Trends in Glycemic Control Among Youth and Young Adults With Diabetes: The SEARCH for Diabetes in Youth Study

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OBJECTIVE

To describe temporal trends and correlates of glycemic control in youth and young adults (YYA) with youth-onset diabetes.

RESEARCH DESIGN AND METHODS

The study included 6,369 participants with type 1 or type 2 diabetes from the SEARCH for Diabetes in Youth study. Participant visit data were categorized into time periods of 2002–2007, 2008–2013, and 2014–2019, diabetes durations of 1–4, 5–9, and ≥10 years, and age groups of 1–9, 10–14, 15–19, 20–24, and ≥25 years. Participants contributed one randomly selected data point to each duration and age group per time period. Multivariable regression models were used to test differences in hemoglobin A_{1c} (HbA_{1c}) over time by diabetes type. Models were adjusted for site, age, sex, race/ethnicity, household income, health insurance status, insulin regimen, and diabetes duration, overall and stratified for each diabetes duration and age group.

RESULTS

Adjusted mean HbA_{1c} for the 2014–2019 cohort of YYA with type 1 diabetes was 8.8 ± 0.04%. YYA with type 1 diabetes in the 10–14-, 15–19-, and 20–24-year-old age groups from the 2014–2019 cohort had worse glycemic control than the 2002–2007 cohort. Race/ethnicity, household income, and treatment regimen predicted differences in glycemic control in participants with type 1 diabetes from the 2014–2019 cohort. Adjusted mean HbA_{1c} was 8.6 ± 0.12% for 2014–2019 YYA with type 2 diabetes. Participants aged ≥25 years with type 2 diabetes had worse glycemic control relative to the 2008–2013 cohort. Only treatment regimen was associated with differences in glycemic control in participants with type 2 diabetes.

CONCLUSIONS

Despite advances in diabetes technologies, medications, and dissemination of more aggressive glycemic targets, many current YYA are less likely to achieve desired glycemic control relative to earlier cohorts.

Optimal glycemic control is the aim of diabetes care. Clinical trials in both type 1 and type 2 diabetes have established the link between glycemic control and the risk for development of diabetes complications (1,2). The SEARCH for Diabetes in

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**A complete list of the members of the SEARCH for Diabetes in Youth Study can be found in the supplementary material online.*

Youth (SEARCH) study first reported its cross-sectional analysis evaluating glycemic control in youth with diabetes in 2009, at a time when limited data were available on glycemic control in large populations in the U.S. (3). This initial work highlighted that a substantial percentage of youth with type 1 and type 2 diabetes had poor glycemic control (HbA_{1c} $\geq$9.5%). SEARCH also helped shed light on disparities in glycemic outcomes in youth, as racial/ethnic minorities are more likely to have higher HbA_{1c} levels compared with non-Hispanic White youth irrespective of the type of diabetes (4).

Since the 2009 SEARCH publication, the landscape of diabetes management has changed dramatically. Most notably, diabetes technology has rapidly evolved, with new technologies being developed and improved every year. The use of continuous subcutaneous insulin infusion and continuous glucose monitoring (CGM) systems in the U.S. has increased, especially among youth with type 1 diabetes (5,6). In addition, to reflect new evidence regarding the risks and benefits of tight glycemic control in children and adolescents with diabetes, recent national and international recommendations endorse lower HbA_{1c} targets, resulting in providers prescribing more intensive diabetes management for all pediatric age groups (7,8).

The T1D Exchange Registry and the Pediatric Diabetes Consortium are two large registry studies in the U.S. that have reported on glycemic control among youth with type 1 diabetes and type 2 diabetes, respectively (9,10). While both have helped to describe the recent state of treatment of youth with diabetes in the U.S., the T1D Exchange Registry and the Pediatric Diabetes Consortium have only been able to comment on glycemic trends over the past decade. Beginning in 2002, SEARCH has recruited a series of incident racially/ethnically and socioeconomically diverse youth cohorts with both type 1 and type 2 diabetes who are well-characterized through a variety of surveys and physical and laboratory assessments soon after diagnosis and have been followed longitudinally. Given the availability of population-based SEARCH longitudinal data related to glycemic control to evaluate the impact of the changing landscape of diabetes management, the study objective was to describe temporal trends in glycemic control by age and diabetes duration in youth-onset diabetes, beginning 1 year after diagnosis. In addition, we sought to identify correlates of glycemic control among youth with type 1 and type 2 diabetes in the 2014–2019 SEARCH cohort of youth and young adults (YYA) to identify groups of patients who may benefit from targeted interventions to improve metabolic control.

RESEARCH DESIGN AND METHODS

Study Population

SEARCH is a population-based registry network that includes five centers located in California, Colorado, Ohio, South Carolina, and Washington. Children and adolescents with diabetes diagnosed before 20 years of age were identified from ongoing surveillance of networks. Comprehensive details pertaining to the recruitment and study visit components of the SEARCH study have previously been published (11). In the first two phases of SEARCH (SEARCH 1 and 2), individuals newly diagnosed with diabetes in 2002–2006 and 2008 were contacted and recruited for a baseline research visit. Incident cases from 2002–2005 were also asked to return for visits at 12, 24, and 60 months after their baseline visit to measure risk factors for diabetes complications. Also, in the first phase of the study (SEARCH 1), prevalent cases of diabetes, diagnosed prior to 2002, were invited for a single visit. In the third phase (SEARCH 3), a subset of SEARCH participants with a duration of diabetes $>$5 years were recruited for an outcome visit between 2011 and 2015, for whom a single assessment of diabetes-related data collection was completed. In the fourth phase (SEARCH 4), all SEARCH participants aged $>$10 years were operationally split into a group invited to another study visit between 2015 and 2019 and those who were only invited to complete surveys. Those invited to the in-person research visit included all individuals with type 2 diabetes, all non-Whites, and a random sample of non-Hispanic Whites with type 1 diabetes. Since SEARCH is a population-based study, the study site that recruited the participant was often not the clinical location where participants received their diabetes care.

Research visits included questionnaire administration along with collection of anthropometric measurements and a blood sample. HbA_{1c} levels were measured from blood samples obtained at a research study visit. Measurement of HbA_{1c} was performed at the Northwest Lipid Metabolism and Diabetes Research Laboratories, University of Washington, which was the central laboratory for the study. Measurements were performed using an automated nonporous ion exchange high-performance liquid chromatography system (Tosoh Bioscience, Montgomeryville, PA). This method has demonstrated to be linear from a total area of 500 to $>$4,500, indicating that the results are accurate within a large range of number of red cells. If the total area is $<$500, results are not reported; if the total area is $>$4,500, the analysis is repeated after sample dilution. A set of quality control samples with low and high levels of HbA_{1c} was analyzed several times per day to monitor the assay performance, and the between-assay coefficients of variation on the two controls were consistently $<$1.0% and $<$0.7%, respectively. Aliquots of six whole blood pools prepared in the laboratory with values of 5.0%, 6.0%, 7.0%, 7.5%, 8.0%, and 9.0% stored under liquid nitrogen and analyzed each month for several days to monitor the longitudinal stability of the assay.

SEARCH participants with a diabetes duration $>$1 year at a study visit were included in the study sample. Diabetes type was based on provider diagnosis within 6 months of diagnosis. Participants with a type 1 diabetes provider diagnosis who were not on insulin were excluded. For all participants, the parent, adolescent or young adult, or both provided consent or assent. The institutional review boards for all sites approved the study protocol.

Statistical Analyses

SEARCH study visits were conducted from 2002 through 2019. All participants with an eligible visit are included in the analytic data set at least once. Participants could have had up to six visits over that time period. A sample of visits for this analysis was randomly selected from the SEARCH data in such a way as to prioritize inclusion in diabetes duration groups (1–4 years, 5–9 years, and $\geq$10 years) and time periods (2002–2007, 2008–2013, and 2014–2019; the 2002–2007 cohort represents the

cohort reported in the initial 2009 SEARCH publication) while ensuring that no participant would have multiple visits within a duration group or time period (Supplementary Fig. 1). By doing this, independence assumptions of statistical methods and analysis stratified by diabetes duration or time period would not be violated due to multiple records per participant. A sensitivity analysis was conducted to verify that the analytic data set was consistent with other randomly drawn samples using the same criteria.

All analyses were stratified by diabetes type. Participant characteristics were summarized using frequencies and percentages for categorical variables or means and SDs for continuous measures. Unadjusted linear regression models stratified by duration group were used to evaluate differences in HbA_{1c} across time periods. Multivariable linear regression models, stratified by duration group, were then used to test differences in HbA_{1c} over time after adjustment for clinical site, age, sex, race/ethnicity, household income, health insurance status, insulin regimen, and disease duration. Repeated-measures linear models were not stratified by diabetes duration ("overall" in tables) to account for the multiple visits (over the three time periods) per participant. Plots were created to investigate the association of age group and time period with HbA_{1c} using results of the fully adjusted stratified multivariable linear models. Multivariable linear models, stratified by diabetes type and adjusted for all covariates, were used to investigate the associations of HbA_{1c} with participant characteristics during the last time period (2014–2019). All analyses were completed using SAS version 9.4 (SAS Institute, Cary, NC).

RESULTS

Longitudinal analysis included 6,369 (n = 5,482 type 1 and n = 887 type 2) SEARCH participants. Descriptive characteristics of the study sample are shown in Table 1. While the sex of participants across the three time periods was fairly similar irrespective of diabetes type, the 2014–2019 sample of YYA with type 1 diabetes is comprised of a higher percentage of non-Hispanic Black and Hispanic participants as compared with earlier cohorts due to the SEARCH 4 sampling strategy. Age and average duration of diabetes increased among participants with both type 1 and type 2 diabetes across successive SEARCH cohorts. There was also an increase in insulin pump use and CGM use in the more recent cohorts of participants with type 1 diabetes.

The estimated average adjusted HbA_{1c} for the 2014–2019 cohort of YYA with type 1 diabetes was 8.8 ± 0.04% (72 mmol/mol) (Table 2). There was a statistically significant difference in HbA_{1c} among the three cohorts, with the average adjusted HbA_{1c} for the 2014–2019 cohort with type 1 diabetes being 0.3% higher than the mean HbA_{1c} for the 2002–2007 cohort (8.5 ± 0.03% [70 mmol/mol]). When examined by diabetes duration, YYA with type 1 diabetes and a diabetes duration of 5–9 years exhibited a temporal trend of worse glycemic control in recent years (2002–2007: 8.6% [70 mmol/mol] vs. 2008–2013: 9.1% [76 mmol/mol] vs. 2014–2019: 9.2% [77 mmol/mol]). There was also a statistically significant increase in HbA_{1c} among the 10–14-, 15–19-, and 20–24-year-old age groups of YYA with type 1 diabetes when comparing mean HbA_{1c} in 2014–2019 to 2002–2007 (Fig. 1*A* and Supplementary Table 1). In 2014–2019, SEARCH participants had relatively comparable glycemic control compared with similarly aged YYA with type 1 diabetes in 2008–2013, except for the 20–24-year-old age group, which had a statistically significant lower adjusted HbA_{1c} (8.7% [72 mmol/mol]) in 2014–2019 compared with 2008–2013 (8.9% [74 mmol/mol]).

In the multivariate analysis of participants with type 1 diabetes from the 2014–2019 cohort, glycemic control (i.e., HbA_{1c}) was significantly associated with race/ethnicity, age, BMI, insulin regimen, blood glucose monitoring frequency, and household income (Table 3). Non-Hispanic Black and Native American YYA with type 1 diabetes had higher HbA_{1c} levels than non-Hispanic White participants (Supplementary Fig. 2). Other statistically significant correlates of poorer glycemic control in the multivariate model for T1D included younger age, lower BMI z-score, not using an insulin pump, infrequent self-monitoring of blood glucose, and lower household income.

The 2014–2019 cohort with type 2 diabetes had an adjusted HbA_{1c} of 8.6 ± 0.12% (70 mmol/mol). There was a statistically significant difference in HbA_{1c} level across the three time periods for participants with type 2 diabetes. The adjusted HbA_{1c} level for the 2014–2019 cohort (8.6% [70 mmol/mol]) was relatively comparable to the 2002–2007 cohort (8.7% [72 mmol/mol] but was higher than the 2008–2013 cohort (8.3% [67 mmol/mol]). When examined by diabetes duration, YYA with type 2 diabetes with a diabetes duration of $\geq$10 years exhibited a temporal trend of worse glycemic control (2008–2013: 8.4% [68 mmol/mol] vs. 2014–2019: 10.1% [87 mmol/mol]). There was no statistically significant difference in the 2014–2019 cohort when compared with similarly aged YYA groups in the other two cohorts (Fig. 1*B* and Supplementary Table 1). Among participants with type 2 diabetes in the 2014–2019 cohort, the multivariate results revealed that HbA_{1c} was associated with BMI and medication regimen, with those on metformin having a lower HbA_{1c} as compared with those on insulin.

CONCLUSIONS

Many YYA with diabetes in the U.S. are not meeting desired glycemic targets despite increased availability of advanced diabetes technologies, newer therapies, and more aggressive glycemic targets over time. Overall, we found that adjusted mean HbA_{1c} has increased for YYA with type 1 diabetes since the start of the SEARCH study, while the adjusted mean HbA_{1c} in YYA with type 2 diabetes is relatively unchanged when comparing the SEARCH 2002–2007 to the most recent 2014–2019 SEARCH cohort. This contrasts with other countries where improved glycemic control and outcomes have been observed in YYA with diabetes. The SWEET project, which includes 22 centers from Europe, Australia, Canada, and India, demonstrated an improvement in glycemic control; individuals $<$25 years of age with type 1 diabetes had a mean adjusted HbA_{1c} that declined from 8.4% [68 mmol/mol] to 7.9% [63 mmol/mol] between 2008–2010 and 2016–2018 (12). Similarly, the National Paediatric Diabetes Audit in England and Wales also reported a decline in median HbA_{1c} of 8.6% [71 mmol/mol] in 2011/2012 to 7.8% [61.5 mmol/mol] in 2019/2020 in the pediatric population with diabetes (13).

Table 1—Characteristics of YYA who participated in SEARCH study visits by study period and diabetes type

	Type 1				Type 2			
	2002–2007 (*N* = 3,398)	2008–2013 (*N* = 2,184)	2014–2019 (*N* = 1,742)	*P* value	2002–2007 (*N* = 379)	2008–2013 (*N* = 327)	2014–2019 (*N* = 519)	*P* value
HbA_{1c} (%)	8.5 (1.5)	8.9 (1.8)	9.1 (2.0)	<0.0001	8.4 (2.8)	8.3 (2.8)	8.9 (2.9)	0.0034
Diabetes duration, years (SD)	4.6 (3.6)	5.8 (2.8)	8.3 (4.4)	<0.0001	2.9 (1.6)	5.3 (3.1)	7.0 (4.5)	<0.0001
Insulin regimen (%)				<0.0001				0.0002
Not on insulin	0	0	0		222 (58.6)	176 (53.8)	275 (53.0)	
Insulin pump	845 (24.9)	976 (44.7)	856 (49.1)		12 (3.2)	25 (7.6)	31 (6.0)	
Basal-bolus injections	1,000 (29.4)	880 (40.3)	781 (44.8)		44 (11.6)	66 (20.2)	104 (20.0)	
Other insulin regimens	1,544 (45.4)	261 (12.0)	77 (4.4)		95 (25.1)	51 (15.6)	92 (17.7)	
Unknown	9 (0.3)	67 (3.1)	28 (1.6)		6 (1.6)	8 (2.4)	17 (3.3)	
Medication regimen (%)				0.3678				<0.0001
Insulin only	3,310 (97.4)	2,120 (97.1)	1,685 (96.7)		63 (16.6)	61 (18.7)	119 (22.9)	
Insulin plus oral agent	88 (2.6)	64 (2.9)	57 (3.3)		94 (24.8)	90 (27.5)	122 (23.5)	
Metformin only	0	0	0		120 (31.7)	98 (30.0)	125 (24.1)	
Other oral agent	0	0	0		58 (15.3)	27 (8.3)	26 (5.0)	
None	0	0	0		44 (11.6)	51 (15.6)	117 (22.5)	
Unknown	0	0	0		0	0	10 (1.9)	
Blood glucose monitoring frequency (%)				<0.0001				<0.0001
Less than once a day	106 (3.1)	496 (22.7)	276 (15.8)		122 (32.2)	52 (15.9)	132 (25.4)	
1–3 times/day	646 (19.0)	474 (21.7)	304 (17.5)		169 (44.6)	95 (29.1)	95 (18.3)	
≥4 times/day	2,506 (73.7)	674 (30.9)	341 (19.6)		64 (16.9)	63 (19.3)	55 (10.6)	
CGM*	0	165 (7.6)	410 (23.5)		0	28 (8.6)	44 (8.5)	
Unknown	140 (4.1)	375 (17.2)	411 (23.6)		24 (6.3)	89 (27.2)	193 (37.2)	
Sex (%)				0.5429				0.5918
Female	1,680 (49.4)	1,073 (49.1)	885 (50.8)		235 (62.0)	205 (62.7)	338 (65.1)	
Male	1,718 (50.6)	1,111 (50.9)	857 (49.2)		144 (38.0)	122 (37.3)	181 (34.9)	
Race/ethnicity (%)				<0.0001				0.0058
Non-Hispanic White	2,622 (77.2)	1,649 (75.5)	1,028 (59.0)		70 (18.5)	60 (18.3)	95 (18.3)	
Non-Hispanic Black	240 (7.1)	180 (8.2)	224 (12.9)		145 (38.3)	128 (39.1)	216 (41.6)	
Hispanic	369 (10.9)	245 (11.2)	363 (20.8)		88 (23.2)	86 (26.3)	145 (27.9)	
Native American	19 (0.6)	10 (0.5)	10 (0.6)		57 (15.0)	29 (8.9)	33 (6.4)	
Other/unknown/multiple	148 (4.4)	100 (4.6)	117 (6.7)		19 (5.0)	24 (7.3)	30 (5.8)	
Age, years (SD)	12.9 (4.4)	15.1 (5.0)	18.0 (5.7)	<0.0001	17.1 (2.8)	19.5 (4.3)	21.4 (5.0)	<0.0001
BMI *z*-score (SD)	0.6 (0.9)	0.6 (0.9)	0.6 (1.0)	0.0758	1.9 (0.8)	1.9 (0.7)	1.9 (0.8)	0.5024

Continued on p. 289

Table 1—Continued

	Type 1				Type 2			
	2002–2007 (*N* = 3,398)	2008–2013 (*N* = 2,184)	2014–2019 (*N* = 1,742)	*P* value	2002–2007 (*N* = 379)	2008–2013 (*N* = 327)	2014–2019 (*N* = 519)	*P* value
Household income (%)				<0.0001				0.0002
<$25,000	423 (12.4)	312 (14.3)	278 (16.0)		145 (38.3)	132 (40.4)	175 (33.7)	
$25,000–49,999	695 (20.5)	357 (16.3)	306 (17.6)		83 (21.9)	54 (16.5)	92 (17.7)	
$50,000–74,999	695 (20.5)	362 (16.6)	231 (13.3)		42 (11.1)	28 (8.6)	33 (6.4)	
>$75,000	1,335 (39.3)	863 (39.5)	555 (31.9)		31 (8.2)	30 (9.2)	38 (7.3)	
Do not know/refused	250 (7.4)	290 (13.3)	372 (21.4)		78 (20.6)	83 (25.4)	181 (34.9)	
Health insurance (%)				<0.0001				0.0002
None	43 (1.3)	60 (2.7)	49 (2.8)		18 (4.7)	47 (14.4)	53 (10.2)	
Other	54 (1.6)	70 (3.2)	88 (5.1)		32 (8.4)	21 (6.4)	37 (7.1)	
Medicaid/Medicare	568 (16.7)	431 (19.7)	425 (24.4)		144 (38.0)	131 (40.1)	229 (44.1)	
Private	2,733 (80.4)	1,623 (74.3)	1,180 (67.7)		185 (48.8)	128 (39.1)	200 (38.5)	

*Not collected prior to 2011 and at baseline visits in 2012 and 2016.

In addition to differences in adjusted HbA_{1c} over time (Table 2), examination by age group demonstrated significant differences in glycemic control (Fig. 1). We found that adjusted mean HbA_{1c} levels for YYA with type 1 diabetes have increased over time across many age groups. Similar to the 2002–2007 SEARCH cohort, adjusted mean HbA_{1c} was highest among 15–19-year-old participants with type 1 diabetes at 9.3% (78 mmol/mol) for the 2014–2019 cohort. However, it is notable that the adjusted HbA_{1c} for this age group in the most recent SEARCH cohort was 0.5% (5 mmol/mol) higher when compared with 2002–2007 (8.8% [73 mmol/mol]). A comparable increase in adjusted mean HbA_{1c} of 0.4% (4 mmol/mol) was observed in emerging adults, as the adjusted HbA_{1c} for 20–24-year-old participants increased from 8.3% (67 mmol/mol) in the 2002–2007 cohort to 8.7% (72 mmol/mol) in the most recent cohort. The mean glycemic control for these age groups is comparable to what has recently been reported by the U.S. T1D Exchange Registry (15–18 years old: 9.3% [78 mmol/mol]; 18–25 years old: 8.9% [74 mmol/mol]), which reported a worsening in glycemic control in U.S. YYA with diabetes between 2010–2012 and 2016–2018 (9). While there have been significant advances in type 1 diabetes management (14), the burden of diabetes self-care remains demanding. Our findings highlight that the need to monitor blood glucose levels frequently or continuously and administer insulin reliably multiple times per day while balancing diet, physical activity, and other life activities continues to be challenging for adolescents and emerging adults with type 1 diabetes.

SEARCH has provided important information about YYA with type 2 diabetes in the U.S over the past two decades (3,15,16). Results from this study demonstrate that despite a growing recognition of the more rapidly progressive decline in β-cell function (17) and accelerated development of diabetes complications in youth-onset type 2 diabetes compared with adult-onset type 2 diabetes (18), glycemic control in U.S. YYA with type 2 diabetes has not improved over time. The adjusted mean HbA_{1c} of YYA with type 2 diabetes with an average diabetes duration of 7.0 years in our sample was 8.6% (70 mmol/mol),

Table 2—Model adjusted* mean HbA_{1c} stratified by diabetes duration

	HbA_{1c} (%)			
	2002–2007	2008–2013	2014–2019	*P* value
Type 1				
Overall	3,398: 8.5 (0.03)	2,184: 8.9 (0.03)	1,742: 8.8 (0.04)	<0.0001
1–4 years	2,288: 8.5 (0.04)	684: 8.6 (0.06)	380: 8.7 (0.09)	0.0444
5–9 years	765: 8.6 (0.07)	1,320: 9.1 (0.05)	670: 9.2 (0.07)	<0.0001
≥10 years	345: 8.6 (0.13)	180: 9.3 (0.13)	692: 9.0 (0.08)	0.0005
Type 2				
Overall	379: 8.7 (0.14)	327: 8.3 (0.13)	519: 8.6 (0.12)	0.0330
1–4 years	336: 8.4 (0.14)	148: 7.9 (0.19)	190: 8.2 (0.19)	0.1349
5–9 years	43: 9.6 (0.44)	154: 8.8 (0.21)	167: 9.2 (0.20)	0.2600
≥10 years	—	25: 8.4 (0.60)	162: 10.1 (0.35)	0.0140

Data are *n*: least squares means (SE). *Adjusted for age, clinical site, disease duration, health insurance status, household income, insulin regimen, race/ethnicity, and sex.

which is comparable to the 8.4% (68 mmol/mol) reported for the Pediatric Diabetes Consortium Type 2 Diabetes Registry for youth with type 2 diabetes with a diabetes duration of ≥4 years (10).

The observed pattern of worsening glycemic control with increasing duration of type 2 diabetes, independent of many other potential correlates, was likely driven in part by the progressive loss of β-cell function in these participants. The adjusted HbA_{1c} of 10.1% (87 mmol/mol) for type 2 diabetes participants with a disease duration of ≥10 years in the most recent SEARCH cohort is very concerning and provides further confirmation of the high degree of treatment failure in YYA with type 2 diabetes, as well as the need for aggressive intervention (19). Given the evidence that lifestyle intervention alone to achieve or maintain normal blood glucose levels in type 2 diabetes is often unsuccessful in YYA, efforts are needed to support medical providers providing care for YYA with type 2 diabetes to become more comfortable with recommended care and the use of pharmacologic agents beyond metformin and insulin, such as liraglutide, in this population (7).

Previous research, including data from meta-analyses and large international registries, has demonstrated that the use of insulin pumps in youth with type 1 diabetes is associated with lower HbA_{1c} as compared with multiple daily injections (20–22). Separately, CGM alone has been associated with improved glycemic control, with the benefits increasing as CGM use increases (23). Similarly, we found that 2014–2019 SEARCH participants using an insulin pump had an HbA_{1c} level that was 0.4% (4 mmol/mol) lower than those managing their type 1 diabetes with basal-bolus injections. CGM users had an ∼0.2% lower HbA_{1c} level even when compared with those who were monitoring their glucose four or more times per day with fingerstick blood glucose checks. It is worth noting, however, that despite the literature supporting the benefits of pump therapy and CGM systems in the YYA population, universal adoption has not been achieved (24,25). For example, while insulin pump use nearly doubled from 2002–2007 (24.9%) to 2014–2019 (49.1%), there was a minimal increase in the 2014–2019 cohort from the 44.7% found to be using insulin pumps in 2008–2013. Previous studies have shown that household income and parental education are predictive of insulin pump use (24,26). Given the challenges that YYA with type 1 diabetes face in achieving the goals of therapy, addressing differences in access and use of diabetes technologies offers a potential avenue to help the YYA population meet glycemic targets.

Robust diabetes education, diabetes device training, and follow-up of YYA and families are essential to help achieve target glycemic outcomes. Historically, structured, person-centered, and empowerment-based education programs for diabetes self-management and diabetes technology use have been delivered mostly in-person by a certified diabetes specialist. With the expansion of telehealth services during the coronavirus disease 2019 pandemic, virtual training sessions to provide diabetes education and start diabetes technology have been shown to be feasible (27–30). The benefits of virtual training can include scheduling flexibility, access to individuals who live in more remote locations, and reaching individuals who experience challenges traveling to appointments and thus help to alleviate health equity issues (29).

We also found that lower BMI was associated with worse glycemic control in participants with type 1 diabetes. This is consistent with observations from the SEARCH for Diabetes in Youth study published over a decade ago (3), as well as more recent studies from Europe (31). While both nonautomated and automated insulin pump delivery systems are associated with improved glycemic control relative to multiple daily insulin injections, some studies have reported that their use may be associated with higher BMI (31,32). The insulin resistance accompanying potential overweight and obesity warrants further examination with implementation of insulin pump therapy.

Racial and ethnic disparities in glycemic control among YYA with type 1 diabetes are well documented (3,4,33,34). Our finding that non-Hispanic Black and Native American YYA with type 1 diabetes had an HbA_{1c} level that was 1.2% (13 mmol/mol) higher than non-Hispanic White YYA, confirms the need to address inequities in diabetes care (35). As we work to address disparities in diabetes care, socioeconomic challenges must also be addressed. We found YYA participants in higher household income categories had improved HbA_{1c} levels. In an era of rapidly rising insulin prices (36) and estimated mean out-of-pocket costs for medical care of ∼$2,500

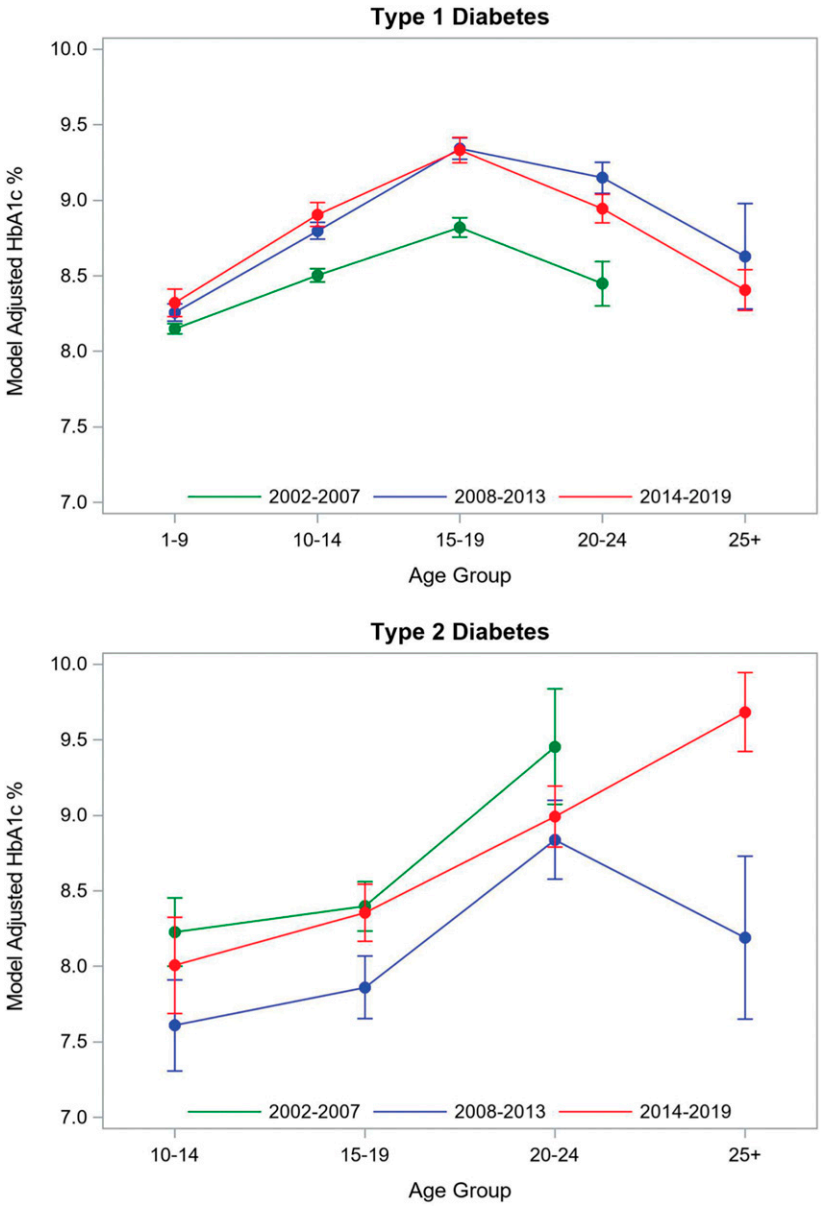

Figure 1—Model adjusted for age, clinical site, disease duration, health insurance status, household income, insulin regimen, race/ethnicity, and sex. Mean HbA_{1c} by age group across study periods.

annually even for those on private health insurance (37), solutions to insulin and diabetes technology affordability are needed.

Recognizing that treating patients with diabetes earlier and more intensively has the potential to confer long-term improvements in public health (38–41), our finding that the majority of YYA with diabetes continue to not meet established glycemic targets represents a missed opportunity for improving lifetime outcomes for patients with diabetes. The transition from pediatric to adult diabetes care is a high-risk period during which there is an increased rate of disengagement from care (42). For YYA with type 1 and type 2 diabetes, unique adherence challenges can range from incomplete knowledge and understanding of treatment regimens and risk for future health to premature shift in responsibility for management from parents to YYA (43). Thus, efforts should be made to successfully transfer YYA with diabetes to an adult-oriented diabetes specialist, who is aware of how best to meet the unique needs of YYA with diabetes and the more aggressive clinical course in this patient population.

While SEARCH is the largest multiethnic population-based study of pediatric diabetes in the U.S., there are limitations to the interpretation of the results. First, data are available only for participants who attended study visits, which might limit the generalizability of our results. Second, we were unable to meaningfully estimate the impact of increased CGM use on glycemic control since we did not have complete information about blood glucose monitoring frequency. However, despite a relatively small confirmed sample of CGM users in the 2014–2019 cohort, we found that CGM users had lower HbA_{1c} levels than those who did not use CGM. Third, we had a relatively small sample size of YYA with type 2 diabetes, particularly in the earlier years of the SEARCH study, highlighting the need for continued longitudinal studies to better characterize trends in glycemic control in YYA with type 2 diabetes. Fourth, since SEARCH is an observational study, we are unable to account for unmeasured residual confounding. Fifth, while we adjusted for race/ethnicity in the models to help account for the sampling variability, it is possible that this adjustment may not completely account for the race-based sampling differences across cohorts.

Data from this large population-based multicenter study confirm that YYA with type 1 and type 2 diabetes in the U.S. are not demonstrating improved glycemic control over time and highlight the need for systematic approaches in the U.S. to support YYA with diabetes, such as those that many European countries have implemented. The establishment and growth of the T1D Exchange Quality Improvement Collaborative (44), which now includes >40 U.S. pediatric and adult diabetes clinics, offers a promising framework to improve health care delivery and dissemination of best practices to accelerate improvement in diabetes outcomes in the U.S. (45). Recognizing that lower HbA_{1c} levels in childhood and young adulthood is associated with lower risk and rate of microvascular and macrovascular complications, this study further underscores the urgent need for implementation of effective treatment

Table 3—Associations of HbA_{1c} with participant characteristics: SEARCH 2014–2019 cohort*

	Type 1 (*n* = 1,805 observations used)			Type 2 (*n* = 478 observations used)		
	Estimate	95% CI	*P* value	Estimate	95% CI	*P* value
Sex			0.07			0.44
Female	Reference			Reference		
Male	−0.16	−0.33, 0.01		−0.18	−0.62, 0.27	
Race/ethnicity			<0.0001			0.34
Non-Hispanic White	Reference			Reference		
Non-Hispanic Black	1.22	0.94, 1.51		0.4	−0.23, 1.03	
Hispanic	0.19	−0.06, 0.44		0.45	−0.32, 1.22	
Native American	1.21	0.09, 2.33		0.66	−0.50, 1.83	
Other/unknown/multiple	0.08	−0.27, 0.43		1.06	−0.01, 2.14	
Age (years)	−0.06	−0.08, −0.04	<0.0001	0.02	−0.06, 0.10	0.58
Diabetes duration (years)	0.01	−0.03, 0.04	0.7545	0	−0.11, 0.11	0.94
BMI *z*-score	−0.23	−0.32, −0.14	<0.0001	−0.43	−0.72, −0.14	0.004
Insulin regimen			<0.0001			
Insulin pump	Reference					
Basal-bolus injections	0.42	0.23, 0.60				
Other insulin regimens	0.83	0.39, 1.26				
Unknown	0.5	−0.19, 1.19				
Medication regimen						<0.0001
Insulin only				Reference		
Insulin plus oral agent				−0.26	−0.89, 0.37	
Metformin only				−3.09	−3.77, −2.42	
Other oral agent				−1.91	−2.98, −0.83	
None				−2.9	−3.57, −2.24	
Unknown				−1.77	−3.35, −0.19	
Blood glucose monitoring frequency			<0.0001			0.49
Less than once a day	Reference			Reference		
1–3 times/day	0.43	0.13, 0.73		−0.16	−0.83, 0.52	
4 or more times/day	−0.31	−0.60, −0.02		−0.47	−1.26, 0.31	
CGM	−0.48	−0.76, −0.20		−0.21	−1.07, 0.65	
Unknown	−1.13	−1.47, −0.80		−0.72	−1.57, 0.12	
Household income			<0.0001			0.33
<$25,000	Reference			Reference		
$25,000–49,999	−0.12	−0.41, 0.18		−0.19	−0.83, 0.46	
$50,000–74,999	−0.55	−0.88, −0.22		−0.56	−1.52, 0.39	
>$75,000	−0.72	−1.02, −0.42		−0.81	−1.76, 0.14	
Do not know/refused	−0.24	−0.53, 0.05		0.08	−0.44, 0.60	
Health insurance			0.27			0.33
Private	Reference			Reference		
Medicaid/Medicare	0.22	−0.01, 0.45		−0.43	−0.96, 0.10	
Other	0.12	−0.27, 0.52		0.16	−0.73, 1.06	
None	0.28	−0.26, 0.82		−0.19	−0.96, 0.10	

*Models adjusted for variables in the table as well as SEARCH site.

strategies to improve metabolic status in YYA with diabetes.

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