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The Effect of a Low-Glycemic Diet vs a Standard Diet on Blood Glucose Levels and Macronutrient Intake in Children with Type 1 Diabetes

ALISHA J. ROVNER, PhD; TONJA R. NANSEL, PhD; LAUREN GELLAR, MS

ABSTRACT

A low-glycemic index (GI) diet may lower postprandial hyperglycemia and decrease the risk for postabsorptive hypoglycemia in people with type 1 diabetes. However, insufficient evidence exists on the efficacy of a low-GI diet to support practice recommendations. The goal of this study was to examine the blood glucose response to and the macronutrient composition of low-GI meals vs usual meals consumed ad libitum at home in children with type 1 diabetes. A within-subject, crossover design was employed. Twenty-three participants were recruited between June and August 2006. Participants wore a continuous blood glucose monitoring system and completed diet diaries on 2 days. On 1 day, participants consumed their usual meal; on another day, participants consumed low-GI meals ad libidum. Order of the 2 days was counterbalanced. The mean GI was 34±6 for the low-GI day and 57±6 for the usual meal day ($P<0.0001$). During the low-GI day, mean daytime blood glucose values (125±28 mg/dL [6.9±1.5 nmol/L] vs 185±58 mg/dL [10.3±3.2 nmol/L], $P<0.001$), blood glucose area above 180 mg/dL (4,486±6,138 vs 26,707±25,038, $P<0.006$), and high blood glucose index (5.1±5.1 vs 13.6±7.6, $P<0.001$) were lower compared to the usual mean day. During the low-GI day, subjects consumed more fiber (24.5±12.3 g vs 14.5±6.1 g, $P<0.007$) and less fat (45.7±12.2 g vs 76.8±32.4 g, $P<0.005$); however, there were no differences in energy, carbohydrate, or protein intake. In this pilot study, a low-GI diet was associated with improved diet quality and a reduction in hyperglycemia.

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A. J. Rovner is a post-doctoral fellow and T. R. Nansel is an investigator with the Division of Epidemiology, Statistics, and Prevention Research, Eunice Kennedy Shriver National Institute of Child Health and Human Development, National Institutes of Health Department of Health and Human Services, Bethesda, MD. L. Gellar is a doctoral degree student, Clinical and Population Health Research Division, University of Massachussets Medical School, Worcester.

Address correspondence to: Alisha J. Rovner, PhD, Division of Epidemiology, Statistics and Prevention Research, NICHD, NIH, DHHS, 6100 Executive Blvd, Room 7B13R, MSC 7500, Bethesda, MD 20892-7510. Email: rovneral@mail.nih.gov

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Nutrition therapy is an essential component of managing type 1 diabetes in children. The goals of nutrition therapy are to maintain optimal metabolic outcomes (ie, blood glucose levels and lipid profiles), to prevent and treat chronic complications of the disease, and to support growth and development (1).

The current American Diabetes Association dietary recommendations for type 1 diabetes focus on counting carbohydrates and matching insulin doses to the grams of carbohydrate consumed to mimic normal pancreatic function and achieve near normal blood glucose levels (1). This regimen implies that equal carbohydrate portions have the same effect on blood glucose; yet several factors, including the molecular structure of the carbohydrate, fiber content, and degree of processing affect blood glucose levels and result in differential blood glucose responses to the same amount of carbohydrate (2). Carbohydrates with a low glycemic index (GI) rank provoke a slower, more sustained blood glucose response; therefore, a low-GI diet has been proposed to improve glycemic control in children with diabetes (3-5). The GI assesses the blood glucose response to a fixed amount of carbohydrate from a food compared to the same amount of carbohydrate from glucose (6). In general, most vegetables (except white potatoes), most fruits, intact whole grains, and legumes have a low GI rank, whereas more refined and processed foods, such as white bread, typically have a high GI rank. The usefulness of a low-GI diet in diabetes management remains controversial (7-9). Proponents of the diet believe that it may control blood glucose better than current diet therapy (3-5,10,11). Alternatively, critics claim that it may limit food choice and increase fat intake (7,8).

Most of the research to date on low-GI diets has been in overweight children (12-14) and few studies have been conducted in children with type 1 diabetes (4,5,15,16). Recently a crossover design study of children with type 1 diabetes in the United States was published (16). The goal of that study was to determine the effect of low-GI meals (mean GI 40) and high-GI meals (mean GI 64) on blood glucose levels in a controlled setting. Participants demonstrated significantly lower daytime mean blood glucose, blood glucose area above 180 mg/dL (10 mmol/L), and high blood glucose index when consuming low-GI

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meals, but no differences were observed for the daytime blood glucose area under 70 mg/dL (3.9 mmol/L), daytime low blood glucose index, or for any nighttime parameters. That study was conducted in a highly controlled setting where all of the food was provided, macronutrient intake was kept consistent between conditions, and intake was monitored. Therefore, it is unknown whether the positive effects of a low-GI diet observed in a supervised setting would be generalizable to a less controlled home setting where children choose what, when, and how much to eat.

This study was conducted in conjunction with the above mentioned study (16). The first experiment determined the effect of high-GI and low-GI meals on blood glucose levels in a controlled setting. The second experiment, the results of which are reported here, extended this research question to the home environment with ad libitum consumption by children, and further examined the effect of low-GI meals on macronutrient intake. The purpose of this study was to determine the blood glucose response to and the macronutrient composition of low-GI meals vs usual meals consumed ad libitum at home by children with type 1 diabetes. The primary hypothesis was that blood glucose levels would be more favorable during consumption of low-GI meals vs usual meals. No hypotheses were made regarding the effect on macronutrient consumption.

METHODS

Recruitment

Children with type 1 diabetes were recruited from a pediatric endocrinology practice in Baltimore, MD, between June and August 2006. Inclusion criteria were diagnosis of type 1 diabetes ≥1 year with insulin dose ≥0.5 u/kg/day and age 7.0 to 16.9 years. Exclusion criteria were any other chronic disease and dietary restrictions that would preclude eating the food provided. A letter was mailed to families of eligible children and then a member of the research team followed-up with a telephone call to invite families to participate and answer questions. The study protocol was approved by the Institutional Review Board at the National Institutes of Health. Participants signed assent forms and their parents signed consent forms before participation.

Study Procedures

The study employed a within-subjects crossover design. Study participation lasted 5 days (3 days for the controlled feeding study followed by 2 days of at-home ad libitum consumption). Results from the two clinic days are published elsewhere (16). Following the clinic days, subjects were provided with instructions for the next 2 days of food consumption at home. On one of the days, subjects consumed their usual diet; on the other day, subjects were provided with low-GI foods (GI ≤55) and instructions on what other foods they were allowed to eat (ie, non–energy-containing beverages and fresh fruit) besides those provided. The foods provided are listed in Table 1. Both diets were consumed ad libitum; subjects chose when and how much to eat. Half of subjects consumed their usual meal first, and half consumed the low-GI diet first.

Table 1. Low–glycemic index (GI) food provided to children with type 1 diabetes for ad libitum consumption at home

Meal[a]	Food	GI[b]
Breakfast	Applesauce, unsweetened	40
	Granola with oats, pumpkin seeds, and flaxseeds	52
Morning snack	Trail mix with:	
	Dried apricots	31
	Dried berries	22
	Peanuts	14
	Almonds	NA[c]
Lunch	Health Valley Vegetable barley soup[d] (barley, carrots, tomatoes, celery, peas, and green beans)	25
	Turkey sandwich on Diabetic Lifestyles sprouted whole-grain bread[e] or wrap with lettuce and tomato	55
	Baby carrots, raw	16
Afternoon snack	Solo low-GI snack bar[f]	25
Dinner	Nutrition Kitchen soy spaghetti[g] (soybeans)	18
	Meatballs	NA
	Salad	NA
Evening snack	Fruit crisp:	
	Apple, pear, or peach	40
	Rolled oats, thick	53
	[or]	
	Baked beans	48
	[or]	
	Diabetes Lifestyles sprouted grain bread[e]	55
	[with]	
	Peanut butter	14
	[or]	
	Hummus	6

[a]Participants were told that they could eat the provided foods at any time of the day and that the menus were just recommendations for what foods to eat at each meal. They were also allowed to consume non–energy-containing beverages and fresh fruit.
[b]GI was based on glucose as reference.
[c]NA=not applicable.
[d]Hain Celestial Group, Melville, NY.
[e]Alvarado Street Bakery, Petaluma, CA.
[f]Solo GI Nutrition, Inc, Edmonton, Alberta, Canada.
[g]Nutrition Kitchen, Las Vegas, NV.

Continuous Glucose Monitoring System

Blood glucose profiles were assessed using a continuous glucose monitoring system (Medtronic MiniMed, Northridge, CA), a portable device that measures interstitial glucose levels (which correspond to blood glucose levels). The system is composed of two major components: a subcutaneous glucose sensor and a small, pager-type monitor. The glucose sensor is inserted into subcutaneous tissue, usually in the abdominal area. Measurements are taken

every 10 seconds, and the average of the measures is recorded every 5 minutes. The system sensor provides readings for up to 3 days, so the sensor was replaced after the third day.

Diet Diaries

Subjects completed diet diaries at home on both days. A trained research assistant taught participants and their parents how to keep the diet diaries and provided a food diary booklet and instructions. Subjects were also called on the days following each diet condition and 24-hour diet recalls using a multiple-pass method were completed by a trained research assistant. The food diaries were used for subsequent dietary analysis unless a food item was unclear in the food diary, in which case the food item was clarified by the 24-hour recall. Macronutrient intake was calculated using the US Department of Agriculture's food database (National Nutrient Database for Standard Reference, release 16-1, 2003, and release 17, 2004, Beltsville, MD) (17). The GI of foods was determined using published values obtained from standard testing procedures using glucose as a reference (18,19).

Hemoglobin A1c

The most recent hemoglobin A1c level, an indicator of blood sugar level during the previous 3 months, was obtained from the medical record.

Statistical Analyses

Continuous variables were described by means and standard deviations. Categorical variables were presented by frequency distributions. Summary values were calculated from the continuous glucose monitoring system data beginning at breakfast and continuing until early morning the following day. Data were included if a minimum of 60% of the data was recorded by the monitoring system. Daytime and nighttime values were calculated for mean blood glucose, blood glucose area above 180 mg/dL (10 mmol/L), and blood glucose area below 70 mg/dL (3.9 mmol/L). For blood glucose area above 180 mg/dL (10 mmol/L) and blood glucose area below 70 mg/dL (3.9 mmol/L), the area under the curve was calculated using the trapezoidal rule (20). The daytime interval began at the first food consumption and ended at 11:00 PM. The nighttime interval began at 11:00 PM and ended at 7:00 AM or at the first food consumption the following day (whichever came first). Two measures of blood glucose variability, the low blood glucose index and the high blood glucose index were also calculated for each time period. These recently developed indexes quantify the extent and frequency of glucose excursions (21). Both blood glucose area above 180 mg/dL (10 mmol/L) and high blood glucose index have been shown to be associated with elevated hemoglobin A1c (20,22). Paired t tests were used to assess differences in daytime blood glucose levels, blood glucose area above 180 mg/dL (10 mmol/L), blood glucose area below 70 mg/dL (3.9 mmol/L), low blood glucose index, high blood glucose index, and macronutrient intake between the usual meal diet and the low-GI diet. Statistical significance was defined as $P \leq 0.05$. Statistical analyses were performed using STATA (version 9.0, 2005, StataCorp, College Station, TX).

RESULTS AND DISCUSSION

Subjects

Twenty-three subjects (43% boys, mean age 13.1 years) participated in the study. Seven subjects had equipment failure (two subjects had no data recorded, and five had insufficient data recorded) from the continuous glucose monitoring system. The age of the 16 subjects with complete glucose monitoring system data was 13.1±2.8 years (range 7.8 to 16.7 years) and 7 (44%) were boys. Mean hemoglobin A1c concentration was 8.9%±2.9%. All participants were on a flexible basal-bolus regimen and the mean duration of diagnosis of type 1 diabetes was 4.3 years. The racial composition was 65% white, 15% African American, 15% biracial, and 5% other race/ethnicity.

Dietary Intake

The mean GI was 34±6 (low GI) for the low-GI day and 57±6 (medium GI) for the usual meal day ($P<0.0001$). There was no difference in energy intake between the low-GI and usual meal days (1,650±452 kcal vs 1,882±571 kcal, $P=0.18$). During the low-GI day subjects consumed more fiber (24.5±12.3 g vs 14.5±6.1 g, $P<0.007$) and less fat (45.7±12.2 g vs 76.8±32.4 g, $P<0.005$), but there were no differences in carbohydrate (219±94 g vs 229±92 g, $P=0.64$) or protein (90±20 g vs. 78±26 g, $P=0.20$) intake.

Blood Glucose

During the low-GI day, mean daytime blood glucose values (125±28 mg/dL [6.9±1.5 nmol/L] vs 185±58 mg/dL [10.3±3.2 nmol/L], $P<0.0012$), blood glucose area above 180 mg/dL (4,486±6,138 vs 26,707±25,038, $P<0.0063$) and high blood glucose index (5.1±5.1 vs 13.6±7.6, $P<0.0013$) were lower compared to the usual meal day. There were no differences in the daytime blood glucose area below 70 mg/dL (3.9 mmol/L) or in the nighttime blood glucose values (Table 2).

These findings suggest that a low-GI diet can improve daytime blood glucose control in children with type 1 diabetes without adversely affecting macronutrient consumption. In fact, on the low-GI day, participants consumed more fiber and less fat, suggesting that a carefully planned low-GI diet may improve diet quality. This is an important finding because the SEARCH for Diabetes in Youth Study reported low fruit, vegetable, and whole grain consumption in youth with type 1 diabetes (23). In our study, subjects consumed 232 kcal less on the low-GI day, which was not statistically significant; however, the study was not powered to detect this small of a difference in energy intake.

This pilot study supports previous studies' findings of a positive effect of a low-GI diet on blood glucose control in children with type 1 diabetes (4,11,16). Although the approach used in our study of providing low-GI foods to children is not a realistic long-term approach, it does suggest the potential for adherence to a low-GI diet, and demonstrated that when this diet was actually followed that it had a positive effect on blood glucose control. The

Table 2. Blood glucose values for low glycemic index (LGI) vs usual meals (UM) dietary conditions in a study to examine the blood glucose response to the macronutrient composition of LGI meals vs UM consumed ad libitum at home in children with type 1 diabetes

Interval[a]	Condition	Mean	Paired difference	Standard deviation	Standard error	*t*[b]	*P* value
Day							
Mean blood glucose, mg/dL[c]	LGI	125.4	60.5	53.7	14.4	−4.1	0.001
	UM	185.9					
Blood glucose area above 180 mg/dL[c]	LGI	4,485.4	22,222.2	25,558.0	6,830.7	−3.3	0.006
	UM	26,707.6					
Blood glucose area below 70 mg/dL[c]	LGI	1,353.2	902.0	2,401.4	641.8	1.4	0.180
	UM	451.2					
High blood glucose index	LGI	5.1	8.5	8.2	2.1	4.0	0.001
	UM	13.6					
Low blood glucose index	LGI	3.1	1.9	3.6	0.9	−2.0	0.070
	UM	1.2					
Night							
Mean blood glucose, mg/dL[c]	LGI	145.8	33.6	64.1	18.5	−1.8	0.096
	UM	179.4					
Blood glucose area above 180 mg/dL[c]	LGI	13,598.4	323.1	23,681.8	6,568.2	−0.1	0.961
	UM	13,921.5					
Blood glucose area below 70 mg/dL[c]	LGI	1,113.6	924.5	2,285.1	633.8	1.5	0.170
	UM	189.1					
High blood glucose index	LGI	8.3	2.4	12.1	3.1	0.8	0.450
	UM	10.7					
Low blood glucose index	LGI	3.6	2.7	5.2	1.4	−1.9	0.080
	UM	0.9					

[a]The daytime interval began at the first food consumption and ended at 11:00 PM. The nighttime interval began at 11:00 PM and ended at 7:00 AM or at the first food consumption the following day (whichever comes first).
[b]Paired sample *t* tests were used to assess differences between the two conditions.
[c]To convert mg/dL glucose to mmol/L, multiply mg/dL by 0.0555. To convert mmol/L glucose to mg/dL, multiply mmol/L by 18.0. Glucose of 180 mg/dL=10 mmol/L.

largest study to date in children with type 1 diabetes was conducted in Australia and randomized 104 children to either a carbohydrate exchange diet or a low-GI diet (4). After 1 year, the low-GI group had better hemoglobin A1c levels and fewer episodes of hyperglycemia. There were no differences in insulin dose, hypoglycemic events, or macronutrient composition of the diets between the groups. In addition, children in the low-GI group did not report more limited food choices than children who consumed a traditional carbohydrate-exchange diet (5). Due to differences in food products, food processing, and dietary intake in different countries, longitudinal studies are needed in the United States to indicate the utility of a low-GI diet in children with type 1 diabetes.

The main limitation of this study was the high rate of continuous glucose monitoring system equipment failure. Because the monitoring system does not provide real-time data, any problems with the equipment could not be determined until after each participant completed their data collection period and data were downloaded. Difficulties with several of the devices were encountered, and the devices were either repaired or replaced; however, data were still lost. Importantly, because the loss of data was due to problems with the devices themselves rather than subject behavior, the loss of data was likely random. Another limitation of this study was that the availability of certain foods that were provided to the participants (eg, low-GI bars and soy pasta) will vary by geographic location. Some low-GI products may be more difficult to find in urban areas or small towns. However, there are enough low-GI products that can be found in most grocery stores, particularly fresh fruits, vegetables, whole grains, and legumes, that this should not be considered a major drawback of the diet.

The GI has been criticized as being a concept that is too complex for diabetes management and has limited clinical usefulness (7,8,24). Critics of a low-GI diet believe that since so many factors affect the glycemic response to a meal that it would be too cumbersome for patients to classify foods according to their GI. Despite these concerns, the American Diabetes Association does recommend encouraging low-GI foods that are high in fiber and other important nutrients (1). Clearly, it is not realistic to expect people to estimate the GI rank of every food they consume; rather they can be provided with an understanding of the general classification of foods as low, moderate, or high on the GI. Another criticism is that some low-GI foods are high in fat, which is particularly concerning for people with diabetes due to their risk of cardiovascular disease. However, this is not the case when focusing on whole, unprocessed low-GI foods—vegetables, fruits, intact or minimally processed whole grains, and legumes—all of which are associated with improved cardiovascular health. The GI is not purported to be the sole criteria by which to select a diet; but when considered along with nutrient density and other relevant factors

may be a useful construct for improving dietary quality and blood sugar control.

CONCLUSIONS

The positive effect of a low-GI diet in children with type 1 diabetes was observed during ad libitum food consumption in home environments in this pilot study. A low-GI diet was associated with improved diet quality and decreased daytime hyperglycemia compared to the childrens' usual diets. However, because this was only a brief feeding study it is unknown if children will adhere to this diet for a longer time period and what the long-term effects on blood glucose levels would be. These findings suggest that longitudinal studies to address these issues are warranted.

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