Greater diet quality is associated with more optimal glycemic control in a longitudinal study of youth with type 1 diabetes[1,2]

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ABSTRACT

Background: Despite the centrality of nutrition in the management of type 1 diabetes, the association of diet quality and macronutrient distribution with glycemic control is ambiguous.

Objective: This study examined longitudinally the association of dietary intake with multiple indicators of glycemic control in youth with type 1 diabetes participating in a behavioral nutrition intervention study.

Design: Participants in a randomized clinical trial of a behavioral nutrition intervention [n = 136; mean ± SD age: 12.8 ± 2.6 y; glycated hemoglobin (HbA1c): 8.1% ± 1.0%; 69.1% using an insulin pump] completed 3-d diet records at baseline and months 3, 6, 9, 12, and 18; masked continuous glucose monitoring (CGM) data were obtained concurrently with the use of the Medtronic iPro CGM system. HbA1c was obtained every 3 mo; 1,5-anhydroglucitol was obtained every 6 mo. Linear mixed-effects regression models estimated associations of time-varying dietary intake variables with time-varying glycemic control indicators, controlling for age, height, weight, sex, Tanner stage, diabetes duration, regimen, frequency of blood glucose monitoring, physical activity, and treatment assignment.

Results: HbA1c was associated inversely with carbohydrate and natural sugar, and positively with protein and unsaturated fat. 1,5-Anhydroglucitol was associated positively with fiber intake and natural sugar. Greater glycemic control as indicated by ≥1 CGM variable was associated with higher Healthy Eating Index–2005, whole plant food density, fiber, carbohydrate, and natural sugar and lower glycemic index and unsaturated fat.

Conclusions: Both overall diet quality and macronutrient distribution were associated with more optimal glycemic control. Associations were more consistent for CGM variables obtained concurrently with dietary intake than for biomarkers of longer-term glycemic control. These findings suggest that glycemic control may be improved by increasing intake of high-fiber, low glycemic–index, carbohydrate-containing foods. This trial was registered at clinicaltrials.gov as NCT00999375. *Am J Clin Nutr* 2016;104:81–7.

Keywords: continuous glucose monitoring, diet quality, glycemic control, type 1 diabetes, youth

INTRODUCTION

Although nutrition is considered a cornerstone of type 1 diabetes management, dietary recommendations for the management of type 1 diabetes have shifted from strict meal plans to an emphasis on carbohydrate estimation, along with healthful eating consistent with dietary guidelines for the general population (1). Consequently, the focus of medical nutrition therapy is on assisting families to integrate the insulin regimen and carbohydrate estimation into their lifestyle, conforming to preferred meal routines, food choices, and physical activity patterns (1, 2). Dietary intake in youth with type 1 diabetes is known to fall short of dietary guidelines (3), and there is some evidence that the necessary focus on carbohydrate intake may detract attention from overall healthful eating (4). This is of particular importance given the increased risk of cardiovascular disease associated with type 1 diabetes (5).

Cross-sectional research suggests that diets characterized by higher carbohydrate (6, 7), lower fat (6–8), lower added sugar (9), higher fiber (9), and higher fruit and vegetable (9, 10) intake are associated with better glycemic control as indicated by lower glycated hemoglobin (HbA1c).[5] However, findings are conflicting, with some studies showing no association (11–13), and one study showing better glycemic control with lower carbohydrate intake (14). In short-term experimental studies, a lower dietary glycemic index has been associated with greater glycemic control (15–18); however, there is insufficient data on the effect of dietary glycemic index in a free-living population. Few longitudinal studies have examined the association of dietary intake with glycemic control. In one small study of 34 children followed for 2 y, greater dietary fat was associated with poorer glycemic control (19). In experimental studies, glycemic control

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[2] Supplemental Tables 1–4 are available from the "Online Supporting Material" link in the online posting of the article and from the same link in the online table of contents at http://ajcn.nutrition.org.

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[5] Abbreviations used: CGM, continuous glucose monitoring; HbA1c, glycated hemoglobin; HEI-2005, Healthy Eating Index–2005; MAGE, mean amplitude of glycemic excursions; NDSR, Nutrition Data System for Research; WPFD, whole plant food density.

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improved on a diet high in dietary fiber (20); however, no differences in glycemic control were seen in a small crossover study comparing a low-fat diet with a standard diet (21).

The purpose of this study was to examine longitudinally the association of dietary intake with glycemic control in a sample of youth with type 1 diabetes participating in a behavioral nutrition intervention trial. Multiple indicators of glycemic control were evaluated, including HbA1c, 1,5-anhydroglucitol (an indicator of recent hyperglycemic excursions), and blood glucose monitoring data obtained concurrently with dietary intake data.

METHODS

Design and participants

Parent–youth dyads (n = 136) participated in a randomized controlled trial of a behavioral nutrition intervention designed to increase the intake of whole plant foods in youth with type 1 diabetes. The study (registered at clinicaltrials.gov as NCT00999375) was conducted at an outpatient, freestanding, multidisciplinary tertiary diabetes center in Boston, Massachusetts. Eligibility criteria included the following: age 8.0–16.9 y, diagnosis of type 1 diabetes for ≥1 y, taking a daily insulin dose of ≥0.5 units/kg, most recent HbA1c 6.5–10.0%, intensive insulin therapy with either an insulin regimen of ≥3 injections/d or insulin pump, ≥1 clinic visit in the previous year, and ability to communicate in English. Exclusion criteria included daily use of premixed insulin, transition to insulin pump therapy in the previous 3 mo, real-time continuous glucose monitoring (CGM) use in the previous 3 mo, participation in another intervention study in the previous 6 mo, presence of gastrointestinal disease such as celiac disease, multiple food allergies, use of medications that interfere substantially with glucose metabolism, or serious mental illness. Sample size was based on detecting meaningful differences in dietary intake and glycemic control between intervention and control conditions, and has been reported in detail previously (22).

Procedures

The study was conducted from August 2010 through May 2013. Participants were recruited by research staff at regular clinic visits and were enrolled in the study for 18 mo. All youth provided assent; parents and youth turning 18 y of age during the trial provided written informed consent. Random assignment was conducted by the data coordinating center and was stratified by age (<13 y or ≥13 y), HbA1c (<8.5% or ≥8.5%), and insulin regimen (injection or insulin pump). Study visits were completed in the clinic; diet records were completed in the home after study visits. Study procedures were approved by the institutional review boards of the participating institutions. Intervention procedures have been described in detail previously; the intervention resulted in improved diet quality but did not affect HbA1c (22).

Measures

Dietary intake

Families completed 3-d youth food records at baseline and 3, 6, 9, 12, and 18 mo. Research assistants instructed families on accurately measuring and reporting food and beverage intake, including use of measuring utensils when at home, and gave them a sample diet record. Families were asked to provide all specific details for each food item, including names of brands or restaurants and specific item labeling (e.g., low fat or 1% milk). Research staff reviewed the completed records on receipt from the family to ensure completeness, and solicited missing information from the family as needed. For visits in which a family did not complete a diet record, 2 nonconsecutive 24-h dietary recalls were obtained by a registered dietitian (1.7% of assessments). Diet records were entered by 2 registered dietitians and verified for consistency and accuracy. Nutrition Data System for Research (NDSR; Nutrition Coordinating Center, University of Minnesota) software from 2012 was used to analyze the records and provide estimates of food group servings, fiber, glycemic index, and percentage of energy intake from fat, saturated fat, carbohydrate, protein, total sugar, and added sugar. The NSDR considers added sugar to be that added during processing or preparation of foods; naturally occurring sugars, including fructose in fruit or lactose in milk, are not included (23). Natural sugar was calculated by the authors by subtracting added sugar from total sugar. The NDSR obtains published measured glycemic index values for each food and links them to foods in the database with the use of methodology described for the National Cancer Institute Diet History Questionnaire Database (24). The NDSR assigns values for foods with no published measured glycemic index values by estimating from similar items, calculating from the available amount of carbohydrate or assigning a default value (23). The glycemic index for the dietary reporting period is calculated with the use of the glycemic index and available carbohydrate for each food. In addition, 2 indicators of overall diet quality were calculated. The Healthy Eating Index–2005 (HEI-2005) measures conformance to the 2005 Dietary Guidelines for Americans, and comprises 12 component scores corresponding to dietary guidelines for intake of total fruit, whole fruit, total vegetables, dark green or orange vegetables and legumes, total grains, whole grains, milk, meat and beans, oils, saturated fat, sodium, and energy from solid fat, alcohol, and added sugars (25). The maximum component score is assigned if intake meets recommended intake levels, and is truncated for intake levels exceeding recommendations. Recommendations and scores are expressed on a per–1000 kcal basis to enable comparability across individuals with varying total energy requirements. Component scores are summed to obtain the total score, with possible values ranging from 0 to 100; a score of 100 indicates meeting intake recommendations for all dietary components. Whole plant food density (WPFD) is a continuous measure that represents the proportion of the diet allocated to whole grains, whole fruit, vegetables, legumes, nuts, and seeds; it is calculated as the total number of cup- or ounce-equivalents per 1000 kcal of total energy consumed (26).

Glycemic control

HbA1c was measured at each clinic visit with the use of a laboratory assay standardized to the Diabetes Control and Complications Trial [reference range: 4–6% (20–42 mmol/mol)]. Initial HbA1c assays were performed with a Tosoh (Tosoh Medics) followed by a Roche Cobas Integra. All values obtained with the Tosoh were standardized to the Roche assay. An enzymatic (glucokinase) assay (GlycoMark) was used to measure 1,5-anhydroglucitol at baseline and 6, 12, and 18 mo. Participants were also assessed by using 3-d masked CGM with the use of the Medtronic iPro Continuous Glucose Monitoring System at baseline and 3, 6, 9, 12, and 18 mo, in conjunction with completion of diet records. The CGM device was inserted subcutaneously by a diabetes nurse educator and calibrated according to standard operating guidelines. Participants were instructed to conduct blood glucose checks 4 times/d before meals or at bedtime. After completion of the monitoring period, the device was returned to the clinic and data was downloaded for analysis. The GlyCulator glycemic variability calculation tool (27) was used to calculate summary indexes across the monitoring period. In addition to the mean glycemia of CGM data, several indexes were examined to obtain a comprehensive understanding of the association of diet with glycemic variability. These included the SD of mean glycemia of CGM data (an indicator of all glucose fluctuations), mean amplitude of glycemic excursions (MAGE; an indicator of the magnitude of glucose fluctuations), percentage of values >180 mg/dL (indicating hyperglycemia), and percentage of values <70 mg/dL (indicating hypoglycemia). Data from participants at any assessment period in which CGM record time was <24 h were not included.

Clinical and demographic data

Date of diagnosis, insulin regimen, age, sex, height, and Tanner stage were extracted from the medical records at each study visit. Demographic characteristics were assessed by parent self-report. Frequency and duration of moderate and vigorous physical activity were assessed with the use of questions from the Behavioral Risk Factor Surveillance System (28). A single continuous variable was calculated by counting each minute of vigorous activity as equivalent to 2 min of moderate activity (29).

Analyses

Baseline participant demographics, disease-related characteristics, dietary intake, and glycemic control indicators were summarized with means and SDs for continuous variables and frequencies for categorical variables. Baseline differences between intervention and control groups were tested with the use of *t* tests for continuous variables and chi-square analysis for categorical variables. Random-effects models estimated associations of time-varying youth dietary intake variables with glycemic control indicators, controlling for youth age, height, weight, sex, Tanner stage, diabetes duration, regimen, frequency of blood glucose monitoring, physical activity, and treatment assignment. Moreover, the interaction of insulin regimen (insulin pump compared with injection) with each dietary intake variable was tested. Each dietary intake variable was also standardized (*z* score), and models were run with the use of these standardized dietary intake variables to facilitate comparison of effect size across dietary intake variables that had different ranges. Analyses were conducted with the use of Stata version 14, mixed command.

RESULTS

Of 622 eligible youth invited to participate, 148 (24%) provided informed consent and 139 (22%) completed baseline. Data were excluded from one sibling each in 3 sibling pairs, resulting in a final sample of 136; 125 (92%) were retained through study completion (longitudinal analyses include all available data from each subject through withdrawal or study completion). Baseline sample characteristics are summarized in **Table 1**. Random-effects models that estimated associations of HbA1c with dietary intake demonstrated that better glycemic control as indicated by lower HbA1c was associated with a higher percentage of energy from carbohydrate, lower percentage of energy from protein, and lower percentage of energy from unsaturated fat (**Table 2**; results with the use of standardized dietary variables are presented in **Supplemental Table 1**). In addition, lower HbA1c was associated with a greater percentage of energy from total sugar; separate models for added and natural sugar indicate that this association was stronger for natural sugar than for added sugar. Models estimating associations of 1,5-anhydroglucitol with dietary quality showed that better glycemic control as indicated by higher 1,5-anhydroglucitol was associated with greater fiber intake and greater percentage of energy from natural sugar.

Greater HEI-2005, WPFD, and fiber intake were associated with more optimal glycemic control as indicated by CGM summary values of mean, SD, percentage of values >180, and MAGE (**Table 3**; results with the use of standardized dietary variables are presented in **Supplemental Table 2**). A lower glycemic index was associated with a lower SD and MAGE; associations with lower mean and percentage of values >180 were not statistically significant. A greater percentage of intake from carbohydrate, percentage of energy from total sugar, and percentage of energy from natural sugar were associated with lower mean and percentage of values >180, but also a greater percentage of values <70. A greater percentage intake from total sugar and natural sugar was also associated with a lower SD, and percentage of intake from natural sugar was associated with a lower MAGE. A greater percentage of intake from total fat and unsaturated fat was associated with greater mean and percentage of values >180, and a lower percentage of values <70, whereas percentage of intake from saturated fat was associated with a lower percentage of values <70.

Interactions of insulin regimen with dietary intake variables on glycemic control indicators are presented in **Supplemental Tables 3 and 4**. Overall, there were few meaningful interaction terms, with no overall pattern or clear difference in the effect of dietary intake on glycemic control by regimen.

DISCUSSION

Findings from this study indicate an association of both macronutrient distribution and diet quality with glycemic control in youth with type 1 diabetes. Higher HEI-2005, WPFD, and intake of fiber, natural sugar, and carbohydrate, and lower glycemic index were associated with multiple measures of better glycemic control. Higher unsaturated fat was associated with several measures of poorer glycemic control. Associations of dietary intake with glycemic control were stronger and more consistently observed for the CGM indicators obtained concurrently with diet than for the biomarkers of longer-term glycemic control. In an analysis of the associations of glycemic control with HbA1c and 1,5-anhydroglucitol, the diet record serves as an estimate of usual intake, but the time period of recording is not equivalent to the time period represented by the glycemic control biomarker. As such, the use of CGM data allows

TABLE 1
Baseline sample characteristics of youth with type 1 diabetes and parents participating in a behavioral nutrition intervention efficacy trial[1]

	All participants (n = 136)	Treatment (n = 66)	Control (n = 70)	P^2
Demographic characteristics				
Youth age, y	12.8 ± 2.6	12.6 ± 2.7	13.0 ± 2.5	0.27
Youth sex				0.31
M	66 (48.5)	35 (53.0)	31 (44.3)	
F	70 (51.5)	31 (47.0)	39 (55.7)	
Youth race/ethnicity				0.17
White, non-Hispanic	123 (90.4)	58 (87.9)	65 (92.9)	
Hispanic	7 (5.2)	6 (9.1)	1 (1.4)	
Black	5 (3.7)	2 (3.0)	3 (4.3)	
Other	1 (0.7)	0 (0.0)	1 (1.4)	
Highest parental educational level[3]				0.48
High school or equivalent	8 (5.9)	4 (6.1)	4 (5.7)	
Junior, technical, or some college	27 (19.9)	11 (16.7)	16 (22.9)	
College degree	46 (33.8)	20 (30.3)	26 (37.1)	
Graduate education	55 (40.4)	31 (47.0)	24 (34.3)	
Family poverty income ratio[3]	5.2 ± 3.1	5.5 ± 3.2	4.9 ± 3.0	0.23
Diabetes characteristics				
Duration of diabetes, y	6.0 ± 3.1	5.6 ± 2.5	6.3 ± 3.6	0.15
Insulin regimen				0.89
Injection only	42 (30.9)	20 (30.3)	22 (31.4)	
Pump	94 (69.1)	46 (69.7)	48 (68.6)	
Frequency of blood glucose monitoring, times/d	5.7 ± 2.4	5.8 ± 2.4	5.6 ± 2.5	0.60
Glycated hemoglobin, %	8.1 ± 1.0	8.1 ± 1.1	8.1 ± 1.0	0.95
Glycated hemoglobin, mmol/mol	65.0 ± 10.9	65.0 ± 10.9	65.0 ± 12.0	0.95
Diet characteristics				
Healthy eating index–2005[4]	54.80 ± 11.78	54.53 ± 11.68	55.05 ± 11.96	0.80
Whole plant food density[5]	1.92 ± 1.00	1.91 ± 1.01	1.93 ± 1.00	0.89
Fiber, g/1000 kcal	8.21 ± 2.62	8.04 ± 2.39	8.36 ± 2.83	0.48
Glycemic index[6]	60.64 ± 4.13	60.48 ± 4.57	60.80 ± 3.70	0.65
Carbohydrate, % kcal	48.12 ± 5.70	48.29 ± 5.51	47.96 ± 5.91	0.74
Protein, % kcal	16.16 ± 2.84	16.03 ± 2.68	16.28 ± 2.99	0.60
Total sugar, % kcal	19.87 ± 5.55	19.64 ± 5.48	20.08 ± 5.65	0.65
Added sugar	11.97 ± 4.75	11.49 ± 4.21	12.42 ± 5.20	0.25
Natural sugar	7.90 ± 4.02	8.16 ± 3.92	7.66 ± 4.12	0.47
Total fat, % kcal	35.73 ± 5.17	35.68 ± 5.24	35.77 ± 5.13	0.92
Saturated fat	12.59 ± 2.43	12.46 ± 2.25	12.72 ± 2.60	0.55
Unsaturated fat	20.15 ± 3.71	20.25 ± 4.04	20.06 ± 3.38	0.76

[1]Values are means ± SDs or n (%).
[2]Comparisons between intervention and control groups with the use of independent t tests for continuous variables or chi-square for categorical variables.
[3]Missing data from 1 participant on highest parental education and from 2 participants on family income.
[4]Indicates conformance to 2005 Dietary Guidelines for Americans [minimum = 0 (no conformance); maximum = 100 (complete conformance)].
[5]Continuous measure representing the total number of cup- or ounce-equivalents per 1000 kcal consumed of whole grains, fruit, vegetables, legumes, nuts, and seeds.
[6]Calculated based on the effect on postprandial glycemia in reference to glucose.

for greater precision in examining the effect of dietary intake on glycemic control.

Dietary fiber and intake of whole plant foods were associated with better glycemic control across several indicators. The mean intake of these dietary components was notably well below dietary guidelines (30), consistent with intake in the general US population (31). Previous research suggests that families may not recognize consumption of these foods as potentially benefitting diabetes management (4, 32). Findings from this study indicate the relevance of overall diet quality in promoting optimal glycemic control, and suggest the importance of efforts to improve diet quality in the clinical management of youth with type 1 diabetes.

The association of glycemic index with glycemic control was observed only for the CGM variables of SD and MAGE; associations with mean and percentage of values >180 were not statistically significant. Findings suggest a clearer effect of glycemic index on blood glucose variability than on mean blood glucose, in contrast to previous experimental studies finding lower mean blood glucose resulting from a lower–glycemic index diet (33). Findings from the current study may reflect the limited variance in glycemic index observed in this sample. A hypothesized pathway by which diet quality may affect glycemic control is the diet's glycemic index (34). However, findings from this study indicating associations of diet quality with glycemic control

TABLE 2
Coefficient estimates from random-effects models of association of time-varying dietary intake with time-varying biomarkers of glycemic control in youth with type 1 diabetes over 18 mo (n = 136)[1]

	HbA1c, %		1,5AG, μg/mL	
	$\beta \pm$ SE	P	$\beta \pm$ SE	P
Healthy Eating Index–2005[2]	0.003 ± 0.003	0.36	0.004 ± 0.008	0.62
Whole plant food density[3]	−0.03 ± 0.03	0.27	0.16 ± 0.08	0.05
Fiber, g	−0.02 ± 0.01	0.06	0.07 ± 0.03	0.03
Glycemic index[4]	0.005 ± 0.007	0.47	−0.03 ± 0.02	0.16
Carbohydrate, % kcal	−0.01 ± 0.005	0.04	0.005 ± 0.01	0.71
Protein, % kcal	0.02 ± 0.01	0.04	−0.04 ± 0.03	0.13
Total sugar, % kcal	−0.02 ± 0.006	0.01	0.004 ± 0.02	0.79
Added sugar	−0.009 ± 0.006	0.15	−0.02 ± 0.02	0.18
Natural sugar	−0.02 ± 0.008	0.05	0.04 ± 0.02	0.03
Total fat, % kcal	0.007 ± 0.006	0.22	0.006 ± 0.02	0.68
Saturated fat	−0.01 ± 0.01	0.25	0.03 ± 0.03	0.35
Unsaturated fat	0.02 ± 0.008	0.02	−0.001 ± 0.02	0.97

[1]Models controlled for youth age, height, weight, sex, Tanner stage, diabetes duration, regimen, frequency of blood glucose monitoring, physical activity, and treatment assignment. HbA1c, glycated hemoglobin; 1,5AG, 1,5-anhydroglucitol.

[2]Indicates conformance to 2005 Dietary Guidelines for Americans [minimum = 0 (no conformance); maximum = 100 (complete conformance)].

[3]Continuous measure representing the total number of cup- or ounce-equivalents per 1000 kcal consumed of whole grains, fruit, vegetables, legumes, nuts, and seeds.

[4]Calculated based on effect on postprandial glycemia in reference to glucose.

in the absence of an association with glycemic index suggest the existence of other mechanisms by which overall diet quality affects glycemic control.

The association of natural sugar with better glycemic control has important clinical implications for nutrition education in families of youth with type 1 diabetes. Research indicates that youth with type 1 diabetes consume less fruit than youth in the general population (12, 35), and it suggests that families may avoid fruit intake because of concerns that the high sugar content of fruit may elevate blood glucose (4). In this study, natural sugar was calculated by subtracting added sugar from total sugar; it therefore did not examine fruit sugar in isolation, and findings do not indicate the effect of fruit in specific on blood glucose. However, these findings do suggest the importance of educating families that natural sugars do not adversely affect blood glucose control, educating them on the benefits of fruit intake, and allaying erroneous concerns that fruit may adversely affect blood sugar. Families also might be counseled regarding lower–glycemic index fruits, which are associated with better glycemic outcomes in persons with type 2 diabetes (36).

Previous research examining the association of dietary intake with glycemic control often has focused on macronutrient intake. In this study, the associations of macronutrient intake with glycemic control were less consistent across multiple indicators of glycemic control than were associations with diet quality. However, our findings are generally consistent with previous cross-sectional research showing positive associations of dietary carbohydrate (6, 7) and adverse associations of dietary fat (6–8) with glycemic control. Previous research has documented a hyperglycemic effect of fat on acute postprandial glucose concentrations (33), which may result from insulin resistance that is induced by free fatty acids along with increased hepatic glucose output (37).

Although higher carbohydrate and lower fat intake were associated with better glycemic control across several indicators, they also were associated with a greater percentage of values

TABLE 3
Coefficient estimates from random-effects models of association of time-varying dietary intake with time-varying indicators of glycemic control from continuous glucose monitoring data in youth with type 1 diabetes over 18 mo (n = 136)[1]

	Mean of BG values		SD of BG values		% of BG values >180 mg/dL		% of BG values <70 mg/dL		MAGE	
	$\beta \pm$ SE	P	$\beta \pm$ SE	P	$\beta \pm$ SE	P	$\beta \pm$ SE	P	$\beta \pm$ SE	P
Healthy Eating Index–2005[2]	−0.41 ± 0.15	0.005	−0.21 ± 0.07	0.003	−0.19 ± 0.08	0.01	0.05 ± 0.03	0.12	−0.59 ± 0.20	0.003
Whole plant food density[3]	−4.35 ± 1.60	0.006	−2.18 ± 0.79	0.006	−2.19 ± 0.82	0.008	0.47 ± 0.32	0.14	−6.74 ± 2.14	0.002
Fiber, g	−2.42 ± 0.62	<0.001	−1.03 ± 0.31	0.001	−1.27 ± 0.32	<0.001	0.20 ± 0.12	0.10	−2.94 ± 0.84	<0.001
Glycemic index[4]	0.68 ± 0.37	0.06	0.43 ± 0.18	0.02	0.33 ± 0.19	0.08	0.01 ± 0.07	0.89	1.07 ± 0.50	0.03
Carbohydrate, % kcal	−0.66 ± 0.26	0.01	0.02 ± 0.13	0.90	−0.36 ± 0.13	0.007	0.18 ± 0.05	<0.001	0.05 ± 0.35	0.89
Protein, % kcal	0.83 ± 0.54	0.12	0.04 ± 0.27	0.88	0.43 ± 0.28	0.12	−0.15 ± 0.11	0.15	0.10 ± 0.73	0.89
Total sugar, % kcal	−1.23 ± 0.29	<0.001	−0.29 ± 0.14	0.04	−0.63 ± 0.15	<0.001	0.22 ± 0.06	<0.001	−0.66 ± 0.39	0.09
Added sugar	−0.41 ± 0.32	0.20	0.04 ± 0.16	0.81	−0.23 ± 0.17	0.17	0.15 ± 0.06	0.02	0.11 ± 0.43	0.80
Natural sugar	−1.76 ± 0.40	<0.001	−0.63 ± 0.20	0.001	−0.88 ± 0.21	<0.001	0.18 ± 0.08	0.02	−1.50 ± 0.54	0.005
Total fat, % kcal	0.64 ± 0.30	0.03	−0.03 ± 0.15	0.82	0.36 ± 0.16	0.02	−0.21 ± 0.06	0.001	−0.10 ± 0.41	0.81
Saturated fat	0.30 ± 0.59	0.61	−0.25 ± 0.29	0.40	0.23 ± 0.30	0.45	−0.26 ± 0.12	0.03	−0.61 ± 0.80	0.44
Unsaturated fat	0.91 ± 0.41	0.03	0.04 ± 0.21	0.86	0.49 ± 0.21	0.02	−0.23 ± 0.08	0.005	0.04 ± 0.56	0.94

[1]Models were controlled for youth age, height, weight, sex, Tanner stage, diabetes duration, regimen, frequency of blood glucose monitoring, physical activity, and treatment assignment. Mean of BG values is the mean of all values across the monitoring period; SD of BG values is the SD of values across the monitoring period (indicator of BG variance); BG >180 mg/dL is an indicator of hyperglycemia; BG <70 mg/dL is an indicator of hypoglycemia; and MAGE is an indicator of BG variance. BG, blood glucose; MAGE, mean amplitude of glycemic excursions.

[2]Indicates conformance to 2005 Dietary Guidelines for Americans [minimum = 0 (no conformance); maximum = 100 (complete conformance)].

[3]Continuous measure representing the total number of cup- or ounce-equivalents per 1000 kcal consumed of whole grains, fruit, vegetables, legumes, nuts, and seeds.

[4]Calculated based on the effect on postprandial glycemia in reference to glucose.

<70. Efforts to improve glycemic control frequently increase the occurrence of hypoglycemia, which could dissuade families from making otherwise healthful changes. As such, providers should assess family perceptions regarding dietary strategies for preventing hypoglycemia, ensure that families are skilled in carbohydrate estimation, and assist them in management strategies to minimize hypoglycemic excursions.

Several limitations should be considered when interpreting these findings. The sample was limited to youth receiving intensive insulin therapy, and excluded youth in poor glycemic control (HbA1c >10.0%). Assessment of dietary intake is known to be susceptible to reporting error; however, food records capture diet with great detail relative to food-frequency questionnaires or diet screeners, and are less susceptible to recall bias (38). Data were obtained in the context of a randomized controlled trial; these findings are presented as secondary data analyses. Study strengths include the longitudinal design, the use of multiple 3-d records to assess dietary intake, and the inclusion of multiple measures of glycemic control, including CGM data. To our knowledge, this is the first study examining the association of dietary intake with glycemic control measured concordantly by diet records and CGM.

Findings from this study indicate the relevance of efforts to improve the overall diet quality of youth with type 1 diabetes for promoting optimal diabetes management. The diets of youth with type 1 diabetes fall far short of meeting dietary guidelines, with inadequate intake of fruit, vegetables, and whole grain; insufficient fiber; and excessive fat and added sugar (3). Findings from this study suggest that glycemic control may be improved by increasing intake of high-fiber, low–glycemic index, carbohydrate-containing foods, particularly whole plant foods.

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REFERENCES

1. Bantle JP, Wylie-Rosett J, Albright AL, Apovian CM, Clark NG, Franz MJ, Hoogwerf BJ, Lichtenstein AH, Mayer-Davis E. Nutrition recommendations and interventions for diabetes: a position statement of the American Diabetes Association. Diabetes Care 2008;31(Suppl 1):S61–78.
2. Smart C, Aslander-van Vliet E, Waldron S. Nutritional management in children and adolescents with diabetes. Pediatr Diabetes 2009;10 (Suppl 12):100–17.
3. Rovner AJ, Nansel TR. Are children with type 1 diabetes consuming a healthful diet?: a review of the current evidence and strategies for dietary change. Diabetes Educ 2009;35:97–107.
4. Mehta SN, Haynie DL, Higgins LA, Bucey NN, Rovner AJ, Volkening LK, Nansel TR, Laffel LMB. Emphasis on carbohydrates may negatively influence dietary patterns in youth with type 1 diabetes. Diabetes Care 2009;32:2174–6.
5. de Ferranti SD, de Boer IH, Fonseca V, Fox CS, Golden SH, Lavie CJ, Magge SN, Marx N, McGuire DK, Orchard TJ, et al. Type 1 diabetes mellitus and cardiovascular disease: a scientific statement from the American Heart Association and American Diabetes Association. Circulation 2014;130:1110–30.
6. Delahanty LM, Nathan DM, Lachin JM, Hu FB, Cleary PA, Ziegler GK, Wylie-Rosett J, Wexler DJ. Association of diet with glycated hemoglobin during intensive treatment of type 1 diabetes in the diabetes control and complications trial. Am J Clin Nutr 2009;89:518–24.
7. Katz ML, Mehta S, Nansel T, Quinn H, Lipsky LM, Laffel LM. Associations of nutrient intake with glycemic control in youth with type 1 diabetes: differences by insulin regimen. Diabetes Technol Ther 2014;16:512–8.
8. Maffeis C, Morandi A, Ventura E, Sabbion A, Contreas G, Tomasselli F, Tommasi M, Fasan I, Constantini S, Pinelli L. Diet, physical, and biochemical characteristics of children and adolescents with type 1 diabetes: relationship between dietary fat and glucose control. Pediatr Diabetes 2011;13:137–46.
9. Overby NC, Margeirsdottir HD, Brunborg C, Andersen LF, Dahl-Jorgensen K. The influence of dietary intake and meal pattern on blood glucose control in children and adolescents using intensive insulin treatment. Diabetologia 2007;50:2044–51.
10. Lodefalk M, Aman J. Food habits, energy and nutrient intake in adolescents with type 1 diabetes mellitus. Diabet Med 2006;23:1225–32.
11. Michaliszyn SF, Shaibi GQ, Quinn L, Fritschi C, Faulkner MS. Physical fitness, dietary intake, and metabolic control in adolescents with type 1 diabetes. Pediatr Diabetes 2009;10:389–94.
12. Nansel TR, Haynie DL, Lipsky LM, Laffel LM, Mehta SN. Multiple indicators of poor diet quality in children and adolescents with type 1 diabetes are associated with higher body mass index percentile but not glycemic control. J Acad Nutr Diet 2012;112:1728–35.
13. Wolever TM, Hamad S, Chiasson JL, Josse R, Leiter L, Rodger WN, Ross S, Ryan E. Day-to-day consistency in amount and source of carbohydrate intake associated with improved blood glucose control in type 1 diabetes. J Am Coll Nutr 1999;18:242–7.
14. Meissner T, Wolf J, Kersting M, Frohlich-Reiterer E, Flechtner-Mors M, Salgin B, Stahl-Pehe A, Holl RW. Carbohydrate intake in relation to BMI, HbA1c and lipid profile in children and adolescents with type 1 diabetes. Clin Nutr 2014;33(1):75–8.
15. Nansel TR, Gellar L, McGill A. Effect of varying glycemic index meals on blood sugar control assessed with continuous glucose monitoring in youth with type 1 diabetes on basal-bolus insulin regimens. Diabetes Care 2008;31:695–7.
16. Parillo M, Annuzzi G, Rivellese AA, Bozzetto L, Alessandrini R, Riccardi G, Capaldo B. Effects of meals with different glycaemic index on postprandial blood glucose response in patients with Type 1 diabetes treated with continuous subcutaneous insulin infusion. Diabet Med 2011;28:227–9.
17. Rovner AJ, Nansel TR, Gellar L. The effect of a low glycemic diet versus a standard diet on blood glucose levels and macronutrient intake in youths with type 1 diabetes. J Am Diet Assoc 2009;109:303–7.
18. Ryan RL, King BR, Anderson DG, Attia JR, Collins CE, Smart CE. Influence of and optimal insulin therapy for a low-glycemic index meal in children with type 1 diabetes receiving intensive insulin therapy. Diabetes Care 2008;31:1485–90.
19. Forsander G, Malmodin B, Eklund C, Persson B. Relationship between dietary intake in children with diabetes mellitus type I, their management at diagnosis, social factors, anthropometry and glycaemic control. Scand J Nutr/Naringsforskning 2003;47(2):75–84.
20. Giacco R, Paril M, Rivellese A, Lasorella G, Giacco A, D'Episcopo L, Riccardi G. Long-term dietary treatment with increased amounts of fiber rich low glycemic index natural foods improves blood glucose control and reduces the number of hypoglycemic events in type 1 diabetic patients. Diabetes Care 2000;23:1461–6.
21. Rosenfalck AM, Almdal T, Viggers L, Madsbad S, Hilsted J. A low-fat diet improves peripheral insulin sensitivity in patients with type 1 diabetes. Diabet Med 2006;23(4):384–92.
22. Nansel TR, Laffel LM, Haynie DL, Mehta SN, Lipsky LM, Volkening LK, Butler DA, Higgins LA, Liu A. Improving dietary quality in youth with type 1 diabetes: randomized clinical trial of a family-based behavioral intervention. Int J Behav Nutr Phys Act 2015;12:58.
23. Austin M, Harnack L, Jasthi B, Kiesling S, King D, Marrone S, Perry C, Pettit J, Seftick S, Setten S, et al. Nutrition Data System for Research. Minneapolis (MN): University of Minnesota; 2012.
24. Olendzki BC, Ma Y, Culver AL, Ockene IS, Griffith JA, Hafner AR, Hebert JR. Methodology for adding glycemic index and glycemic load values to 24-hour dietary recall database. Nutrition 2006;22: 1087–95.
25. Guenther PM, Reedy J, Krebs-Smith SM, Reeve BB, Basiotis PP. Development and evaluation of the Healthy Eating Index-2005: technical report. Washington (DC): Center for Nutrition Policy and Promotion, US Department of Agriculture; 2007. Available from: http://www.cnpp.usda.gov/HealthyEatingIndex.htm.
26. Lipsky LM, Cheon K, Nansel TR, Albert P. Candidate measures of whole plant food intake are related to biomarkers of nutrition and health in the US population (NHANES 1999-2002). Nutr Res 2012;32: 251–9.

27. Czerwoniuk D, Fendler W, Walenciak L, Mlynarski W. GlyCulator: a glycemic variability calculation tool for continuous glucose monitoring data. J Diabetes Sci Technol 2011;5:447–51.
28. Centers for Disease Control and Prevention. Behavioral Risk Factor Surveillance System Survey Questionnaire. Atlanta (GA): CDC, US Department of Health and Human Services; 2001.
29. Centers for Disease Control and Prevention. A data users guide to the BRFSS physical activity questions: how to assess the 2008 physical activity guidelines for Americans. Atlanta (GA): Division of Nutrition, Physical Activity, and Obesity, National Center for Chronic Prevention and Health Promotion, CDC; 2008.
30. Otten JJ, Hellwig JP, Meyers LD. Dietary Reference Intakes: the essential guide to nutrient requirements. In: Medicine I, editor. Washington (DC): The National Academies Press; 2006.
31. Moshfegh A, Goldman J, Cleveland L. What we eat in America, NHANES 2001-2002: usual nutrient intakes from foods compared to dietary reference intakes. Washington (DC): Agricultural Research Service, US Department of Agriculture; 2005.
32. Gellar LA, Schrader K, Nansel TR. Healthy eating practices: perceptions, facilitators, and barriers among youth with diabetes. Diabetes Educ 2007;33:671–9.
33. Bell KJ, Smart CE, Steil GM, Brand-Miller JC, King B, Wolpert HA. Impact of fat, protein, and glycemic index on postprandial glucose control in type 1 diabetes: implications for intensive diabetes management in the continuous glucose monitoring era. Diabetes Care 2015;38:1008–15.
34. Brand-Miller J, Hayne S, Petocz P, Colagiuri S. Low-glycemic index diets in the management of diabetes: A meta-analysis of randomized controlled trials. Diabetes Care 2003;26:2261–7.
35. Mayer-Davis EJ, Liese NM, Bell RA, Dabelea DM, Johansen JM, Pihoker C, Rodriquez BL, Thomas J, Williams D. Dietary intake among youth with diabetes: the SEARCH for Diabetes in Youth Study. J Am Diet Assoc 2006;106:689–97.
36. Jenkins DJ, Srichaikul K, Kendall CW, Sievenpiper JL, Abdulnour S, Mirrahimi A, Meneses C, Nishi S, He X, Lee S, et al. The relation of low glycaemic index fruit consumption to glycaemic control and risk factors for coronary heart disease in type 2 diabetes. Diabetologia 2011;54:271–9.
37. Roden M, Price TB, Perseghin G, Petersen KF, Rothman DL, Cline GW, Shulman GI. Mechanism of free fatty acid-induced insulin resistance in humans. J Clin Invest 1996;97:2859–65.
38. Thompson FE, Subar AF. Dietary assessment methodology. Edition ed. In: Coulston AM, Boushey CJ, editors. Nutrition in the prevention and treatment of disease. Burlington (MA): Elsevier Academic Press; 2008. p. 3–39.