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Physical fitness, dietary intake and metabolic control in adolescents with type 1 diabetes

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Abstract

Purpose—We examined whether physical fitness and dietary intake predicted better glycemic control and lipid profile in adolescents with type 1 diabetes (T1DM).

Methods—The sample consisted of 109 adolescents with T1DM (age, 15.3 ± 1.9 yrs; diabetes duration, 6.2 ± 3.7 yrs; BMI, 23.3 ± 4.0 kg/m²; HbA1c, 8.7 ± 1.6 %). Stepwise regression analyses were performed with the following independent variables (age, sex, duration of diabetes, BMI, Tanner stage, physical fitness, and average carbohydrate, total and saturated fat intake) and the following dependent variables (total cholesterol, LDL-c, HDL-c, triglycerides, and HbA1c). Physical fitness was measured by VO_{2peak} during progressive cycle ergometry and three day food intake was analyzed using Nutritionist ProTM software.

Results—Sex and VO_{2peak} explained 19% of the variance for HbA1c. Age, VO_{2peak} and saturated fat intake predicted 23% of the variance for total cholesterol, although only diabetes duration and saturated fat intake predicted LDL-c (11%). Duration of diabetes explained 5% of the variance in triglyceride levels and there were no significant independent predictors for HDL-c.

Conclusion—Greater fitness levels predicted both better glycemic control and total cholesterol in adolescents with T1DM, whereas lower saturated fat affected total cholesterol but not glycemic control. These findings support the importance of physical fitness and diets of lower saturated fat for overall metabolic health in adolescents with T1DM.

Keywords

Diabetes; Youth; Exercise; Nutrition; Blood Lipids; fitness

Introduction

One of the most common concerns among adolescents diagnosed with type 1 diabetes (T1DM) is glycemic control. Poor glycemic control in addition to hyperlipidemia have been shown to substantially increase risk for future cardiovascular complications including endothelial dysfunction (1), activation and maintenance of the proinflammatory immune response (2), in addition to poor quality of life (3). Increased physical activity to promote fitness and a diet that includes carbohydrate counting and decreased saturated fat intake are recommended therapeutic modalities in the management of diabetes. Although increased physical fitness is known to reduce metabolic risk factors, relatively little is known regarding the effects of both dietary intake and physical fitness on glycemic control in youth with T1DM.

Along with a prescribed pharmacological regime (i.e. insulin), increased physical fitness and proper nutrient intake are required self-management practices for adolescents with T1DM. The American Diabetes Association (ADA) and the American Heart Association (AHA) recommend improving lifestyle strategies in youth to optimize glycemic control and to reduce cardiovascular risk (4), albeit physical activity has been prescribed to youth with T1DM for decades (5). Currently, the American College of Sports Medicine and other health agencies do not have recommendations specific to youth with T1DM although youth with T1DM are encouraged to follow the recommendations for all youth which are participation in 30 to 60 minutes of moderate-intensity physical activity on most, preferably all days of the week (6).

A recent analysis by NHANES objectively measured current levels of physical activity amongst the U.S. population. Authors report that physical activity decreases as youth age, is lower in females and youth older than 12 years are only engaging in half of the daily recommended levels of moderate vigorous activity. Moreover, by age 16, vigorous activity is almost nonexistent (7). Higher levels of physical activity are required to achieve an improvement in cardiovascular fitness. Cardiorespiratory fitness is inversely associated with fat mass (8), hyperlipidemia (9), and glucose metabolism (10). Unfortunately, approximately one third of U.S. youth fail to meet recommended standards for cardiorespiratory fitness (11) and youth with T1DM show reduced amounts of moderate to vigorous physical activity compared to youth without T1DM, (12) a striking statistic that may potentiate the risk for morbidity and mortality in this population. Several modifiable risk factors, specifically body mass index (BMI), physical fitness and nutrition, are amenable to interventions to improve glycemic control.

Despite current ADA recommendations for reducing risks for future complications related to diabetes through healthy eating habits and regular physical activity, youth are consuming more than the daily recommendations. Less than 50% of youth with T1DM meet recommendations for total fat, fruits, vegetables or grains (13). It is widely accepted that high saturated fat and cholesterol intakes are often associated with lipid abnormalities, all cause mortality, and hyperinsulinemia in adults as well as children (14). Furthermore, current AHA guidelines state the presence of diabetes to be equivalent to having cardiovascular disease and using aggressive nutritional therapy should be instituted to improve the patient's metabolic profile [i.e., to reduce low density lipoprotein cholesterol (LDL-c) and triglycerides and increase high density lipoprotein cholesterol (HDL-c) levels] (15). More recently, dietary carbohydrates have also come under debate in respect to their role in promoting cardiovascular risk through their effects on blood lipids (16,17).

Purpose

We therefore examined whether physical fitness and macronutrient composition predicted better glycemic control and a healthier lipid profile in adolescents with T1DM. The primary aim of the study was to determine if age, sex, diabetes duration, BMI, physical fitness

($\text{VO}_{2\text{peak}}$), Tanner stage, total and saturated fat intake or carbohydrate intake were related to overall metabolic health, measured by fasting lipids and glycemic control.

Methods

All study procedures, including HIPAA authorization, written parental permission and youth assents were reviewed and approved by Institutional Review Boards of the University of Illinois at Chicago and the University of Chicago. All data were collected at the General Clinical Research Center at the University of Illinois at Chicago.

Subjects

Participants were included if they were diagnosed with type 1 diabetes for at least 1 year and were between the ages of 13 to 18 years of age. Youth were excluded if they were still in their initial year of diagnosis to allow for an adjustment period for establishing individual therapies for insulin regimens. Other exclusion criteria included developing diabetes as a secondary condition to treatment for other chronic conditions (e.g. cancer), having a known cardiac defect, or for females, being pregnant. The sample consisted of adolescents receiving routine medical care in an outpatient clinic of a large metropolitan university-based childhood diabetes center located in Chicago, Illinois. The sample population is representative of the overall clinic population that includes individuals with diverse socioeconomic statuses. Data collection occurred between March 2001 and March 2007.

Procedures

All participants were asked to arrive at the University of Illinois at Chicago, General Clinical Research Center (GCRC) following an overnight fast where the following procedures were performed.

Standing height and weight were determined to the nearest centimeter and kilograms, respectively. BMI was calculated as weight in kilograms divided by the square of height in meters. Recent HbA1c was determined using the Abbott Imx[®] assay method for quantitative measurement of whole blood (Abbott Park, IL). The Beckman Synchron CX-7 Analyzer (Beckman-Coulter, Brea, Calif) was used to determine total cholesterol, triglycerides and HDL-c. LDL-c was calculated using the Friedewald equation (18). Tanner stage was determined by a pediatric endocrinologist or attending nurse practitioner a few weeks prior to of the day of data collection.

Cardiovascular Fitness

Peak oxygen consumption ($\text{VO}_{2\text{peak}}$) was chosen for this study since youth often fail to meet the objective criteria of achieving a plateau for a true $\text{VO}_{2\text{max}}$ measure. $\text{VO}_{2\text{peak}}$ was determined as previously described (19). Briefly, the McMaster cycle protocol was used and is a recommended protocol for youth since it is based on the height of the adolescent and uses a gender-specific workload, with a total optimal exercise time of 8 to 12 min.

Dietary Recall

Three day 24-hour food record was used to assess the daily food intake including supplements, if any. Food records were entered into a nutrition analysis software program, Nutritionist Pro[™] (San Bruno, Calif), which can be used to perform a nutrient analysis of food records, diets, recipes, and menus and compare this information to specific nutrient requirements. A registered dietitian interviewed each teen to obtain clarification on portion sizes and any condiment use to decrease the potential of reporting errors. The 3-day food record has shown to be a valid and reliable source for assessing nutrient intake in adolescents (20).

Data analyses

The primary aim of the study was analyzed using stepwise multiple regression procedures in the SPSS statistical program (Version 14.0, SPSS, Inc., Chicago, IL). Upon evaluating multicollinearity diagnostic procedures, multiple analyses were run with the following independent variables: age, sex, diabetes duration, absolute $\text{VO}_{2\text{peak}}$, BMI, Tanner stage, average total and saturated fat intake, and average carbohydrate intake and the following dependent variables: total cholesterol, LDL-c, HDL-c, triglycerides and HbA1c.

Results

Physical characteristics of the participants are presented in Table 1. The study sample consisted of 109 adolescents mostly (52%) in Tanner stage 5. Sixty eight percent ($n=74$) of youth used multiple injections while 30% ($n=33$) utilized pump therapy and 2% ($n=2$) were also taking Glucophage (metformin). Youth's total cholesterol was 167 ± 31.4 mg/dL, LDL-c was 102.3 ± 25 mg/dL, HDL-c was 52.4 ± 11.7 mg/dL and triglycerides were 60 ± 39.7 mg/dL. Glycemic control measured by HbA1c was $8.7 \pm 1.6\%$. On average youth consumed 2371.5 ± 675.3 calories of which 49% (295.7 ± 92.1 g) were from carbohydrates, 14% (87.2 ± 30.3 g) were from protein and 37% (97.7 ± 34.7 g) were from fat, of which 35% (34.2 ± 13.0 g) was from saturated fat.

Significant predictors for glycemic control and lipids are presented in Table 2. Significant beta weights for each of the dependent variables are noted in Table 2. Stepwise regression analysis revealed $\text{VO}_{2\text{peak}}$ and sex predicted 19% ($R^2 = 0.189$) of the variance for HbA1c. In other words, being male was associated with poorer metabolic control. $\text{VO}_{2\text{peak}}$, age, and saturated fat intake predicted 23% ($R^2 = 0.229$) of the variance for total cholesterol. In contrast to total cholesterol, cardiovascular fitness fell out of the model in respect to LDL-c, HDL-c and triglycerides. Only diabetes duration and saturated fat intake predicted a total of 11% ($R^2 = 0.107$) of the variance for LDL-c with diabetes duration predicting 6% ($R^2 = 0.062$). There were no significant independent predictors for HDL-c and the only independent predictor for triglyceride levels was diabetes duration which explained 5% ($R^2 = 0.054$) of the variance.

Discussion

Adult patients diagnosed with diabetes are shown to have an increased risk for cardiovascular events (21). Known cardiovascular risk factors consist of longstanding diabetes, age, poor glycemic control, hypertension, dyslipidemia and obesity (22); many of these risks are now observed in the pediatric diabetic population (23). Thus the need for preventative interventions for this at-risk population is paramount to ensure future generations can maintain a high quality of life while living with diabetes.

Studies in adults show that regular physical activity and/or high cardiovascular fitness improve hyperlipidemia, hypertension and glycosylated hemoglobin (24,25), although studies in youth with T1DM are varied (26–30). Furthermore, in both adults and youth, dietary intake effects metabolic parameters such as glucose control (16,17) and lipid profile (31–33). Thus, physical activity and/or cardiovascular fitness are not the only contributing factor to metabolic control.

Our investigation is the first to examine both cardiovascular fitness and measures of dietary intake in association with metabolic control in adolescents with T1DM. A main finding of this study is that cardiovascular fitness and daily intake of saturated fat, rather than total fat, both play an important role in overall metabolic health in youth with T1DM. Other investigations (16,17,19,26) have examined the individual associations between cardiovascular fitness and metabolic control or dietary intake and metabolic control, but not the combined effects of fitness and diet on glycemia and lipid profiles.

Our data and others (19,26,27) reveal cardiovascular fitness is inversely associated with HbA1c in youth with T1DM. Austin et al. (27) revealed an inverse association ($R = -0.42$; $P = 0.002$) between cardiovascular fitness and HbA1c. Furthermore, Arslanian et al. revealed positive associations between insulin-mediated glucose utilization and cardiovascular fitness in youth diagnosed with T1DM (26). Consistent with a previous report by Faulkner et al., (19) that included this dataset of adolescents with T1DM, along with a subset of adolescents with type 2 DM, glucose control estimated 6% of the variance in cardiovascular fitness. These studies provide evidence of the potential impact of fitness on glucose control.

In individuals with T1DM, investigations with adults (16) and adolescents (17) reveal an association between carbohydrate intake and HbA1c. Buyken et al. (16) found total carbohydrate intake was positively associated with higher HbA1c, whereas an increased intake of vegetable carbohydrates were inversely related to HbA1c. Interestingly, Wiltshire et al. (17) also revealed that total carbohydrate intake was inversely related to HbA1c, and that a positive association was observed between saturated fat intake and HbA1c. In contrast our data did not reveal any associations between carbohydrate or fat intake and HbA1c. Differences may be due in part to how dietary intake was assessed. Wiltshire et al. used a food frequency questionnaire which determines dietary intake averaged over the last year whereas in the present investigation, we used a 3-day dietary recall. Limitations to dietary recalls are well known (34,35) but estimates from diet records have shown to better align with actual current intake than estimates from the food-frequency questionnaire (36).

In adults, as well as in youth, cardiovascular fitness (27) and longitudinal exercise intervention studies (37,38) have produced inconsistent results with respect to blood lipids. Most investigations have shown improvements in HDL-c, although reductions in LDL-c, total cholesterol and triglycerides are less frequently observed (38). In youth diagnosed with T1DM few investigations have examined the link between cardiovascular fitness and blood lipids. For instance Austin et al. assessed fitness levels in 58 adolescents with T1DM and 18 adolescents without diabetes matched for age, BMI and Tanner stage. The authors concluded that cardiovascular fitness was inversely associated with total cholesterol, LDL-c and triglycerides in youth with type 1 diabetes (27). In our study, both cardiovascular fitness and saturated fat intake were associated only with total cholesterol, but not with LDL-c, HDL-c or triglycerides.

The associations between total and saturated fat intake and abnormal lipid profile have been observed for years (39) although recent reports are contradictory (16,17). For instance Wiltshire et al. assessed total cholesterol, LDL-c, HDL-c and triglycerides in 79 children and adolescents with T1DM and 61 age- and sex-matched controls (17). Wiltshire et al. found an inverse relationship between the percentage of complex carbohydrates, rather than energy from fat, and HDL-c ($\beta = -0.35$, $P = 0.006$) and a positive association with triglycerides ($\beta = 0.33$, $P = 0.01$). In contrast to Wiltshire et al. a study by Saito et al (40) conducted in young Japanese children and adolescents diagnosed with T1DM, showed that youth who had high total cholesterol and LDL-c also consumed more energy from total fat, saturated fat and cholesterol and lower amounts from polyunsaturated fats. Our data partially agree with Saito et al. and convey that saturated fat intake, but not total fat, is positively associated with total cholesterol and LDL-c. In contrast to Wiltshire and colleagues we did not find any associations between carbohydrate intake and lipid profile. One limitation to our finding is the assessment of average carbohydrates. Using average carbohydrates does not provide information on the separate effects of high versus low glycemic index carbohydrates. Thus, the results should be interpreted cautiously.

Conclusion

Our results support the hypothesis that higher levels of fitness and diets low in saturated fat intake are important components in the overall metabolic health of youth diagnosed with T1DM. Improvements in cardiovascular fitness are not easily attained in youth but adjustments to saturated fat intake may prove to be more feasible. Prospective studies are warranted to examine the effects of lifestyle interventions focusing on the feasibility of improving cardiovascular fitness and/or decreasing saturated fat intake.

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Abbreviations

T1DM	type 1 diabetes
ADA	American Diabetes Association
AHA	American Heart Association
CDC	Center for Disease Control
BMI	Body mass index
GCRC	General Clinical Research Center
LDL-c	Low density lipoprotein cholesterol
LDL-c	High density lipoprotein cholesterol

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Table 1

Subject Characteristics

	T1DM
n	109
Gender (n)	
Male	60 (55%)
Female	49 (45%)
Race	
White	73 (67%)
Black	30 (26%)
Hispanic	6 (7%)
Duration of DM (yrs)	6.2 ± 3.7
Tanner Stage	
1	1 (0.9%)
2	4 (3.7%)
3	20 (18.3%)
4	27 (24.8%)
5	57 (52.3%)
Height (cm)	166.7 ± 10.2
Weight (kg)	65.1 ± 14.6
BMI (kg/m²)	23.3 ± 4.0
Age (yrs)	15.3 ± 1.9
VO₂ (L/min)	2.3 ± 0.8
VO₂ (ml/kg/min)	34.7 ± 8.9

VALUES ARE MEANS ± SD

Table 2

Regression Analyses

	Beta	t	p	R ² change	R ²
Recent HbA1c					
VO _{2peak} (ml/min)	-.001	-4.821	.001 [†]	.147	.147
Sex	-.770	-2.273	.025 [*]	.042	.189
Total Cholesterol					
Age (yrs)	5.626	3.698	.001 [†]	.056	.056
Saturated Fat (g)	1.014	4.238	.001 [†]	.061	.117
VO _{2peak} (ml/min)	-.015	-3.808	.001 [†]	.112	.229
LDL Cholesterol					
Duration (yrs)	1.748	2.69	.008 [*]	.062	.062
Saturated Fat (g)	.409	2.26	.026 [*]	.045	.107
Triglycerides					
Duration (yrs)	2.554	2.403	.018 [*]	.054	.054

* p < 0.05;

[†] p < 0.001