FEATURE ARTICLE

Factors Associated With Achieving Target A1C in Children and Adolescents With Type 1 Diabetes: Findings From the T1D Exchange Quality Improvement Collaborative

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The optimal care of type 1 diabetes involves consistent glycemic management to avoid short-and long-term complications. However, despite advancements in diabetes technology and standards, achieving adequate glycemic levels in children and adolescents remains a challenge. This study aimed to identify factors associated with achieving the recommended A1C target of <7% from the United States–based multicenter T1D Exchange Quality Improvement Collaborative cohort, including 25,383 children and adolescents living with type 1 diabetes.

Data from the Diabetes Control and Complications Trial/Epidemiology of Diabetes Interventions and Complications studies have shown that type 1 diabetes treatment requires tight glycemic management, as reflected by A1C, to prevent acute and chronic diabetes-related complications (1,2). The American Diabetes Association's (ADA's) most recent Standards of Medical Care in Diabetes recommends that A1C goals be individualized and reassessed over time and that a target <7% is appropriate for many children with type 1 diabetes (3). Nevertheless, data from the T1D Exchange clinic registry have shown that only a minority of children, adolescents, and adults with type 1 diabetes achieved the previous A1C target of <7.5%, and there was no overall improvement between 2010 and 2012 (4) or between 2016 and 2018, when A1C actually increased, particularly in adolescents (5).

A study describing the extent of variation in A1C levels among youth with type 1 diabetes across and within eight high-income countries (seven in Western Europe and the United States) found a higher mean A1C in the United States than in some European countries, and the lowest A1C in Sweden (6). A further study, including 70% of Swedish children and adolescents with type 1 diabetes, demonstrated that the mean A1C there decreased from 2010 to 2014 and that quality improvement collaboratives played a significant role in this achievement (7).

Diabetes technology has been demonstrated to lower A1C, improve quality of life, and decrease rates of acute complications such as diabetes-related ketoacidosis (DKA) and severe hypoglycemia (SH) in children and adolescents with type 1 diabetes (5,8–11). Such technology includes insulin pumps and continuous glucose monitoring (CGM) systems. Use of diabetes technology in the pediatric population with type 1 diabetes has increased worldwide in the past decade (5,12,13). However, consistent use is lowest among youth from families with low socioeconomic status (SES), who often also have the highest A1C levels; in fact, the device

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use and A1C gaps have widened over the past decade (14). A large U.S. study revealed that even after adjustment for SES, marked disparities in insulin treatment method and treatment outcomes existed between minority (Hispanic and non-Hispanic Black) and non-Hispanic White children and adolescents (15). Furthermore, multiple studies have demonstrated inequities in health outcomes in youth and adults with type 1 diabetes (16–19).

The T1D Exchange Quality Improvement Collaborative (T1DX-QI) is a United States–based multicenter learning health system established to improve care delivery for people with type 1 diabetes (20). This study aimed to identify factors associated with achievement of the recommended glycemic goal of A1C <7% in the T1DX-QI cohort.

Research Design and Methods

The T1DX-QI was established in 2016 and now includes 47 U.S. diabetes centers engaged in data-sharing and quality improvement (QI) practices to drive systems changes. The T1DX-QI is the first learning collaborative in the United States dedicated to the care of people living with type 1 diabetes and aims to accelerate QI interventions through shared learning and continuous review of best practices. Additional information about the T1DX-QI has been previously described (20).

Data were combined and analyzed from 16 T1DX-QI pediatric clinics. Data from January 2017 to February 2022 representing 25,383 children and adolescents (up to 18 years of age) with a type 1 diabetes duration ≥1 year were included in the analysis. Information on sociodemographic variables, diabetes device use, clinical outcomes, and depression or anxiety screening status (for patients 13–18 years of age) was extracted from the T1DX-QI electronic health record (EHR) database. For individuals with multiple encounters during the study period, data from the most recent clinic visit were used.

Descriptive statistics were used to summarize the data. Continuous variables were reported as mean ± SD, and categorical variables were reported as frequency and percentage. Patient characteristics were described and compared among subgroups with A1C <7%, 7–9, and >9%. Characteristics included age in years (analyzed as a continuous and a categorical variable [0–5, 6–12, and 13–18 years]), sex, duration of diabetes, race/ethnicity, insurance status, diabetes device use, BMI *z* score, and depression or anxiety screening status. Race/ethnicity was classified as either non-Hispanic White, non-Hispanic Black, Hispanic, or "other." The latter category was composed of individuals who identified as Asian, American Indian or Alaskan Native, Native Hawaiian, more than one race and those for whom race/ethnicity status was unknown or not reported. Insurance status was categorized as private, public, and "other" (insurance status reported as other or unknown). Device use was categorized as users or nonusers based on whether patients were noted in the EHR to be using a CGM system, insulin pump, or both at their most recent clinic visit. Diabetes outcomes included DKA and SH events and were defined as categorical variables, with patients reporting at least one event within the time of interest being classified as having had a DKA or SH event. Patients who were 13–18 years of age were considered to have screened positive for depression with a nine-item Patient Health Questionnaire (PHQ-9) score ≥5 or a two-item PHQ-2 score >0 and to be positive for anxiety if their score on the seven-item Generalized Anxiety Disorders (GAD-7) questionnaire was ≥5. Information on demographic data, race/ethnicity, insurance status, A1C, DKA events, SH events, insulin pump use, CGM use, BMI *z* score, and depression and anxiety screening was obtained from each site via data-sharing with the coordinating center from the EHR. *P* values were calculated using a Fisher exact or χ^2 test to examine the association between categorical variables and a *t* test or Kruskal-Wallis test for continuous variables.

Adjusted odds ratios (ORs) from logistic regression analysis were generated to examine patient characteristics associated with an A1c <7%. Characteristics analyzed included race/ethnicity, insurance type, use of CGM, use of an insulin pump, mean BMI *z* score, and depression and/or anxiety screening status for patients 13–18 years of age. Results are presented as ORs with corresponding 95% CIs. All tests were two-sided, with type 1 error set at 5%. Analyses were performed using statistical software R, v. 3.6.2, (R Foundation, Vienna, Austria).

This project was deemed nonhuman subject research by the Western Institutional Review Board; therefore, consent or waiver of consent was not required. All participating centers also obtained local institutional review board approvals as appropriate. De-identified EHR data from each site were provided to a centralized site to be analyzed.

Results

A total of 25,383 patients with type 1 diabetes were included in the analysis, with a mean age of 13.3 years (SD 3.9 years, range 1–18 years); their duration of type 1

diabetes ranged from 1 to 18 years, with mean duration of 8 years (SD 4.4 years); and 48% were female.

Patients were clustered in groups according to their A1C level with 4,673 patients (18%) in the A1C <7% group, 11,030 (44%) in the A1C 7–9% group, and 9,680 (38%) in the A1C >9% group. Patient characteristics, including demographics, use of diabetes technology, and diabetes outcomes, are summarized in Table 1.

There were no differences in sex among groups, but patients in the A1C >9% group were older, with a mean age of 13.9 ± 3.7 years compared with 13.04 ± 3.9 years in the A1C <7% group and 12.9 ± 4.1 years in the A1C 7–9% group (P <0.001) (Table 1). The distribution of A1C groups by age is shown in Figure 1.

Among patients with an A1C <7%, fewer were of non-Hispanic Black (9%), Hispanic (9%) or other (16%) race/ethnicity versus non-Hispanic White (66%) compared with patients in the highest A1C group (P <0.001) (Table 1). The distribution of A1C groups by race/ethnicity is shown in Figure 2. Among patients with an A1C <7%, more had private insurance (55%) when compared with the A1C >9% group (P <0.001) (Table 1). The proportion of children and adolescents with an A1C <7% who used a CGM system (60%), an insulin pump (40%), or both (35%) was significantly higher than the A1C >9% group (45, 27, and 20%, respectively; P <0.001) (Table 1). Rates of acute complications were significantly different among groups (P <0.001), with fewer DKA episodes among the A1C <7% group (9%) when compared with the A1C 7–9% group (14%) and the A1C >9% group (24%) (P <0.001). SH was less common in the A1C <7% group (4%) than in the A1C 7–9% group (5%) and the A1C >9% group (6%) (P <0.001), although SH was still relatively infrequent overall. The mean BMI z score was higher in the A1C <7% group (0.83 ± 1.1) when

TABLE 1 Characteristics of Pediatric Patients With Type 1 Diabetes (N = 25,383) Grouped by A1C

Characteristic	Patients With A1C <7% (n = 4,673)	Patients With A1C 7–9% (n = 11,030)	Patients With A1C >9% (n = 9,680)	P
Age, years	13.04 ± 3.9	12.9 ± 4.1	13.9 ± 3.7	<0.001
Age-group, years				<0.001
0–5	224 (5)	635 (6)	396 (4)	
6–12	1,617 (35)	4,001 (36)	2,536 (26)	
13–18	2,832 (61)	6,394 (58)	6,748 (70)	
Duration of type 1 diabetes, years	8.9 ± 4.5	7.5 ± 4.3	8.1 ± 4.2	<0.001
Female sex	2,160 (46)	5,286 (48)	4,655 (48)	0.02
Race/ethnicity				<0.001
NH White	3,071 (66)	7,743 (70)	5,129 (53)	
NH Black	429 (9)	889 (8)	1,989 (21)	
Hispanic	431 (9)	895 (8)	1,025 (11)	
Other	742 (16)	1,503 (14)	1,537 (16)	
Insurance type				<0.001
Public	1,243 (27)	3,051 (28)	4,258 (44)	
Private	2,588 (55)	5,839 (53)	3,756 (39)	
Other	842 (18)	2,140 (19)	1,666 (17)	
CGM use	2,795 (60)	6,852 (62)	4,352 (45)	<0.001
Insulin pump use	1,888 (40)	5,233 (47)	2,651 (27)	<0.001
CGM and insulin pump use	1,634 (35)	4,198 (38)	1,925 (20)	<0.001
Patients with DKA event	425 (9)	1,511 (14)	2,347 (24)	<0.001
Patients with SH event	186 (4)	522 (5)	619 (6)	<0.001
BMI z score	0.83 ± 1.1	0.81 ± 1	0.77 ± 1	0.002

Data are mean ± SD or n (%). NH, non-Hispanic.

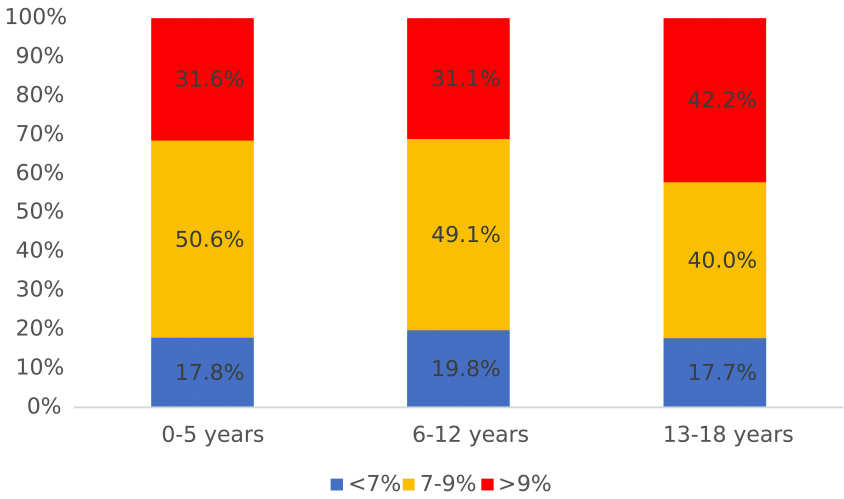

FIGURE 1 A1C distribution by age.

compared with the A1C 7–9% group (0.81 ± 1) and the A1C >9% group (0.77 ± 1) ($P = 0.002$) (Table 1).

In this cohort of 25,383 children and adolescents, 15,974 patients were 13–18 years of age, and among those, 8,898 completed a PHQ-9, PHQ-2, or GAD-7 screening and were included in the analysis for depression and anxiety screening status. Patients were clustered in groups according to their A1C level with 1,544 patients (17.3%) in the A1C <7% group, 3,763 (42.2%) in the A1C 7–9% group, and 3,591 (40.3%) in the A1C >9% group (Table 2). Patients with an A1C <7% were less likely to have a positive screening for depression or anxiety symptoms (21%) compared with those in the A1C 7–9% group (24%) and the A1C >9% group (32%) (P <0.001).

Table 3 shows results from a logistic regression analysis examining the association between patient characteristics and A1C <7% in individuals 0–12 and 13–18 years of age. These two age-groups were used to allow the inclusion of anxiety and/or depression screening status as a factor in the logistic regression analysis. The odds of having an A1C <7% were lower in individuals of non-Hispanic Black race/ethnicity for both the younger age-group (OR 0.64, 95% CI 0.53–0.77, P <0.001) and the older age-group (OR 0.53, 95% CI 0.42–0.67, P <0.001). Privately insured patients had increased odds of having an A1C <7%, among the younger age-group (OR 1.84, 95% CI 1.62–2.09) and the older age-group (OR 1.53, 95% CI 1.32–1.77) (P <0.001 for both). Patients who used a CGM system had higher odds of having an A1C <7% for both the younger age-group (OR 1.20, 95% CI 1.05–1.37, $P = 0.006$) and the

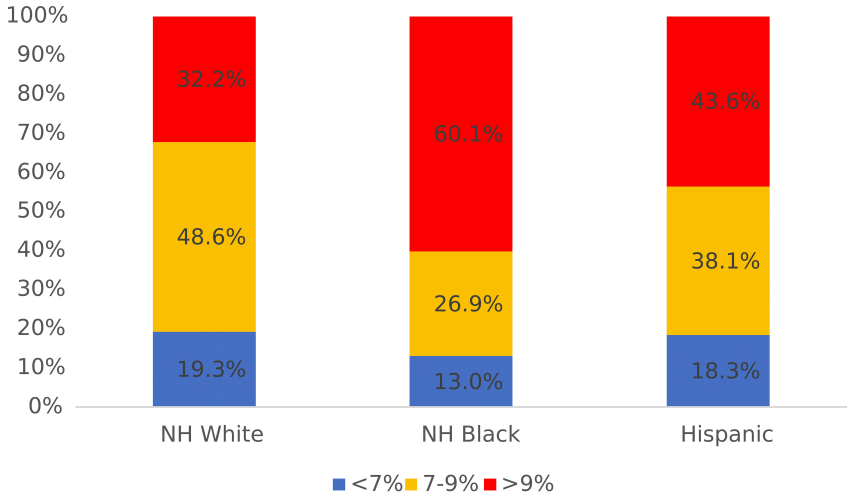

FIGURE 2 A1C distribution by race/ethnicity. NH, non-Hispanic.

TABLE 2 Depression and/or Anxiety Screening in Youth With Type 1 Diabetes 13–18 Years of Age (*N* = 15,975)

Screening Status	Patients With A1C <7% (*n* = 2,832)	Patients With A1C 7–9% (*n* = 6,394)	Patients With A1C >9% (*n* = 6,748)	*P*
Patients screened for depression and or anxiety	1,544 (55)	3,763 (59)	3,591 (53)	<0.001
Patients screened positive for depression and/or anxiety	324 (21)	895 (24)	1,151 (32)	<0.001

Data are *n* (%).

older age-group (OR 1.19, 95% CI 1.05–1.35, $P = 0.007$). There was no relationship between having an A1C <7% and using an insulin pump use for either the younger age-group (OR 1.08, 95% CI 0.95–1.22, $P = 0.2$) or the older age-group (OR 0.91, 95% CI 0.81–1.03, $P = 0.2$). Mean BMI *z* score was not associated with an A1C <7% for the younger age-group (OR 1.05, 95% CI 0.99–1.12, $P = 0.1$). However, the odds of having an A1C <7% were higher for the older age-group with a higher mean BMI *z* score (OR 1.07, 95% CI 1.02–1.13, $P = 0.004$). A positive depression or anxiety screening decreased the odds of having an A1C <7% among the older age-group (OR 0.71, 95% CI 0.62–0.81, $P < 0.001$).

Discussion

This is the largest study in the literature looking into factors associated with optimal glycemic management in children and adolescents with type 1 diabetes. The ADA-recommended A1C target as of 2022 of <7% for youth with type 1 diabetes was achieved by only a small percentage of children and adolescents <18 years of age (18%). Only 19.5% of children ≤12 years of age and 17.7% of children 13–18 years of age met the target. Previous reports from the T1D Exchange clinic registry have shown that just 17% of patients <18 years of age (in the 2016–2018 study) (5) and only 22% of children 6–12 years of age and 17% of children 13–17 years of age (in the 2010–2012 study) (4) met the prior ADA A1C target of <7.5%. Similar to previous reports, our data showed that adolescents were, among all age-groups, the furthest from the A1C goal of <7% (4,21), reflecting the challenges associated with increased autonomy in diabetes care during this age and the psychosocial and hormonal changes of adolescence (5,22).

Children and adolescents with type 1 diabetes who achieved an A1C <7% were less likely to be non-Hispanic Black, more likely to have private insurance, and more likely to use CGM. Although biological differences in glycation of hemoglobin between non-Hispanic Black and non-Hispanic White groups have been

TABLE 3 Factors Associated With A1C <7% in Children and Adolescents With Type 1 Diabetes by Age (*N* = 25,383)

Characteristic	Patients 0–12 Years of Age (*n* = 9,409)	*P*	Patients 13–18 Years of Age (*n* = 15,974)	*P*
Race/ethnicity				
NH White (ref)	–		–	
NH Black	**0.64 (0.53–0.77)**	**<0.001**	**0.53 (0.42–0.67)**	**<0.001**
Hispanic	1.03 (0.85–1.24)	0.7	1.10 (0.89–1.35)	0.3
Insurance				
Public (ref)	–		–	
Private	**1.84 (1.62–2.09)**	**<0.001**	**1.53 (1.32–1.77)**	<0.001
CGM use (yes)	**1.20 (1.05–1.37)**	**0.006**	**1.19 (1.05–1.35)**	**0.007**
Pump use (yes)	1.08 (0.95–1.22)	0.2	0.91 (0.81–1.03)	0.2
BMI *z* score	1.05 (0.99–1.12)	0.1	**1.07 (1.02–1.13)**	**0.004**
Screened positive for depression and/or anxiety	–		**0.71 (0.62–0.81)**	**<0.001**

Data are OR (95% CI). Bold type indicates statistical significance. NH, non-Hispanic; ref, reference category.

reported, it has been shown that these account for a small fraction of the differences found between these racial/ethnic groups (23). Multiple studies have reported that minority racial/ethnic populations are more likely to have higher A1C, face increased barriers in access to care (including provider-level barriers [24]), have more acute complications, and are less likely to use diabetes technology (15–19,25).

As expected, acute complications associated with type 1 diabetes were significantly less frequent in the group with an A1C <7%.

Type of insurance may play a significant role in glycemic management given that non-Hispanic Black and Hispanic populations are more likely to have public insurance, potentially interfering with access to diabetes technology in some states (17). There were significantly fewer patients using CGM, insulin pumps, or both in the A1c >9% group, but CGM use alone was the only factor associated with having an A1C <7%. Similar findings were reported by a T1D Exchange study on the influence of technology and SES on glycemic levels that demonstrated an association between CGM use and lower A1C independent of insulin delivery type (insulin pump or multiple daily injections), suggesting that CGM may be a mediator in the relationship between SES and A1C (26). There is a need for effective interventions and policies to promote equitable care. Unrestricted CGM coverage for youth with type 1 diabetes on public insurance was shown to improve engagement and A1C and to provide a gateway to obtaining a hybrid closed-loop (HCL) system to improve diabetes management (27).

We have recently shown that the use of an HCL insulin delivery, an emerging technology combining an insulin pump and CGM data with a closed-loop algorithm controller to automate insulin delivery, was associated with lowerA1C levels and higher time in the target glycemic range for both pediatric and adult populations (28). The beneficial lowering of A1C seen with HCL systems surpasses those from using a pump and CGM without a connecting HCL algorithm (29).

Mean BMI *z* score was higher among the A1C <7% group, and, although there was no relationship between A1C and BMI *z* score on the logistic regression analysis for the 0–12 year age-group, higher mean BMI *z* score was associated with having an A1C <7% for the 13–18 year age- group. Weight gain has been a subject of concern with intensive glycemic management since Diabetes Control and Complications Trial researchers reported greater weight gain in individuals in their intensive treatment group (30). Recent results from the SWEET prospective multicenter diabetes registry, including patients with type 1 diabetes who were 2–18 years of age, showed that switching from multiple daily insulin injections to an insulin pump is significantly associated with improvement in A1C levels but increased BMI standard deviation score over time (31).

Although challenges remain in the collection of mental health screening measures on all eligible patients, youth with type 1 diabetes appear to have a greater incidence of depression, anxiety, and psychological distress compared with their peers (32). A higher percentage of patients with type 1 diabetes and an A1C >9% (in the 13–18 year age-group) screened positive for depression and/or anxiety. In addition, patients with a positive screening were less likely to reach the A1C goal of <7%. Our data aligns with previous studies indicating that behavioral problems are associated with elevated A1C level (33) and that depression and anxiety are often co-occurring with less frequent glucose monitoring and less effective glycemic management (34,35).

The results of this study confirm that significant disparities exist in the achievement of glycemic targets among youth with type 1 diabetes. Children and adolescents from lower SES and racial/ethnic minority groups have more diabetes complications (15) and higher diabetes-associated costs (36). Identification of modifiable risk factors that may lead to these disparities is needed, with programs tailored to target specific socially and medically vulnerable youth with type 1 diabetes. Participation in a QI collaborative was one of the significant factors among Swedish centers that observed improved A1C in children and adolescents compared with centers that did not (7). Therefore, having access to a quality registry to report data online, receive ongoing benchmarking feedback, compare results, and share learning with other clinics can be an effective way to promote the achievement of glycemic targets.

The strength of our study is that it is the largest cohort to date to assess factors associated with optimal glycemic management in children and adolescents with type 1 diabetes, with a broad representation of patients from 16 pediatric diabetes sites across the United States. However, there are also some limitations. First, this study had a cross-sectional design, which does not allow determination of causality of CGM use or rates of DKA or SH with glycemic targets. Data on patients' level of education and family income, which are important factors in glycemic management, were not

available for this analysis. Additionally, differences in diabetes technology use may be influenced by unmeasured variables such as patient preference or provider biases in interpreting patients' device preparedness. We included only three racial/ethnic groups, including Non-Hispanic White, Non-Hispanic Black, and Hispanic, because they were the major categories from our cohort with sufficient cohort sizes for analysis. The results reported to the central data site were harmonized among sites so that equivalent data were being reported. Most centers involved in this study are academic-based diabetes practices, and the results may not be generalizable outside of this setting. Finally, data were obtained from EHR systems and may be subject to documentation inaccuracies.

In summary, this study highlights social disparities in reaching glycemic targets and supports previous findings that CGM use is beneficial in effective management of blood glucose levels. Routine assessment of psychosocial issues that could affect diabetes management and appropriate referrals to mental health professionals are recommended. More studies are needed to examine factors associated with optimal A1C levels in children and adolescents living with type 1 diabetes.

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DUALITY OF INTEREST

O.E. is a compensated Health Equity Advisory Board member for Medtronic Diabetes and serves as a principal investigator for investigator-led projects sponsored by Abbott, Eli Lilly, Insulet, and Medtronic. No other potential conflicts of interest relevant to this article were reported.

AUTHOR CONTRIBUTIONS

C.D.-B. wrote the first draft of the manuscript. C.D.-B., O.E., and L.M.J. developed the concept for the manuscript. N.N. and S.R. analyzed the data. O.E. and L.M.J. critically revised the early draft of the manuscript. S.M., N.-H.Y.J., R.M., O.O., A.K., R.I., and M.K.K. critically reviewed and edited the manuscript. All authors researched the references, revised the manuscript, and approved the final version. N.N. is the guarantor for this work and, as such, had full access to all the data and takes responsibility for the integrity of the data and the accuracy of the data analysis.

PRIOR PRESENTATION

Some of the data reported in this article were presented at the American Diabetes Association's virtual 81st Scientific Sessions, 25–29 June, 2021.

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