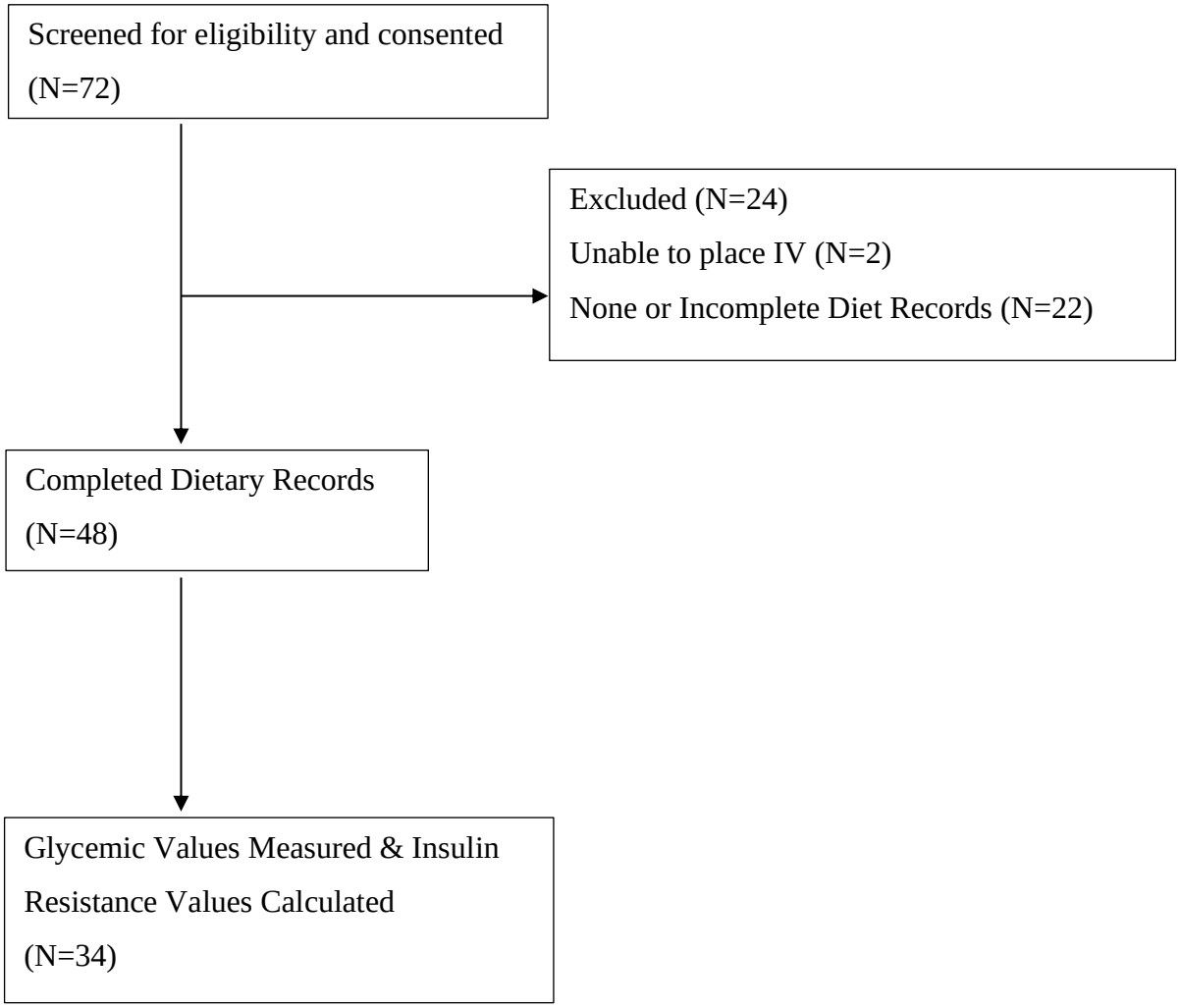


Figure 2.1 Participant Flow Diagram

Table 2.1Participant Demographics

| | |
|---|---|
| **Diabetes Status** | 42% Prediabetes |
| **Gender** | 59.2% Female |
| **Race** | |
| **White** | 57% |
| **African Americn** | 32% |
| **Age** | 16.2 ± 2.7 years |
| **HbA1c (%)** | 5.4 ± 0.3 |
| **Fasting Blood Glucose (mg/dL)** | 92.5 ± 7.2 |
| **2 Hour Glucose (mg/dL)** | 117.0 ± 25.9 |
| **Time Spent MVPA (Min)** | 18.5 ± 22.4 |

Age is presented as means ± standard deviations. (N=48) HbA1c- glycated hemoglobin. MVPA- moderate to vigorous physical activity.

Table 2.2 Glycemic & Insulin Resistance Measures by Diabetes Status

| | **Pre-Diabetes** | **Normoglycemia** | **P-Value** |
|---|---|---|---|
| **BMI Z-Score** | 2.2 ± 0.4 | 2.1 ± 0.5 | 0.778 |
| **HbA1c (%)** | 5.5 ± 0.3 | 5.3 ± 0.2 | 0.231 |
| **2 Hour Glucose (mg/dL)** | 131.2 ± 27.7 | 105.6 ± 16.6 | 0.003* |
| **Fasting Blood Glucose (mg/dL)** | 95.5 ± 6.9 | 89.8 ± 6.7 | 0.453 |
| **HOMA-IR** | 5.3 ±2.7 | 5.1 ± 2.8 | 0.944 |
| **WBISI** | 2.3 ± 1.6 | 2.5 ± 1.1 | 0.746 |
| **DI** | 4.4 ±4.9 | 9.1 ± 6.8 | 0.016* |

Values presented as means ± standard deviations Differences between groups were determined using independent sample t-tests (N=34). A *p-value <0.05 is significant.

Table 2.3 Dietary Data by Diabetes Status

| | Pre-Diabetes | Normoglycemia | P-Value |
|---|---|---|---|
| **Energy (kCal)** | 1637.1 ± 526.2 | 1775.3 ± 457.3 | 0.317 |
| **Added Sugar Consumption (% of kCal)** | 9.4 ± 5.0 | 11.0 ± 5.1 | 0.904 |
| **Fruit Consumption (Cups)** | 0.8 ± 0.9 | 1.2 ± 0.9 | 0.663 |
| **Vegetable Consumption (Cups)** | 1.7 ± 0.9 | 2.1 ± 1.4 | 0.296 |
| **Total Dietary Fiber (g)** | 11.4 ± 5.2 | 13.0 ± 3.2 | 0.093 |
| **Sodium (mg)** | 3137.3 ± 946.2 | 3075.5 ± 936.7 | 0.531 |
| **Saturated Fats (% calories from SFA)** | 11.8 ± 2.7 | 11.5 ± 2.8 | 0.767 |

Differences between groups were determined using independent sample t-tests (N=48). A *p-value <0.05 is significant. Dietary data reported is an average of three days of intake.

Table 2.4 Associations Among Added Sugar Consumption and Glycemic Values

| | % Calories from Added Sugar | |
|---|---|---|
| | **R-Value** | **P-Value** |
| **HbA1c** | -0.237 | 0.063 |
| **Fasting Blood Glucose** | 0.208 | 0.090 |
| **2-Hour Glucose** | 0.017 | 0.457 |

Results from the Pearson correlation (N= 34) *P<0.05 was considered significant.

Table 2.5 Associations Among Added Sugar Consumption and Insulin Resistance Measures

| | % Calories from Added Sugar | |
|---|---|---|
| | **R-Value** | **P-Value** |
| **HOMA-IR** | 0.129 | 0.234 |
| **Matsuda Index (WBISI)** | -0.069 | 0.350 |
| **DI** | -0.118 | 0.253 |

Results from the Pearson correlation (N= 34) *P<0.05 was considered significant.

# CHAPTER 3. CONCLUSIONS AND FUTURE DIRECTIONS

## 3.1. Conclusions

To conclude, we did not find a significant association between percent energy from added sugar and glycemic and insulin resistance and beta-cell function outcomes, however the study lacked sufficient power and there may have been an association present that we were unable to detect. Previous studies in adolescents have found associations between added sugar intake and glycemia and insulin resistance in obese adolescents. Studies with sufficient power that can more accurately capture energy intakes, especially intakes from added sugar in sugar sweetened beverages are needed.

## 3.2. Future Directions

Going forward, we plan to account for energy underreporting to increase the validity of our dietary data. It may also prove beneficial to add a feature to the TADA application that specifically asks about beverage consumption. This study was initially powered for 91 participants, which we believe may be achievable in the future with continued recruitment efforts. Future directions for this study are to examine if the dietary intakes and quality differ between control and interventions groups, and if those differences are reflected in the participants glycemic and insulin resistance or beta-cell function outcomes.

T2D in adolescents is a public health concern because of its increase in incidence and threat to the quality of life of our young adults. As nutrition researchers, we understand that diet plays a strong role in disease prevention and maintaining an overall healthy life. Identifying possible areas for future dietary intervention to decrease diabetes risk, such as decreasing added sugar consumption or increasing fruit and vegetable consumption, is vital.

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# VITA

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