Objectives. To characterize the intake of macronutrient and fiber in adolescents with type 1 diabetes (T1D) and examine their association with health indicators. Methods. Baseline data from an RCT were examined. Adolescent-parent dyads (n = 257, mean age 12 ± 1.2 years, 49.4% girls) reported dietary intake via two separate 24-hour recall interviews during a two-week period. Demographic and medical variables were abstracted from questionnaires and medical charts. Results. Controlling for demographic and diet variables, a higher percentage of daily energy intake from fats was associated with poorer HbA1c. In contrast, an association between higher percentage of energy intake from proteins and carbohydrates was found with higher systolic and diastolic BP, respectively. Conclusions. Many early adolescents with T1D did not meet diabetes nutritional guidelines. Lower adherence to nutritional guidelines, specifically more than recommended energy intake from fats, was associated with poorer HbA1c. Addressing nutritional guidelines and increasing adherence as part of treatment may improve health outcomes for youth with T1D.
with adults who have type 1 diabetes also indicates difficulty
adhering to nutrition guidelines (e.g., [13, 14]). Given the
importance of dietary intake to glycemic control and to
the health of youth with T1D, the nutritional content and
behaviors of this population merit careful investigation.

Nutritional guidelines based on both the American Dia-
betes Association (ADA; [15]) and the International Society
for Pediatric and Adolescent Diabetes (ISPAD; [7]) support
using medical nutritional therapy (MNT) in order to opti-
mize the metabolic profiles (i.e., lower LDL plasma levels)
of individuals with diabetes and to offset risk factors for
cardiovascular disease [4, 5, 9]. Specifically, MNT recom-
mends provision of individualized nutrition plans as an
essential component of disease management for type 1
diabetes. MNT can include counseling about carbohydrate
counting, as well as specific recommendations for nutritional
intake and associated behavioral strategies [15, 16]. More-
ever, planning should take into account insulin regimen
and personal and familial food preferences [7, 15]. For exam-
ple, nutrition recommendations may vary based on insulin
regimen. Conventional insulin therapy generally refers to a
more structured insulin regimen in which youth have a set
range of carbohydrate intakes per meal and fewer injections
(e.g., 2–3 per day). Individuals on flexible/basal bolus therapy
(administered via multiple injections or a pump) are able to
use an insulin-to-carbohydrate ratio for food intake to tailor
their insulin administration to what they choose to eat [9].
Flexible insulin regimens are associated with better glycemic
control [17], yet they may inadvertently facilitate consump-
tion of unhealthy foods and use of processed/packaged foods.
The latter approach, in particular, may be appealing to the
adolescent because it simplifies carbohydrate counting [18].

Few studies have explored specific macronutrient and
fiber intake in adolescents with T1D. Initial evidence of
suboptimal nutrition and its adverse relation to metabolic
control has been demonstrated [19–23]. Although dietary
intake is generally associated with concurrent glycemic
control measured via continuous glucose monitoring [22], a
direct intervention to improve dietary behaviors in youth
did not result in improved glycemic control [24], suggesting
that adherence to nutritional guidelines may be necessary
for improved glycemic control, but not sufficient on its
own. However, dietary behaviors also relate to other health
indicators. For example, dietary intake, specifically low
consumption of vegetables and fish, is related to retinal prob-
lems in youth with T1D [25]. Higher fiber intake is associated
with reduced inflammation and lower mortality risk in adults
with T1D [26, 27].

Given the association of dietary intake with health
outcomes, the first aim of the current study is to describe
the macronutrient and fiber intake of early adolescents with
T1D. The second goal is to evaluate the association of macro-
nutrient and fiber intake with important health indicators
including glycemic control (hemoglobin A1c; HbA1c), obe-
sity as indicated by body mass index, dyslipidemia as indexed
by levels of plasma LDL, and hypertension as indexed by
systolic and diastolic blood pressure (BP). It is hypothesized
that only a small percentage of early adolescents with T1D
will meet diabetes-specific nutritional guidelines and that
macronutrient and fiber intake, as well as adherence to
guidelines, will be associated with health indicators.

2. Methods

2.1. Participants. Early adolescents, aged 11 to 14, and their
parents participated in a randomized controlled trial (RCT)
at two mid-Atlantic children’s hospitals. Participation in
the RCT entailed completion of four brief sessions of
behavioral intervention or diabetes education in conjunction
with quarterly diabetes clinic visits over the course of 1 to 1
and 1/2 years. The intervention and outcomes are described
in greater detail in a previously published paper [28]. The
data for the current study were drawn from the baseline
assessments of all of participants in the RCT with at least
one completed dietary interview.

Eligibility requirements of the RCT included diabetes
duration of at least 1 year, absence of severe complications
(e.g., retinopathy and nephropathy) or other medical diagno-
ses (e.g., cancer and asthma), and English fluency. The
sample consisted of 257 dyads composed of one adolescent
with T1D (49% girls) and one parent (91% mothers). Mean
age at baseline was 12.8 years (SD = 1.2), mean illness
duration was 5.1 years (SD = 3.1), and mean HbA1c was
73 mmol/mol (SD = 4). Two-thirds (64%) of the samples
were prescribed a flexible insulin regimen, i.e., ≥4 injections
or basal/bolus injections, or continuous subcutaneous insulin
infusion/pump. Participant characteristics are summarized in
Table 1.

2.2. Procedures. Institutional review boards from each
institution approved the larger study. Eligible families were
identified from clinic lists and were mailed an informational
letter. These families then received a follow-up telephone
call from trained research assistants. At regularly scheduled
diabetes clinic visit, each participant and his/her parent
provided consent and assent, completed self-report question-
naires, and participated in separate parent and child 24-hour
nutrition and diabetes self-care interviews. A second 24-hour
retrospective dietary interview was completed over the tele-
phone within two weeks of the baseline assessment. Compli-
tion of questionnaires took approximately 45 minutes, and
each interview was approximately 15 minutes. Families
received a $25 gift card in appreciation of their time. Of
the 404 eligible families successfully contacted, 285 con-
sent to participate (71%). Those who declined consent
primarily cited lack of interest or time as the reason. Com-
pleted baseline data were provided by 257 parent-adolescent
dyads (89%).

2.3. Measures

2.3.1. Background Information. Demographic and medical
information was obtained via questionnaire and a retrospec-
tive review of the medical charts. Socioeconomic status (SES)
was calculated based on parental occupation and education
[29], with higher scores related to lower SES. Coding was
completed by research assistants. When there was not a clear
category for a current career, the research assistant discussed
with a senior study staff member and a joint decision was made. Insulin regimen was categorized as conventional (2–3 fixed injections/day) or flexible (≥4 injections, basal/bolus or pump) therapy. Parents reported the type of their child’s nutrition plan (i.e., carbohydrate counting and exchanges) and the percentage of time their child adhered to his/her nutrition plan on average (i.e., ≤25% of the time, 26–50% of the time, 51–75% of the time, and >75% of the time). HbA1c and LDL cholesterol concentration were measured via blood assay at regular clinic visits and extracted from the medical record to represent metabolic control and lipid profile, respectively. HbA1c was assessed with the same measurement technology at each site (DCA 2000, 4.3–5.7%, Bayer Inc., Tarrytown, NY, USA). Height and weight also were measured at the baseline clinic visit, and body mass index (BMI) for age and gender percentile was calculated. Blood pressure (BP) also was measured and recorded.

### 2.3.2. Nutrition

To assess macronutrient and fiber intake, youth and one parent separately completed the 24-hour diabetes interview (DI) [30]. The DI is a diary-like interview in which parents and adolescents separately describe the completion of diabetes self-care tasks and nutritional intake over the previous 24 hours. Parents and adolescents each completed the DI on the same day on two different occasions within a two-week span. The responses of each parent and youth report were combined for each interview using a formula created by the research team [31] and scored using the Food Processor® Nutrition Software (ESHA Research, Salem, OR, USA). A combination of the two reports via decision rules overcomes common parent-child discrepancies and reduces bias and source error [30]. To further increase reliability, an average score of the two interviews was analyzed. For the current analyses, percentage of energy intake composed of carbohydrates, proteins, and fats, as well as grams dietary fiber, was evaluated. The 24-hour dietary recall method is a reliable, valid, well-established measure of diabetes self-care behavior [32, 33], energy, and nutritional intake.

Parent- and youth-reported dietary intake was compared to current nutritional recommended guidelines (Table 2) for adolescents with TID provided by the American Diabetes Association (ADA). The International Society for Pediatric and Adolescent (ISPAD) guidelines also were consulted as a secondary source when specific guidelines did not exist by the ADA [4, 9]. These guidelines differ from standard guidelines in that recommended ranges are similar, but narrower for adolescents with diabetes than in the general population (e.g., % of energy intake from carbohydrates is recommended at 45–65% for healthy adolescents and 50–55% for adolescents with diabetes) [34].

### 2.4. Data Analytic Plan

Analyses were conducted using SAS software, version 9.3 (SAS Institute Inc., Cary, NC). One of the 257 parent-adolescent dyads who completed baseline questionnaires was excluded from dietary analysis because they did not report dietary intake. To quantify the portion of the sample that met nutritional guidelines, each nutritional variable was recoded into dichotomous variables based on the cutoff recommended level for each nutrient (i.e., 0 = did not meet guidelines; 1 = met guidelines). Next, bivariate associations between dietary intake, demographic variables, metabolic control, blood pressure, and lipid profile were assessed with general linear regression. Nonlinear relationships between significant nutrition variables and health indicators also were explored by including exponential variables in linear models. Following bivariate analyses, in order to evaluate the overall and unique contributions of hypothesized predictors to outcomes, multivariable linear regression models were conducted by including demographic variables associated with a health indicator at $p \leq 0.10$ in Step 1. Step 2 added nutrition variables associated with a health indicator at $p \leq 0.10$ to Step 1 (model 2). Finally, a fully saturated model was tested that included demographic and nutrition variables associated with any health indicator at $p \leq 0.10$ (model 3). Health indicators not associated with any nutrition variables were not included in the model testing.

### Table 1: Demographic and baseline characteristics.

| Variable                   | Mean (SD) or % | Range   |
|----------------------------|----------------|---------|
| **Demographic**            |                |         |
| Youth age (years)          | 12.8 (1.2)     | 11–15.3 |
| Youth sex, % girls         | 49.4           |         |
| Youth ethnicity, % Caucasian | 69.5           |         |
| Hollingshead SES, % level 1 or 2 | 53.8           |         |
| **Medical**                |                |         |
| Diabetes duration (years)  | 5.1 (3.1)      | 1–13.6  |
| Insulin regimen            |                |         |
| 2–3 injections per day (%) | 35.3           |         |
| Basal/bolus (≥4 shots per day, %) | 20.4           |         |
| CSII insulin pump (%)      | 44.3           |         |
| **Nutrition intake**       |                |         |
| % energy from carbohydrates (DI) | 49.6 (8.3)      | 19.8–74.0 |
| % energy from fats (DI)    | 35.3 (7.4)     | 12.8–55.0 |
| % energy from proteins (DI) | 15.9 (4.0)     | 6.7–29.8 |
| Dietary fiber (g/1000 kcal (g/4184 kJ), DI) | 14.7 (6.3)      | 3.8–38.3 |
| **Health indicators**      |                |         |
| HbA1c (mmol/mol)           | 73 (4)         | 37–130  |
| Systolic blood pressure (mmHg) | 113.8 (10.6)   | 85–148  |
| Diastolic blood pressure (mmHg) | 64.0 (8.1)    | 44–94   |
| LDL cholesterol (mg/dL)    | 89.3 (28.9)    | 6.0–187.0 |
| BMI percentile             | 69.4 (24.5)    | 3–99    |

Note: SES = socioeconomic status; DI = dietary interview; BMI = body mass index.
3. Results

3.1. Nutritional Recommendations. The proportion of participants who met nutritional recommendations by category and by type of regimen is summarized in Table 2. Only 25.8% of the samples met the guidelines for the percentage of their energy intake comprised of carbohydrates, 51.2% ate less than recommended, and 23.8% ate more than recommended. Only 45.9% of participants achieved recommendations for percentage of their energy intake from proteins, 44.7% ate less than recommended, and 9.3% ate more than recommended. Only 42% of youth met the guidelines for percent of energy intake as fats, and 51.6% of participants consumed more fats than recommended. Only 47.6% met the minimum guidelines for intake of dietary fiber. Participants on a flexible insulin regimen were significantly more likely to meet dietary fiber guidelines as compared to those on a conventional regimen ($\chi^2(1) = 5.23, p = 0.02$).

3.2. Adherence. Approximately half of parents (51.7%) reported that their child followed their nutrition plan less than 75% of the time. Using 75% of the time as a cutoff, parents of youth on a flexible regimen were significantly more likely to report that their child followed their nutrition plan the majority of time than those on a conventional regimen ($\chi^2(1) = 13.65, p < 0.001$).

3.3. Health Recommendations. Targets for HbA1c were met more frequently by those participants on a flexible regimen versus conventional regimen ($\chi^2(1) = 4.03, p = 0.05$). Of the health outcomes evaluated, only 21.3% achieved an HbA1c below 58 (mmol/mol) and was within the glycemic goal target range. Consideration of weight revealed 64.8% had a BMI percentile within the normal range, although 21.4% were classified as overweight and 13.6% had obesity. Moreover, 64.5% of participants had measured LDL cholesterol levels less than 100 mg/dL (2.59 mmol/L). Approximately 90% had measured blood pressure below 130/80 mmHg. These health indicators did not differ significantly by type of insulin regimen ($\chi^2$ all $p > 0.05$).

3.4. Bivariate Associations. Bivariate associations between demographic and nutrition variables and all health indicators are presented in Table 3. Demographic associations were quite varied, with longer duration of disease associated with higher systolic BP ($\beta = 0.46, p = 0.04$) and higher LDL ($\beta = 1.53, p = 0.03$). Lower SES category was related to poorer HbA1c ($\beta = 0.61, p < 0.001$), as was a conventional insulin regimen ($\beta = 0.69, p = 0.002$). Non-Caucasian ethnicity and older age were each associated with every poorer health indicator except BMI percentile, which was not statistically significantly related to either non-Caucasian ethnicity or age. A higher percentage of energy intake from proteins was the only nutrient associated with higher systolic BP ($\beta = 0.42, p = 0.01$), whereas a higher percentage of energy intake from carbohydrates was significantly associated with higher diastolic BP ($\beta = 0.13, p = 0.04$). The majority of nutritional variables were associated with HbA1c including fats ($\beta = 0.05, p < 0.001$), carbohydrates ($\beta = -0.05, p < 0.001$), and dietary fiber ($\beta = -0.04, p = 0.02$). No significant nutrition associations were noted for BMI percentile or LDL, and no evidence of nonlinear associations were seen.

3.5. Regressions Predicting Health Indicators. Results of regression analyses are shown in Table 4. Overall, in Step 1, demographic variables accounted for 9% of the variance in systolic BP, with older age ($\beta = 2.09, p < 0.001$) and longer diabetes duration ($\beta = 0.43, p < 0.05$) significantly contributing to the model predicting systolic BP. The addition of nutritional variables in Step 2 increased the variance explained by 2% points. Specifically, controlling for relevant demographic factors, a higher percentage of energy intake from proteins was significantly associated with higher systolic BP ($\beta = 0.36, p = 0.03$). Although nutritional variables were not significantly associated with diastolic BP.

| Nutritional intake | Conventional (%) | Flexible (%) |
|--------------------|------------------|--------------|
| % energy from carbohydrates | 50–55 | 24.7 | 26.6 |
| % energy from proteins | 15–20 | 48.8 | 44.7 |
| % energy from fats | <35 | 35.6 | 46.1 |
| Cholesterol (mg/day) | <200 | 54.4 | 57.6 |
| Dietary fiber (g/1000 kcal (g/4184 kJ)) | 14 | 37.8 | 52.9 |

| Health indicators | Conventional (%) | Flexible (%) |
|-------------------|------------------|--------------|
| HbA1c (mmol/mol) | ≤58 | 14.1 | 25.2 |
| BMI (normal, %) | 5th–85th | 58.9 | 68.5 |
| Systolic BP (mmHg) | <130/80 | 93.0 | 91.9 |
| Diastolic BP (mmHg) | <100 | 97.7 | 96.9 |
| LDL cholesterol (mg/dL (mmol/L)) | <100 | 62.5 | 52.1 |

1Recommendation from the International Society for Pediatric and Adolescent Diabetes. 2Recommendation from the American Diabetes Association. *Values significantly different between regimens.
Table 3: Bivariate associations among demographic and nutritional variables and all health measures.

|                      | Systolic BP | Diastolic BP | HbA1C | BMI% | LDL |
|----------------------|-------------|--------------|-------|------|-----|
|                      | $\beta$     | $p$ value    | $\beta$ | $p$ value | $\beta$ | $p$ value | $\beta$ | $p$ value | $\beta$ | $p$ value |
| Age                  | 2.18        | $<0.0001$    | 0.92   | 0.03 | 0.17 | 0.05 | 0.63 | 0.62 | 4.46 | 0.007 |
| Sex (boys vs. girls) | 0.47        | 0.73         | -0.72  | 0.49 | 0.09 | 0.68 | -4.72 | 0.13 | -2.20 | 0.59  |
| Duration             | **0.46**    | **0.04**     | 0.18   | 0.31 | 0.003 | 0.82 | -0.15 | 0.77 | **1.53** | **0.03** |
| SES                  | 1.17        | 0.14         | 0.68   | 0.27 | **0.61** | $<0.0001$ | 1.86 | 0.32 | 2.13 | 0.37  |
| Ethnicity (non-Caucasian vs. Caucasian) | **2.96** | **0.04** | 2.78 | 0.01 | 0.84 | 0.0003 | 5.53 | 0.10 | **8.77** | **0.04** |
| Insulin regimen      | -0.85       | 0.55         | 1.41   | 0.19 | **0.69** | **0.0002** | 5.29 | 0.10 | 3.82 | 0.37  |
| Fats (% energy)      | 0.0001      | 0.99         | -0.14  | 0.06 | **0.05** | **0.0002** | -0.02 | 0.92 | -0.28 | 0.33  |
| Carbohydrates (% energy) | -0.05 | 0.51 | 0.13   | 0.04 | -0.05 | **0.0004** | 0.10 | 0.58 | 0.07 | 0.78  |
| Proteins (% energy)  | **0.42**    | **0.01**     | 0.14   | 0.28 | 0.05 | 0.07 | 0.31 | 0.42 | 0.78 | 0.12  |
| Dietary fiber        | -0.09       | 0.42         | -0.12  | 0.13 | **-0.04** | **0.02** | -0.21 | 0.39 | -0.38 | 0.22  |

Fats (in range versus)
- Less than recommended: 0.0001, 0.99, 0.14, 0.28, 0.05, 0.07, 0.31, 0.42, 0.78, 0.12
- More than recommended: 0.0001, 0.99, 0.14, 0.28, 0.05, 0.07, 0.31, 0.42, 0.78, 0.12

Carbohydrates (in range versus)
- Less than recommended: 0.0001, 0.99, 0.14, 0.28, 0.05, 0.07, 0.31, 0.42, 0.78, 0.12
- More than recommended: 0.0001, 0.99, 0.14, 0.28, 0.05, 0.07, 0.31, 0.42, 0.78, 0.12

Proteins (in range versus)
- Not in range: 0.0001, 0.99, 0.14, 0.28, 0.05, 0.07, 0.31, 0.42, 0.78, 0.12
- In range: 0.0001, 0.99, 0.14, 0.28, 0.05, 0.07, 0.31, 0.42, 0.78, 0.12

Dietary fiber (in range versus)
- Not in range: 0.0001, 0.99, 0.14, 0.28, 0.05, 0.07, 0.31, 0.42, 0.78, 0.12
- In range: 0.0001, 0.99, 0.14, 0.28, 0.05, 0.07, 0.31, 0.42, 0.78, 0.12

Table 4: Multivariable associations between demographic and nutritional variables and nutrition-associated health measures.

|                | Systolic BP | Diastolic BP | HbA1C | BMI% | LDL |
|----------------|-------------|--------------|-------|------|-----|
|                | $\beta$     | $p$ value    | $\beta$ | $p$ value | $\beta$ | $p$ value | $\beta$ | $p$ value | $\beta$ | $p$ value |
| Demographic variables
| Age            | 2.14$^4$    | 2.09$^4$    | 2.05$^4$ | 0.92$^*$ | 0.92$^*$ | 0.66 | 0.19$^*$ | 0.17$^*$ | 0.17$^*$ |
| Duration       | 0.42$^*$    | 0.43$^*$    | 0.37    | —      | —      | 0.11 | —      | —      | —      | —      | 0.009 |
| SES$^2$        | —          | —           | 1.32    | —      | —      | 0.26 | 0.50$^4$ | 0.44$^4$ | 0.46$^4$ |
| Ethnicity$^3$  | 2.94$^*$    | 2.51        | 2.39    | 2.77†  | 2.89†  | 1.85 | 0.36    | 0.44    | 0.42    |
| Insulin regimen$^4$ | —         | —           | 0.11    | —      | —      | 0.03 | 0.35    | 0.26    | 0.26    |
| Nutrition variables
| Fats (% energy intake) | —       | —           | 0.11    | —      | —      | -0.03 | 0.09    | —      | 0.05$^*$.5 | 0.05$^*$.5 |
| Carbohydrates (% energy intake) | —       | —           | 0.11    | —      | —      | 0.11 | 0.27$^*$ | —      | 0.005$^5$ | 0.004    |
| Proteins (% energy intake) | —       | 0.36$^*$    | 0.47$^*$ | —      | —      | 0.31 | —      | 0.04    | 0.04    |
| Dietary fiber   | —          | 0.00        | 0.00    | —      | —      | -0.12 | —      | 0.02    | 0.02    |

$^1$Estimates based on linear regression analysis. Model 1 includes demographic variables significant at $p < 0.10$ in bivariate models. Model 2 includes variables in model 1 + nutrition variables significant at $p < 0.10$ in bivariate models. Model 3 is a fully saturated model that includes all variables significant for any outcome in bivariate models. $^2$SES: categorical with lower categories indicating higher SES. $^3$Non-Caucasian coded as 0 vs. Caucasian coded as 1. $^4$Flexible regimen coded as 1.

Controlling for relevant demographic factors, inclusion of nutritional variables marginally improved $R^2$ (6% vs. 4%), showing contribution to the variance in diastolic BP. In Step 3, a higher percentage of energy intake from carbohydrates was associated with higher diastolic BP ($\beta = 0.27$, $p < 0.05$). The health indicator most highly associated with study variables was HbA1c, as 20% of the variance in outcome was accounted for by the model including relevant demographic and nutrition variables. A higher percentage of energy intake from fats was associated with higher HbA1c.
controlling for all other variables in the model ($\beta = 0.05$, $p = 0.02$). Fully saturated models did not alter these conclusions or improve percentage of variance explained.

4. Discussion

The current study reveals that many primarily middle-class early adolescents with T1D do not meet national nutritional guidelines set by the American Diabetes Association [4]. Nevertheless, most health indicators are relatively favorable and within normal limits at this age, despite suboptimal glycemic control. Perhaps more importantly, the current study provides evidence that adherence to nutritional guidelines for macronutrient intake is associated with better glycemic control, consistent with prior research. Additionally, this study demonstrates a link between higher percentage of energy intake from fats and poorer glycemic control in a young adolescent T1D sample, above and beyond the contribution of demographic and other dietary variables. Finally, longer diabetes duration was related to higher systolic blood pressure and higher LDL in the current pediatric sample, consistent with the increased risk of hyperlipidemia in diabetes [35, 36].

A higher percentage of energy intake from fats was related to poorer glycemic control after accounting for other study demographic, disease, and nutritional factors. Taken together, demographic variables and diet variables explained 20% of the variance in glycemic control, consistent with existing T1D research [22, 37]. In contrast, a higher percentage of energy intake from proteins was associated with higher systolic BP and a higher percentage of energy intake from carbohydrates related to higher diastolic BP. In the current sample, nutritional intake was not associated with BMI percentile or LDL cholesterol. Further, insulin regimen, conventional versus flexible, did not distinguish groups on the basis of nutritional intake or health indicators, with the exception of HbA1c, for which a higher percentage of participants on a flexible regimen met the guidelines. These findings are slightly different from previous research [37] that found variation in nutrition and health status by insulin regimen.

The current study illustrates that a sizable majority of youth did not meet ADA or ISPAD nutritional guidelines and may be at risk for cardiovascular disease and other health complications later in life. Early inklings of this risk are found in the present association between longer disease duration and higher LDL cholesterol and higher systolic blood pressure. Diabetes carries a known morbidity for hyperlipidemia, and therefore, youth may benefit from close monitoring of health status and macronutrient intake, particularly saturated fats, to prevent onset of cardiovascular disease [38]. Parents were aware that their adolescents were not following their nutritional plan, as over half (51%) reported that their adolescent followed their specific nutrition plan less than 75% of the time. However, parents of youth on flexible regimens were more likely to report that their adolescents were following nutrition guidelines. In support of our findings, existing studies have reported that adolescents with T1D do not meet the recommended ADA guidelines [39, 40].

Our study adds to the literature by finding an association between dietary intake and health indicators of glycemic control and blood pressure in early adolescents. That is, specific dietary components in the present study had a direct relation to established health indicators, beyond the contribution of demographic factors and general nutritional status which were controlled statistically. Previous work has examined the association between nutrition and health status in Chinese adults with T1D, whose diets likely are dissimilar to those of American adolescents [41]. Nevertheless, links were found among dietary patterns with HbA1c and LDL cholesterol in this Asian sample. Work in youth with T1D indicates that carbohydrate intake, when examined alone, is associated with lipid profiles, BMI, and HbA1c [20] and saturated fat intake is associated with HbA1c [19]. The current study not only supports these findings but also adds new information through examination of multiple demographic and nutritional variables simultaneously, regardless of insulin regimen. Adolescents and their parents may perceive that improved insulin delivery and dosing systems allow more freedom in food choices, but these data indicate that a heart-healthy diet has ramifications beyond traditional short- and long-term cardiac status and, in fact, directly relates to level of glycemic control.

A novel direct association also was found between macronutrient consumption and BP, although BP was not elevated overall in the current sample. Specifically, consumption of a higher percentage of energy from proteins related to higher systolic BP and a higher percentage of energy intake from carbohydrates related to diastolic BP. Importantly, evidence of dietary links to glycemic control and BP status based on just two samples of nutritional intake from two days is compelling and requires further study. More subtle associations may be found with more extensive sampling and other methods of assessing dietary intake. With an average disease duration in the present sample of just five years, the importance of understanding the dietary correlates of glycemic and cardiac status is underscored by the fact that longer diabetes duration was associated with higher LDL levels, a known risk factor for cardiovascular disease [42].

Consistent with previous literature [43, 44], Table 3 shows that demographic variables were associated with nutrition behaviors and diabetes health indicators. Specifically, older age places youth at risk for poorer health indicators overall. However, age was not associated with patterns of nutritional intake. Longer disease duration was associated with higher systolic BP and LDL. Non-Caucasian adolescents with T1D reported similar nutritional intake to Caucasians but were more likely to have overall poorer health indicators, suggesting that factors other than nutritional behaviors may place minority youth at greater risk for cardiovascular disease. Consistent with previous literature, low SES was associated with higher HbA1c values (e.g., [45]). Differences in disease-related variables, such as duration of illness and insulin regimen, may place early adolescents at different levels of risk for a confluence of poorer nutritional behaviors and health indicators. For example, longer duration of illness was associated with a higher systolic BP leading to a potential risk of hypertension and was associated with higher LDL,
which potentiates for dyslipidemia. Adolescents on flexible regimens may have higher intake of carbohydrates and lower intake of proteins than peers on conventional regimens, which could be important for dieticians counseling adolescents on flexible regimens regarding the importance of adhering to nutrition guidelines.

5. Clinical Implications

When youth with T1D are first diagnosed, especially as younger children, their care and management fall solely to their parents. At the time of diagnosis, most families receive “survival skills” training, which incorporates nutrition guidelines and medical nutrition therapy. However, early adolescence represents a period of increased independence and self-management, as well as greater freedom in food choices. Early adolescents may not be routinely included in initial diabetes education such that they may be unaware of the importance of balanced nutrition to manage their HbA1c and to prevent future health risk. The present study’s findings underscore the ADA recommendation of yearly meetings with a registered dietician such that nutrition counseling is a routine and frequent part of diabetes education and management. Particularly pressing is the need to help early adolescents understand the importance of adherence to nutrition recommendations to optimize their glycemic control and to decrease their risk for future cardiovascular disease [5, 9].

Given that education alone is not always sufficient to produce changes in behavior, for optimal efficacy, nutrition counseling could include focus on individual and cultural preferences, motivation, and self-efficacy to make healthful choices, as well as familial financial considerations. When adolescents and families have difficulty adhering to nutritional guidelines, clinical psychologists may be a critical component of care in order to promote adherence. Integration of technology may be an appealing facet of diabetes care to engage adolescents and promote self-monitoring behaviors as a means to support healthful decision-making. Technology may represent a fruitful avenue to keep nutritional education and reeducation updated and enjoyable.

6. Limitations

The current study is strengthened by the use of multimethod and multisource data at multiple time points. However, the cross-sectional nature of the study makes it impossible to determine casual relations among demographic, nutritional, and health variables. Moreover, the number of analyses increases risk for type 1 error. Future research should examine these relationships longitudinally, particularly as adolescents reach young adulthood and beyond. Moreover, although parents and youth reported their nutritional intake at two different time points using the gold standard for assessment of dietary intake, self-report of food intake is often underreported [32] and may not accurately represent actual consumption. Future research should incorporate other methods, such as direct observation or innovative technologies such as remote food photography method [46]. Other factors that affect glycemic control, such as meal timing, physical activity, and insulin dosing, should be simultaneously evaluated. Although the current sample is representative of the two institutions from which it was drawn, it may not be representative of all youth with type 1 diabetes.

7. Conclusions

Overall, many early adolescents with T1D did not meet guidelines for nutritional intake. Nonadherence to nutritional guidelines, above and beyond the influence of demographic variables, was associated with poorer HbA1c and places youth at risk for later health complications. Regular nutritional education, particularly for early adolescents, along with behavioral adherence to the guidelines may prove crucial for maintenance of better glycemic control and prevention of future cardiovascular disease.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflict of interest.

Acknowledgments

The authors would like to acknowledge the NIH/NIDDK for the funding to perform the current study (5R01DK070917-04 awarded to CH). The authors would also like to thank the W.T. Gill, Jr., Summer Fellowship for the support for a summer project to complete the paper (educational scholarship awarded to Lyndsay O’Brecht). They would also like to thank the research staff who contributed to the data collection and analysis.

References

[1] J. S. Borus and L. Laffel, “Adherence challenges in the management of type 1 diabetes in adolescents: prevention and intervention,” Current Opinion in Pediatrics, vol. 22, no. 4, pp. 405–411, 2010.
[2] J. Silverstein, G. Klingensmith, K. Copeland et al., “Care of children and adolescents with type 1 diabetes: a statement of the American Diabetes Association,” Diabetes Care, vol. 28, no. 1, p. 186–212, 2005.
[3] D. M. Nathan, P. A. Cleary, J. Y. Backlund et al., “Intensive diabetes treatment and cardiovascular disease in patients with type 1 diabetes,” The New England Journal of Medicine, vol. 353, no. 25, pp. 2643–2653, 2005.
[4] American Diabetes Association, “11. Children and adolescents,” Diabetes Care, vol. 38, Supplement 1, pp. S70–S76, 2015.
[5] J. L. Chiang, M. S. Kirkman, L. M. Laffel, A. L. Peters, and Type 1 Diabetes Sourcebook Authors, “Type 1 diabetes through the life span: a position statement of the American Diabetes Association,” Diabetes Care, vol. 37, no. 7, pp. 2034–2054, 2014.
[6] Diabetes Control and Complications Trial/Epidemiology of Diabetes Interventions and Complications, L. M. Delahanty, D. M. Nathan et al., “Association of diet with glycated hemoglobin during intensive treatment of type 1 diabetes in the diabetes control and complications trial,” The American Journal of Clinical Nutrition, vol. 89, no. 2, pp. 518–524, 2009.

[7] K. Lange, P. Swift, E. Pankowska, T. Danne, and ISPAD clinical practice consensus guidelines 2014, “Diabetes education in children and adolescents,” Pediatric Diabetes, vol. 15, Supplement 20, pp. 77–85, 2014.

[8] N. C. Overby, H. D. Margeirsodttr, C. Brunborg, L. F. Andersen, and K. Dahl-Jorgensen, “The influence of dietary intake and meal pattern on blood glucose control in children and adolescents using intensive insulin treatment,” Diabetologia, vol. 50, no. 10, pp. 2044–2051, 2007.

[9] C. E. Smart, F. Annan, L. P. Bruno, L. A. Higgins, and C. L. K. Lange, P. Swift, E. Pankowska, T. Danne, and ISPAD clinical practice consensus guidelines 2014. Nutritional management in children and adolescents with diabetes,” Pediatric Diabetes, vol. 15, Supplement 20, pp. 135–153, 2014.

[10] S. R. Patton, “Adherence to diet in youth with type 1 diabetes,” Journal of the American Dietetic Association, vol. 111, no. 4, pp. 550–555, 2011.

[11] E. C. Banfield, Y. Liu, J. S. Davis, S. Chang, and A. C. Frazier-Wood, “Poor adherence to US dietary guidelines for children and adolescents in the National Health and Nutrition Examination Survey population,” Journal of the Academy of Nutrition and Dietetics, vol. 116, no. 1, pp. 21–27, 2016.

[12] V. S. Helgeson, L. Viccaro, D. Becker, O. Escobar, and L. Siminerio, “Diet of adolescents with and without diabetes: Tasting candy for potato chips?,” Diabetes Care, vol. 29, no. 5, pp. 982–987, 2006.

[13] K. A. K. Davison, C. A. Negrato, R. Cobas et al., “Relationship between adherence to diet, glycemic control and cardiovascular risk factors in patients with type 1 diabetes: a nationwide survey in Brazil,” Nutrition Journal, vol. 13, no. 1, pp. 1–11, 2014.

[14] S. S. Soedamah-Mutlu, N. Chaturvedi, J. H. Fuller, M. Toeller, and EURODIAB, “Do European people with type 1 diabetes consume a high atherogenic diet? 7-year follow-up of the EURODIAB prospective complications study,” European Journal of Nutrition, vol. 52, no. 7, pp. 1701–1710, 2013.

[15] American Diabetes Association, J. P. Bantle, J. Wylie-Rosett, C. M. Apovian, N. G. Clark, and M. J. Franz, “Nutrition recommendations and interventions for diabetes: a position statement of the American Diabetes Association,” Diabetes Care, vol. 31, Supplement 1, pp. S61–S78, 2008.

[16] American Diabetes Association, “3. Foundations of care and comprehensive medical evaluation,” Diabetes Care, vol. 39, Supplement 1, pp. S23–S35, 2016.

[17] M. A. Testa, J. Gill, M. Su, R. R. Turner, L. Blonde, and D. C. Simonson, “Comparative effectiveness of basal-bolus versus premix analog insulin on glycemic variability and patient-centered outcomes during insulin intensification in type 1 and type 2 diabetes: a randomized, controlled, crossover trial,” The Journal of Clinical Endocrinology and Metabolism, vol. 97, no. 10, pp. 3504–3514, 2012.

[18] A. J. Rovner and T. R. Nansel, “Are children with type 1 diabetes consuming a healthful diet? a review of the current evidence and strategies for dietary change,” The Diabetes Educator, vol. 35, no. 1, pp. 97–107, 2009.

[19] C. Maffeis, A. Morandi, E. Ventura et al., “Diet, physical, and biochemical characteristics of children and adolescents with type 1 diabetes: relationship between dietary fat and glucose control,” Pediatric Diabetes, vol. 13, no. 2, pp. 137–146, 2012.

[20] T. Meissner, J. Wolf, M. Kersting et al., “Carbohydrate intake in relation to BMI, HbA1c and lipid profile in children and adolescents with type 1 diabetes,” Clinical Nutrition, vol. 33, no. 1, pp. 75–78, 2014.

[21] S. F. Michaliszyn, G. Q. Shabi, L. Quinn, C. Fritschi, and M. S. Faulkner, “Physical fitness, dietary intake, and metabolic control in adolescents with type 1 diabetes,” Pediatric Diabetes, vol. 10, no. 6, pp. 389–394, 2009.

[22] T. R. Nansel, L. M. Lipsky, and A. Liu, “Greater diet quality is associated with more optimal glycemic control in a longitudinal study of youth with type 1 diabetes,” American Journal of Clinical Nutrition, vol. 104, no. 1, pp. 81–87, 2016.

[23] M. Saito, H. Kuratsune, H. Nitta et al., “Plasma lipid levels and nutritional intake in childhood- and adolescence-onset young type 1 diabetic patients in Japan,” Diabetes Research and Clinical Practice, vol. 73, no. 1, pp. 29–34, 2006.

[24] T. R. Nansel, L. M. B. Laffel, D. L. Haynie et al., “Improving dietary quality in youth with type 1 diabetes: randomized clinical trial of a family-based behavioral intervention,” International Journal of Behavioral Nutrition and Physical Activity, vol. 12, no. 1, p. 58, 2015.

[25] S. Keel, C. Itsiopoulos, K. Koklanis, M. Vukicevic, F. Cameron, and L. Brazionis, “Prevalence and risk factors for diabetic retinopathy in a hospital-based population of Australian children and adolescents with type 1 diabetes,” Journal of Pediatric Endocrinology and Metabolism, vol. 29, no. 10, pp. 1135–1142, 2016.

[26] F. S. R. Bernaud, M. Beretta, C. do Nascimento et al., “Fiber intake and inflammation in type 1 diabetes,” Diabetology & Metabolic Syndrome, vol. 6, no. 1, pp. 66–10, 2014.

[27] D. A. J. M. Schoenaker, the EURODIAB Prospective Complications Study Group, M. Toeller, N. Chaturvedi, J. H. Fuller, and S. S. Soedamah-Muthu, “Dietary saturated fat and fibre and risk of cardiovascular disease and all-cause mortality among type 1 diabetic patients: the EURODIAB prospective complications study,” Diabetologia, vol. 55, no. 8, pp. 2132–2141, 2012.

[28] C. S. Holmes, R. Chen, E. Mackey, M. Grey, and R. Streisand, “Randomized clinical trial of clinic-integrated, low-intensity treatment to prevent deterioration of disease care in adolescents with type 1 diabetes,” Diabetes Care, vol. 37, no. 6, pp. 1535–1543, 2014.

[29] A. A. Hollingshead, Four-Factor Index of Social Status, Yale University, New Haven, CT, 1974, Unpublished manuscript.

[30] S. B. Johnson, J. Silverstein, A. Rosenblom, R. Carter, and W. Cunningham, “Assessing daily management in childhood diabetes,” Health Psychology, vol. 5, no. 6, pp. 545–564, 1986.

[31] C. S. Holmes, R. Chen, R. Streisand et al., “Predictors of youth diabetes care behaviors and metabolic control: a structural equation modeling approach,” Journal of Pediatric Psychology, vol. 31, no. 8, pp. 770–784, 2006.
medical treatments in pediatric psychology,” *Journal of Pediatric Psychology*, vol. 33, no. 9, pp. 916–936, 2008.

[34] US Department of Health and Human Services & US Department of Agriculture, “2015–2020 Dietary Guidelines for Americans,” 2015, 8th edition, http://health.gov/dietaryguidelines/2015/guidelines/.

[35] The Diabetes Control and Complications Trial/Epidemiology of Diabetes Interventions and Complications (DCCT/EDIC) Study Research Group, “Intensive diabetes treatment and cardiovascular disease in patients with type 1 diabetes,” *New England Journal of Medicine*, vol. 353, no. 25, pp. 2643–2653, 2005.

[36] K. O. Schwab, J. Doerfer, W. Hecker et al., “Spectrum and prevalence of atherogenic risk factors in 27,358 children, adolescents, and young adults with type 1 diabetes: cross-sectional data from the German diabetes documentation and quality management system (DPV),” *Diabetes Care*, vol. 29, no. 2, pp. 218–225, 2006.

[37] M. L. Katz, S. Mehta, T. Nansel, H. Quinn, L. M. Lipsky, and L. M. B. Laffel, “Associations of nutrient intake with glycemic control in youth with type 1 diabetes: differences by insulin regimen,” *Diabetes Technology & Therapeutics*, vol. 16, no. 8, pp. 512–518, 2014.

[38] J. B. Buse, H. N. Ginsberg, G. L. Bakris et al., “Primary prevention of cardiovascular diseases in people with diabetes mellitus: a scientific statement from the American Heart Association and the American Diabetes Association,” *Diabetes Care*, vol. 30, no. 1, pp. 162–172, 2007.

[39] E. J. Mayer-Davis, M. Nichols, A. D. Liese et al., “Dietary intake among youth with diabetes: the SEARCH for Diabetes in Youth Study,” *Journal of the American Dietetic Association*, vol. 106, no. 5, pp. 689–697, 2006.

[40] N. C. Overby, V. Flaaten, M. B. Veierod et al., “Children and adolescents with type 1 diabetes eat a more atherosclerosis-prone diet than healthy control subjects,” *Diabetologia*, vol. 50, no. 2, pp. 307–316, 2007.

[41] L. M. Jaacks, J. Crandell, M. A. Mendez et al., “Dietary patterns associated with HbA1c and LDL cholesterol among individuals with type 1 diabetes in China,” *Journal of Diabetes and its Complications*, vol. 29, no. 3, pp. 343–349, 2015.

[42] P. W. F. Wilson, R. B. D’Agostino, D. Levy, A. M. Belanger, H. Silbershatz, and W. B. Kannel, “Prediction of coronary heart disease using risk factor categories,” *Circulation*, vol. 97, no. 18, pp. 1837–1847, 1998.

[43] V. S. Helgeson, L. Siminerio, O. Escobar, and D. Becker, “Predictors of metabolic control among adolescents with diabetes: a 4-year longitudinal study,” *Journal of Pediatric Psychology*, vol. 34, no. 3, pp. 254–270, 2009.

[44] J. J. Jacobsen, M. H. Black, B. H. Li, K. Reynolds, and J. M. Lawrence, “Race/ethnicity and measures of glycaemia in the year after diagnosis among youth with type 1 and type 2 diabetes mellitus,” *Journal of Diabetes and its Complications*, vol. 28, no. 3, pp. 279–285, 2014.

[45] S. Zilioli, D. A. Ellis, J. M. Carre, and R. B. Slatcher, “Biospsychosocial pathways linking subjective socioeconomic disadvantage to glycemic control in youths with type 1 diabetes,” *Psychoneuroendocrinology*, vol. 78, pp. 222–228, 2017.

[46] C. K. Martin, J. B. Correa, H. Han et al., “Validity of the remote food photography method (RFPM) for estimating energy and nutrient intake in near real-time,” *Obesity*, vol. 20, no. 4, pp. 891–899, 2012.