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BLOOD GLUCOSE MONITORING AND METABOLIC CONTROL IN YOUTH
WITH TYPE 1 DIABETES: RELATION TO DISEASE CARE

A thesis submitted in partial fulfillment of the requirements for the degree of Master of
Science at Virginia Commonwealth University

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Abstract

BLOOD GLUCOSE MONITORING AND METABOLIC CONTROL IN YOUTH WITH TYPE 1 DIABETES: RELATION TO DISEASE CARE

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Better disease care behaviors in youth with type 1 diabetes (T1D) are strongly related to better metabolic control (HbA1c). However, HbA1c results are only available, on average, every three months, and may not accurately capture intricacies of blood glucose fluctuations. Youth then must rely on blood glucose levels obtained throughout the day to determine which disease care behaviors to perform to maintain optimal metabolic control. Youth may have difficulty performing these disease care behaviors properly or consistently, which makes parental monitoring a crucial aspect of the diabetes regimen. Additionally, youth who experience frequent or severe hypoglycemia may develop a fear of hypoglycemia, which may impact their disease care behaviors and blood glucose levels directly.

Average blood glucose levels strongly related to HbA1c which verifies HbA1c as a good indicator of average blood glucose levels. The Average Daily Risk Range

(ADRR) index had a stronger relation to HbA1c than Mean Amplitude of Glycemic Excursions (MAGE) index; however, the percentage of blood glucose levels below, within, and above range may be the best indicator of glycemic variability, as it is more easily calculated and understood. More parental monitoring related to more diabetes prevention behaviors but not intervention behaviors or less glycemic variability.

Blood Glucose Monitoring and Metabolic Control in Youth with Type 1 Diabetes: Relation to Disease Care

Type 1 diabetes (T1D) is a chronic illness that affects 0.22% of youth in the United States and involves a variety of disease care behaviors. Adherence to the diabetes care regimen, critical for avoidance of health complications over time, is measured by glycosylated hemoglobin (HbA1c) levels; however, these are only available, on average, every three to four months to guide disease care decisions. Blood glucose monitoring is an alternate way to measure adherence to disease care, and in contrast to the average of HbA1c over a longer period, youth can use blood glucose monitors several times a day to measure and adjust acute fluctuations. These glycemic fluctuations, if chronic, may lead to long-term health complications. Psychosocial factors, such as youth and parent fear of hypoglycemia and parental monitoring, can affect youth disease care behaviors, blood glucose levels, and ultimately metabolic control.

The proposed study will examine blood glucose data and frequency of blood glucose monitoring as it relates to HbA1c. Blood glucose levels have been significantly related to HbA1c levels in a number of studies; however, to this date, blood glucose data has not been delineated into categories of below, within, and above the ADA recommended levels. Separation of blood glucose data into categories may reveal a clearer picture of the association. The contribution by youth and parent fear of hypoglycemia to the relation between HbA1c and blood glucose levels below, within, and above range will be examined. Glycemic variability has also been shown to have a strong relation to HbA1c, but measures of glycemic variability have not been assessed in depth to this date. Two measures of glycemic variability, Average Daily Risk Range (ADRR) and Mean Amplitude of Glycemic Excursions (MAGE), will be compared to

determine which is more closely correlated with HbA1c. Finally, the impact of parental monitoring on prevention and intervention behaviors in response to blood glucose levels will be examined.

T1D will be explained first, followed by a description of metabolic control and two methods of assessing metabolic control. Then, the youth diabetes regimen will be introduced and disease care behaviors explained. Lastly, youth and parent fear of hypoglycemia and parental monitoring will be examined to determine the relation to metabolic control. The relations between psychosocial factors, disease care behaviors, and indicators of metabolic control will be examined in the context of bioecological theory.

Type 1 Diabetes

Type 1 diabetes (T1D) is an autoimmune disease with short- and long-term health complications (Singer, Coley, Samet, & Nathan, 1989). T1D accounts for approximately 10% of all cases of diabetes, with 215,000 youth diagnosed in 2011 (American Diabetes Association [ADA], 2011). T1D is characterized by immune system destruction of the insulin-producing cells of the pancreas. Insulin allows glucose obtained from nutritional intake to permeate the cellular membrane for energy and stimulates liver and muscle cells to store glucose as glycogen (Johnson, 1988). When insulin is destroyed, the body is unable to regulate blood glucose levels, and excess glucose accumulates in the blood (Johnson, 1988). When glucose from nutritional intake enters the bloodstream, it merges with red blood cells in a process called glycosylation (Cnop et al., 2005). With excess glucose in the blood, more hemoglobin is glycosylated, which results in higher HbA1c levels (Fishbein & Palumbo, 1995).

If the multifaceted diabetes regimen is not followed, both long term and acute complications can result. Ideally, all individuals in a youth's environment must understand and participate in the diabetes treatment of a youth to avoid complications. Acute complications may include hyperglycemia or hypoglycemia, which result in symptoms of dizziness, confusion, weakness, hunger, thirst, and irritability (Johnson, 1988). Long term complications include organ damage due to retinopathy, neuropathy, and nephropathy (ADA, 2011; Expert Committee on the Diagnosis and Classification of Diabetes Mellitus, 2002).

Diabetes in the Context of Bioecological Theory

Diabetes is a chronic illness influenced by biological, psychological, and social factors within the family. The bioecological theory views a youth's context as a set of nested structures, or structures within structures, which highlight the transactional nature of human development (Bronfenbrenner, 1977). A youth primarily exists in his or her home, which is the foundation for development; secondary settings, such as school, surround this primary environment and influence a youth's growth. Furthermore, a youth's interpersonal interactions have reciprocal influence, and youth affect others' development as well. A youth is the center of his or her individual ecosystem, and the proximal surrounding environment is the microsystem. A microsystem is a set of interactions between a youth and his or her immediate environment. This setting is a place where a youth engages in activities in distinct roles for periods of time. An example of a youth's microsystem is home or school, two places where a youth's functions conspicuously differ. Parental monitoring primarily exists at this level of a youth's ecosystem; straightforward interactions between a youth and parent most commonly take

place at home, which is also where most disease care behaviors are anchored. Because most of a youth's diabetes supplies are at home, and a youth's day begins and ends in the home, it is important for a parent to be involved in the daily routine to provide a stable framework for the diabetes regimen.

The second layer of a youth's ecology is the mesosystem, which is a system of microsystems. An example of a mesosystem is the interrelation between a youth's school and home. This is a vital transition for a youth with T1D; if their diabetes regimen is inconsistent between these two systems, metabolic control may suffer due to resultant glycemic excursions (Silverstein et al., 2005). External to the microsystem is the exosystem, which is the connection between two or more settings, one of which does not ordinarily encompass a youth. An example is a youth's home and a parent's workplace. A parent preoccupied with thoughts of work may forget to monitor their youth's blood glucose as frequently as recommended. These examples show the influence exerted by parental monitoring at these levels of a youth's environment, and potential availability to monitor or make modifications to the disease care regimen.

The outermost ring of Bronfenbrenner's ecological model is the macrosystem, which prototypically exists as society and sets patterns for activities and structures to occur at the concrete level. This includes culture and social beliefs. A youth who believes he or she should be embarrassed about having T1D is likely to modify his or her behavior accordingly, which may result in a reduction in blood glucose monitoring, or refusal to administer insulin in response to hyperglycemia. Any decline in self-care behaviors resulting from transactions at any systems level may affect metabolic control.

Bronfenbrenner postulated that the four levels of a developing youth's ecosystem change over time, and emphasizes interactions between a youth and his or her environment, as well as interactions between levels (1977). The transactional framework should be in the forefront when considering youth development. In the structure of psychosocial development, a youth who is predisposed to anxiety is influenced by interactions he or she has within the microsystem, exchanges between mesosystems, and exosystems. The macrosystem sets a larger cultural context which influences all levels and interactions as well, resulting in the emergence or absence of disease-specific anxiety, fear of hypoglycemia, in a youth. Within these contexts, a youth's fear of hypoglycemia may be influenced or catalyzed by a parents' anxiety, and potentially causes a reinforcement loop of anxious interactions.

Factors to be examined in this study exist at the micro-, macro-, and exosystem level. A youth's fear of hypoglycemia relates to behavior at home and interactions with family members. Anxiety may manifest itself in avoidance behaviors such as avoidance of insulin injection. Interpersonal interactions also may become strained due to a youth's anxious emotional state, or a parent's reaction to a youth's reduced self-care behaviors. Hypoglycemia, hyperglycemia, and glycemic excursions effect physical and emotional reactions to the micro- and macro-systems. Finally, parental monitoring affects the micro- and macro-systems, and is influenced by the exosystem. Consistency in the diabetes regimen is crucial, and parental monitoring is necessary for this stability across microsystems. The exosystem sets a larger stage for attitudes about diabetes care. These bonds are bidirectional transactions, which embodies youth development. A chronic illness like T1D adds a layer of complexity to the theoretical model.

Hyperglycemia

Hyperglycemia occurs with too little insulin in the body to allow cellular uptake of blood glucose, typically identified when blood glucose levels exceed 200 milligrams of glucose per deciliter of blood (mg/dL). Symptoms of hyperglycemia include frequent urination, increased thirst and appetite, blurred vision, fatigue, and weight loss (Silverstein et al., 2005). If not treated properly, hyperglycemia may lead to diabetic ketoacidosis (DKA), a state in which the body metabolizes fat for energy, and creates ketones that accumulate in the bloodstream and are expelled through the urine (Scibilia, Finegold, Dorman, Becker, & Drash, 1986). Symptoms of DKA include nausea, vomiting, and dry mouth. Treatment for DKA consists of fluid replacement, electrolyte replacement, insulin therapy, or exercise (Scibilia et al., 1986). Left alone to manage mild or moderate hyperglycemia, many youth do nothing (Johnson, Perwien, & Silverstein, 2000; Wysocki, Greco, & Buckloh, 2003). Determination of the relation between intervention and prevention behaviors taken by youth and parental monitoring will help explain how to improve disease care behaviors among youth with T1D.

Hypoglycemia

Hypoglycemia occurs when blood glucose drops below 70 mg/dL, indicating insufficient fuel for bodily needs. Symptoms include shakiness, dizziness, headache, and difficulty paying attention. Cognitively, patients also may experience declines in planning and decision making, attention to detail, and reaction time (Ryan et al., 1990). If untreated with glucose, hypoglycemia can lead to seizures, coma, and ultimately death. The American Diabetes Association (2011) recommends hypoglycemia be treated with 15 to 20 grams of carbohydrates or sugars, wait 15 minutes, retest and repeat as needed

until euglycemia is achieved. Youth are more likely to take corrective action with hypoglycemia, but often overtreat such that it is followed by an episode of hyperglycemia (Hardin, 2004; Susman-Stillman, Hyson, Anderson, & Collins, 1997; Wysocki et al., 2003). Younger age is a consistently reported risk factor for hypoglycemic episodes, with rates in preschool-age youth three-fold higher than those in adolescents, suggesting a need for more parent or adult monitoring (Bognetti et al., 1997; Levine, Anderson, Butler, Brackett, & Laffel, 2001). Other reported risk factors include lower HbA1c levels (DCCT, 1993; Mortensen & Hougaard, 1997), male gender (Davis et al., 1998), and longer duration of diabetes (Bott, Bott, Berger, & Mühlhauser, 1997; DCCT, 1993). While lower blood glucose levels correlate with better metabolic control ($p < 0.001$) and fewer long-term diabetes-related complications such as retinopathy ($p = 0.087$) and nephropathy ($p = 0.042$; DCCT, 1993), a greater likelihood of severe hypoglycemia is present. Beyond acute hypoglycemia, more chronic cognitive sequelae such as diminished memory, reading impairment, and reduced visuo-spatial ability may be found in youth with diabetes onset before age seven, or disease duration of more than five years (Puczynski, Puczynski, & Ryan, 1992).

Long-term T1D Complications

Retinopathy is an ocular manifestation of systemic disease (ADA, 2002). When blood glucose levels are consistently elevated, blood vessels are unable to contain the excess volume caused by higher sugar concentration and burst, ultimately leading to blindness if uncorrected (Mayo Foundation for Medical Education and Research [MFMER], 2010). Neuropathy occurs when nerves are damaged by continuous hyperglycemia. Decreased blood flow causes pain, loss of feeling in extremities, muscle

cramps, numbness, and weakness (MFMER, 2010). Diabetic nephropathy is a progressive kidney disease caused by angiopathy of capillaries in the kidney glomeruli (Berkman & Rifkin, 1973). Symptoms result from gradual kidney failure, and patients usually resort to kidney dialysis treatment if the disease worsens (Berkman & Rifkin, 1973).

The landmark Diabetes Control and Complications Trial (DCCT, 1993) found good metabolic control predicts a reduction in the rate and progression of future disease complications. Complications are minimized if youth perform recommended disease care behaviors and maintain a lower HbA1c level, indicative of less glycosylation and better metabolic control. Disease care behaviors must be consistent and accurate, which requires support from all systems within a youth's environment.

Metabolic Control

Glycosylated hemoglobin (HbA1c) measures average plasma glucose concentration over the previous two to three months, and is a composite index of metabolic control (Clarke, Snyder, & Nowacek, 1985). Research indicates that the major proportion of HbA1c is related to a shorter period of the previous two to four weeks, and may be more heavily influenced by afternoon and evening blood glucose levels (Rohlfing et al., 2002). Blood glucose levels in the preceding 30 days contribute approximately 50% to the final result, and blood glucose levels from 90–120 days earlier contribute only 10% (Goldstein, Little, Wiedmeyer, England, & Rohlfing, 1993; Tahara, 1993). Due to uneven temporal contributions to HbA1c, it has been suggested that measures of glycemic variability be included as indicators of overall metabolic control (Brownlee & Hirsch, 2006; DCCT, 1995; Hirsch & Brownlee, 2005; Kovatchev, 2006). HbA1c is the

most commonly used index of metabolic control to benchmark disease complications. Non-diabetic HbA1c levels range from 4% to 5.9%. Typically, HbA1c levels in youth with T1D range from 6% to above 14% (Silverstein et al., 2005). Lower scores are better and indicate less glucose in the bloodstream is 'glycosylated', or irreversibly bound to hemoglobin molecules. HbA1c is higher in diabetic youth due to the lack of insulin in the blood and resulting excess sugar in the bloodstream. Although HbA1c is an accurate overall measure of metabolic control, it does not provide information about day-to-day blood glucose fluctuations, or immediate, real-time feedback which patients can instantaneously use to make medical or lifestyle choices (Dailey, 2007).

Once blood glucose levels are known, steps can be taken to correct high or low blood sugars to avoid acute complications of thirst, nausea or dizziness, and shakiness, respectively. Lowered HbA1c occurs as a result of better diabetes regimen adherence; HbA1c is strongly correlated with average blood glucose levels in adults, ranging from ($r = 0.62$) to ($r = 0.66$), respectively (Derr, Garrett, Stacy, & Saudek, 2003; Service & O'Brien, 2007). A very strong correlation exists between average blood glucose levels and HbA1c in adolescents, ($r = 0.71, p < .0001$; Hempe, Gomez, McCarter, & Chalew, 2002). Poorer metabolic control in adults is correlated with higher levels of HbA1c and wider fluctuations in blood glucose levels, confirming HbA1c as a good measure of average glycemia (Derr et al., 2003). Although much research has examined the relation between average blood glucose levels and HbA1c, little of this research has been conducted in youth populations with T1D. Research with pediatric populations is difficult to conduct, as this age group is complex. Youth's roles within microsystems are fluid during transitional periods and affect the interactional layers of a youth's ecosystem

(Strawhacker, 2001). Accounting for levels of parental monitoring is a key difference between adult and pediatric studies. Parental monitoring in blood glucose levels is increasingly studied as a key factor related to better disease management in pediatric diabetes research. Recognition and treatment of out-of-range blood glucose levels is a responsibility managed by many parents of youth with T1D, and decreased blood glucose monitoring in adolescence is frequently related to poorer metabolic control (Anderson et al., 2002; Ingerski, Anderson, Dolan, & Hood, 2010; Sander, Odell, & Hood, 2010).

Glycemic Variability

A principal factor affecting metabolic control is idiosyncratic variations in blood glucose events (Wearden, Hynd, Smith, Davies, & Tarrrier, 2006). Adults with T1D who attribute blood glucose fluctuations to individual unpredictability report poorer metabolic control (Wearden et al., 2006). Researchers have begun to focus on phenotypic glycation responses, or individual differences in the relation between HbA1c levels and average blood glucose levels in individuals with similar preceding blood glucose levels.

Phenotypic glycation responses in adolescents were examined as a possible explanation for the relation between average blood glucose levels and metabolic control in adolescents (Hempe et al., 2002). Investigators found a strong linear correlation between average blood glucose levels and HbA1c in adolescents, but results suggest sample variability in HbA1c levels is attributable to idiosyncratic blood glucose responses among individuals. Results led authors to conclude that average blood glucose levels and HbA1c were not interchangeable measures of metabolic control, and youth with T1D would benefit from more than one overall indicator of metabolic control. Additional research should be conducted to explore the validity of these findings, and discern

whether this connection may be explained by typical hormonal fluctuations present during adolescence (Amiel et al., 1986) or the difficulty of parent/youth teamwork to manage disease care (Anderson, Ho, Brackett, Finkelstein, & Laffel, 1997; Anderson et al., 2002).

Extreme glycemic variability in adults with T1D results in an activation of oxidative stress, which may lead to complications due to poorer metabolic control (Brownlee, 2001). Oxidative stress is an imbalance between production and manifestation of reactive oxygen species and a biological system's ability to readily detoxify the reactive intermediates or to repair the resulting damage. This process can damage all components of the cell. Oxidative stress is involved in many diseases, such as atherosclerosis, heart failure, and heart attacks (Gems & Partridge, 2008). A wider fluctuation in blood glucose levels is strongly correlated with poorer metabolic control ($r = 0.65, p < .001$; Derr, Garrett, Stacy, & Saudek, 2003). Evidence suggests disease complications may occur due to glycemic excursions, which may not consistently be reflected in HbA1c levels. Consequently, measures of blood glucose fluctuations are recommended for inclusion with HbA1c as a more comprehensive marker of metabolic control (Brownlee & Hirsch, 2006; DCCT, 1995; Hirsch & Brownlee, 2005; Kovatchev, 2006).

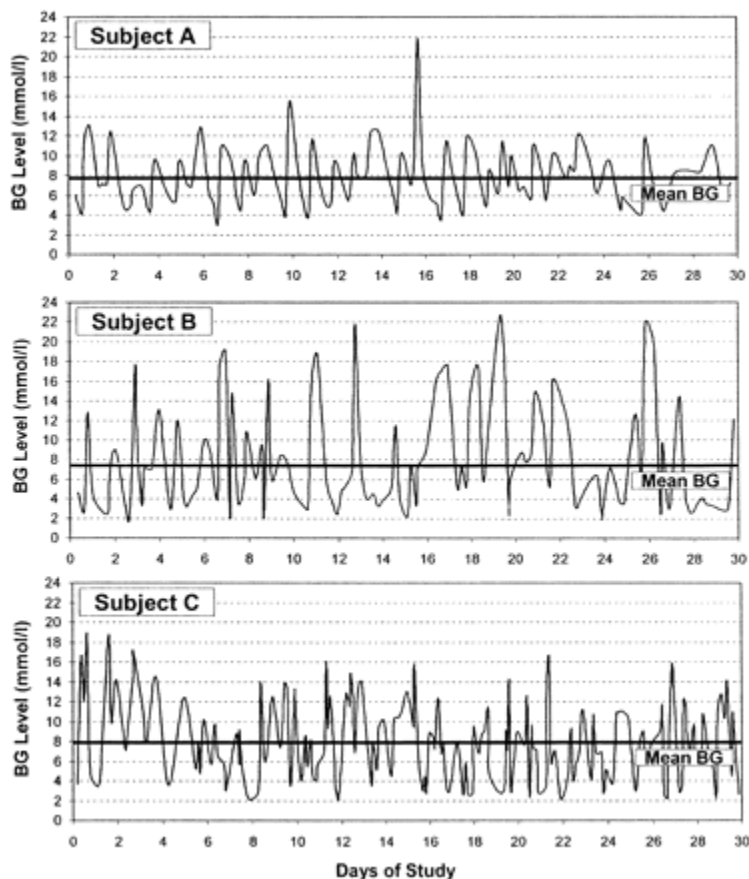
Many methods exist by which blood glucose fluctuations are analyzed. The methods investigated in this study include Average Daily Risk Range (ADRR) and Mean Amplitude of Glycemic Excursions (MAGE).

Average Daily Risk Range (ADRR). The ADRR formula requires at least 14 days out of 30 days where three blood glucose readings were taken per day (Kovatchev et

al., 2006). Blood glucose values are normalized using a logarithmic data transformation that matches the clinical and numerical center of the blood glucose scale, thus making the transformed data symmetric; without this data transformation, many parametric statistical assumptions are violated unknowingly. After this transformation, investigators found the low blood glucose index predicted the occurrence of severe hypoglycemia ($r = 0.68, p < 0.001$), the high blood glucose index predicted the occurrence of hyperglycemia ($r = 0.60, p < 0.001$), and the high blood glucose index correlated with the subjects' glycosylated hemoglobin ($r = 0.63, p < 0.001$), while raw blood glucose data did none of those (Kovatchev, Cox, Gonder-Frederick, & Clarke, 1997). After the data are transformed, blood glucose readings are converted into risk values, using all of the readings below the mean and all of the readings above the mean as overall indicators of risk for hypo- and hyperglycemia (Kovatchev et al., 2006). The ADRR values may be categorized into three groups: low risk, moderate risk, and high risk. The optimal data period was one month, with three to five blood glucose checks per day.

ADRR has several attributes which set it apart from alternative measures of glycemic variability. Besides creating a more balanced picture of daily fluctuations, the ADRR method of centering blood glucose levels also ensures greater validity and sensitivity of the data, rendering results clinically meaningful. With more valid blood glucose data, interpretations made may be more consequential. ADRR also significantly predicts the risk of severe hypo- and hyperglycemia, which other variability measures, and HbA1c, are unable to do. Valid prediction of glycemic events could aid in identification of youth at risk for severe glycemic events, and subsequently modify treatment plans to improve metabolic control and reduce glycemic fluctuations. Re-

analysis of data suggests the ADRR captures group and/or treatment effects undetected by HbA1c (Cox et al., 1995). Finally, because the transformation included in the ADRR calculation centers blood glucose data at zero, it may be applied to any data sample without parametric re-estimation or risk of violating statistical assumptions (Kovatchev et al., 1997). As stated above, in contrast to previously used measures of glycemic variability, ADRR applies equal weight to hypo- and hyperglycemia, rendering it a balanced measure of overall glycemic variability than those that previously exist. A table is included below. Although the three participants have the same HbA1c level, daily blood glucose levels and fluctuations are very different.



The graphical representation (Kovatchev et al., 2006) above makes it clear that in order to properly assess metabolic control among youth with T1D, a measure of glycemic

variability should be included along with the traditional HbA1c level during the endocrinology appointment.

Mean Amplitude of Glycemic Excursions (MAGE). MAGE is the other most prevalent method used to measure average daily fluctuations in blood glucose levels. To calculate MAGE, the difference from the previous blood glucose value is calculated for each individual blood glucose value. Each difference score is compared against the average of all blood glucose values in that day and only differences exceeding one standard deviation from the average are included. The arithmetic mean of the remaining differences is calculated, resulting in the glycemic variability value. Participants with T1D were found to have larger, or worse, MAGE values than participants without T1D, and “unstable diabetics” had larger MAGE values than “stable diabetics” (Service et al., 1970). Diabetic participants were categorized as “highly unstable,” “moderately unstable,” and “stable” based on their relative difficulty in maintenance of euglycemia throughout the study. MAGE is strongly correlated with total variability ($r = 0.89$) and within day variability ($r = 0.87$), but less strongly correlated with various measures of between day variability, ranging from $r = 0.46$ to $r = 0.76$ (Rodbard, 2009).

MAGE has been used in several clinical studies that measured cognitive performance, oral insulin efficacy and improvement in metabolic control (Marfella et al., 2010; Rizzo et al., 2010; Rodbard, Jovanovic, & Garg, 2009). In older adults with type 2 diabetes (T2D), a larger MAGE was associated with poorer cognitive functioning, independent of HbA1c levels (Rizzo et al., 2010). MAGE was found to decrease when more efficacious oral insulin was added to the insulin regimen of adults with T2D (Marfella et al., 2010). Continuous glucose monitoring was found to improve MAGE,

HbA1c, and average blood glucose levels in adults with T1D (Rodbard et al., 2009).

MAGE is the predominant calculation used in blood glucose data analysis for T1D and T2D (Monnier & Colette, 2008).

The ADRR and MAGE indices of glycemic excursion were compared following development of the ADRR calculation, albeit only with adult populations. The ADRR was found to better predict hypoglycemia than MAGE (Kovatchev, et al., 2006). Authors maintain ADRR weighs hypo- and hyperglycemia equally, while other glycemic variability measures bias towards hyperglycemia. ADRR was shown to be more sensitive than MAGE to the degree of glucose fluctuations, although MAGE was found to be more sensitive in detecting the percentage of glucose values “within range” (Rodbard et al., 2009). Available evidence suggests a better understanding of the relation between glycemic variability measures and HbA1c will aid in monitoring overall metabolic control of youth with T1D, as well as tailoring care to prevent complications due to glycemic excursions.

Disease Care Behaviors

Daily recommendations for T1D include administration of insulin, adjustment of insulin levels in response to blood glucose levels, maintenance of a healthy diet, exercise, and several blood glucose level checks throughout the day (Silverstein, et al., 2005). Diabetes regimens vary based on youth differences, but adherence is generally defined as the degree to which a youth’s disease care behaviors correspond to medical or health advice (Haynes, 1979).

An overall adherence rate of 50% is estimated for disease care behaviors in most pediatric chronic illnesses (Litt & Cuskey, 1980), but rates may vary depending on the

complexity of the disease care regimen, age of the patient, or whether the treatment regimen is short- or long-term (Sackett & Snow, 1979; Epstein & Cluss, 1982).

Adolescents describe performance of disease care behaviors as increasingly difficult over time (Kovacs et al., 1989). In a meta-analysis of 21 studies, poorer disease care behaviors related to higher HbA1c levels (Hood, Peterson, Rohan, & Drotar, 2009).

Insulin regimen, nutrition, and exercise are all important factors which influence metabolic control; however, the frequency of blood glucose monitoring is consistently shown to have a strong correlation with metabolic control (Anderson, Ho, Brackett, Finkelstein, & Laffel, 1997; Jones et al., 2003).

Insulin Regimen

The most common types of insulin regimen are Basal/Bolus regimens, Continuous Subcutaneous Insulin Infusion (CSII) via an insulin pump, and Multiple Daily Injections (MDI) (Silverstein et al., 2005). The MDI regimen consists of two or three injections of short- and intermediate-acting insulin, sometimes combining both types into one injection. Insulin doses are adjusted based on blood glucose readings, exercise, and nutritional intake. The MDI regimen requires a strict injection schedule to be effective (Silverstein et al., 2005).

Basal/Bolus regimens use short-acting boluses, or bursts, of insulin to compensate for meals and snacks, and long-lasting basal insulin rates to maintain consistent levels of insulin in the body (Silverstein et al., 2005). Basal/Bolus regimens are more flexible than multiple daily injections due to the basal rate of long-lasting insulin present. Long-lasting insulin is typically administered in the morning to compensate for food consumed while the youth is awake, with supplemental short-acting insulin injections as needed.

Insulin pump therapy, or CSII, requires a catheter to be inserted under the skin. The pump continuously administers a steady flow of microunits of insulin through the catheter tube (Boland, Grey, Oesterle, Fredrickson, & Tamborlane, 1999). The basal rate can be changed at any time, and boluses of insulin can be delivered as needed without injections via an indwelling catheter, provided sufficient insulin levels are available in the pump reservoir. Insulin pump therapy reduces the risk of long-term complications from diabetes due to the continuous steady flow of insulin which better mimics natural physiology and results in better metabolic control (Boland et al., 1999).

The stepwise transition from MDI to Basal/Bolus to CSII regimens includes qualitative changes in disease care behaviors. While blood glucose monitoring is crucial for every insulin regimen, each increase in regimen intensity necessitates more frequent blood glucose tests, which results in better metabolic control if the new regimen is implemented properly (Chisholm et al, 2007). Youth and parents should be thoroughly educated before a change in regimen to ensure a seamless transition. Each regimen utilizes a unique combination of insulin, based on intensity and complexity.

Frequency of Blood Glucose Monitoring

The ADA recommends youth check blood glucose levels four or more times a day (ADA, 2011; Silverstein et al., 2005). If youth with T1D neglect aspects of their regimen, blood glucose levels will vary beyond the prescribed range of greater than 70 mg/dl and less than 200 mg/dl, and ultimately result in poorer HbA1c levels if prolonged (Hood, Rohan, Peterson, & Drotar, 2010). Blood glucose monitoring is a tool for youth to access and keep blood glucose levels within range, and frequency of blood glucose

monitoring is moderately correlated with metabolic control ($r = 0.44$, $p < .02$; Anderson, et al., 1997).

Conventional Blood Glucose Monitoring

Blood glucose meters allow youth to monitor if they are in an optimal blood glucose range, and modify disease care behaviors to stay within this range (Silverstein, et al., 2005). Ideally, youth use blood glucose readings to adjust the amount of insulin taken, to coordinate the amount of food consumed, and to determine levels of physical activity. Individual regimen differences exist; youth on MDI typically only adjust insulin for extreme hyperglycemia, while youth using Basal/Bolus and insulin pump regimens are able to make acute insulin adjustments based on unplanned snacks or exercise.

Blood glucose meters measure the concentration of glucose in the blood. After pricking a finger with a lancet, youth place a drop of blood on a test strip inserted into a meter, which calculates the amount of glucose in the sample. Blood glucose monitors are able to calculate blood glucose levels in a matter of seconds. This is critical, particularly for hypoglycemia, which can worsen rapidly. When used correctly, glucose meters demonstrate a high degree of clinical accuracy on par with laboratory instruments used to measure blood glucose (Renard, 2005; Weinzimer et al., 2005).

Current meters also include a clock and memory capacity which allows youth to review results and detect patterns in their blood glucose numbers. In a study of 47 youth with T1D, 74% referenced historical readings from a blood glucose meter to modify their diabetes regimen at least once during the four-week long study (Wysocki, Hough, Ward, Allen, & Murgai, 1992). Data did not correlate significantly with HbA1c, but modestly

related to more diabetes knowledge and better treatment adherence ($r = -0.37, p < 0.01; r = 0.31, p < 0.025$).

Blood glucose meters may also have other data management capabilities, which allow data to be downloaded to diabetes-specific computer software, where information can be compiled to construct charts and graphs. Additional information such as food consumed and exercise may be added to form a more complete picture of the patient's diabetes management. Technological advances in meters also may allow a wireless connection to the user's insulin pump, which permits diabetes information, such as insulin boluses and blood glucose numbers, to be viewed in one place for ease of treatment decisions. Downloading blood glucose monitor data is useful because families, as well as a health care provider, can review a month or more of blood glucose numbers. A more comprehensive appraisal of the data allows youth and parents to see patterns and appropriately adjust treatment, if necessary.

Nutrition

Nutritional intake increases blood glucose levels and can be used to treat hypoglycemic episodes; conversely, meals and snacks require treatment with insulin to prevent hyperglycemia. Little dietary research on youth with T1D is available, so healthy eating guidelines for all youth are encouraged (Silverstein et al., 2005). A low-glycemic diet improves nutritional intake and reduces episodes of hyperglycemia due to the overall reduction in glycemic content of food ingested (Rovner, Nansel, & Gellar, 2009). Total carbohydrate content of meals and snacks is used to establish insulin doses before eating (Mehta, Quinn, Volkening, & Laffel, 2009; Wolever et al., 1999). Youth who report

higher levels of compliance to nutritional guidelines also report increased blood glucose monitoring (Mehta et al., 2008).

Exercise

Exercise is an effective way to lower blood glucose levels via enhanced absorption of cellular glucose into cells (Johnson, 1988; Silverstein et al., 2005). Despite the positive effects of exercise on blood glucose, studies find no relation between adults' physical fitness level and HbA1c (Campaigne, Gilliam, Spencer, Lampman & Schork, 1984; Raile et al., 1999). The American Diabetes Association (2011) recommends youth adhere to guidelines set by the Centers for Disease Control (CDC) and American Academy of Sports Medicine in 2009, and engage in moderate physical activity for a minimum of 30 to 60 minutes daily. Youth also should monitor blood glucose levels before, during, and after exercise, and ingest 15 grams of carbohydrates before activity in order to keep blood glucose levels steady (Silverstein et al., 2005). Before starting a new exercise regimen, consultation with a youth's health care provider is recommended in the event insulin doses require modifications to accommodate blood glucose changes resulting from exercise.

Prevention and Intervention Behaviors

In this study, intervention and prevention behaviors are defined as youth responses to and preparations for high and low blood glucose levels, respectively (Iannotti et al., 2006). As mentioned above, recommendations exist that should be followed in order to maintain euglycemia, and when hypo- or hyperglycemia occurs, actions must be taken in order to return to euglycemia. Intervention behaviors may include nutritional intake in reaction to hypoglycemia and insulin administration, water

ingestion, and exercise in response to hyperglycemia. Prevention behaviors include administration of insulin before meals and snacks, or carbohydrate intake prior to physical activity. However, youth with T1D do not always follow guidelines, and several studies have attempted to integrate the layers of a child's ecosystem in order to promote higher levels of disease care behaviors (Anderson, Brackett, Ho, & Laffel, 1999; Ellis et al., 2005). No studies have examined the relation between parental monitoring and prevention and intervention behaviors in youth. Establishment of this correlation will add further detail to the existing connection between parental monitoring, disease care behaviors, and metabolic control.

Blood Glucose Recommendations by Age Group

Blood glucose recommendations are separated into age groups due to different developmental concerns. As the bioecological theory suggests, microsystems of youth at these age groups are qualitatively different; for example, younger youth may not yet attend school, and older youth may be employed or otherwise away from home for long periods of time.

Youth under six years old may be unable to effectively convey symptoms of hypoglycemia (Desrocher & Rovet, 2004), and nighttime hypoglycemia is also a greater concern for this age group. Further, the total caloric intake and mealtime schedule of this age group is less predictable, so insulin administration must be given carefully to avoid extreme glycemc excursions. Glycemc excursions are characterized by variable blood glucose readings, with the presence of more extreme hyper- and hypoglycemia (Garg et al., 2006). Before meals, recommended blood glucose levels are between 100 and 180 mg/dl. At bedtime and during the night, preferred levels range between 110 and 200

mg/dl, in order to avoid hypoglycemic episodes due to lack of caloric intake. The ADA recommends an HbA1c of less than 8.5% for this age group (2011).

For youth aged six to twelve, many concerns of the younger group are less significant because youth in this age group more effectively communicate the symptoms of hypoglycemia. Even so, parents still need to assume primary responsibility for the diabetes regimen (Johnson et al., 1982). Blood glucose levels before meals are recommended between 90 and 180 mg/dl, and levels before bedtime and during sleep between 100 and 180 mg/dl. An HbA1c of <8% is recommended (ADA, 2011).

For adolescents aged 13 to 19, there is more research concerning treatment recommendations (Silverstein et al., 2005). Blood glucose levels before meals should be between 90 and 130 mg/dl and levels ranging from 90 to 150 mg/dl are advised for bedtime and throughout the night. Recommended HbA1c levels are slightly higher than adults to avoid episodes of hypoglycemia, so the standard suggestion for this group is 7.5% or less (ADA, 2011).

Fear of hypoglycemia

Youth fear of hypoglycemia. T1D requires increased developmental responsibility for adolescents, which can be associated with generalized anxiety, and specifically, youth fear of hypoglycemia (Borus & Laffel, 2010). Youth may develop a fear of hypoglycemia due to previously explained negative physical symptoms, unconsciousness, and the possibility of death (Gonder-Frederick et al., 2006). Youth with anxiety symptoms and T1D may have elevated blood glucose levels which can increase anxiety because of the considerable disease care behaviors required, as well as possible complications if HbA1c levels are too high (Anderson et al., 2002; Anderson,

Miller, Auslander, & Santiago, 1981). Fear of hypoglycemia in youth is a disease specific indicator of anxiety pertinent to the present investigation.

Hypoglycemia is the most common adverse event associated with insulin administration in T1D (Wild et al., 2007). Reported incidence rates of severe hypoglycemia (<70 mg/dL) that can result in seizures or unconsciousness range from .02 to 1.26 episodes per year in youth (Dammacco, Torelli, Frezza, Piccinno, & Tansella, 1998; Davis, Keating, Byrne, Russell, & Jones, 1998; Ludvigsson & Nordfeldt, 1998; Mortensen & Hougaard, 1997). Youth fear of hypoglycemia also is related to more frequent hypoglycemia and glycemic variability (Irvine, Cox, & Gonder-Frederick, 1992; Polonsky, Davis, Jacobson, & Anderson, 1992; Shiu & Wong, 2002).

Youth may respond incorrectly to an episode of hypoglycemia, perhaps due to its negative cognitive effects of dizziness, light-headedness, and diminished attention (Johnson, Perwien, & Silverstein, 2000; Lobmann et al., 2000; Ryan et al., 1990). Incorrect hypoglycemic responses include checking ketones or inaction. If youth are unable to effectively treat hypoglycemia and blood glucose levels drop as a result, they may experience seizures and unconsciousness. Severe episodes of hypoglycemia are very frightening for youth with T1D and may generate or reinforce a youth and parent fear of hypoglycemia. Youth may have difficulty detecting hypoglycemia; youth failed to detect 41% of blood glucose readings below 55 mg/dL. Participants also incorrectly believed blood glucose levels to be too high, when they were too low, 11% of the time (Gonder-Frederick et al., 2008). Youth also may have difficulty differentiating between anxiety and hypoglycemia (Polonsky et al., 1992).

Several studies have explored the incidence of fear of hypoglycemia in youth. A history of seizures or loss of consciousness due to severe hypoglycemia relates to higher levels of hypoglycemic fear, greater worry about diabetes, and a greater negative impact of diabetes on a youth's life (Marrero, Guare, Vandagraff, & Fineberg, 1997). Girls have higher worry scores than boys on the Hypoglycemic Fear Survey (Gonder-Frederick et al., 2006). A correlation between youth fear of hypoglycemia and lower insulin adherence ($r = -0.39$, $p < .05$) suggests youth fear of hypoglycemia may result in attempts to stay hyperglycemic (Di Battista, Hart, Greco & Gloizer, 2009).

Parent fear of hypoglycemia. Anxiety literature has long demonstrated a relationship between parent and youth anxiety in healthy populations (Cooper, Fearn, Willets, Seabrook, & Parkinson, 2006; Lenane et al., 1990; McClure, Brennan, Hammen, & Le Brocque, 2001; Turner, Beidel, & Costello, 1987), but research is lacking when applied to a disease-specific measure of anxiety such as youth fear of hypoglycemia.

Elevated fear of hypoglycemia in parents is associated with poorer metabolic control in their youth, more severe hypoglycemic events during the past year, and comorbid disease in youth (Haugstvedt, Wentzel-Larsen, Graue, Sjøvik, & Rokne, 2009; Patton, Dolan, Henry, & Powers, 2007). Parents with a higher fear of hypoglycemia monitored youth's blood glucose numbers more frequently throughout the day (Haugstvedt et al., 2009). Metabolic control in youth is modestly correlated with high parent scores on the Hypoglycemic Fear Behavior Subscale ($r = 0.41$, $p = 0.05$), which implies that parents of youth with higher average blood glucose levels frequently perform behaviors aimed at preventing hypoglycemia (Patton, et al., 2007). Parental fear of hypoglycemia may translate into maladaptive behavior if youth are not old enough to

perform the majority of disease care behavior; for example, parents may keep youth's blood glucose levels higher to prevent severe hypoglycemic episodes.

Parental monitoring

Increased parental monitoring consistently relates to better diabetes disease care behaviors and metabolic control (Miller-Johnson et al., 1994; Wysocki et al., 2009). However, as youth grow older, parents become less involved and give more responsibility to youth, which results in decreased adherence to the diabetes regimen, including less frequent blood glucose monitoring, poorer diet, and higher HbA1c (Ellis, Naar-King, Frey, Rowland, & Greger, 2003; Miller-Johnson et al., 1994). Parental monitoring in the diabetes regimen is crucial to healthy navigation of diabetes in adolescence.

T1D is a complex disease, and parental monitoring is considered a necessary factor for successful management of T1D (Anderson, Bracket, Ho, & Laffel, 1999; Anderson et al., 2009). The ADA (2011) recommends parents assume responsibility for the majority of blood glucose monitoring until youth are at least eight years old. Current recommendations emphasize shared diabetes responsibility between parent and youth through adolescence (Silverstein et al., 2005). Parental attempts to stay involved in diabetes care during the transition from youth to adolescence may lead to increased levels of parent-youth conflict (Amato 2001; Amato & Keith 1991). Several longitudinal studies show that parent-youth conflict may lead to poorer metabolic control (Laffel et al., 2003; Williams, Laffel, & Hood, 2009). If parental monitoring and family conflict are not separated, parental monitoring may be misattributed as deterioration of metabolic control.

In examination of the transition from youth to adolescence, transformation of a youth's ecology should be examined as well. Not only does the parent-youth relationship change due to perceptions of increased maturity, but teachers and other figures in a youth's life may have qualitatively different expectations for them (Strawhacker, 2001). A higher HbA1c also typically occurs during this transition, due to impaired insulin action in puberty (Amiel et al., 1986). This may frustrate youth and lead to more fluctuations in blood glucose levels as a result of increased anxiety (Silverstein et al., 2005). The literature consistently supports the positive influence of parental monitoring on overall adherence to a diabetes regimen, but parental monitoring has not been specifically linked to youth correction of high or low blood glucose levels (Helgeson, Reynolds, Siminerio, Escobar, & Becker, 2008). Validation of this relation will further emphasize the positive influence of parental monitoring on youth disease care behaviors.

Statement of Problem

The purpose of the present study was to evaluate the relation among biological, behavioral, and psychosocial factors, and metabolic control (HbA1c). Confirmation of a relation between average blood glucose levels and HbA1c could confirm the latter as a representative indicator of overall metabolic control in youth. Parental monitoring was investigated as a mediator of this relation. If level of parental monitoring mediates the relation between glycemic variability and metabolic control, intervention programs may be constructed to improve metabolic control of youth by maintaining parental monitoring. Blood glucose monitoring was examined to determine if more frequent blood glucose monitoring correlates with better metabolic control. Confirmation of this hypothesis will reinforce the literature and support current ADA recommendations of several blood

glucose checks throughout the day (ADA, 2011). Two measures of glycemic variability, ADRR and MAGE, were compared on the basis of correlation with HbA1c to determine which is more highly correlated. Determination of the more accurate technique will determine the best method by which to analyze blood glucose fluctuations. Youth and parent fear of hypoglycemia were examined as a moderator of the relation between blood glucose levels below, within, and above range, and HbA1c. Since previous episodes of severe hypoglycemia are associated with youth and parent fear of hypoglycemia, an attempt may be made to prevent hypoglycemic episodes by maintaining hyperglycemia, which could result in elevated HbA1c. Finally, parental monitoring was assessed to determine if it contributes to Prevention and Intervention behaviors performed in response to out of range blood glucose levels. A better understanding of these relations may aid clinicians in development of treatment programs for youth and their parents aimed at improving metabolic control.

Few, if any, studies to date have used downloaded blood glucose readings from routine clinical care as a measure of glycemic variability and assessed their association with psychosocial factors, specifically fear of hypoglycemia and parental monitoring. Further, the ADRR analysis of glycemic variability has not been used in youth populations, and a significant relation to HbA1c will help establish its utility in pediatric studies. Confirmation of the proposed relations in this study may help guide treatment recommendations as well as intervention formulation for fluid, multi-layered youth populations.

Hypotheses

1. Average blood glucose levels will significantly relate to metabolic control (HbA1c).
2. Higher frequency of blood glucose monitoring will be related to better metabolic control.
3. ADRR will be more highly related than MAGE with metabolic control.
4. Parental monitoring will be positively related to more Intervention and Prevention Behaviors in response to hyperglycemia and hypoglycemia.

Mediators/Moderators

1. The relation between average blood glucose levels over the previous 30 days and metabolic control will be mediated by parental monitoring, with increased parental monitoring related to better metabolic control.
2. Fear of hypoglycemia will moderate the relation between the percentage of blood glucose levels below, within, and above range and metabolic control, with increased youth and parent fear of hypoglycemia related to more out-of-range blood glucose levels and poorer HbA1c levels.

Method

Participants

Participants were adolescents recruited between ages 11 and 14 along with a parent or chief caregiver, who visited a healthcare practitioner at one of two metropolitan pediatric endocrinology clinics. Data were collected from follow-up assessments of a longitudinal randomized clinical trial (RCT) of parental monitoring in youth's T1D care. Inclusion criteria required a diagnosis of T1D for at least one year prior to enrollment, no

other major chronic illness or injury, absence of mental disability, and fluency in reading and writing English. This sample was comprised of 106 participants; 64 girls (61.0%), mean age of 14 years ($SD = 1.3$), 30-day average blood glucose level of 216 mg/dl ($SD = 53.7$) and HbA1c of 8.8 ($SD = 1.5$). The sample was self-identified as 69.5% Caucasian, 17.1% African American, 6.7% Hispanic, and 6.7% Pacific Islander or Other. Participant characteristics are displayed in Table 1.

Table 1.

Participant Characteristics (n=107)

	<i>n (%)</i>
Male	41 (39%)
Female	64 (61%)
Ethnicity: Caucasian	73 (69%)
African American	18 (17%)
Hispanic	7 (7%)
Pacific Islander	1 (1%)
Other	6 (6%)
Insulin Regimen: CSII or pump	54 (53%)
Intensive	29 (28%)
Conventional	19 (19%)

Procedure

Sample youth and parents were participants in a RCT intended to prevent deterioration in youth diabetes disease care. Written parental consent and youth assent were obtained and youth and one parent were seen in conjunction with their regular pediatric endocrinology appointment. Through study follow-up assessments, collection of blood glucose data became available for analysis. During an evaluation, a trained research assistant interviewed parent and youth separately and disseminated questionnaires. Youth and families received \$75 for participation. Data were drawn from the most current session available for a youth that had accompanying blood glucose data. At least three blood glucose values per day over a 30-day period were extracted from youths' blood glucose meters as a requirement for study inclusion; if blood glucose data were not obtained at an appointment, the participant was excluded from participation in these analyses.

Measures

Blood Glucose Levels

Blood glucose levels from the previous 30 days were obtained from participant's blood glucose meters' memory. Both ADRR and MAGE provide optimal results from 30 days of data; however, a minimum of 14 days in the previous 30 with three blood glucose checks is necessary for the glycemic variability calculations (Kovatchev et al., 2006; Service et al., 1970). Only conventional blood glucose meters were included. Data were obtained during assessments at youth's endocrinology visits. Blood glucose meters were downloaded onto a laptop computer through the use of brand-supplied specific software and cables. If blood glucose meters were unable to be downloaded, numbers were manually copied from meters by research assistants in the clinic and later entered into a

computer database. Family generated blood glucose logs that were hand-written were not included due to concerns about their reliability (Gonder-Frederick, Julian, Cox, Clarke, & Carter, 1988). If families did not have downloadable or blood glucose meter data that could be transcribed in the clinic, their assessment data could not be included in the study.

Blood glucose levels were classified into three categories: readings below recommended range (<70 mg/dl), readings within recommended range (70-200 mg/dl), and readings above recommended range (>200 mg/dl). These ranges were calculated to determine independently the correspondence of each glycemic variability measure with ADA blood glucose range criteria and examine the sensitivity of each measure to ADA blood glucose range criteria.

Blood Glucose Monitoring

The 24-hour Diabetes Interview (Holmes, et al., 2006 adapted from Johnson, 1986) is a disease care measure which focuses on highly specific behavior over a relatively brief time period. Administration time is approximately 25 minutes, per interview for parent and youth, separately. The seven disease care domains include: 1) Frequency of Blood Glucose Monitoring, 2) Meal/Snack Frequency, 3) Percentage of Daily Calories from Fats and 4) Carbohydrates, 5) Exercise Duration, 6) Exercise Frequency, and 7) Insulin Regimen. This study only utilized the Frequency of Blood Glucose Monitoring domain. Parent and youth are interviewed on two separate occasions within a two week period. Participants are asked to recall the previous 24-hours in temporal sequence from the time the youth wakes. The interviewer records all diabetes relevant activities which include: Insulin injections, blood glucose monitoring, nutritional

intake, and exercise. The interviewer asks the time, who performed a behavior, whether an adult observed, and whether a parent or adult discussed the activity with the youth for each disease care behavior. Blood glucose levels are obtained from a youth's blood glucose meter read by the parent or youth. Those who administer the 24-hour interview submit to an intensive training process to ensure inter-rater reliability and familiarity with the measure and scoring process. Acceptable parent-youth agreement, test-retest reliability, internal consistency, and predictive validity have been found (Freund, Johnson, Silverstein, & Thomas, 1991; Johnson, 1986).

ADRR

The ADRR calculation requires at least 14 days out of 30 days where three blood glucose readings were taken per day (Kovatchev et al., 2006). Blood glucose values are normalized using a logarithmic data transformation that matches the clinical and numerical center of the blood glucose scale, thus making the transformed data symmetric; without this data transformation, many parametric statistical assumptions are violated unknowingly. After the data are transformed, blood glucose readings are converted into risk values, using all of the readings below the mean and all of the readings above the mean as overall indicators of risk for hypo- and hyperglycemia (Kovatchev et al., 2006). ADRR values are distributed into three categories based on established categories derived from data with adult samples: levels lower than 20 indicative of low risk, values 20 to 40 demonstrative of moderate risk, and values greater than 40 characteristic of high risk (Kovatchev et al., 2006).

MAGE

To compute MAGE, the difference from the previous blood glucose value is calculated for each individual blood glucose value. Each difference score is compared against the average of all blood glucose values in that day and only differences exceeding one standard deviation from the average are included. The arithmetic mean of the remaining differences is calculated, resulting in the MAGE value. MAGE values have a possible range of 20 to greater than 125. MAGE values greater than 125 indicate the participant is an “unstable diabetic” (Service et al., 1970).

Parental monitoring

The Parental Monitoring of Diabetes Care Scale (PMDS) is a 19-item questionnaire that measures parental monitoring and involvement in their youth’s daily diabetes management and care (Ellis et al., 2008). It has two versions, one parent-report and one child-report; for this study, parent and child report scores were averaged and the resultant mean score was used in statistical analyses. Eighteen items are rated on a five-point Likert scale (1 = more than once a day to 5 = less than once a week), while the last item is an open-ended item. Subscales include 1) Supervision of the Availability of Medical Supplies/Devices, 2) Monitoring of Blood Glucose Checking, 3) Oversight of Diet, 4) Monitoring of Nonadherence, and 5) Direct Oversight of Diabetes Management Behaviors. A total score is obtained by summing all items after reverse scoring; possible scores range from 18-90. This study examined the summation of all subscales for a total parental monitoring score. Analyses show the mean total score to be 72.87 +/- 9.83, with acceptable internal consistency (.81) and test-retest reliability (.80) (Ellis et al., 2008).

Fear of hypoglycemia

The original Hypoglycemic Fear Survey (HFS; Irvine, Cox, & Gonder-Frederick, 1987) was used to measure fear experienced with respect to hypoglycemia, with both parent and youth versions. Youth and parent report were averaged in this study to describe the family's overall fear of their child becoming hypoglycemic. The HFS is a 27-item self-report scale later revised to include only 23 items rated on a five-point Likert scale (0 = *never* to 4 = *always*) (1994). Subscales include Worry and Behavior, but only the Worry subscale from the youth version was used. A total score is attained by summing all responses, with possible scores ranging from zero to 52. Analyses show the mean total score to be 38 +/- 12, with superior internal consistency (.96) and good test-retest reliability (.64-.76) (Irvine, Cox, & Gonder-Frederick, 1994).

Diabetes Care Behavior

The Diabetes Behavior Rating Scale (DBRS) is a self-report measure of youth disease care which uses report by parent and youth separately (Iannotti et al., 2006). Subscales include Daily Prevention Behaviors (0 = never to 4 = always), Modification of Diabetes Care Plan (0 = never to 5 = five times), Intervention Behaviors (0 = none to 5 = five times), and Other Diabetes Care Practices (0 = never to 5 = five times). This study only examined the Intervention and Prevention Behavior subscale responses averaged from youth and parent questionnaires. Only these subscales were included because they reflect self-care behaviors performed in reaction to or prevention of blood glucose values out of range. Intervention and Prevention Behavior subscale responses provide information about youth responses to and preparations for high and low blood sugars. Analyses show the mean total score to be .75 +/- .10, with satisfactory internal

consistency (.84), test-retest reliability (.71), and parent/youth agreement (.48) (Iannotti et al., 2006).

Metabolic Control

Metabolic control was determined by HbA1c level at the time of a youth's medical appointment. The HbA1c level was measured with a Bayer DCA 2000 Analyzer, which delivers in office results in five minutes at the time of a youth's endocrinology appointment. DCA 2000 Analyzer HbA1c values are strongly correlated with the Diabetes Control and Complications Trial/Epidemiology of Diabetes Interventions and Complications central laboratory values ($r = .940, p < .001$), which serve as a reference standard against which other assays are compared (Tamborlane et al., 2005). HbA1c levels were obtained from medical records after meeting with participants and obtaining consent at initial assessment.

Socioeconomic Status

Socioeconomic status (SES) was determined with the Hollingshead Index of Socio-Economic Status (Hollingshead, 1975). Parents of youth participants completed this worksheet with information regarding marital status, employment status, and education level for both parents (except in single parent households). Scores range from 8-66 and are grouped into five social classes: Class V (8-17), Class IV (18-28), Class III (29-47), Class II (48-59), and Class I (60-66). Lower classes (higher scores) indicate higher SES. Raw scores were used in these analyses.

Data Analysis Plan

Initial data cleansing identified univariate and multivariate outliers, which were transformed, Winsorized, or removed, based on the severity of deviation from the data

set. Residual scatterplots were examined for normality, linearity, and homoscedasticity, and data were checked for multicollinearity, and singularity. Each participant's blood glucose data were examined to verify three or more blood glucose checks per day, at least 14 days out of 30, were performed. If these criteria were not met, the participant was excluded from analyses. Blood glucose values were then formatted appropriately for each formula and calculations were performed to obtain ADRR and MAGE values for each participant.

A correlation coefficient matrix was completed to determine correlations between HbA1c and all variables of interest, including average blood glucose levels per participant, frequency of blood glucose monitoring, MAGE, and ADRR values. Pearson's r was also calculated to determine the relation of parental monitoring to Intervention and Prevention behaviors performed by youth, as measured by the DBRS. Hierarchical multiple regressions were performed with average blood glucose levels as the independent variable, HbA1c as the dependent variable, and PMDS total parental monitoring score entered as a mediator. Blood glucose levels were then classified into three categories: readings below recommended range (<70 mg/dl), readings within recommended range (70-200 mg/dl), and readings above recommended range (>200 mg/dl). Hierarchical regression analyses were performed for youth and parent fear of hypoglycemia on the HFS and the percentage of blood glucose readings below, within, and above range predicting HbA1c.

Results

A logarithmic transformation was performed on the variable "Frequency of Blood Glucose Monitoring" due to high skewness and kurtosis values. Homogeneity of variance of the data was confirmed by a nonsignificant Levene's Test of Equality of

Variances for each variable. Finally, graphs of all variables confirmed normal distribution of the data.

This study sample was comprised of mostly middle-class participants, with a mean Hollingshead Index of 46.6 ($SD = 13.2$). The sample generally was in moderate metabolic control, with a mean HbA1c level of 8.8% ($SD = 1.5$). The average sample blood glucose value was 216 mg/dl with a range of 124-400 mg/dl ($SD = 53.7$). On average, blood glucose levels were checked 3.9/day ($SD = 1.4$). Both ADRR and MAGE values were found to be high in this sample, with 67.6% maintaining “high risk” ADRR values and 85.9% categorized as “unstable diabetic range” according to their MAGE values. No participants had “low risk” ADRR values and only 14.1% of participants were in the “stable diabetic range” per MAGE values. Parental monitoring scores were high for this sample, with a mean score of 75.8 ($SD = 6.8$) on the PMDS. Prevention and Intervention scores were in the moderate range, with means and standard deviations of 46.2 ($SD = 9.2$) and 25.4 ($SD = 4.9$), respectively. Scores on the Hypoglycemic Fear Survey were low, indicating a minimal youth and parent fear of hypoglycemia among these youth, with a mean score of 14.9 ($SD = 7.6$). Means and standard deviations of all psychosocial and disease care variables examined in this study are reported in Table 2. The correlation matrix of all variables is displayed in Table 3.

Table 3.

Correlations between Demographic, Disease Care, Psychosocial Variables from Sample

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
1. Age	-												
2. HbA1c	.061	-											
3. Avg BG Level	.083	.660***	-										
4. % Below	.018	-.354***	-.615***	-									
5. % Within	-.041	-.529***	-.838***	.255**	-								
6. % Above	.004	.612***	.895***	-.637***	-.833***	-							
7. ADRR ^a	.111	.422***	.605***	.067	-.703***	.419***	-						
8. MAGE ^b	.179	.405***	.564***	-.025	-.578***	.291*	.834***	-					
9. BG Freq	.109	-.08	.015	-.045	.021	-.007	-.089	.043	-				
10. HFS ^c	.015	.272**	.157	.021	-.176	.165	.125	-.003	.016	-			
11. Prev	-.428***	-.279**	-.304**	.135	.154	-.152	-.153	-.387***	-.010	-.239*	-		
12. Int	-.164	-.158	-.208*	.147	.153	-.193*	-.072	-.117	-.249*	.000	.259**	-	
13. PMDS ^d	-.345***	-.259**	-.243*	.071	.153	-.121	-.241*	-.444***	.143	-.104	.668***	.051	-
14. SES	.098	-.343***	-.424***	.154	.326***	-.319**	-.221	-.134	-.084	-.228*	.148	.387***	-.031

Note. *p<.05. **p<.01. ***p<.001. ADRR^a: lower values indicate lower glycemic variability. MAGE^b: lower values indicate lower glycemic variability. HFS^c: higher values indicate more fear of hypoglycemia. PMDS^d: higher scores indicate more parental monitoring. Socio-economic Status (SES): Higher scores indicate higher SES.

Relation between Average Blood Glucose Levels and HbA1c

Pearson's r was calculated to determine the relation between HbA1c and average blood glucose levels. There was a significant positive correlation between metabolic control and average blood glucose levels ($r = .66, p < .001$).

Relation between Frequency of Blood Glucose Monitoring and HbA1c

Pearson's r was calculated to determine the relation between HbA1c and frequency of blood glucose monitoring. The transformed frequency of blood glucose monitoring variable was used in this analysis. Frequency of blood glucose monitoring was not found to be correlated with metabolic control as hypothesized, ($r = -.08, p = .419$).

Relation among HbA1c, ADRR, and MAGE

Pearson's r was calculated to determine the relation between HbA1c and MAGE and ADRR. ADRR and MAGE were equivalently correlated with HbA1c, with correlations of ($r = .42, p < .001$) and ($r = .41, p < .001$), respectively.

Relation among Parental Monitoring, Intervention Behaviors, and Prevention Behaviors

Pearson's r was calculated to determine the relation between parental monitoring and intervention and prevention behaviors as performed by youth. Prevention behaviors were strongly correlated with parental monitoring, ($r = .67, p < .001$). Intervention behaviors were not related to parental monitoring as hypothesized, ($r = .05, p = .610$).

Effect of Parental Monitoring on Relation between Average Blood Glucose Levels and HbA1c

A Baron & Kenny mediation analysis (1986) was performed with multiple regressions to determine whether parental monitoring mediated the relation between average blood glucose levels and HbA1c. Multiple regression indicated a relation between average blood glucose levels and HbA1c ($B = .02, \beta = .66, p = .000$). Next, a relation between average blood glucose levels and parental monitoring ($B = -.03, \beta = -.24, p = .013$) was established. However, the effect of parental monitoring on HbA1c was not significant ($B = -.11, \beta = -.02, p = .173$). As a final step in the mediation analysis, a regression was conducted with both parental monitoring and average blood glucose levels as predictors of HbA1c. As Figure 1 illustrates, the relation between average blood glucose levels and HbA1c was not mediated by parental monitoring, because the relation between average blood glucose values and HbA1c remained significant ($B = .01, \beta = .64, p = .001$).

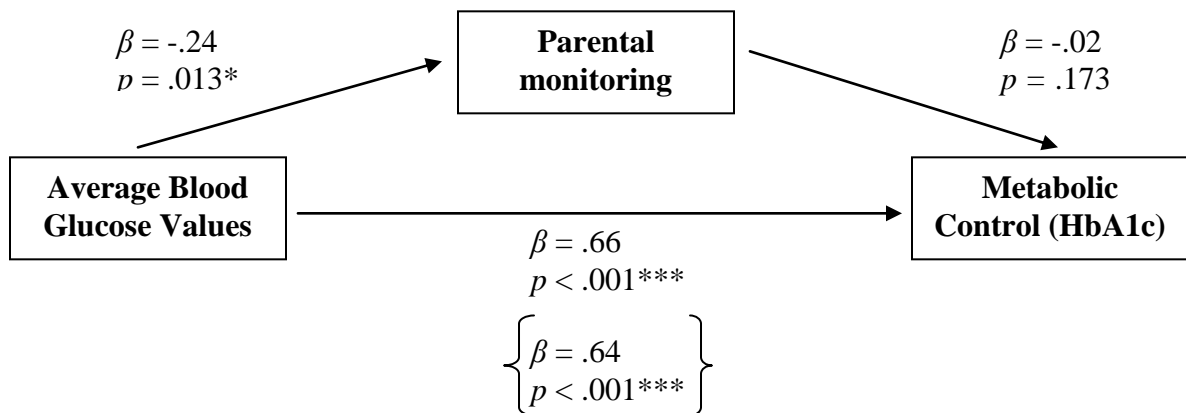


Figure 1. Standardized regression coefficients for the relation between average blood glucose values and metabolic control as mediated by parental monitoring. The standardized regression coefficient between average blood glucose values and metabolic control controlling for parental monitoring is in brackets.

Effect of Fear of Hypoglycemia on Percentage of Blood Glucose Levels Below, Within, and Above Range, and HbA1c

A Baron & Kenny moderation analysis (1986) was performed to determine whether fear of hypoglycemia moderated the relation between percentage of blood glucose levels below, within, and above range, and HbA1c. Using a hierarchical multiple regression equation in PASW, the percentage of blood glucose levels below, within, or above were entered in step 1. In step 2, the percentage of blood glucose levels below, within, or above were entered and HFS scores. In step 3, percentage of blood glucose levels below, within, or above range were entered; HFS scores; and the interaction term of the two variables. Results are presented below in Table 4.

Table 4.

Moderation Analyses Examining Effects of Fear of Hypoglycemia on the Relations between Percentage of Blood Glucose Levels Below, Within, and Above Range and HbA1c

	% Below			% Within			% Above		
	B	t	P	B	t	p	B	t	P
Step 1									
%	-.07	-3.80	.000	-.05	-6.30	.000	.05	7.87	.000
Step 2									
%	-.08	-3.89	.000	-.05	-6.20	.000	.05	7.88	.000
HFS	.04	1.35	.180	-.01	-.67	.503	.03	1.27	.206
Step 3									
%	-.09	-3.55	.001	-.05	-5.97	.000	.05	7.84	.000
HFS	.04	1.37	.173	-.01	-.68	.498	.02	1.24	.217
% x HFS	-.00	.31	.759	-.00	.72	.474	.00	-.31	.761

Percentage of blood glucose levels below range were inversely related to HbA1c ($\beta = -.07, t = -3.80, p = .000$). Fear of hypoglycemia was not significantly related to HbA1c ($\beta = .04, t = 1.35, p = .180$). Fear of hypoglycemia did not significantly moderate

the association between percentage of blood glucose levels below range and HbA1c ($\beta = .00, t = .31, p = .759$) (See Figure 2).

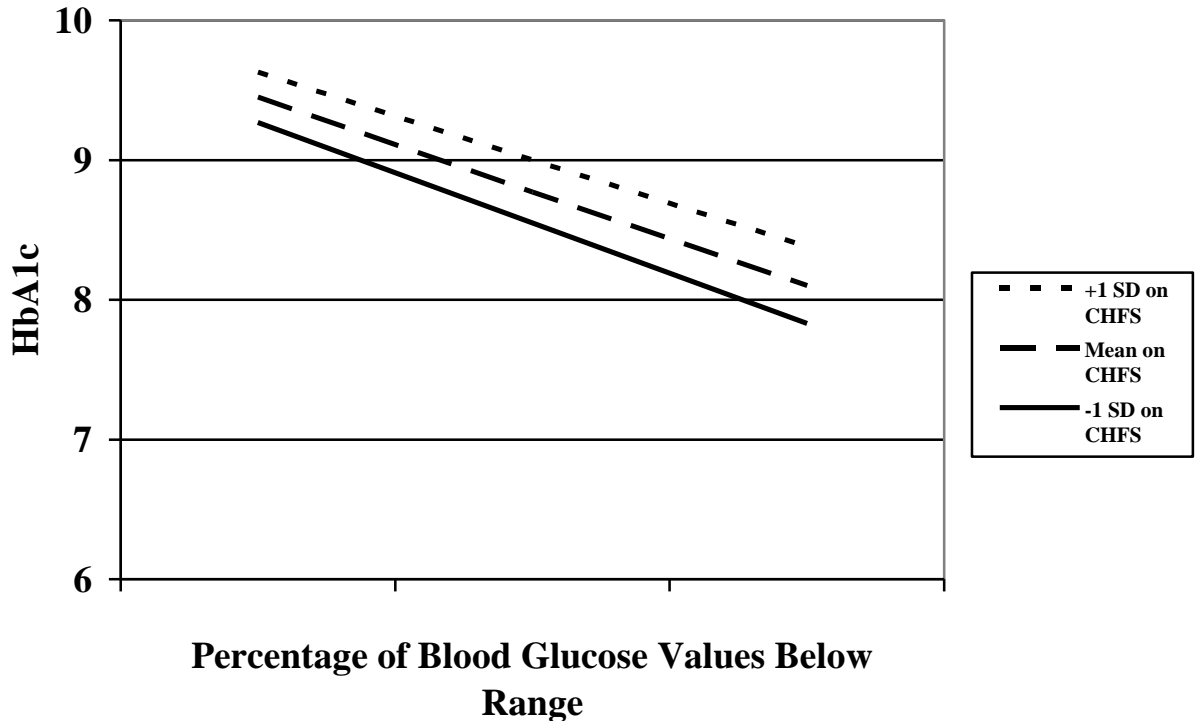


Figure 2. Sample slopes of blood glucose values below range predicting HbA1c for 1 SD below the mean of fear of hypoglycemia, the mean of fear of hypoglycemia, and 1 SD above the mean of fear of hypoglycemia.

Percentage of blood glucose levels within range were inversely related to HbA1c ($\beta = -.05, t = -6.30, p = .000$). Fear of hypoglycemia was not significantly related to HbA1c ($\beta = -.01, t = -.67, p = .50$). Fear of hypoglycemia did not significantly moderate the association between percentage of blood glucose levels below range and HbA1c ($\beta = .00, t = .72, p = .47$) (See Figure 3).

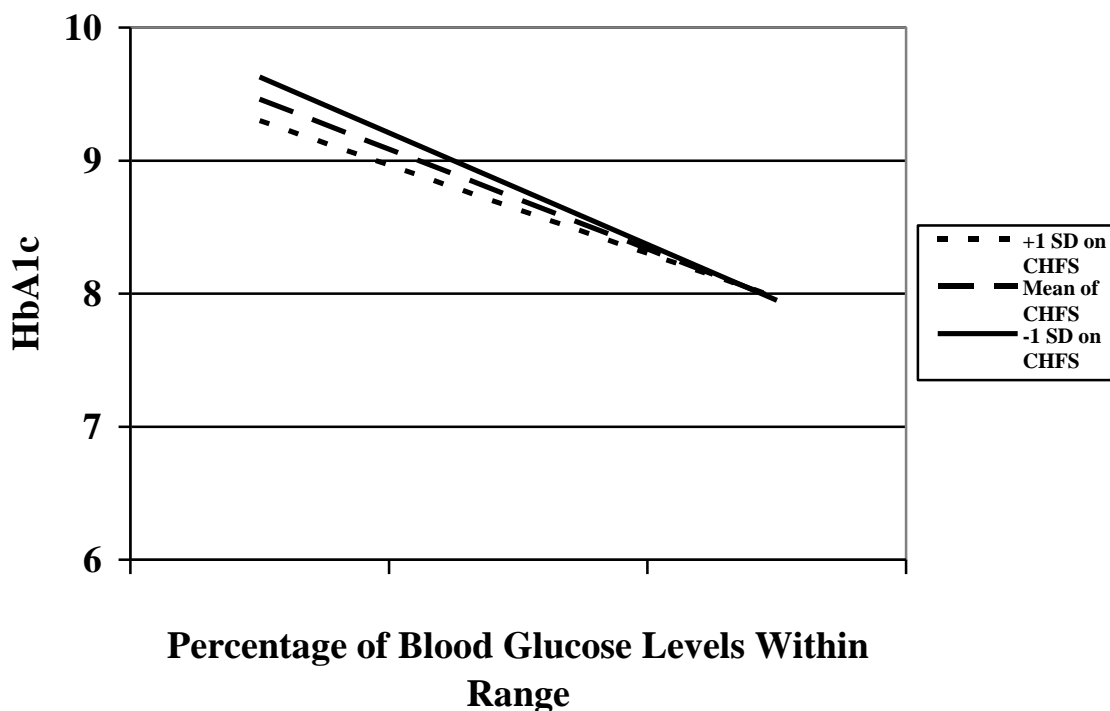


Figure 3. Sample slopes of blood glucose values within range predicting HbA1c for 1 SD below the mean of fear of hypoglycemia, the mean of youth and parent fear of hypoglycemia, and 1 SD above the mean of fear of hypoglycemia.

Percentage of blood glucose levels above range were positively related to HbA1c ($\beta = .05, t = 7.87, p = .000$). Fear of hypoglycemia was not significantly related to HbA1c ($\beta = .03, t = 1.27, p = .206$). Fear of hypoglycemia did not significantly moderate the association between percentage of blood glucose levels above range and HbA1c ($\beta = .00, t = -.31, p = .761$) (See Figure 4).

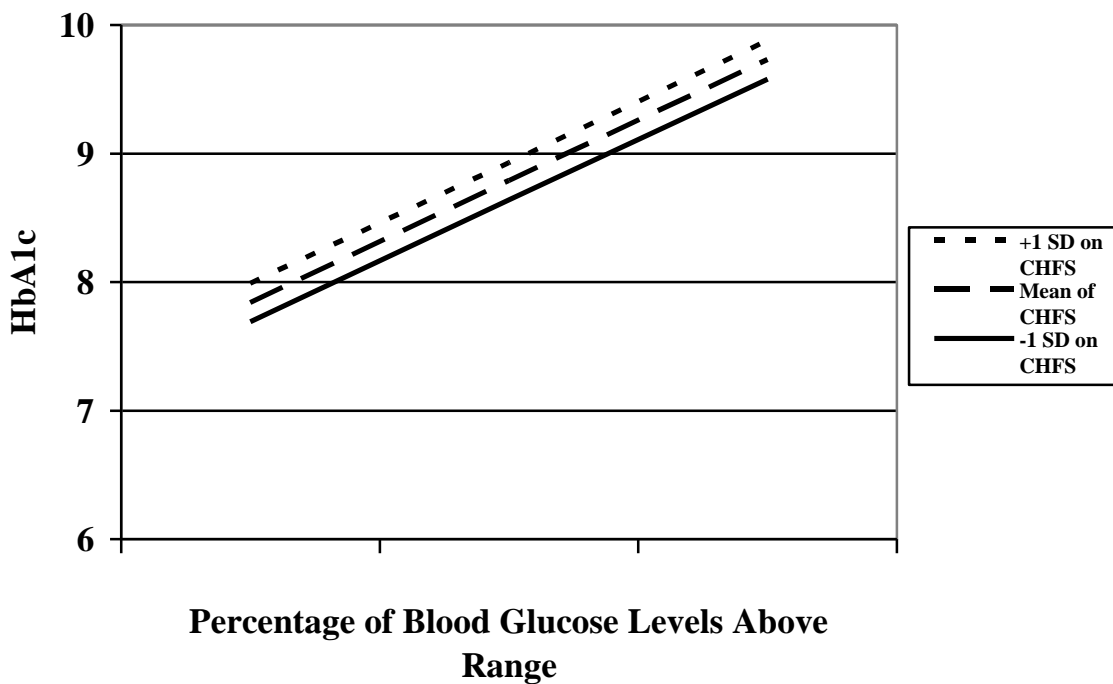


Figure 4. Sample slopes of blood glucose values above range predicting HbA1c for 1 SD below the mean of fear of hypoglycemia, the mean of fear of hypoglycemia, and 1 SD above the mean of fear of hypoglycemia.

Unanticipated significant correlations were found among variables; only significant findings related to SES, as well as ADRR high risk values will be reported and discussed. SES was significantly correlated with HbA1c ($r = -.34, p = .001$), average blood glucose level ($r = -.42, p = .000$), percentage of blood glucose values within range ($r = .33, p = .001$), percentage of blood glucose values above range ($r = -.32, p = .002$), and intervention behaviors ($r = .39, p = .000$). The ADRR high risk values were significantly correlated with HbA1c ($r = .55, p = .000$), average blood glucose level ($r = .90, p = .000$), percentage of blood glucose values below range ($r = -.39, p = .001$), within range ($r = -.79, p = .000$), percentage of blood glucose values above range ($r = .69, p =$

.000), prevention behaviors ($r = -.24, p = .042$), and parental monitoring ($r = -.27, p = .023$).

Comparison of ADRR and MAGE to Percentage of Blood Glucose Levels Below, Within, and Above Range

Comparison of ADRR and MAGE to blood glucose levels below, within, and above recommended range was made to determine the correspondence of each glycemic variability measure with ADA blood glucose range criteria and examine the sensitivity of each measure to ADA blood glucose range criteria. ADRR was significantly related to the percentage of blood glucose levels within range ($r = -.70, p = .000$) and blood glucose levels above range ($r = .42, p = .000$). MAGE was significantly related to the percentage of blood glucose levels within range ($r = -.58, p = .000$) and blood glucose levels above range ($r = .29, p = .014$). Neither glycemic variability measure was related to percentage of blood glucose levels below range.

***Post-hoc* Analyses**

Post-hoc exploratory analyses with HbA1c, SES, and measures of metabolic control were conducted to explore whether once controlling for SES, if ADRR or MAGE added any information to HbA1c above any other metabolic control measures. A series of hierarchical multiple regressions were performed. Average blood glucose value was consistently the strongest predictor of HbA1c, followed by percentage of blood glucose values below range, blood glucose values above range, and blood glucose values within range. Results are shown below in Tables 5 through 8.

In a hierarchical multiple regression using SES, average blood glucose level, percentage of blood glucose levels below range, percentage of blood glucose levels

within range, and percentage of blood glucose levels above range as predictors of HbA1c, all were significant except for SES. Average blood glucose levels were positively related to HbA1c ($\beta = .02, t = 3.63, p = .000$), as were percentage of blood glucose levels below range ($\beta = .08, t = 2.61, p = .011$), within range ($\beta = .06, t = 2.36, p = .021$), and above range ($\beta = .05, t = 2.42, p = .018$). Results are shown below in Table 5.

Table 5.

Hierarchical Multiple Regression Examining Relation of HbA1c to Socioeconomic Status, Average Blood Glucose Level, Percent Below, Within, and Above Range

	B	HbA1c	
		t	P
SES	> -.01	-.65	.517
Average BG	.02	3.63	.000
% Below	.08	2.61	.011
% Within	.06	2.36	.021
% Above	.05	2.42	.018

In a hierarchical multiple regression using SES, average blood glucose level, and ADRR as predictors of HbA1c, only average blood glucose level was a significant predictor of HbA1c ($\beta = .01, t = 2.82, p = .007$). Results are shown below in Table 6.

Table 6.

Hierarchical Multiple Regression Examining Relation of HbA1c to Socioeconomic Status, Average Blood Glucose Level, and ADRR

	B	HbA1c	
		t	P
SES	-.01	-1.07	.29
Average BG	.01	2.82	.007
ADRR	.02	1.22	.227

In a hierarchical multiple regression using SES, average blood glucose level, and MAGE as predictors of HbA1c, only average blood glucose level was a significant predictor of HbA1c ($\beta = .01, t = 3.19, p = .002$). Results are shown below in Table 7.

Table 7.

Hierarchical Multiple Regression Examining Relation of HbA1c to Socioeconomic Status, Average Blood Glucose Level, and MAGE

	B	HbA1c	
		<i>t</i>	<i>P</i>
SES	-.01	-1.15	.254
Average BG	.01	3.19	.002
MAGE	.00	1.14	.259

In a hierarchical multiple regression using SES and average blood glucose level as predictors of HbA1c, only average blood glucose level was a significant predictor of HbA1c ($\beta = .02, t = 6.93, p = .000$). Results are shown below in Table 8.

Table 8.

Hierarchical Multiple Regression Examining Relation of HbA1c to Socioeconomic Status and Average Blood Glucose Level

	B	HbA1c	
		<i>t</i>	<i>P</i>
SES	-.01	-.955	.342
Average BG	.02	6.93	.000

The utility of separate high and low risk values in the ADRR calculation was also explored. A Baron & Kenny mediation analysis (1986) was performed with multiple regressions to determine whether parental monitoring mediated the relation between ADRR high risk values and HbA1c. Multiple regression indicated a relation between ADRR high risk values and HbA1c ($B = .05, \beta = .549, p = .000$). Next, a relation between

ADRR high risk values and parental monitoring ($B = -.54, \beta = -.27, p = .023$) was established. As a third step, a relation between parental monitoring and HbA1c ($B = -.06, \beta = -.26, p = .008$) was established. As a final step in the mediation analysis, a regression was conducted with both parental monitoring and average blood glucose levels as predictors of HbA1c. The relation between ADRR high risk values and HbA1c was not mediated by parental monitoring, because the relation between average blood glucose values and HbA1c remained significant ($B = .05, \beta = .52, p = .000$), and the relation between parental monitoring and HbA1c became nonsignificant ($B = -.02, \beta = -.11, p = .302$).

Discussion

The current study explored pediatric blood glucose levels and compared different measures of glycemic variability to a traditional measure of metabolic control (HbA1c). Also, the current study sought to confirm existing research establishing frequency of blood glucose monitoring as a predictor of better metabolic control. The relation of parental monitoring with intervention and prevention behaviors was examined. Finally, parental monitoring and fear of hypoglycemia were explored as potential mediators and moderators, respectively, of the relation between glycemic variability and metabolic control.

Average blood glucose levels were strongly related to HbA1c, confirming HbA1c as an appropriate composite indicator of average blood glucose levels over the previous 30-day period. Current findings replicate, in a pediatric sample, relations found between average blood glucose levels and HbA1c in adult populations with T1D (Hempe et al., 2002). As most blood glucose meters may be downloaded, parents and youth may view individual blood glucose levels over time, as well as a youth's average blood glucose

value, and gain an approximation of his or her average level of metabolic control. This information will allow families to make adjustments in between their 3-month endocrinology appointments. Additionally, blood glucose monitors allow families or youth to track specific disease care behaviors (e.g., checking blood glucose levels before sports practice) and to detect declines or fine-tune their insulin regimen.

Increased frequency of blood glucose monitoring is strongly related to better metabolic control in the literature (Anderson et al., 1997; Bott et al., 1994; Vanelli, Cerutti, Chiarelli, Lorini, & Meschi, 2005). However, the current study did not find a relation between frequency of blood glucose monitoring and metabolic control. In this sample, youth who checked blood glucose levels more frequently did not have lower HbA1c levels compared with youth who checked blood glucose levels less frequently. Several factors may contribute to the present lack of a relation; first, the sample was limited to participants who remembered to bring their blood glucose meter to their appointment, possibly excluding youth in poorer metabolic control who forgot or purposefully did not bring their meter. Unintentionally forgetting to bring a meter is a statistical shortcoming, while purposefully not bringing a meter is a diabetes care issue. Finally, if youth with multiple blood glucose meters neglected to bring one of them, (e.g., they left their school meter at the nurse's office), their data were incomplete, falsely reflecting a lower frequency of blood glucose monitoring.

Thus far in the literature, neither ADRR nor MAGE have been used to examine glycemic variability in pediatric populations with T1D. Both were related to HbA1c, with ADRR and MAGE accounting for a small amount of the variance in HbA1c. These findings establish each technique as an appropriate measure of glycemic variability in

youth with T1D; however, average blood glucose level (automatically calculated by most blood glucose meters) accounted for more than twice the amount of variance in HbA1c than ADRR or MAGE.

While each glycemic variability method provides information about blood glucose excursions, application is limited to youth who perform at least three or more checks per day. ADRR requires at least 15 days out of a 30-day range that individuals check blood glucose levels at least three times each day. Thus, data from youth who neglect to check their blood glucose three or more times per day are not eligible for analysis by this method. Additionally, ADRR and MAGE are both time-consuming to compute without specialized software. Finally, ADRR and MAGE values in this sample were very high, in with 79 to 91% in the 'high risk' categories, indicating greater glycemic variability among youth in comparison with adult populations on which these measures were developed. Sample average ADRR and MAGE values in adult populations range from 25.5 (SD=7.95; Bruttomesso et al., 2007) to 33 (Kim et al., 2011), and 65.6 (SD=34.9; Fabricatore, Ebbeling, Wadden & Ludwig, 2011) to 69.0 (SD=18.1; Marfella et al., 2009), respectively.

The risk categories established by ADRR and MAGE may not be the most appropriate ranges for pediatric glycemic variability. Adolescents' blood glucose levels oscillate due to fluctuations in hormone production (Amiel et al., 1986). However, a recalibration of a glycemic variability measure specifically for youth may provide useful descriptive information within this group who experience a high level of glycemic variability. If glycemic variability is to serve as a complementary measure of youths' metabolic control, it must accurately reflect swings in blood glucose values. Neither

glycemic variability measure was significantly associated with percentage of blood glucose levels below range, indicating that neither measure is sensitive to hypoglycemic fluctuations in blood glucose levels. Measures of glycemic variability should also provide information above and beyond HbA1c, which did not occur in the current sample.

Existing blood glucose variability measures such as ADRR and MAGE add little, if any, descriptive information to youths' metabolic control. If families seek additional information about youths' blood glucose levels and how they relate to youths' metabolic control, a more useful measure may be the percentage of blood glucose levels below, within, and above the ADA recommended range of blood glucose values. Families may calculate this comparison independently at home with a calculator, and it provides similar information as more complex calculations such as ADRR or MAGE. Home calculation of the percentage of blood glucose values below, within, and above ADA recommended ranges may not be a realistic recommendation for daily diabetes management, but families could obtain this information if they desired. Blood glucose levels within and above range were more strongly correlated with HbA1c than ADRR or MAGE, and easier to interpret (see Table 3). Many blood glucose meters, when downloaded, automatically calculate the percentage of blood glucose levels below, within, and above individually programmed ranges of blood glucose values, as well as the youth's average blood glucose level.

Parental monitoring was strongly correlated with prevention behaviors, accounting for a large proportion of the variance in prevention behaviors performed by families. The prevention behaviors subscale includes options such as "having supplies

available,” which parents are more apt to do than youth. Parental monitoring was not correlated with intervention behaviors; youth may be more intrinsically motivated to address hypo- or hyperglycemia, as they don’t necessarily require parental prompting to address high or low blood glucose levels. Conversely, youth may not perform intervention behaviors as frequently as they perform prevention behaviors. Intervention behaviors require decisions to be made which are not set in the diabetes regimen, may be unexpected, and may occur at a time when the youth is away from his or her parents. Thus, it may be more difficult for youth to perform these novel intervention behaviors compared with more “automatic” prevention behaviors. Parents could work with youth and problem-solve different situations to prepare them to act in these circumstances. For example, parent and youth could explore solutions to treating hyperglycemia during sporting events or planning for hypoglycemia by always carrying a fast-acting carbohydrate.

Parental monitoring did not mediate the relation between average blood glucose levels and HbA1c. This is most likely due to the strong mathematical relation between average blood glucose levels and HbA1c, such that HbA1c levels may be expressed as average blood glucose level for most patients with T1D (Lenters-Westra & Slingerland, 2008; Nathan et al, 2008; Sultanpur, Deepa, & Kumar, 2010). Further, perhaps it is not surprising that the association between average blood glucose levels and HbA1c, two biologic indicators, exceeds that of a relation with a psychosocial variable.

Fear of hypoglycemia did not moderate the relation between the percentage of blood glucose levels below, within, and above range and HbA1c. The percentage of blood glucose levels below, within, and above range accounted for more of the variance

in HbA1c compared to fear of hypoglycemia. Overall, youths' and parents' fear of hypoglycemia demonstrated a weak relation with the percentage of blood glucose levels below range but no significant relations to levels within and above range. While results were congruent with expected hypotheses of a relation between fear of hypoglycemia and BG ranges, the association was weak, which contradicted expectation that youth who feared low BG levels would maintain hyperglycemia.

Percentage of blood glucose values above range had the strongest relation to HbA1c, followed by percentage of values within range, and was least related to percentage of values below range. Results suggest that HbA1c may be most heavily influenced by hyperglycemia, followed by euglycemia and hypoglycemia, which is consistent with previous literature regarding HbA1c composition (Goldstein et al., 1993; Rohlfing et al., 2002; Tahara, 1993).

As prevention behaviors increased in the sample, MAGE values decreased, which suggests that lower glycemic variability is related to preventive disease care behaviors. This indicates that youth who reliably perform the recommended number of blood glucose checks and administer insulin on schedule as prescribed by their physician have lower HbA1c values.

The literature has consistently shown a relation between SES and HbA1c in those with T1D (Carter et al., 2008; Secrest et al., 2011; Tahirovic & Toromanovic, 2010). Higher SES allows families to afford healthier foods and live in lower-stress environments, both of which play a part in better metabolic control and may contribute to the relation between SES and HbA1c. In turn, youth from lower SES families have higher HbA1c which places them at greater long-term risk for complications from diabetes (DCCT, 1994). There is a wealth of literature describing the strategies health

professionals use with lower SES families. These include culturally sensitive assessment tools by clinicians, engagement of community resources, support of public policy allowing access to affordable healthcare, and access to affordable, high-quality child care and support services (American Psychological Association [APA], 1998; APA, 1992; Kawachi & Kennedy, 1997). Resources for free test strips for blood glucose meters, healthier food at a lower cost, or support groups for youth with T1D to lower stress among youth and families may also be included. Approaches such as these assist families in finding solutions for barriers that may prevent youth from performing self-care behaviors completely or consistently.

Parental monitoring did not mediate the relation between ADRR high risk values and HbA1c. This finding may be due to the strong mathematical relation between ADRR high risk values and HbA1c. Additionally, the association between ADRR high risk values and HbA1c, two biologic indicators, exceeds any relation with a psychosocial variable. The failure of ADRR high risk values to provide information beyond glycemic control reinforces the conclusion that the percentage of blood glucose levels below, within, and above range, are most useful to families, as they provide information beyond HbA1c which is relatively easy to obtain and interpret.

Limitations

Limitations in this study relate primarily to the availability of participants' blood glucose data. Both of the glycemic variability indices under consideration, ADRR and MAGE, have criteria that exclude youth who do not check their blood glucose regularly, at least three times a day. Also, these formulas were developed using continuous blood glucose monitoring (CGM), which has advantages over conventional blood glucose

monitoring, such as a blood glucose reading every one to five minutes (Neithercott, 2011). All youth in the current sample used conventional blood glucose meters. Thus data were lost if they failed to bring one of their meters to their appointment to be downloaded and their data was unusable if they failed to complete sufficient blood glucose checks. In addition to missing blood glucose data from meters, research assistants occasionally forgot or were unable to download participant blood glucose meters. Finally, as the download of blood glucose data was added after the start of the RCT study, blood glucose data were incomplete for early participants. All of these factors resulted in a reduced sample size and lower statistical power (Kazdin, 2003).

Future Directions

The current study demonstrated the use of blood glucose data downloaded from pediatric participants' blood glucose meters in a research capacity. In the future, blood glucose data may be used to replace some parts of parent and youth questionnaires. For example, the question of blood glucose monitoring frequency could be replaced with the easy download of a blood glucose meter. This may be more accurate than a self-report measure and take the same amount of time as filling out a form. As described previously, ADRR and MAGE values in the current adolescent sample were high, with 79% of the sample falling in the "high risk" category for ADRR values and 91% of the sample falling in the "unstable diabetic range" for MAGE values. This renders relations to other variables difficult to interpret.

A glycemic variability measure normed on adolescent samples and tailored for youth could be explored in further studies, as results from the current study suggest limited clinical utility of the existing measures. Percentage of blood glucose levels

below, within, and above the recommended range proved to be simpler to calculate and to more accurately portray blood glucose patterns than a composite index from either glycemic variability measure. Blood glucose percentages also are more readily interpreted by professionals and families. While ADRR and MAGE indicated that 80% or more of the population was high risk, almost half, 41%, of all BG values in the sample were within the ADA recommended range. Nevertheless, approximately 60% of BG values were out-of-range which indicates that this issue is significant in pediatric groups. Families should continue to be provided an HbA1c level every three months, and if they are interested in fine-tuning their child's diabetes regimen, percentage of blood glucose values below, within, and above may be provided to guide self-care behaviors.

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List of References

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Appendix A

* attached in PDF document

Appendix B

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Appendix C

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Appendix D

* attached in PDF document

Appendix E

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Vita

Adrienne Paige Borschuk was born on June 23, 1987 in Baltimore, Maryland. She received her Bachelor of Arts in Psychology from Syracuse University and graduated magna cum laude in May 2009. She served as a research assistant for the Diabetes Adolescent Research Team one year prior to starting the Doctoral program at Virginia Commonwealth University.