



Predictors of Increased Carotid Intima-Media Thickness in Youth With Type 1 Diabetes: The SEARCH CVD Study

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OBJECTIVE

Youth with type 1 diabetes have worse cardiovascular (CV) risk factors and higher carotid intima-media thickness (IMT) than their peers without diabetes. Whether the burden of CV risk factors over time is associated with carotid IMT at follow-up in youth with type 1 diabetes is not known.

RESEARCH DESIGN AND METHODS

Two hundred ninety-eight youth with type 1 diabetes (mean age 13.3 ± 2.9 years, 87.6% non-Hispanic white, 53.7% male) had two study visits 5 years apart. CV risk factors, including BMI, lipids, blood pressure, hemoglobin A_{1c}, and smoking status, were assessed at both visits, and carotid IMT was measured at follow-up using B-mode ultrasonography. Linear regression models with an area under the curve measurement that incorporated the baseline and follow-up CV risk factors were used to evaluate the relationship with carotid IMT at follow-up.

RESULTS

All CV risk factors worsened significantly over time (except LDL cholesterol) ($P < 0.05$). From baseline to follow-up, the number of abnormal CV risk factors also increased ($P < 0.05$). Predictors of carotid IMT were older age, male sex, and higher BMI z score area under the curve (all $P < 0.05$).

CONCLUSIONS

The CV risk factor burden increases over time in youth with type 1 diabetes. BMI z score was the only modifiable CV risk factor that predicted carotid IMT. This study highlights the critical need to better understand the risk factors that influence carotid IMT early in the course of type 1 diabetes.

Adults with childhood-onset type 1 diabetes are at increased risk for premature cardiovascular disease (CVD) morbidity and mortality compared with the general population (1). The antecedents of CVD begin in childhood (2), and early or pre-clinical atherosclerosis can be detected as intima-media thickening in the artery wall (3). Carotid intima-media thickness (IMT) is an established marker of atherosclerosis because of its associations with CVD risk factors (4,5) and CVD outcomes, such as myocardial infarction and stroke in adults (6,7).

Prior work, including data from our study, has shown that youth with type 1 diabetes have higher carotid IMT than control subjects (8–13). In cross-sectional studies, risk factors associated with higher carotid IMT include younger age at

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diabetes onset, male sex, adiposity, higher blood pressure (BP) and hemoglobin A_{1c} (HbA_{1c}), and lower vitamin C levels (8,9,11). Only one study has evaluated CVD risk factors longitudinally and the association with carotid IMT progression in youth with type 1 diabetes (14). In a German cohort of 70 youth with type 1 diabetes, Dalla Pozza et al. (14) demonstrated that CVD risk factors, including BMI z score (BMIz), systolic BP, and HbA_{1c}, worsened over time. They also found that baseline HbA_{1c} and baseline and follow-up systolic BP were significant predictors of change in carotid IMT over 4 years. No studies have evaluated CVD risk factors over time in a U.S. cohort, and no study has attempted to quantify the burden of CVD risk factors over time on carotid IMT.

Thus, the aims of the current study were 1) to evaluate CVD risk factors over time in youth with type 1 diabetes by using measurements that incorporate risk factor data from a baseline and follow-up visit, and 2) to determine the association between the burden of CVD risk factors over time and follow-up carotid IMT.

We hypothesized that a worse CVD risk factor burden over time will be associated with a higher carotid IMT at follow-up.

RESEARCH DESIGN AND METHODS

Study Participants

Participants in this study were enrolled in SEARCH CVD, an ancillary study to the SEARCH for Diabetes in Youth that was conducted in two of the five SEARCH centers (Colorado and Ohio). Extensive details of the main SEARCH study have been published and are summarized by Hamman et al. (15). Participants were eligible for SEARCH CVD if they had physician-diagnosed type 1 diabetes. The baseline SEARCH visit of 406 participants with type 1 diabetes was conducted in 2004–2005 and included questionnaires, demographics, anthropometrics, and laboratory data. A follow-up SEARCH CVD visit was conducted between 2009 and 2011, where questionnaires, demographics, anthropometrics, and laboratory data were repeated and carotid IMT measurements were obtained. The goal of the follow-up study was to recruit >200 adolescents with type 1 diabetes from

the original cohort. This report includes 298 youth who completed both baseline and follow-up SEARCH CVD visits (16,17). The study was reviewed and approved by each local institutional review board, and all participants provided written informed consent or assent.

Anthropometric and Metabolic Measurements

The baseline and follow-up research visits followed the same standard protocol (16,17). Each visit was conducted after at least an 8-h fast. Medications, including short-acting insulin, were withheld until blood draw was completed. Race and ethnicity were self-reported, and participants were categorized as non-Hispanic White (NHW) or other racial/ethnic group (Hispanic, African American, and Asian/Pacific Islander). Participants completed standardized questionnaires for medical history, medications, and smoking status (never, former [no cigarettes in the past 30 days], or current) (18). Height and weight were measured twice during each visit and averaged. BMI was calculated as an average of two measures of weight (kg) divided by height in meters squared, and age and sex-specific BMIz were derived (19). Resting systolic and diastolic BPs were measured three times with an aneroid sphygmomanometer and averaged. Mean arterial pressure (MAP) was calculated as $([2 \times \text{diastolic BP}] + \text{systolic BP}) / 3$.

Measurements of HbA_{1c}, total cholesterol, triglycerides, and HDL cholesterol (HDL-C) were performed as previously described (17). LDL cholesterol (LDL-C) was calculated by the Friedewald equation or measured by beta quantification if triglycerides were ≥ 400 mg/dL.

Definitions of CVD Risk Factors

The thresholds for defining CVD risk factors in this study were generated from published criteria for ideal targets in youth with diabetes (20–22). CVD risk factors were defined as present if

- 1) BMI ≥ 85 th percentile for sex and age;
- 2) systolic or diastolic BP ≥ 90 th percentile for sex, age, and height;
- 3) LDL-C ≥ 130 mg/dL;
- 4) HDL-C ≤ 30 mg/dL;
- 5) triglycerides ≥ 130 mg/dL if age ≥ 10 years or ≥ 100 mg/dL if age < 9 years;

6) HbA_{1c} $\geq 7.5\%$; or

7) patient-reported status as a current smoker.

Carotid Outcome Measurements

Carotid IMT measurements were obtained using standardized B-mode ultrasound images from the right- and left-side neck at the common, bifurcation (bulb), and internal carotid arteries in the longitudinal and transverse views. All ultrasound images were obtained with a variable frequency linear array probe (5–12 MHz). Pulsed Doppler echocardiographic measurements were obtained at the internal carotid artery to confirm correct placement. Images were obtained at the predetermined angles of 90°, 120°, and 150° on the right side and 210°, 240°, and 270° on the left side for each participant. Multiple loops were stored, burned to disk, and transmitted to the vascular reading center in Ohio for reading of far wall mean IMT by a manual trace method (AMICAS VERICIS software, Merge Healthcare, Chicago, IL). A mean IMT value calculated by averaging the IMT measurements from the six predetermined angles for each carotid segment is reported. Analyses of carotid studies on >800 participants had coefficients of variability for all carotid measures ranging from 1.8 to 5.5%, indicating good reproducibility within published guidelines (10).

Statistics

Data are presented as mean and SD or number and percentage. Differences between baseline and follow-up anthropometrics and CVD risk factors were tested with paired *t* tests for continuous variables or McNemar test for categorical variables. CVD risk factor thresholds are as described in “Definitions of CVD Risk Factors.”

To determine significant CVD risk factors associated with carotid IMT, a stepwise approach was taken using general linear models. All models adjusted for age at baseline (in years), race (NHW vs. other), sex (male vs. female), duration of diabetes at follow-up (in years), and clinic site (OH vs. CO). An area under the curve (AUC) measurement (a continuous variable) for each CVD risk factor (except smoking) was derived using baseline and follow-up data and length of time between visits. Separate models were explored for common, bulb, and internal carotid IMT. Models 1–5 explored

individual effects of AUC measurements of standard lipids, BP, insulin sensitivity, HbA_{1c}, and BMI over time on carotid IMT. Model 6 assessed the association between current smoking status (yes/no) at either the baseline or the follow-up visit and carotid IMT.

Model 1 assessed the effects of the LDL-C, HDL-C, and triglycerides AUC. Model 2 assessed MAP AUC. MAP was used instead of systolic or diastolic BP to account for baseline distending pressure of the artery wall (23). Model 3 included insulin sensitivity AUC because lower insulin sensitivity (or insulin resistance) is believed to partially explain some of the increased CVD risk in youth with type 1 diabetes (24). Insulin sensitivity was estimated using the following equation: $\log IS = 4.64725 - 0.02032 \times \text{waist in cm} - 0.00235 \times \text{TG in mg/dL} - 0.09779 \times \text{HbA}_{1c} \%$. This equation was developed and validated using direct measurements of glucose disposal rate from euglycemic-hyperinsulinemic clamps (25). Model 4 evaluated HbA_{1c} AUC, model 5 assessed BMIz AUC, and model 6 evaluated smoking. Model 7 included all significant variables from models 1–6 and can be viewed as the overall model. For all

models, variables with $P < 0.05$ were considered significant.

RESULTS

Characteristics of SEARCH participants at baseline and follow-up are presented in Table 1. At the initial visit, youth with type 1 diabetes were a mean age of 13.3 ± 2.9 years (range 7.6–21.3 years) and had an average disease duration of 3.6 ± 3.3 years. NHW accounted for 87.6% of the cohort, and 53.7% of the cohort was male. At baseline, 3.4% of the cohort reported to be currently smoking. Four participants reported taking an ACE inhibitor/angiotensin receptor blocker, and one reported use of a lipid-lowering medication.

Follow-up data were obtained at a mean age of 19.2 ± 2.7 years, when the average duration of type 1 diabetes was 10.1 ± 3.9 years. At follow-up, frequency of current smoking had increased to 23.8%. CVD risk factors, including BMIz, systolic and diastolic BP, HbA_{1c}, lipid levels, and insulin sensitivity, were all significantly worse at follow-up except for LDL-C, which was not significantly different. At follow-up, 12 (3.0%) participants reported taking an ACE inhibitor/angiotensin receptor

blocker, and 25 (6.0%) reported taking a lipid-lowering drug.

CVD Risk Factors

Table 2 shows the frequency of CVD risk factors at baseline and follow-up. At baseline, high HbA_{1c} was the most common CVD risk factor, present in 72.6% of the cohort. High BMI was observed in 26.7%. High LDL-C level was the most common lipid abnormality, present in 10.3%. Forty percent of participants had two or more CV risk factors (Fig. 1).

At follow-up, the frequency of participants in each risk category increased significantly, except for HDL-C where the frequency decreased significantly from baseline to follow-up (all $P < 0.05$). At follow-up, high BMI was present in more than one-third of the cohort, and high triglyceride levels were the most frequently observed lipid abnormality (32.3%). Figure 1 shows that more than one-half (53%) of participants had two or more CVD risk factors at follow-up.

Predictors of Follow-up Carotid IMT

At follow-up, the mean IMT for youth with type 1 diabetes in the common carotid was 0.60 ± 0.10 mm, the bulb IMT was 0.62 ± 0.10 mm, and the internal IMT was 0.55 ± 0.12 mm. General linear models were constructed to explore risk factors associated with follow-up common, bulb, and internal carotid IMT (Table 3A–C). Older age at the baseline visit and male sex were significantly associated with all carotid IMT outcomes. HDL-C AUC (model 1), MAP (model 2), insulin sensitivity AUC (model 3), and BMIz AUC (model 5) were significantly associated with follow-up common carotid IMT after adjusting for age, race, sex, duration of diabetes, and clinic site. However, in the final model (model 7) for common carotid IMT that included each significant CV risk factor, only BMIz was significant. Similarly, HDL-C AUC, insulin sensitivity AUC, and BMIz AUC were associated with follow-up internal carotid IMT, but in the final model, only BMIz AUC was significant. HbA_{1c} AUC and smoking were not associated with any carotid IMT outcomes in either the individual models or the final model. Of all the CVD risk factors explored, higher BMIz AUC was the only one significantly associated with follow-up common and internal carotid IMT in multivariable analyses. A borderline association was

Table 1—Characteristics of SEARCH CVD study participants at the baseline and follow-up visits

	Baseline (n = 298)	Follow-up (n = 298)	P value
Age (years)	13.3 ± 2.9	19.2 ± 2.7	<0.001
Duration of diabetes (years)	3.6 ± 3.3	10.1 ± 3.9	<0.001
Race (NHW)	261 (87.6)	—	—
Male sex	160 (53.7)	—	—
Smoking status			<0.001
Never	233 (88.6)	160 (53.7)	
Former	21 (8.0)	67 (22.5)	
Current	9 (3.4)	71 (23.8)	
Height (cm)	157.3 ± 14.2	171.4 ± 9.4	<0.001
Weight (kg)	53.4 ± 17.0	73.8 ± 15.2	<0.001
BMI (kg/m ²)	21.1 ± 4.3	25.1 ± 4.8	<0.001
BMIz	0.5 ± 1.0	0.6 ± 0.9	0.003
Systolic BP (mmHg)	103 ± 9	112 ± 10	0.003
Diastolic BP (mmHg)	67 ± 9	70 ± 9	<0.001
Total cholesterol (mg/dL)	166 ± 27	171 ± 35	0.008
LDL-C (mg/dL)	97 ± 23	98 ± 29	0.469
HDL-C (mg/dL)	55 ± 13	53 ± 14	0.010
Triglycerides (mg/dL)	70 ± 38	96 ± 60	<0.001
HbA _{1c} (%)	8.2 ± 1.4	8.9 ± 1.8	<0.001
HbA _{1c} (mmol/mol)	66 ± 15.3	74 ± 19.7	<0.001
Insulin sensitivity score	9.10 ± 2.6	6.37 ± 2.0	<0.001

Data are mean ± SD or n (%). P values were determined by paired t tests for continuous variables and McNemar test for categorical variables.

Table 2—CVD risk factors at baseline and follow-up (n = 298)

	Baseline	Follow-up	P value
Elevated BMI	79 (26.7)	102 (34.5)	<0.001
Elevated systolic or diastolic BP	29 (9.9)	58 (19.5)	<0.001
Elevated LDL-C	30 (10.3)	39 (13.5)	<0.001
Low HDL-C	9 (3.0)	4 (1.3)	<0.001
Elevated triglycerides	23 (7.9)	93 (32.3)	<0.001
Elevated HbA _{1c}	212 (72.6)	234 (78.8)	<0.001
Current smoker	9 (3.4)	71 (23.8)	<0.001

Data are n (%). Elevated defined as BMI \geq 85th percentile for sex and age; systolic or diastolic BP \geq 90th percentile for sex, age, and height; LDL-C \geq 130 mg/dL; and triglycerides \geq 130 mg/dL if age \geq 10 years or \geq 100 mg/dL if age <9 years. Low HDL-C defined as \leq 30 mg/dL. All P values were determined by McNemar test.

also observed for BMIz AUC and the carotid bulb IMT ($P = 0.075$).

CONCLUSIONS

This study demonstrates for the first time to our knowledge that the degree and burden of CVD risk factors increases over time in youth with type 1 diabetes. This study also shows that higher BMIz over time was the only modifiable risk factor associated with follow-up carotid IMT.

Previous cross-sectional studies have demonstrated that adolescents with type 1 diabetes have worse CVD risk profiles and higher carotid IMT than control subjects (8–13). Risk factors shown to associate with higher IMT are age of diabetes onset; higher adiposity, lipid levels, BP, and HbA_{1c}; and lower vitamin C levels (8,9,11). Specifically, Dalla Pozza et al. (14) found that younger age at diabetes onset, systolic BP (mean

111.3 \pm 11.3 mmHg) and total cholesterol levels (mean for females 185 \pm 32.0 mg/dL, mean for males 168 \pm 28.4 mg/dL) were significantly associated with a higher common carotid IMT in adolescents at age 14 years. In addition, Heilman et al. (9) found HbA_{1c} (mean 9.8 \pm 1.5%) was borderline associated with a higher carotid IMT ($r = 0.39$, $P = 0.05$).

Before the current study, no published reports had assessed the impact of changes in CVD risk factors and carotid IMT in U.S. adolescents with type 1 diabetes. A study conducted in 70 German children with type 1 diabetes (mean baseline age 12.6 \pm 2.5 years) examined longitudinally the effect of CVD risk factors on carotid IMT, reporting that over 4 years, BMIz, systolic BP, and HbA_{1c} worsened, whereas LDL-C and HDL-C did not (14). Additionally, the authors noted that higher baseline HbA_{1c} and higher baseline and follow-up systolic BP were significantly associated with change in carotid IMT over time in linear regression models. Limitations of that study included loss of >50% of the original cohort, use of individual baseline and follow-up CVD risk factor data instead of an AUC measurement that accounts for burden of risk factors over time, and no report of diastolic BP, triglycerides, or insulin sensitivity measurements (14).

In the current study, we show that older age (at baseline) and male sex were significantly associated with follow-up IMT. By using AUC measurements, we also show that a higher BMIz exposure over \sim 5 years was significantly associated with IMT at follow-up. From baseline to follow-up, the mean BMI increased from within normal limits

(21.1 \pm 4.3 kg/m²) to overweight (25.1 \pm 4.8 kg/m²), defined as a BMI \geq 25 kg/m² in adults (26,27). This large change in BMI may explain why BMIz was the only modifiable risk factor to be associated with follow-up IMT in the final models. Whether the observed increase in BMIz over time is part of the natural evolution of diabetes, aging in an obesogenic society, or a consequence of intensive insulin therapy is not known. However, this finding points to obesity as a common CVD risk factor in both type 1 and type 2 diabetes, despite the clear differences in the pathophysiology of the two types of diabetes. Weight loss in obese adolescents has been shown to be beneficial at improving carotid IMT (28,29). Whether weight loss improves carotid IMT and reduces CVD risk in youth with type 1 diabetes remains to be determined.

After adjusting for baseline covariates, we found no association between lipids, BP, and HbA_{1c} over time and follow-up IMT. The reasons for the lack of independent association are not known, but we postulate that although total cholesterol, HDL-C, triglycerides, and systolic and diastolic BP worsened over time, the mean values at baseline and follow-up remained below thresholds defined as CVD risk factors (20–22). This could explain the discrepant results between our study and the study by Dalla Pozza et al. (14), in which an association between mean systolic BP and change in IMT over time was observed. The systolic BP at follow-up in the Dalla Pozza et al. cohort was in the prehypertension range (mean systolic BP 122 \pm 11.5 mmHg), whereas that in the current study at follow-up BP was in the normal range (mean systolic BP 112 \pm 10 mmHg). Alternatively, lipid levels and BP may only be important CVD risk factors when duration of diabetes has been >5 years. Similar findings have been observed in the Diabetes Control and Complications Trial (DCCT) and its follow-up cohort the Epidemiology of Diabetes Interventions and Complications (EDIC) study, where traditional CVD factors did not associate with future IMT until nearly one decade later (30). This may also explain why HbA_{1c} AUC, although clearly abnormal at both baseline and follow-up, was not associated with follow-up carotid IMT in the current study.

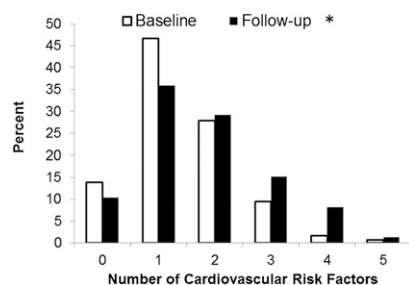


Figure 1—Number of cardiovascular risk factors at baseline and follow-up. Shown are the percentage of participants with zero to five cardiovascular risk factors at baseline and follow-up data. Cardiovascular risk factors were BMI \geq 85th percentile for sex and age; systolic or diastolic BP \geq 90th percentile for sex, age, and height; LDL-C \geq 130 mg/dL; and triglycerides \geq 130 mg/dL if age \geq 10 years or \geq 100 mg/dL if age <9 years. Low HDL-C was defined as \leq 30 mg/dL. *Mean number of risk factors was higher from baseline to follow-up ($P < 0.05$).

Table 3—Predictors associated with follow-up common, bulb, and internal carotid IMT

	A: Predictors associated with follow-up common carotid IMT																					
	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6		Model 7									
	β	SE	P value	β	SE	P value	β	SE	P value	β	SE	P value	β	SE	P value							
Age at baseline (years)	0.005	0.002	0.011	0.007	0.002	0.001	0.005	0.002	0.034	0.006	0.002	0.003	0.007	0.002	<0.001	0.005553	0.002227	0.0133	0.008	0.002	<0.001	
NHW	-0.015	0.017	0.365	-0.015	0.016	0.344	-0.011	0.017	0.508	-0.019	0.017	0.252	-0.010	0.016	0.521	-0.01695	0.0177	0.3392				
Male sex	0.040	0.011	0.001	0.046	0.011	<0.001	0.048	0.012	<0.001	0.043	0.011	<0.001	0.046	0.011	<0.001	0.038555	0.011522	0.0009	0.043	0.012	<0.001	
Duration of diabetes (years)	0.005	0.002	0.012	0.004	0.002	0.030	0.003	0.002	0.054	0.003	0.002	0.083	0.001	0.001	0.474	0.000187	0.001556	0.2307				
Clinic site (OH)	0.016	0.012	0.173	0.015	0.011	0.191	0.017	0.012	0.137	0.013	0.011	0.245	0.007	0.011	0.523	0.014295	0.011687	0.2224				
LDL-C AUC (per 100 mg/dL \times year increase)	0.000	0.003	0.935																			
HDL-C AUC (per 100 mg/dL \times year increase)	-0.016	0.006	0.011																			
Triglycerides AUC (per 100 mg/dL \times year increase)	-0.004	0.002	0.062																			
MAP BP AUC (per 100 mmHg \times year increase)	-0.017	0.007	0.016																			
Insulin sensitivity AUC (per 10 units \times year increase)							-0.009	0.004	0.028													
HbA _{1c} AUC (per 10% \times year increase)							-0.009	0.005	0.062													
BMiZ AUC (per 1 z score \times year increase)													0.003	0.001	0.011							
Current smoker at either visit																0.000461	0.012746	0.9711				
Model R ²	0.142			0.126			0.121			0.119			0.131			0.094						

	B: Predictors associated with follow-up internal carotid IMT																				
	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6		Model 7								
	β	SE	P value	β	SE	P value	β	SE	P value	β	SE	P value	β	SE	P value						
Age at baseline (years)	0.007	0.003	0.004	0.008	0.002	0.001	0.005	0.003	0.046	0.008	0.002	0.001	0.008	0.002	<0.001	0.006497	0.002749	0.0188	0.008	0.002	<0.001
NHW	0.005	0.020	0.802	0.006	0.020	0.746	0.011	0.020	0.590	0.006	0.020	0.779	0.010	0.019	0.614	0.006108	0.02175	0.7791			
Male sex	0.053	0.014	<0.001	0.057	0.013	<0.001	0.063	0.014	<0.001	0.055	0.013	<0.001	0.060	0.013	<0.001	0.054763	0.014237	0.0002	0.058	0.014	<0.001
Duration of diabetes (years)	0.003	0.002	0.202	0.002	0.002	0.260	0.004	0.002	0.060	0.002	0.002	0.315	0.001	0.002	0.550	0.002136	0.001927	0.2686			
Clinic site (OH)	0.026	0.014	0.065	0.030	0.013	0.025	0.029	0.014	0.036	0.028	0.014	0.037	0.022	0.014	0.107	0.029792	0.014469	0.0405	0.023	0.014	0.113
LDL-C AUC (per 100 mg/dL \times year increase)	0.006	0.004	0.129																		
HDL-C AUC (per 100 mg/dL \times year increase)	-0.016	0.008	0.032																		
Triglycerides AUC (per 100 mg/dL \times year increase)	-0.001	0.003	0.765																		
MAP BP AUC (per 100 mmHg \times year increase)	-0.006	0.008	0.456																		
Insulin sensitivity AUC (per 10 units \times year increase)							-0.012	0.005	0.012												
HbA _{1c} AUC (per 10% \times year increase)																					

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Table 3—Continued

	B: Predictors associated with follow-up internal carotid IMT																					
	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6		Model 7									
	β	SE	P value	β	SE	P value	β	SE	P value	β	SE	P value	β	SE	P value							
BMI z AUC (per 1 z-score \times year increase)																						
Current smoker at either visit																						
Model R^2	0.141		0.129	0.129	0.146	0.146	0.126	0.149	0.149	0.001	0.009	0.003	0.001	0.003	0.001	0.031						
																0.9336						
																0.111						
																0.149						
C: Predictors associated with follow-up bulb carotid IMT																						
	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6		Model 7									
	β	SE	P value	β	SE	P value	β	SE	P value	β	SE	P value	β	SE	P value							
Age at baseline (years)	0.005	0.002	0.027	0.005	0.002	0.017	0.004	0.003	0.080	0.005	0.002	0.022	0.006	0.002	0.013	0.003702	0.002481	0.1369	0.005	0.002	0.013	
NHW	-0.018	0.019	0.347	-0.014	0.018	0.428	-0.017	0.019	0.362	-0.017	0.019	0.374	-0.015	0.018	0.419	-0.01089	0.019656	0.5881				
Male sex	0.030	0.010	0.008	0.029	0.012	0.020	0.036	0.013	0.006	0.032	0.012	0.011	0.034	0.012	0.006	-0.02382	0.012827	0.0645	-0.031	0.012	0.011	
Duration of diabetes (years)	0.000	0.002	8.993	-0.001	0.002	0.707	0.001	0.002	0.551	0.000	0.002	0.993	-0.001	0.002	0.754	0.000	0.001734	0.9708				
Clinic site (OH)	-0.016	0.013	0.218	-0.018	0.013	0.153	-0.013	0.013	0.328	-0.015	0.013	0.2229	-0.022	0.013	0.080	-0.0134	0.013034	0.3049				
LDL-C AUC (per 100 mg/dL \times year)	0.007	0.004	0.052																			
HDL-C AUC (per 100 mg/dL \times year increase)	-0.006	0.007	0.434																			
Triglycerides AUC (per 100 mg/dL \times year increase)	-0.002	0.003	0.458																			
MAP BP AUC (per 100 mmHg \times year increase)	0.004	0.008	0.592																			
Insulin sensitivity AUC (per 10 units \times year increase)				-0.005	0.005	0.300																
HbA _{1c} AUC (per 10% \times year increase)							0.000	0.006	0.972													
BMI z AUC (per 1 z score \times year increase)																						
Current smoker at either visit																						
Model R^2	0.067		0.018	0.018	0.057	0.057	0.050	0.064	0.064	0.002	0.001	0.033	0.002	0.001	0.033	0.005913	0.014173	0.6769	0.002	0.001	0.075	

Bolded P values are significant. Only parameters considered in each model are listed.

Current smoking status (at either baseline or follow-up) was also not associated with carotid IMT. Potential explanations for this lack of association may be due to underreporting of self-reported smoking behaviors (31). Additionally, the duration of smoking may have been short, or the quantity of cigarettes smoked may have been too small to have detectable effects on the vasculature. Finally, there may be a threshold effect of smoking (in terms of both dose and duration) at which accelerated vascular changes occur. Given that prior work in middle-aged adults has clearly documented adverse effects of smoking on the vasculature (32), additional studies with quantification of cotinine are needed before conclusions can be drawn about the effects of smoking on carotid IMT in youth with type 1 diabetes.

Similar to studies in adults (30), we identified few risk factors that associate with follow-up carotid IMT. Other work, including previously published data from our group, suggested that worsening insulin resistance (or decreased insulin sensitivity) may be an important CVD risk factor in youth with type 1 diabetes (33). However, after adjusting for BMI_z in the current study, we did not find a statistically significant association between insulin sensitivity AUC and follow-up IMT, despite the worsening of insulin sensitivity over time. This finding suggests that the duration or degree of exposure may be important.

Data from the DCCT/EDIC cohorts have suggested nontraditional risk factors, including acute phase reactants, thrombolytic factors, cytokines/adipokines (34), oxidized LDL, and advanced glycation end products (30) may be important biomarkers of increased CVD risk in adults with type 1 diabetes. However, many of these nontraditional risk factors, including acute phase reactants, thrombolytic factors, and cytokines/adipokines, were not found to associate with IMT until 8–12 years after the DCCT ended, at the time when traditional CVD risk factors were also found to predict IMT. Collectively, these findings suggest that many traditional and nontraditional risk factors are not identified as relevant until later in the atherosclerotic process and highlight the critical need to better identify risk

factors that may influence carotid IMT early in the course of type 1 diabetes because these may be important modifiable CVD risk factors of focus in the adolescent population.

Strengths of the current study include a large cohort of youth with type 1 diabetes, follow-up CVD risk factor data after 5 years (the longest follow-up to date in youth), and the ability to evaluate the association between CVD risk factors over time and follow-up IMT in a young adolescent cohort (mean age 18 years at follow-up). Limitations of the study include carotid IMT measurements obtained only at one time point, lack of physical activity data, and the inability to assess nontraditional biomarkers. Additionally, we quantified adiposity only in terms of BMI, which does not capture information on lean body mass or types of fat. Finally, generalizability of the results to other type 1 diabetes cohorts with a worse CVD risk profile may be limited. However, the risk factor profile we report is consistent with that of the larger SEARCH cohort (35), large type 1 diabetes cohorts in the U.S. and U.K. (36,37), and the DCCT study cohort at baseline (38).

In conclusion, we demonstrate that the CVD risk factor burden increases over time in youth with type 1 diabetes. Although BMI_z was the only identified risk factor to predict follow-up IMT at this age, it is possible that increases in dyslipidemia, BP, smoking, and HbA_{1c} are related to carotid IMT but only after longer duration of exposure.

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References

- Soedamah-Muthu SS, Fuller JH, Mulnier HE, Raleigh VS, Lawrenson RA, Colhoun HM. All-cause mortality rates in patients with type 1 diabetes mellitus compared with a non-diabetic population from the UK general practice research database, 1992–1999. *Diabetologia* 2006;49:660–666
- Pathobiological Determinants of Atherosclerosis in Youth (PDAY) Research Group. Natural history of aortic and coronary atherosclerotic lesions in youth. Findings from the PDAY Study. *Arterioscler Thromb* 1993;13:1291–1298
- O’Leary DH, Polak JF. Intima-media thickness: a tool for atherosclerosis imaging and event prediction. *Am J Cardiol* 2002;90:18L–21L
- Heiss G, Sharrett AR, Barnes R, Chambless LE, Szklo M, Alzola C. Carotid atherosclerosis measured by B-mode ultrasound in populations: associations with cardiovascular risk factors in the ARIC study. *Am J Epidemiol* 1991;134:250–256
- O’Leary DH, Polak JF, Wolfson SK Jr, et al.; CHS Collaborative Research Group. Use of sonography to evaluate carotid atherosclerosis in the elderly. The Cardiovascular Health Study. *Stroke* 1991;22:1155–1163
- Chambless LE, Heiss G, Folsom AR, et al. Association of coronary heart disease incidence with carotid arterial wall thickness and major risk factors: the Atherosclerosis Risk in Communities (ARIC) Study, 1987–1993. *Am J Epidemiol* 1997;146:483–494
- Lorenz MW, Markus HS, Bots ML, Rosvall M, Sitzer M. Prediction of clinical cardiovascular events with carotid intima-media thickness: a systematic review and meta-analysis. *Circulation* 2007;115:459–467
- Dalla Pozza R, Bechtold S, Bonfig W, et al. Age of onset of type 1 diabetes in children and carotid intima medial thickness. *J Clin Endocrinol Metab* 2007;92:2053–2057
- Heilman K, Zilmer M, Zilmer K, et al. Arterial stiffness, carotid artery intima-media thickness and plasma myeloperoxidase level in children with type 1 diabetes. *Diabetes Res Clin Pract* 2009;84:168–173
- Jaiswal M, Urbina EM, Wadwa RP, et al. Reduced heart rate variability is associated with increased arterial stiffness in youth with type 1 diabetes: the SEARCH CVD study. *Diabetes Care* 2013;36:2351–2358
- Odermarsky M, Lykkesfeldt J, Liuba P. Poor vitamin C status is associated with increased carotid intima-media thickness, decreased microvascular function, and delayed myocardial repolarization in young patients with type 1 diabetes. *Am J Clin Nutr* 2009;90:447–452
- Palombo C, Kozakova M, Morizzo C, et al. Circulating endothelial progenitor cells and large artery structure and function in young subjects with uncomplicated type 1 diabetes. *Cardiovasc Diabetol* 2011;10:88
- Rabago Rodriguez R, Gómez-Díaz RA, Tanus Haj J, et al. Carotid intima-media thickness in pediatric type 1 diabetic patients. *Diabetes Care* 2007;30:2599–2602
- Dalla Pozza R, Beyerlein A, Thilmany C, et al. The effect of cardiovascular risk factors on the longitudinal evolution of the carotid intima medial thickness in children with type 1 diabetes mellitus. *Cardiovasc Diabetol* 2011;10:53

15. Hamman RF, Bell RA, Dabelea D, et al.; SEARCH for Diabetes in Youth Study Group. The SEARCH for Diabetes in Youth study: rationale, findings, and future directions. *Diabetes Care* 2014;37:3336–3344
16. Dabelea D, Talton JW, D'Agostino R Jr, et al. Cardiovascular risk factors are associated with increased arterial stiffness in youth with type 1 diabetes: the SEARCH CVD study. *Diabetes Care* 2013;36:3938–3943
17. Shah AS, Black S, Wadwa RP, et al. Insulin sensitivity and arterial stiffness in youth with type 1 diabetes: the SEARCH CVD study. *J Diabetes Complications* 2015;29:512–516
18. Shah AS, Dabelea D, Talton JW, et al. Smoking and arterial stiffness in youth with type 1 diabetes: the SEARCH Cardiovascular Disease Study. *J Pediatr* 2014;165:110–116
19. Kuczmarski RJ, Ogden CL, Guo SS, et al. 2000 CDC growth charts for the United States: methods and development. *Vital Health Stat* 11 2002; 2002:1–190
20. Standards of medical care in diabetes—2015: summary of revisions. *Diabetes Care* 2015;38(Suppl.):S4
21. Kavey RE, Allada V, Daniels SR, et al.; American Heart Association Expert Panel on Population and Prevention Science; Council on Cardiovascular Disease in the Young; Council on Epidemiology and Prevention; Council on Nutrition; Council on Physical Activity and Metabolism; Council on High Blood Pressure Research; Council on Cardiovascular Nursing; Council on the Kidney in Heart Disease; Interdisciplinary Working Group on Quality of Care and Outcomes Research. Cardiovascular risk reduction in high-risk pediatric patients: a scientific statement from the American Heart Association Expert Panel on Population and Prevention Science; the Councils on Cardiovascular Disease in the Young, Epidemiology and Prevention, Nutrition, Physical Activity and Metabolism, High Blood Pressure Research, Cardiovascular Nursing, and the Kidney in Heart Disease; and the Interdisciplinary Working Group on Quality of Care and Outcomes Research. *J Cardiovasc Nurs* 2007;22:218–253
22. Maahs DM, Daniels SR, de Ferranti SD, et al.; American Heart Association Atherosclerosis, Hypertension and Obesity in Youth Committee of the Council on Cardiovascular Disease in the Young, Council on Clinical Cardiology, Council on Cardiovascular and Stroke Nursing, Council for High Blood Pressure Research, and Council on Lifestyle and Cardiometabolic Health. Cardiovascular disease risk factors in youth with diabetes mellitus: a scientific statement from the American Heart Association. *Circulation* 2014;130:1532–1558
23. Oliver JJ, Webb DJ. Noninvasive assessment of arterial stiffness and risk of atherosclerotic events. *Arterioscler Thromb Vasc Biol* 2003;23:554–566
24. Snell-Bergeon JK, Nadeau K. Cardiovascular disease risk in young people with type 1 diabetes. *J Cardiovasc Transl Res* 2012;5:446–462
25. Dabelea D, D'Agostino RB Jr, Mason CC, et al. Development, validation and use of an insulin sensitivity score in youths with diabetes: the SEARCH for Diabetes in Youth study. *Diabetologia* 2011;54:78–86
26. National Institutes of Health. Clinical guidelines on the identification, evaluation, and treatment of overweight and obesity in adults—the evidence report [published correction appears in *Obes Res* 1998;6:464]. *Obes Res* 1998;6(Suppl. 2):51S–209S
27. Physical status: the use and interpretation of anthropometry. Report of a WHO Expert Committee. *World Health Organ Tech Rep Ser* 1995;854:1–452
28. de Lima Sanches P, de Mello MT, Elias N, et al. Improvement in HOMA-IR is an independent predictor of reduced carotid intima-media thickness in obese adolescents participating in an interdisciplinary weight-loss program. *Hypertens Res* 2011;34:232–238
29. Wunsch R, de Sousa G, Toschke AM, Reinehr T. Intima-media thickness in obese children before and after weight loss. *Pediatrics* 2006;118:2334–2340
30. Lopes-Virella MF, Hunt KJ, Baker NL, Lachin J, Nathan DM, Virella G; Diabetes Control and Complications Trial/Epidemiology of Diabetes Interventions and Complications Research Group. Levels of oxidized LDL and advanced glycation end products—modified LDL in circulating immune complexes are strongly associated with increased levels of carotid intima-media thickness and its progression in type 1 diabetes. *Diabetes* 2011;60:582–589
31. Connor Gorber S, Schofield-Hurwitz S, Hardt J, Levasseur G, Tremblay M. The accuracy of self-reported smoking: a systematic review of the relationship between self-reported and cotinine-assessed smoking status. *Nicotine Tob Res* 2009;11:12–24
32. Paul TK, Chen W, Srinivasan SR, He J, Berenson GS. Contrast of the impact of multiple cardiovascular risk factors on the femoral and carotid intima-media thickness in asymptomatic young adults: the Bogalusa Heart Study. *Atherosclerosis* 2011;216:359–364
33. Nadeau KJ, Regensteiner JG, Bauer TA, et al. Insulin resistance in adolescents with type 1 diabetes and its relationship to cardiovascular function. *J Clin Endocrinol Metab* 2010;95:513–521
34. Hunt KJ, Baker NL, Cleary PA, Klein R, Virella G, Lopes-Virella MF; DCCT/EDIC Group of Investigators. Longitudinal association between endothelial dysfunction, inflammation, and clotting biomarkers with subclinical atherosclerosis in type 1 diabetes: an evaluation of the DCCT/EDIC cohort. *Diabetes Care* 2015;38:1281–1289
35. Kershner AK, Daniels SR, Imperatore G, et al. Lipid abnormalities are prevalent in youth with type 1 and type 2 diabetes: the SEARCH for Diabetes in Youth Study. *J Pediatr* 2006;149:314–319
36. Edge JA, James T, Shine B. Longitudinal screening of serum lipids in children and adolescents with Type 1 diabetes in a UK clinic population. *Diabet Med* 2008;25:942–948
37. Reh CM, Mittelman SD, Wee CP, Shah AC, Kaufman FR, Wood JR. A longitudinal assessment of lipids in youth with type 1 diabetes. *Pediatr Diabetes* 2011;12:365–371
38. The Diabetes Control and Complications Trial Research Group. The effect of intensive treatment of diabetes on the development and progression of long-term complications in insulin-dependent diabetes mellitus. *N Engl J Med* 1993;329:977–986